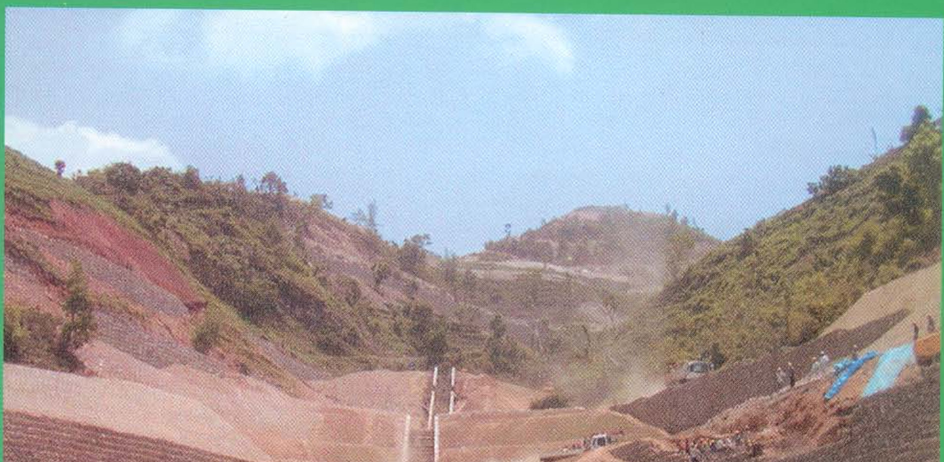
His Majesty's Government of Nepal
Ministry of Physical Planning and Works
Department of Roads

Guide to
ROAD SLOPE PROTECTION WORKS



June 2003

This Guide to Road Slope Protection Works is the first step in helping institutionalize the planned off-road maintenance in DOR. Activities on off-road maintenance shall be started in few sample Division Road Offices [DRO] and expanded in a sustainable manner to cover all the DROs. It shall be built in the SMD process.

This Guide has been prepared by Japanese experts under a short term JICA Technical Assistance. The DOR wishes to express its heartfelt thanks to JICA and the experts for this. DOR also has provided extensive inputs to make the Guide more user-friendly in Nepalese context for use by DRO staffs. A team comprising SDEs DR Regmi, DN Chalise and Engineers DMS Shrestha, AK Mull has worked hard to bring the Guide to the final shape. Thanks are due to all DDGs, SDEs, the team, and others who have provided their inputs. We also acknowledge with appreciation the Working Committee and the Standards Committee who by discussing and providing valuable comments assisted in the preparation of this Guide.

It is not the end but a means to contribute to achieve our end goal. It has to be tested and perhaps improved in future based on the feedback from the actual workplace. In such case DOR is confident to receive sustained support from JICA - a development partner of Nepal since long.

Madan Gopal Maleku
Director General, Department of Roads

Foreword

Road construction, maintenance, and operation in Nepal are challenging tasks. The rugged topography, dissected by numerous rivers and streams, poses many challenges and constraints for its efficient and effective maintenance and smooth operation of traffic.

Eighty percent of the terrain in Nepal comprises hills and mountains. Fifty two percent of the population sustains their life in these areas. Seventy percent of the Strategic Road Network [~5000 km] passes through this terrain. Road sector plans envisage adding ~ 1000 and ~ 5000 km within next 5 and 20 years respectively.

The cumulative and long-term benefits of road development are many, but the goal remains the same - sustainable use. With adding of the network, slope related problems such as land slides, slope failures, rock falls, rock mass failures, debris flow, and toe cutting also arise; all leading to road closures. Road closures limit the transport service delivery to the people leading the public to raise questions, which does not contribute to the road agency's image in the public.

DOR has already established a Planned Maintenance Management System [PMMS] of road maintenance through its Strengthened Maintenance Division [SMD] Program. As the change process requires many factors such as institutional capacity, enhancement in knowledge, skill and particularly the attitude amongst the stakeholders; it is rather a slow process. The PMMS has been successfully adopted in on-road activities within SMD. Now it is the right time to initiate the PMMS of the off-road activities. This will make the road safer and convenient, which shall lead to efficient and effective transport service delivered to people through the DOR.

Foreword

I am very much delighted to hear that JICA Experts along with his counterparts from DOR have come up with a guide-book which will give guidance to DOR officials and field staff for managing slope disaster.

On this occasion, I would also like to mention a few words on the importance of the guide-book. Nepal is a mountainous country with most of the area covered by hills and mountain. The mountains are new ranges and are very fragile in nature. In this regard, construction and maintenance of roads in the hilly areas have always been a challenge to Department of Roads (DOR), which is the main HMG/N department responsible for road construction and maintenance. Despite the challenges, road construction have taken place with a total of 15,905 km of road network, which also includes national highways totaling 2,974 km. However, the maintenance of the network has not been able to keep up with the increase in the road network. One of the major reasons for the degrading condition of road is the slope failure mainly due to heavy rain. This has created traffic obstruction, danger to travelers, increase in cost & time to road users and degradation of road condition & environment. One of the prime examples is the Krishna Bhir landslide, which affects the people of Kathmandu valley in numerous ways due to obstruction of traffic several times in a year. Therefore, from past observation, we can say that the slope failures can be a hindrance to the socio-economic progress of Nepal.

The focus of DOR until now was mainly maintenance and rehabilitation after the slope failure occurs. However, rehabilitating the slope failure needs a lot of resources. Therefore, timely mitigation, prevention and maintenance work is one of the effective measures to avoid slope disasters in a cost effective manner. With many years in road construction and maintenance, DOR realized this issue and requested JICA for technical cooperation for mitigating and managing slope failures in advance by institutionalizing slope management through timely inspection mechanism. Appreciating the importance of the issue and in response to DOR request, JICA extended technical cooperation by dispatching a slope stabilization expert from early February to end of March 2003.

This guide-book prepared with the joint effort of JICA experts and DOR officials will surely strengthen the institutional mechanism for the protection of road slopes by monitoring, inspecting and recommending suitable measures in a systematic manner. We at JICA are confident that DOR will effectively utilize this guide-book and even improve it toward a better one.

Eitaro MITOMA
Resident Representative
JICA Nepal Office

Abbreviations

AADT	Annual Average Daily Traffic
CF	Cut Slope Failure
CL	Collapse
DF	Debris Flow
DOR	Department of Roads
DRO	Division Road Office
EF	Embankment Failure
GEU	Geo-Environment Unit
HMIS	Highway Management Information System
IAEG	International Association of Engineering Geology
ICIMOD	International Centre for Integrated Mountain Development
JICA	Japan International Co-operation Agency
LS	Landslide
MB	Maintenance Branch
MBT	Main Boundary Thrust
MCT	Main Central Thrust
RF	Rock Fall
RM	Rock Mass Failure
SDC	Swiss Agency for Development and Co-operation
SMD	Strengthened Maintenance Division
TA	Technical Assistance

Glossary

Anchoring	fix structure with anchors
Berm	a horizontal step provided in cut and embankment slopes
Bio-engineering	use of living plants to fulfill engineering purpose
Bi-annual inspection	inspection carried out twice in a year i.e. before and after monsoon
Countermeasure	measure applicable to control the failure
Consequence	a result of disaster
Collapse	slope failure in loose, porous soil, and rocks
Crib wall	wall constructed with elements from precast reinforced concrete/timber/steel
Disaster	a sudden slope failure resulting road closure
Debris flow	rapid flow of boulder, gravel, sand, silt, and clay mixed with a large quantity of water
Embankment failure	slump or collapse in road embankment
Emergency inspection	inspection carried out when there is disaster
Fragile	easily broken or damaged
Frame work	structural frame as a part of wall construction
Ground anchor	anchors used in soil and rock mass
Hazard	the probability of disaster
Horizontal drill drain	drilled drain to lower groundwater table
Inspection	assessment of slopes
Landslide	mass - sliding movement of highly weathered rocks, debris and soil along a slip surface
Mitigation	making less severe
Pile work	vertical members inserted into landslide to resist the sliding force
Regular inspection	inspection carried out regularly
Risk	danger or threat to road and structures
Rock fall	free fall or rolling down of loose rocks/boulders
Rock mass failure	sliding of rock mass (wedge/plane slide)
Rock bolt	anchors used to tie the rock mass
Sub-surface drains	drains used for draining shallow groundwater
Shotcrete work	mechanized spraying of cement mortar or concrete
Stone pitching	armoring slope surface with stones or concrete blocks
Soil nail	slender steel rods inserted into the soil layers

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CHAPTER 1 ROAD SLOPE DISASTER MANAGEMENT

1.1 CONCEPT OF ROAD SLOPE DISASTER MANAGEMENT

1.1.1 Objective

The total road network in Nepal is around 16,000 km at present. Out of the total road network about 5,000 km length is strategic road network, which forms important infrastructure for social and economical activities in Nepal. These roads are prone to frequent traffic blockade due to slope disasters induced by harsh natural conditions such as steep topography, fragile geology, heavy rainfall, river floods and earthquakes. The road slope disaster management can play vital role in delivering efficient and effective transport services to road users. Objectives of the road slope disaster management are as follows:

1) tomaintain the traffic operation
2) to secure the traffic safety
3) to reduce the environmental degradation
4) tominimize the traffic operation cost

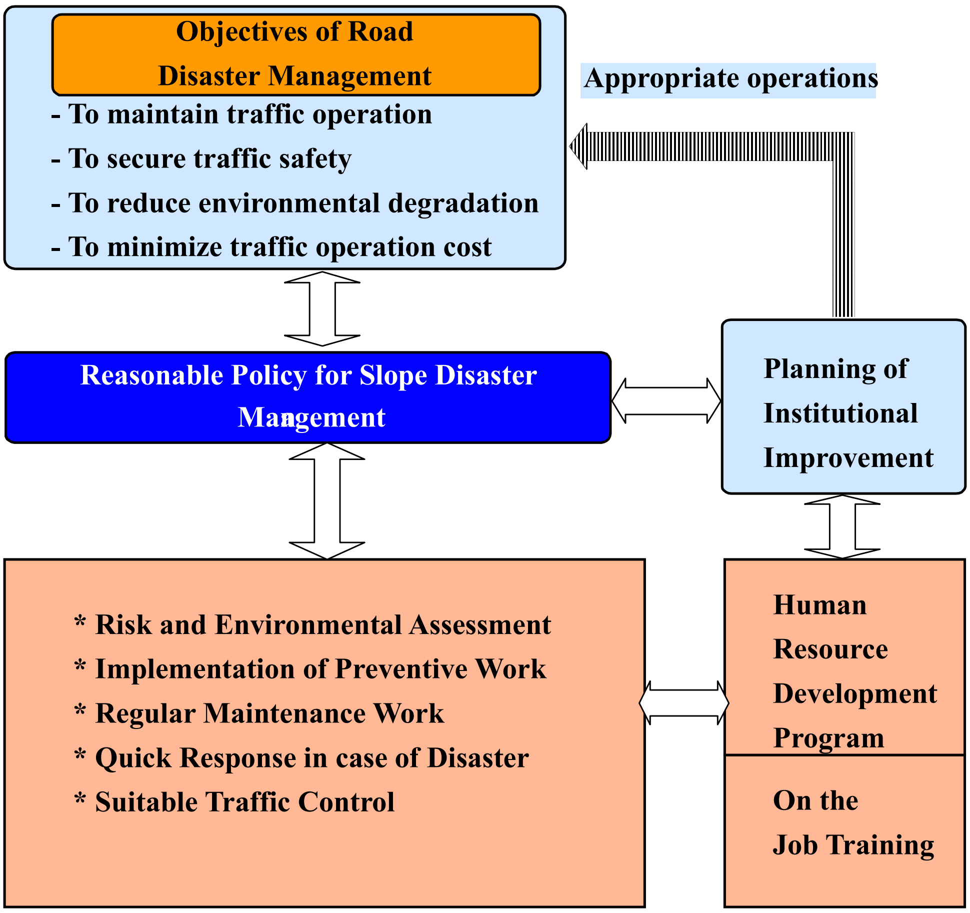

Figure 1.1: Concept of Road Slope Disaster Management

To achieve the objectives, following tasks are required.

1) Understand the conditions of Strategic Roads on disaster probability and environmental impacts (Risk and Environmental Assessment)
2) Formulate Reasonable Standard Policy and Plan for Slope Disaster Prevention
3) Implement Preventive Works
4) Continue Regular Maintenance Works to keep the slope and other road structures in good condition
5) Response quickly in case of Disaster
6) Manage Traffic Operation in case of Disaster
7) Develop Human Resources
8) Strengthen the Road Maintenance Organisation

1.1.2 System for Road Slope Disaster Management

Proposed system for Road Slope Disaster Management in Nepal is shown below.

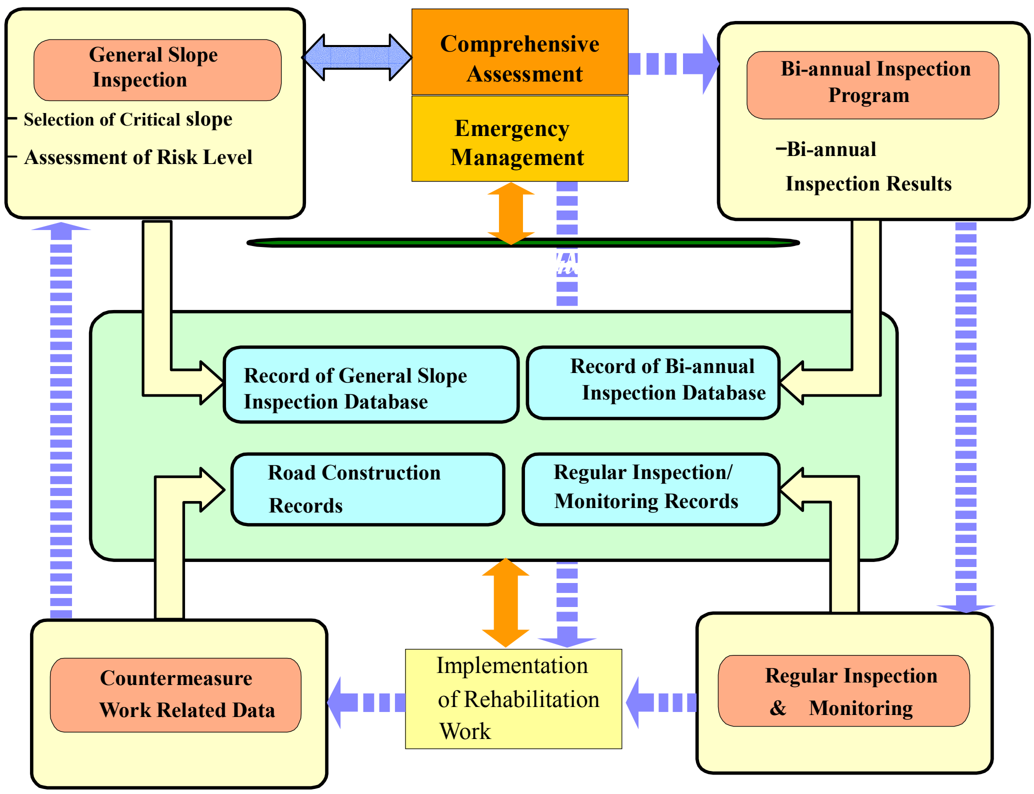

Figure 1.2 Proposed System of Road Slope Disaster Management

Basic components for Road Slope Disaster Managementare listed in the Table below.

Table 1.1: Basic Components of Road Disaster Management

Basic Component	Description
General Slope Inspection: Carried out jointly by Geo-Environment Unit (GEU), DOR and Division Road Office (DRO) (for first time)	- Selection of Critical Slope Section - Assessment of the Slope Failure Hazard - Assessment of Consequence of the Slope Failure - Assessment of Risk Level of the Slope Failure - Annual Implementation Planning of Countermeasure Works (with Priority) - Formulation of Short, Medium, and Long- Term Plan
Comprehensive Risk Assessment: Evaluated by Maintenance Branch (MB) & Design and Planning Branch/GEU in DOR	- Prioritisation of Critical Slopes - Planning Improvement of Organisation for Disaster Management
Emergency (or Crisis) Management: Coordinated by DOR Head Office, Regional Directorate and executed by DRO with support from Heavy Equipment Division (HED)	- Emergency Response Plan - Crisis Management Organisation - Reporting/ Communication System - Co-ordination/ Cooperation with Other Related Agency - Logistics for Emergency Road Opening Work - Training for Emergency Management - Traffic Management - Information to Road Users
Regular Inspection and Monitoring Data kept in DRO	- Regular Inspection to Check Road Condition - Monitoring for Critical Slope - Execution of Routine Maintenance
Bi-annual Inspection Carried out by DRO and Data Forwarded to MB	- Update the Slope Record - Re- evaluate the Risk Level - Plan Countermeasure Works
Implementation of Rehabilitation Work Data of Implemented Countermeasure Works Forwarded to MB	- Site Investigation and Design of Countermeasure Works - Implementation of Countermeasure Works - Records of implemented Countermeasure
Data Base of Road Disaster Management Preparedby DRO and MB	- Record of General Inspection - Record of Bi-annual Inspection - Record of Regular Inspection - Record of Road Construction / Rehabilitation - Record of Historical Disasters

1.2 General Slope Inspection

General Slope Inspection consists of following three stages, which are discussed below.

1.2.1 Selection of Critical Slope Section

The DRO selects critical slope sections on the basis of followings;

a) High frequency of disaster (every year)
b) Active deformations on the slopes/ roads
c) High probability of slope disaster (geological setting of the slope)

Selected critical slopes shall be recorded in the inspection sheet indicating the location in available topographical map (1:25,000).

1.2.2 General Inspection of Critical Slopes

General Inspection of selected critical slopes shall be carried out and details are filled in the following record sheets and a copy of which shall be forwarded to the Maintenance Branch, DOR.

a) General Information of the Road Section with Location on topographical map (1:25,000); Form A
b) General Sketch of the Road Section; Form B
c) Photograph; Form C
d) Slope Feature, Form D
e) Slope Hazard Assessment; Form E
f) Consequence/ Risk Level Assessment; Form F

The above mentioned standard forms are given in the Appendix.

1.2.3 Implementation Planning

The Maintenance Branch finalizes the implementation plan on the basis of information provided by DRO through the General Inspection.

Table 1.2: Framework of Implementation Plan

<table>
<tr><th>Time Frame</th><th>Time Period</th><th>Slope Criteria</th><th>Note</th></tr>
<tr><td>a) Emergency Plan</td><td>To be implemented urgently
(from budget for Emergency works)</td><td>Evaluated as Risk Level I on highly important road sections</td><td>To be treated as urgent repair work</td></tr>
<tr><td>b) Short term Plan</td><td>Within 1 to 2 years</td><td>Rated as Risk Level I on important road</td><td rowspan="3">Budget & improvement of organisation should be planned</td></tr>
<tr><td>c) Medium-term Plan</td><td>Within 3 to 5 years</td><td rowspan="2">Master Plan for Strategic Road Network</td></tr>
<tr><td>d) Long-term Plan</td><td>Within 6 to 10 years</td></tr>
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1.3 RISK ASSESSMENT

1.3.1 General Flow of Risk Assessment

Figure 1.3 shows the workflow for road slope disaster management, which consists of three stages as mentioned in the section 1.2

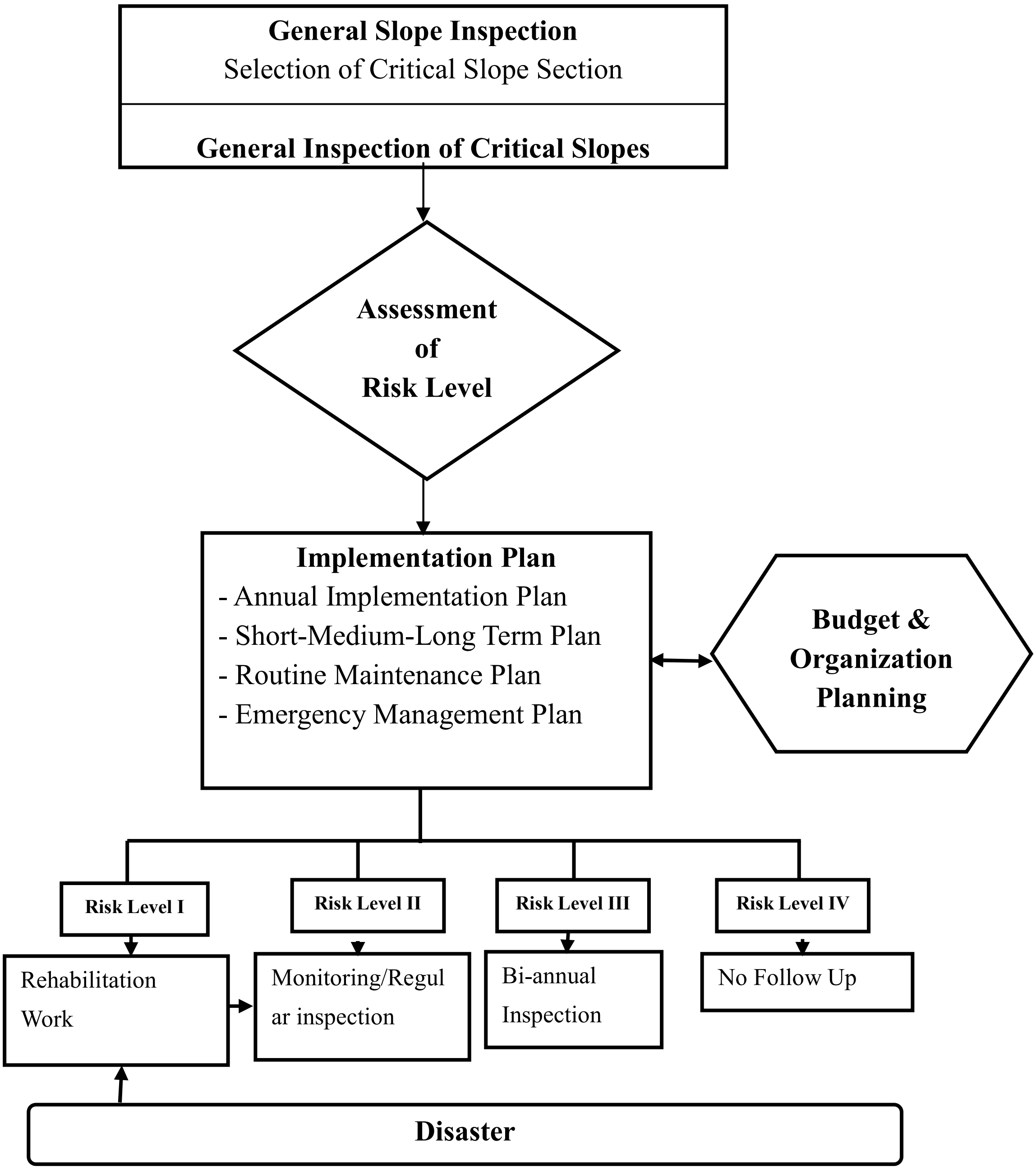


Figure 1.3: General Flow of Risk Assessment

1.3.2 Slope Hazard Assessment

The assessment of Landslides, Debris Flow and Embankment Failure is carried out considering the hazard level and topographic conditions. Hazard levels are defined as A, B and C to reflect its level from highest to lowest.

(1) Landslide

Hazard Level	Conditions
High (A)	- A large number of clear deformations such as scarps, bulges, side cracks, and - Visible movements of cracks, subsidence, upheaval, and toe erosion.
Medium (B)	- Obvious landslidetopography such as bulge, stepped land, but - No visible movement is found
Low (C)	- Suspicious landslide topography , but no evidence of deformation at present

(2) Debris Flow

Hazard Level	Conditions
High (A)	Frequent Occurrence: Within every two years
Medium (B)	Periodical Occurrences: Over five years
Low (C)	Traces of collapses are in the source area, but Debris flow occurrence is rare

(3) Embankment Failure

Hazard Level	Conditions
High (A)	- Frequent occurrence of slope failures disturbing traffic operation - Visible deformations such as tension crack and settlement
Medium (B)	- Periodical occurrence but traffic operation is normal - Visible deformations such as tension crack or settlement
Low (C)	- No repair work is required in structures, drainages, and vegetation - No deformations in the slope

1.33 Assessment of Consequence of Slope Failure

Consequence of the Road Slope Failure is assessed on the basis of criteria mentioned in the table below. Consequence effects are also categorized in three different levels as High, Medium and Low depending upon the consequence of slope failures on mainly four criteria. In case of different consequences levels in different criteria the highest shall govern for assessing the risk level. Criteria for assessment of consequence of slope failures are not limited but may vary for different road sections depending upon their importance.

Table1.3: Assessment of Consequences

Criteria \ Consequences	High a	Medium b	Low c
1) AADT (A)	A≧800	150≦A ＜800	A＜150
2) Public Asset	Very Important	Important	Less Important
3) Number of Private House (H)	H≧10	3＜H≦10	H＜3
4) Time for Reopening (P-days)	P≧3	1＜P≦3	P＜1

1.3.4 Assessment of Risk Level

Slope Hazard of the road sections and its consequence shall be evaluated by means of qualitative and semi-quantitative criteria. Risk Levels are classified into four levels; Level-I, Level-II, Level-III and Level-IV as shown in the Table 1.4 . The risk level assessment is proposed to be evaluated on the basis of the combination of the slope hazard level and its consequences as shown in the Table 1.5.

Table 1.4: Assessment of Risk Level

Risk Assessment		Consequence of the Slope Failure		
		a	b	c
Slope Hazard Level	A	I	I	II
	B	I	II	III
	C	II	III	IV

Table 1.5: Risk Level and Suggested Actions

Risk Level	Combination	Action
I	Aa, Ab, Ba	Implementation of Countermeasures (1st Priority)
II	Ac, Bb, Ca	Monitoring (monitoring by measurement of landmass movement and/or regular inspection)
III	Bc, Cb	Bi-annual Inspection (before and after monsoon)
IV	Cc	No more follow-up until some changes occur

Proposed combination of Slope Hazard and its Consequence to determine the Risk Level is flexible and could be changed depending upon available resources and strategy.

1.4 Road Slope Inspection

Road Slope Inspection is defined as the normal inspection carried out by DROs focussing on slope stability. Following three types of slope inspection are proposed;

(1) Regular Slope Inspection,
(2) Bi-annual Slope Inspection, and
(3) Emergency Slope Inspection.

Slope inspection shall include the filling in new or updating of Road Slope Inspection Sheets as well as recording of the following Slope Inspection Record Forms.

a) Inspection Record; Form R-A
b) Disaster Record; Form R-B
c) Countermeasure Record; Form R-C
d) Inspection Summary: Form R-D
e) Disaster Summary; Form R-E
f) Countermeasure Summary: Form R-F
g) Road Closure Record; Form R- E

The above mentioned standard recording forms are given in the Appendix.

1.4.1 Regular Slope Inspection

The frequency of Regular Slope Inspection is recommended minimum once a month, in general. It may be adjusted in accordance with slope conditions, traffic volume, important structures and social conditions. This Inspection is carried out in order to assess the slope stability and to initiate suitable action for prevention of slope failure disasters. The scope of Regular Slope Inspection is as follows;

1) To check the road conditions for smooth traffic operation (risk of possible traffic obstruction, particularly by stones/rock fragments or debris from hill slope)
2) To check the condition of road structures, pavements, shoulders, drainage, walls, and vegetation works.
3) To check condition on the road or in the adjacent area which are likely to affect the road traffic or slope stability.
4) To take necessary emergency action, in case any urgent event is identified
5) When any damage or unusual state is found with road structure during inspection, it should be carefully observed and recorded for reporting and further follow-up.

14.2 Bi-annual Slope Inspection

The scope of Bi-annual Slope Inspection shall include:

1) The interval of Bi-annual Slope Inspection is recommended two times in a year (before and after monsoon season).
2) The purpose of Bi-annual Slope Inspection is to check the slope conditions in detail (before monsoon) and to assess the damage and deterioration of each road structures (after monsoon).
3) When the Inspector finds indication of hazard in a slope, it shall be recorded and reported to DRO and Maintenance Branch in DOR and concerned agencies.
4) Bi-annual Slope Inspection shall focus mainly;
   a) The slopes identified as of Risk Level I, II and III during the General Inspection

b) Inspection shall be made basically by visual observation of the slope, as well as other road features including vegetation, slope surface works, drainage (on-slope), wall and fence at toe, and
c) Pavement, drainage (roadside), shoulders, culvert, which are located adjacent to the slope as well as riverside structures.

5) During the inspection, careful attention should be paid to the Deformation/ Settlement/ Erosion / Scouring/ Rock Fall/ Debris/ Cracks/ Pavement and Road Structures.
6) Generally, inspection shall be made on foot covering the slope area.
7) The Standard Slope Inspection Forms shall be filled and recorded as a part of slope database.
8) Engineers and technicians of the respective DRO shall carry out the inspection and prepare the slope data records

1.4.3 Emergency Slope Inspection

Emergency Slope Inspection shall be carried out after the event of Disaster or very high intensity rainfall in the vicinity. The objective of this inspection is to make proper planning and decision for disaster prevention as well as restoration of traffic operation. Inspection shall be made basically on the following locations.

a) Sections which are prone to recurrent disaster
b) Selected slopes evaluated as Risk Level I and II. Advance planning for Disaster Management is advised for highly risky road sections.

Information on the slopes that collected during Emergency Slope Inspection shall be immediately reported to the DRO and Maintenance Branch in DOR. Necessary emergency action should be taken without delay depending upon the extent of Slope Failure/ Disaster.

14.4 Points to be Considered for Slope Inspection

The following points should be considered while preparing for slope inspection and reporting in order to carry out effective management of a slope disaster.

1) Engineers and Technicians involved in the slope inspection should thoroughly check the general slope inspection and its updated reports. During the inspection they should also carry the copy of past records.
2) Location and Status of critical slopeswith Risk Level I & II should be given higher priority.
3) Any indication of slope failure that observed during inspection are to be immediately reported to concerned agencies.
4) Standard slope inspection forms with the following information should be prepared for reporting;
   a) Location Map

b) Sketches of the Site (plan & sections)
c) Photographs
d) Concept of Proposed Repair or Rehabilitation Works

Points to be considered for General, Regular, Bi-annual and Emergency slope inspection are also presented in Table 1.6.

Table 1.6: Points for Observation and Recording

Position	Structure	Points for Observation and Recording
On-Road	Pavement	Depression, longitudinal or transversal cracks or any defects? (New or progressing?)
		Fallen rocks or debris on the road from hill slope?
	Shoulder	Depression, opened cracks or any defects? (New or progressing?)
Road Side	Drain & Culvert	Drainage obstruction due to blockade or broken by fallen rocks, debris and/or any defects?
	Wall	Fallen material in pocket, breakage, deformation, cracks, tilting, depression, inadequate interlocking, or any defects?
On- Slope	Slope	Rock fall or slope failure: (new or progressing?)
		Depression, swelling, opened cracks, or any defects? (new or progressing?)
		Marked erosion of Gully type (new or progressing ?)
		Spring water or running water on slope or in drains:(any change in discharge and turbidity?)
		Fallen tree or tilting trees on the slope (new or progressing?)
	Slope Works	Breaking, deformation, cracks, tilting, depression, or any defects? (new or progressing?)
River Side	River Protection	River scouring (new or progressing?) Protection works (in sound conditions?)

Training programs shall be arranged in advance for the inspection procedure and recording the slope data.

15 Recording System of Slope Inspection and Maintenance

1.5.1 Importance of Records

Recording and reporting on the slope inspection and maintenance work is an essential procedure in the slope disaster management. The importance of which are;

1) The information collected during Slope Inspection and Maintenance is useful in identifying on-coming slope failure in the near future. In such a situation, suitable action could be taken as soon as possible in order to prevent occurrence of slope disaster that may cause damage to the road traffic and facilities

2) Records and information on the condition of slopes and applied countermeasures are useful to successor staff in DROs for continuity of maintenance activities.

3) Historical records of disaster occurrences and countermeasure implementation provide useful information to prepare further effective and efficient slope management plan.

15.2 Slope Related Database

For planning of Slope Disaster Management the slope related database such as records on slope inspection, disaster occurrences, and countermeasure implementation to be collected and updated by the DROs as well as Maintenance Branch, DOR as shown in Table 1.7

Table 1.7: Slope Related Database

Description of Database		Responsible Organization
Slope Inspection Record	General Slope Inspection	DRO and Maintenance Branch, DOR
	Regular Inspection Record	Once a month in general; Relevant Standard Forms can be used.(DRO)
	Bi-annual Inspection Record	Two times in a year; before & after Monsoon (DRO)
	Emergency Slope Inspection Record	At the time of emergency Relevant Standard Forms shall be used (DRO)
Monitoring Record	Rainfall data	Annual Rainfall data, Rainfall data related with big scale disasters, (DRO)
	Instrument measurement data of mass movement	Any kind of monitoring records for slope (DRO)
Relevant Slope Management Records	Topographical Maps Soil Investigation Report Countermeasure Works	(DRO)

15.3 Format for Slope Recording Sheet

The Standard formats of recording and summary sheet for slope inspection and maintenance are listed in Table 1.8 and attached in the Appendix.

Table 18: Standard Formats

Description of Standard Formats		Note
Recording Sheet	**Slope Inspection Record**	Distinct findings thatlikely to lead slope instability shall be recorded.
	Slope Disaster Record	Slope failures affecting road/ traffic operation shall be recorded.
	Slope Countermeasure Record	All types of countermeasures that applied in slopes shall be recorded.
Summary Sheet	**Slope Inspection Summary**	Lists of all inspected slopes shall be recorded.
	Slope Disaster Summary	List of Slope disasters shall be recorded.
	Slope Countermeasure Summary	List of all slope countermeasures shall be recorded.

16 Road Maintenance

Road maintenance is a continuous process to keep the road in safe and in good conditions. Following three **"R"** are most important practices to observe

a) Record correctly on the Regular Inspection
b) Report quickly to DRO and Maintenance Branch in DOR when found any abnormality
c) Respondimmediately to the matters to be treated

The following activities are important for road maintenance purpose. The details on maintenance of On-Road, Road Side Support and Bridges according to their types such as Routine, Recurrent and Preventive maintenance are described in the DOR Manual **"Road Maintenance Manual for Engineers and Overseers, 2055"** which covers mainly;

1. Materials on the Roads
   If fallen material from hillside slope such as soil, boulder and trees are found, they shall be removed to suitable disposal place.

2. Maintenance of Drainage System
   It is required that the drainage systems on roadside as well as off-road drains shall be kept functioning. If the drainage system is found damaged or clogged, it shall be repaired or cleaned at earliest possible time.

3. Retaining Walls
   Masonry and concrete retaining walls have weep holes for water drain. In some cases, plants grow in the weep holes and block the drainage function of the wall. These weep holes shall be cleaned from time to time.

4. Gabion Wall

   As life of wire is considered to be 15-20years in general, it is necessary to check the condition of the wire. In case of failure of gabion wall suitable repair measures and or structures shall be considered.

5. Gully Erosion

   To prevent the gully erosion, following measures can be applied depending upon the site condition.

   - Construction of catch-drain
   - Construction of channel drain at embankment
   - Turfing
   - Stone riprap
   - Channel drain at outer boundary of shoulder

6. Bio- Engineering

   Maintenance of Bio –engineering works includes;

   - Thinning trees and shrubs
   - Pruning plants
   - Repair vegetative structures such as Palisades, Facine, Brush Layering and Turf
   - Vegetation enrichment
   - Removal of following trees;
     - Unwanted shrubs and trees,
     - Dead trees or those trees, which may fall down themselves,
     - Tree obstructing the traffic or driver's line of sight,
     - Trees surcharging the steep slope,
     - Trees thatneeded to be removed for widening of road.

If season is appropriate and land is fertile, grass seeding can be done to protect the slope surface erosion. Turfing and plantation of suitable species of grass, shrubs, trees, bamboo and other vegetation can be used to control the surface erosion as well as protection of slopes. Growth of Grass, Tree and Bamboos used in bioengineering may also result in obstruction for road traffic and driver's line of sight leading to traffic accidents. Therefore, it is necessary to prune the trees and mow the grasses in regular basis as maintenance work.

Selection of suitable species of plants, grasses, grass seeds, and plantation season with details of maintenance activities are described in "Road Side Bio- Engineering Reference Manual , "Road Side Bio-Engineering Site Hand Book and other relevant documents published by Geo-Environment Unit, DOR.

7. River Bank Protection
   It is important to check the effectiveness of structures in river control and bank protection works. If damages are found it should be immediately reported for the necessary remedial action.

8) Small scale landslides to be treated by;
   - Reshaping to decrease the slope angle
   - Removing the soil mass and dumping it at appropriate place
   - Implementing suitable drainage and retaining structures such as Dry Stone Masonry, Gabion, Cement Masonry and Cribwork.

1.6.1 Road Slope Maintenance

Protection and maintenance work in road corridor and its vicinity are called "Road Side Support Maintenance . Under this category, the protection and maintenance work for road slopes and structures are such as culverts, retaining walls, drain systems, vegetation and river control works.

Road slope maintenance plays important role in the overall road maintenance works. Routine slope maintenance and implementation of preventive countermeasures are most effective for avoiding the possible slope disasters. However, implementation of preventive countermeasures demands much budgetary funding to meet all the requirements. Thus the significance of routine slope maintenance work should be given highest priority.

16.2 Necessity for Slope Maintenance

Slopes differ from road structures that are made of artificial material, soil, concrete, or bitumen. Slopes consist of natural materials, soil and rocks, which have many uncontrollable factors. Slope stability is subject to many factors such as, topography, geological structure, type of rocks and soils, grade of weathering, surface and ground water conditions, effectiveness of protection work, rainfall, and earthquakes. In due course of time various natural and artificial factors contribute to road slope instability despite of proper design and implementation during construction stage. Major natural and artificial factors are;

1) Weathering effect
   Weathering effect is the deterioration of strength and other properties of rocks, soils, and slope protection works in due course of time after completion of construction. Even after several years of road construction and its successful operation, slope failures could occur due to weathering effect due to factors, which may not have been possible to foresee during the construction phase.

2) Effect of Rainfall
   High intensity rainfall is most influential for slope instability in this country. Similarly prolonged rainfall during monsoon period weakens the shear resistance of soil, increases pore water pressure at the slip surface and weight of the groundmass resulting in slope failures.

3) Artificial Factors
   Road Encroachment, Irrigation System, De-forestation, Uncontrolled Quarrying and Construction of Access Roads are among the major artificial factors contributing instabilities in the road slopes.

As many Natural and Artificial factors influence change in the road slope stability conditions, it is very difficult to predict and assess the stability of slope at the time of its design and construction. A continuous monitoring of road slopes and their timely maintenance are therefore indispensable.

CHAPTER 2 SELECTION OF SLOPE PROTECTION WORK

2.1 General

About 70% of the strategic road network in Nepal lies in hill and mountainous terrain with steep slopes and fragile rocks that are prone to slope failure, especially during monsoon season. Various type of slope failures such as Landslide, Debris Flow and Embankment Failures occur frequently along these roads and its vicinity. Proper procedure of slope protection should be applied for planning and designing slope protection methods. In general, following points are to be considered while planning a slope protection work.

1) Suitable countermeasures for road slope failures should be based on a better understanding of the characteristics of road slope failures. Field investigations should start with a comprehensive evaluation of general conditions (Topography, Geology, Vegetation, Failure Type and its Mechanism, Scale of Failure, etc).

2) Water management is an essential factor in controlling slope stability. Suitable drainage system is the most important factor for the safety of both natural and artificial slopes. Quick and effective drainage of surface and spring water, and lowering of ground water table are basic methods for stabilising slopes.

3) In most of the cases Earthwork comprising of Cutting unstable portion of a slope at top and Embankment in the toe part of the landslide can stabilise the slope.

4) Combination of Water Management and Earthworks shall be considered as primary control measures.

5) Restrain measures such as retaining wall and structures like gabion wall and stone masonry can stabilise the slope when failure scale is small and or when the movement of landslide is low.

6) Bio- Engineering shall be considered in every case of slope failures. Proper application of bio-engineering contributes to basic stabilisation of the slope and reduction of negative environmental impact.

7) In large scale slope failures monitoring and control measures should be planned and applied prior to implementation of restrain measures.

2.2 Countermeasure Planning Procedure

Slope protection planning shall consider three approaches such as Risk Reduction, Risk Retention and Risk Avoidance depending on the scale of slope failures as shown Figure 2.1

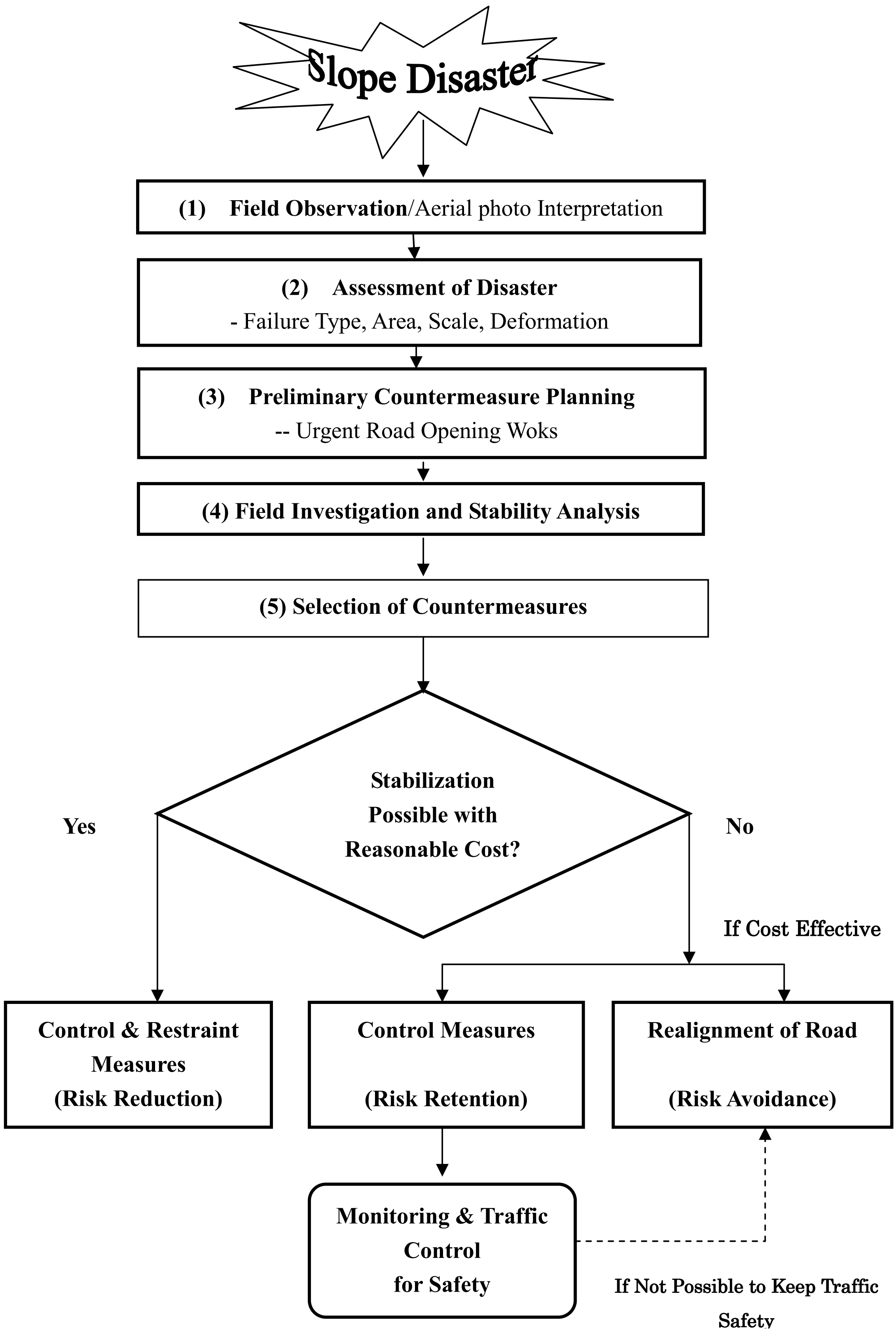


Figure 2.1: Countermeasure Planning Procedure

1) Field Observation

It is recommended that a field observation be carried out by an experienced engineer capable to assess the disaster. At this stage, an aerial photo interpretation is also recommended for understanding the general condition of the failures, especially for a large scale landslide or debris flow.

2) Assessment of Disaster

To assess the disaster mechanism, judgement shall be made based on Failure Type, Area, Scale (volume), Deformation Level etc. At this stage, preliminary countermeasure planning shall be made based on mechanism of disaster. Judgement of the deformation level is significant while designing the slope protection work and traffic operation safety.

3) Preliminary Countermeasure Planning

Preliminary countermeasure planning shall include not only the comprehensive countermeasures but also temporary treatment. Surface drainage works and earthworks are some of the most important and effective works to improve safety of the traffic operation. Especially, draining out of surface, spring and groundwater are effective methods for stabilising the slopes. Additional field survey and investigation shall be planned on the basis of complexity of the failure mechanism.

4) Field Investigation and Stability Analysis

In case of complex and large-scale landslides the field investigation and stability analysis shall be carried out to clarify the mechanism and scale of the landslide. Reasonable restrain measures and rehabilitation plan can be made from the result of the investigation and stability analysis.

5) Selection of Countermeasure

Selection of countermeasures shall be based on the following three approaches;

a) Risk Reduction: Control and Restrain Measures to stabilise the slope
b) Risk Retention: Control Measures, Monitoring and the Traffic Control Safety
c) Risk Avoidance: Realignment of Road

As the cost of countermeasures after a slope failure occurrence is often several times more than that of the same during pre-slope failure stage, it is better to plan to prevent the recurrence of the slope failure through Control and Restraint Work (Risk Reduction). But, slope failures in Nepal are often too large to stabilise by reasonable countermeasure works. If the road relocation (Risk Avoidance) is not cost effective, we have to opt for retaining the risk (Risk Retention). In such a case, suitable control measures and monitoring plan shall be needed to secure the traffic safety.

- **Control and Restraint Measures**
  The control and restraint measures shall be carried out in order to prevent the recurrence of the slope failure. The control measure is mainly composed of the earthwork, water management and bio-engineering work. The restraint work consists mainly retaining structures, anchoring, piling and other slope protection works.

- **Control Measures**
  The control measure is mainly composed of the earthwork, water management and bio-engineering work. Earthworks and Drainages are essential factors in improvement of slope stability.

- **Monitoring and Traffic Control for Safety**
  After implementing control measures, suitable monitoring plan shall be made to secure the traffic safety. Attention should be paid during Regular and Bi-annual Inspection of slopes.

- **Realignment of Road**
  Realignment of road will be selected in case;
  cost effective solution are available for relocation,
  control measures are ineffective to operate the traffic.

It is recommended that the data used for design, records of field inspection, history of damages, repair works, and stabilization works shall be compiled and preserved for use in future design, maintenance, and preventive works.

2.3 Criteria for Selection of Countermeasures

2.3.1 Classification of Slope Failure Type

Assessment of classification of slope failures, its mechanism and scale is important for planning suitable countermeasures.

According to Japanese Classification the types of slope failure are classified into the following six types considering their mode of failure and mechanism. This classification is also applicable to slope failures in Nepal.

(1) Collapse (CL), (2) Rock Fall (RF), (3) Rock Mass Failure (RM),
(4) Landslide (LS), (5) Debris Flow (DF), (6) Embankment Failure (EB)

1) Collapse (CL)

This refers to failure of loose and porous soil and rocks from slope when the loose materials are filled with water during rainfall or are shaken by earthquake. This type of failure occurs suddenly with rapid movement and without prior indication. Mechanism of collapse is the breakdown of loose and porous part of the slope itself.

2) Rock Fall (RF)

Free fall or rolling down of a rock or few rocks individually from a steep slope or cliff. This type of failure occurs suddenly and prone to occur during rainfall and or earthquake. This type of failure could occur with no relation to weather conditions. Generally, the size of rock fall is small and is less than 5 m^3.

3) Rock Mass Failure (RM)

Rock mass failures in a rock slope consist of planar slides, wedge slides, and toppling. The mechanism is closely related to geological discontinuities. Deformation of rock mass indicates possibility of rock mass failure. In general, the size of rock mass failure is more than 100 m^3.

4) Landslide (LS)

Landslides are mass sliding movement of highly weathered rocks or debris and or soil along a rupture surface of the slope. It is characterized by its deformed slope landscape. The size of landslide is generally more than 5,000 m^3 and may range up to millions of cubic meters.

5) Debris Flow (DF)

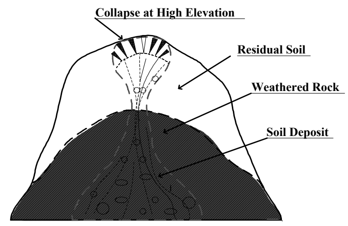
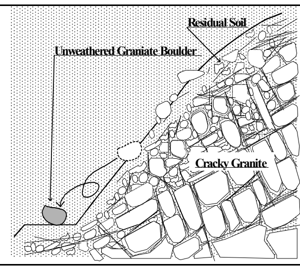
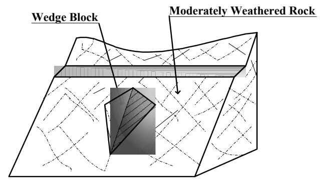
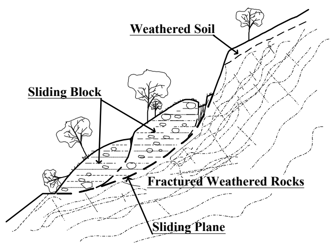
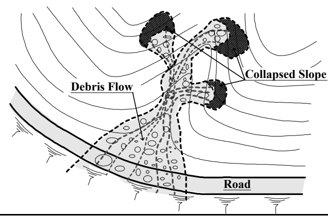
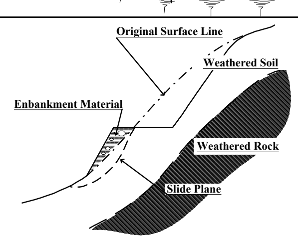
Source of debris flow is located in the upstream of the road slope. Debris flow consisting of rapid flow of boulder, gravel, sand, silt and clay mixed with a large quantity of water is mainly generated by slope collapse and heavy rainfall. It flows down the riverbed with gradient of over 20-degrees and stops to deposit with gradient of under 10 degrees.

6) Embankment Failure (EB)

Embankment failures consist of all types of slope failures such as the slump, collapse of slopes, and settlement of road surfaces. The embankment failures may occur due to insufficient compaction, lack of drainages and scouring at the toe.

Example with schematic illustration for road slope failures is shown in the Table 2.1.

Table 2.1: General Features of Slope Failure

FAILURE TYPE	Characteristics	SCHEMATIC ILLUSTRATION
1. Collapse (CL)	- Collapsing materials are residual soils and highly weathered or jointed rocks. - Prone to occur onsteep slopes. - Mostly triggered by rainfall infiltration - Similar to slump failure in some cases. - Size is generally less than1,000m^3	
2. Rock Fall (RF)	- Free fall or rolling down of hard rocks and boulders - Occur on steep slope and cliff. - Falls occur due to gravity and joints failure. - Size is generally less than 5 m^3.	
3. Rock Mass Failure (RM)	- Materials are hard jointed rocks. - Failure modes include wedge slide, plane slide and toppling. - Size is generally more than 5,000 m^3	
4. Landslide (LS)	- Materials may be soils, debris and or highly weathered rocks. - Marked by gentle and deformed topographic features -Mainly influenced by increased pore-water pressure by infiltration -Size is generally more than 5,000 m^3.	
5. Debris Flow (DB)	- Rapid flow of boulder, gravel, sand, silt and clay mixed with large quantity of water. - Occurs in a contributory area that contains collapsible slopes	
6.Embankment Failure (EB)	- Slump or collapse of embankment slope, - Settlement of road surface - Scouring of toe part	

2.3.2 Classification of Countermeasure Work

Countermeasures for slope failure are classified into three categories and nine groups, depending upon its purpose and application. A suitable combinationof these measures should be applied after assessment of slope failure and its mechanism, importance of the assets to be protected, and the cost-effectiveness. General categories and groups of countermeasures for slope failure are listed in the Table 2.2.

Table 2.2: Countermeasures for Slope Failures

Category	Group
Control Measures	Earthworks: Cutting and Filling, Bio-Engineering: Various methods of vegetation and small scale engineering work in the slope and its vicinity, Water Management: Surface and Sub-surface drainage
Restraint Measures	Slope Work: Stone pitching, Frame work, Anchoring: Rock bolt, Nailing and Ground anchor, Walls and Resisting Structures: Gabion, Stone masonry, Frame wall etc., Protection work: Rock Fall Wire-net, Check Dam, Piling Work: Steel pipe, Pile, Shaft work
Alternative Works	Re-alignment of Road: Route relocation or Re-alignmentby Bridge or Tunnel

All slopes are vulnerable for slope failure, which may be caused by gravity action, rise in pore-water pressure during heavy rain and/or earthquake. Application of "Control Measures should be given at the initial stage of slope failure. Restraint Measures are to be considered as additional measures. Alternative works such as relocation or realignment of road is expensive and therefore it should be applied only if there is no other solution.

Classification and applicability of countermeasures for road slope failure is presented in Table 2.3

Table 2.3: Classification and Application of Countermeasures

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

○: Applicable, △: Limited case, ×: Not applicable, **LS** : Landslide, **CL** : Collapse, **EF** : Embankment Failure, **DF** : Debris Flow

** Series of retaining wall refers to multiple walls along cross section,

Note: Common countermeasures for Rock Fall **(RF)** and Rock Mass Failure **(RM)** are covered within proposed countermeasures for Landslide **(LS)** and Collapse **(CL).** Separate countermeasures for **RF** and **RM** are recommended to be referred in relevant documents.

2.4 Countermeasure Selection for Landslide

2.4.1 Features of Landslide

Landslides are concentrated mainly on those slopes gentler than 30 degrees and associated mostly with rainfall. Their occurrence mechanisms mainly involve a potential weak layer (or surface) and increase of pore-water pressure in the weak layer. Landslides are mostly caused by factors such as geological structure, rock weathering, precipitation anomalies, lateral erosion, road cutting, and so on. It may be up to 100-2000 m long and 50-1000 m wide. Landslides occurrences usually result in significant damage to road network and its structures. A typical diagram of complex landslide and its features are presented in Figure 2.2 and 2.3. The maincharacteristics of landslides are:

- Geology: frequently occurring within specific geologic zones and main structural lines such as Main boundary Thrust (MBT) or Main Central Thrust (MCT).
- Morphology: occurring on gentle slopes of 5 to 30 degrees in inclination.
- Sliding surface: distinctly thin and soft layer, in some cases multiple layers
- Sliding activity continuous and recurrent.
- Rate of displacement: insensible, in most cases less than 10 mm/day.
- Displaced material: almost remaining in original condition.
- Main trigger: rise in groundwater level due to rainfall.
- Sliding scale: may be up to 100-2000 m long, 50-1000 m wide and 5-50 m deep.

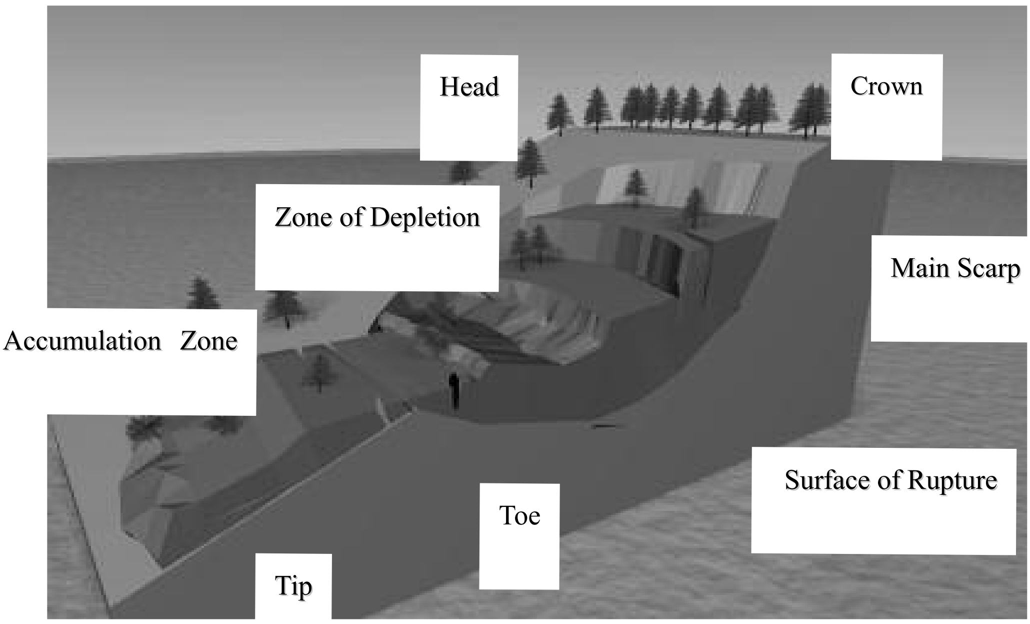
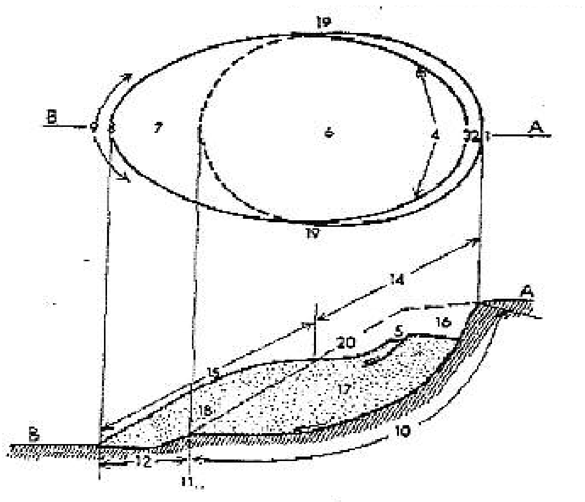


Figure 2.2: Diagram of Complex Landslide (after Varns 1976; modified)



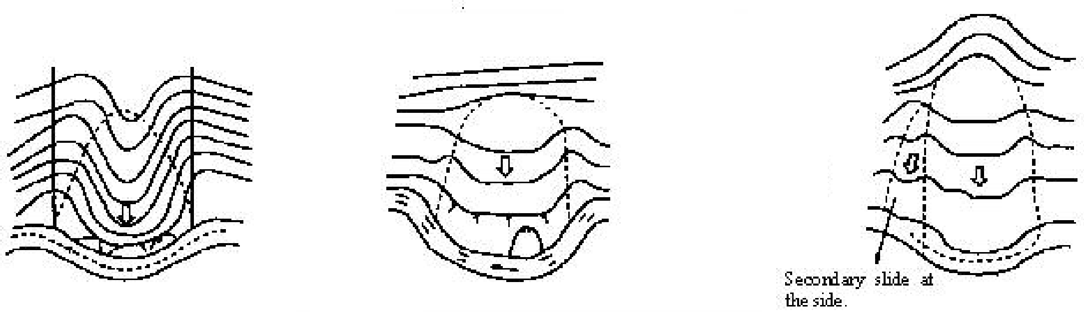
Idealized Landslide Diagrams (1990 IAEG Commission on Landslide)

NO.	Name	DEFINITION
1	Crown	Practically undisplaced material adjacent to highest parts of main scarp
2	Main scarp	Steep surface on undisturbed ground at upper edge of landslide caused by movement of displaced material (13,stippled area) away from undisturbed ground; it is visible part of surface of rupture (10)
3	Top	Highest point of contact between displaced material (13) and main scarp (2)
4	Head	Upper parts of landslide along contact between displaced material, and main scarp (2)
5	Minor scarp	Steep surface on displaced material of landslide produced by differencial movements within displaced material
6	Main body	Part of displaced material of landsiled that overlies surface of rupture between main scarp (Z) and toe of surface of rupture (11)
7	Foot	Portion of landslide that has moved beyond roe of surface rupture (11) and overlies ovoriginal ground surface (20)
8	Tip	Point on toe (9) farthest from top (3) of landslide
9	Toe	Lower, usually curved margin of displaced material of a landslide, most distant from main sscrap (2)
10	Surface of rupture	surface that forms (or that has formed) lower boundary of displaced material (13) below original ground surface (20), mechanical idealization of surface of rupture is called slip surface in Chapter 13
11	Toe of surface of rupture	Intersection (usually buried) between lower part of surface of rupture (10) of a landslide and original ground surface (20)
12	Surface of Sep.	Part of original ground surface (20) now overlain by foot (7) of landslide
13	Displaced Mat.	Material dispalced from its original position on slope by movement in landslide ;forms both deplated mass (17) and accumulation (18); it is strippled in Figure 3-4
14	Zone of Dep.	Area of landslide within which displaced material (13) lies below original ground surface (20)
15	Zone of Acc.	Area of landslide within which displaced material lies above original ground surface (20)
16	Depletion	Volume bounded by main scrap (2), depleted mass (17), and original ground surface (20)
17	Depleted Mass	Volume of displaced material that overlies surface of rupture (10) but underlies oginal ground surface (20)
18	Accumulation	Volume of displaced material (13) that lies above original ground surface (20)
19	Flank	Undisplaced material adjacent to sides of surface of rupture; compass directions are preferable in describing flanks,but if left and right used, they refer to flanks as viewed from crown.
20	Original ground	Surface of slope that existed before landslide tool place.

Figure 2.3: Definition of Landslide Features (after IAEG Commission 1990)

Moreover, these landslides, as stated before, are usually continuous and recurrent, and therefore, exhibit specific morphological characteristics. These morphological characteristics are summarised as follows:

- Surface deformation: head scarps, cracks, toe collapses, a marshy zone or a crack on one or both sides of landslide area.
- Micro relief: depressions, upheaval, bulge, stepped up paddy field.
- Abnormal landforms: convex ridge, convex plateau and concave mound followed by a gentle slope are shown in Figure 2.4.



Convex-ridge type Convex-plateau type Concave- single mound type

Figure 2.4: Typical Landforms for Landslide (After Watari et al., 1987)

- Water fluctuation: pond, swamps, marshes, linear springs, and erosion streams.
- Irregular contour line: contour lines are dense in the upper section of a landslide area, sparse in the middle section, and dense again in the lower section.

The above morphological characteristics, which are recognised through site reconnaissance, and interpretation of photographic and topographic features, can be used to identify and assess a landslide area and its movement direction. These distinct features for identification are:

- Landslide area: bordered by head scarps (or cracks), toe bulges (or small collapses) and side cracks.
- Movement direction: perpendicular to head scarps or head cracks, and almost parallel to side cracks.
- Depth of sliding surface: approximately equal to the 1/7 to 1/10 of the width of a landslide.
- Shape of sliding surface: can be identified by using the locations of toe and head of a landslide, landslide type and the depth of sliding surface.

2.4.2 Countermeasures for Landslide

Countermeasures for landslides can be broadly divided in to two categories as Control Works, Restrain Works and Alternative Works. Control works involve improvement of natural conditions such as, topography, groundwater, or other conditions that indirectly control movement of hole or part of landslide. Restraint works are basically construction of structural elements. If the scale of landslide is large and cannot be stabilized by reasonable countermeasures, an alternative shall be studied.

Table 2.4: Classification of Countermeasures Against Landslides

Category/ Group		Countermeasure Works	
CONTROL MEASURES	**Earth Work**	Earth Work	Cutting
			Filling
	Bio-engineering	Vegetation	Hydro seeding
			Re-Vegetation
	Water Management	Surface Drainage	Drain Ditch
			Cascade
		Subsurface Drainage	Horizontal Drain Hole
			Sub-surface drains
RESTRAINT MEASURES	**Slope Work**	Frame Work	Frame Work
	Anchoring	Anchoring	Rock Bolt
			Ground Anchor
	Wall and Resisting Structures	Retaining Wall	Gabion Wall, Crib Wall
			Cement Masonry, Concrete
	Pile Work	Pile Work	Steel Pile (Pipe or H section)
			Shaft Work or Bore Pile
ALT. WORK	**Realignment of Road**		Diversion,Bridge and/or Tunnel
			Route Relocation

2.4.3 Countermeasure Selection Process for Landslide

Appropriate countermeasure should be selected considering the following points.

1) The works selected should address the mechanism(s) of the landslide, the relationship between precipitation, groundwater and landslide movement, geological, topographical and soil properties, the scale and type of landslide and its likely rate of movement.
2) Control works should be considered as the primary measure for landslide control whereas,restrain t works for stabilization of landslides in order to protect publicassets.
3) Surface drainage works should be immediately carried out to minimise the infiltration of rainwater where landslide movement is closelyrelate d to rainfall.
4) Control works should be performed at first when a landslide is active.

5) Restraint works should be followed after reduction of landslide movement through implementing control works.
6) Cost-effective combination of control and restraint works should be selected. A flowchart for selection of countermeasures against landslides is presented in Figure 2.5.

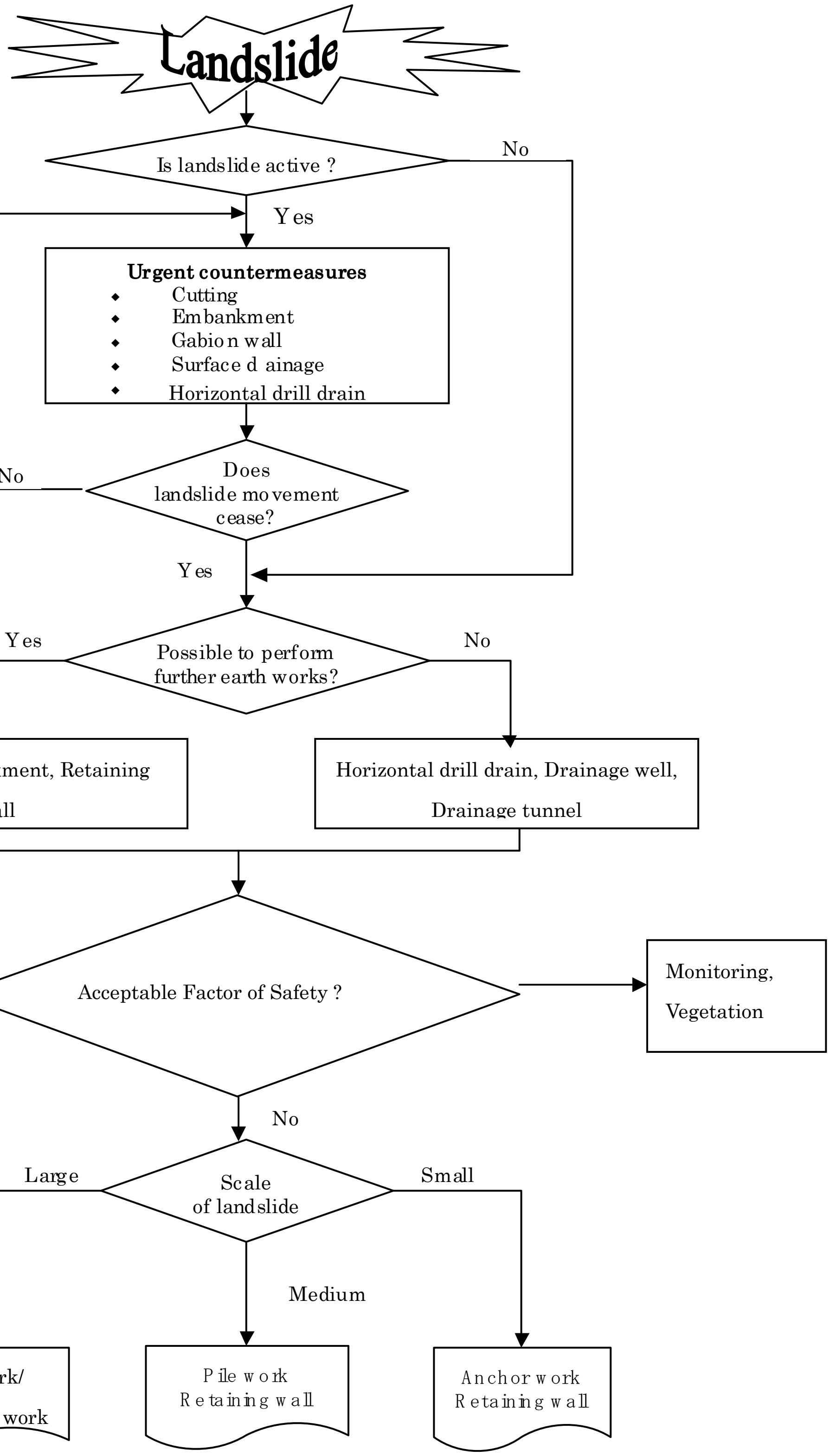


Figure 2.5: Flow Chart for Selection of Countermeasures Against Landslides

2.5 Countermeasure Selection for Collapse

2.5.1 Features of Collapse

Collapserefers to f ailure of loose and porous soil and rocks from slope when the loose materials are saturated with water during rainfall or are shaken by earthquake. This type of failure occurs suddenly with rapid movement and without prior indication.

2.5.2 Countermeasure for Collapse

Heavy rainfall and earthquakes frequentlycause collapses in cut slopes. Many cut slopes are stable during normal conditions but become unstable during or after heavy rainfall. To prevent collapse, either the sliding force must be decreased or sufficient resistance to overcome the sliding force must be added by structures. Suitable countermeasures should be planned based on field conditions. Classification of countermeasures for collapse is given below.

Table 2.5: Classification of Countermeasures Against Collapse

Category/ Group		Countermeasure Works	
CONTROL MEASURES	**Earthwork**	Earthwork	Cutting
			Filling
	Vegetation	Vegetation	Hydro seeding
			Re-Vegetation
	Water Management	Surface Drainage	Drain Ditch
			Cascade, Culverts
		Subsurface Drainage	Sub surface drains
			Horizontal Drilled Drain
RESTRAINT MEASURES	**Slope Work**	Pitching Work	Stone Pitching
		Shotcrete Work	Shotcrete (mortar)
			Shotcrete (concrete)
		Frame Work	Frame work
	Anchoring	Anchoring	Soil Nail
			Rock Bolt
			Ground Anchor
	Wall and Resisting Structures	Retaining Wall	Gabion Wall, Crib Wall
			Stone Pitching Wall
			Concrete Block Wall
		Catch Work	Catch Concrete Wall
	Pile Work	Pile Work	Steel Pipe Pile
			Steel Pile (H section)

2.53 Countermeasure Selection Process for Collapse

An adequate and effective measure for preventing collapse should be selected in consideration of the anticipated causes (topographical, geological, and meteorological), its shape, mechanism, and scale of failures. In general, the following the following criteria should be considered while selecting the countermeasures.

1) Wherever possible, re-cutting work should be selected in overhanging and highly fractured or weathered rock slopes. Slope stability and harmony with the surrounding environment should be considered while planning cutting works.

2) In principle, surface drainage work should be planned and implemented first. Subsurface drainage works should be adopted if spring water exists during normal time and/or rainfall, or a depression exists near the top of the slope.

3) Vegetation, as low cost measure, should be applied on slopes to prevent surface erosion due to rainfall. Where slopes are unsuitable for vegetation, such as fractured or weathered rock slopes measures such as pitching work, shotcrete work, and frame work should be considered.

4) Retaining wall is selected if the toe of a slope is to be stabilised or if it is used as supporting structure for other measures. However, a sound foundation is recommended for retaining structures.

5) Anchoring and/or pile works should be planned if collapse is not controlled by other measures.

Figure 2.6 shows a flow chart for the selection of countermeasures to prevent collapse in cut slope failures.

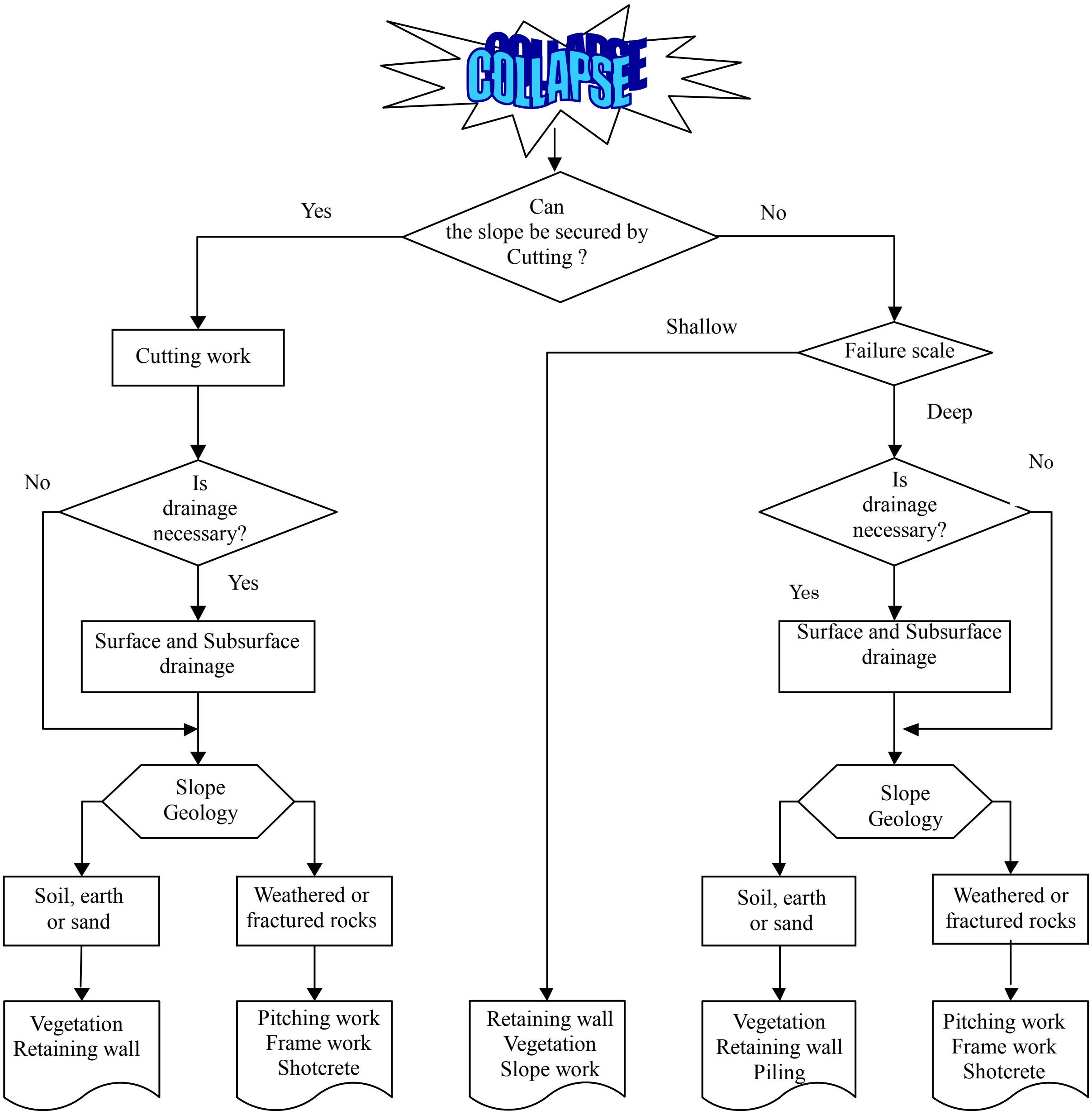


Figure 2.6: Flow Chart for Selection of Countermeasures Against Collapse

2.6 Countermeasure Selection for Embankment Failures

2.6.1 Features of Embankment Failure

Embankment failures consist of all types of slope failures such as the slump, collapse of slopes, and settlement of road surfaces. The embankment failures may occur due to insufficient compaction, lack of drainages and scouring at the toe.

2.6.2 Countermeasures for Embankment

Generally, embankment failure results from;

(1) toe failure of an embankment slope,

(2) scouring on the surface of an embankment slope,
(3) rising pore water pressure within an embankment,
(4) slope gradient steeper than the standard gradient,
(5) settlement of an embankment's ground foundation.

Therefore, countermeasures for embankment failures consist mainly of slope protection and drainage works.

Table 2.6: Classification of Countermeasures for Embankment Failures

Category/ Group		**Countermeasure Works**	
CONTROL MEASURES	**Earth Work**	Earth Work	Embankment
	Vegetation	Vegetation	Hydroseeding
			Re-Vegetation
	Water Management	Surface Drainage	Drain Ditch
			Cascade, Culverts
		Subsurface Drainage	Horizontal Drilled Drain
			Subsurface Drains
RESTRAINT MEASURES	**Slope Work**	Pitching Work	Stone Pitching
		Frame Work	Frame Work
	Anchoring	Anchoring	Soil Nail
			Ground Anchor
	Wall and Resisting Structures	Retaining Wall	Gabion Wall
			Stone Pitching Wall
			Concrete Block Wall
			Cement Masonry Wall
			Frame Wall
			Pile Wall

2.6.2 Countermeasure Selection Process for Embankment

Appropriate measures for preventing embankment failures should be selected with consideration of the causes, mechanism and scale of the anticipated embankment failure, embankment materials, and foundation conditions. In general, the following criteria should be considered while selecting the countermeasures for embankment failure.

1) A standard embankment slope (refer table 3.1) should be designed where sufficient land is available. If sufficient space is not available a retaining structure should be considered.

2) The surface of an embankment slope should be protected by suitable vegetation cover depending upon the susceptibility of embankment materials.

3) Effective drainage work for surface and groundwater is essential, for long-term stability of the embankment slopes.

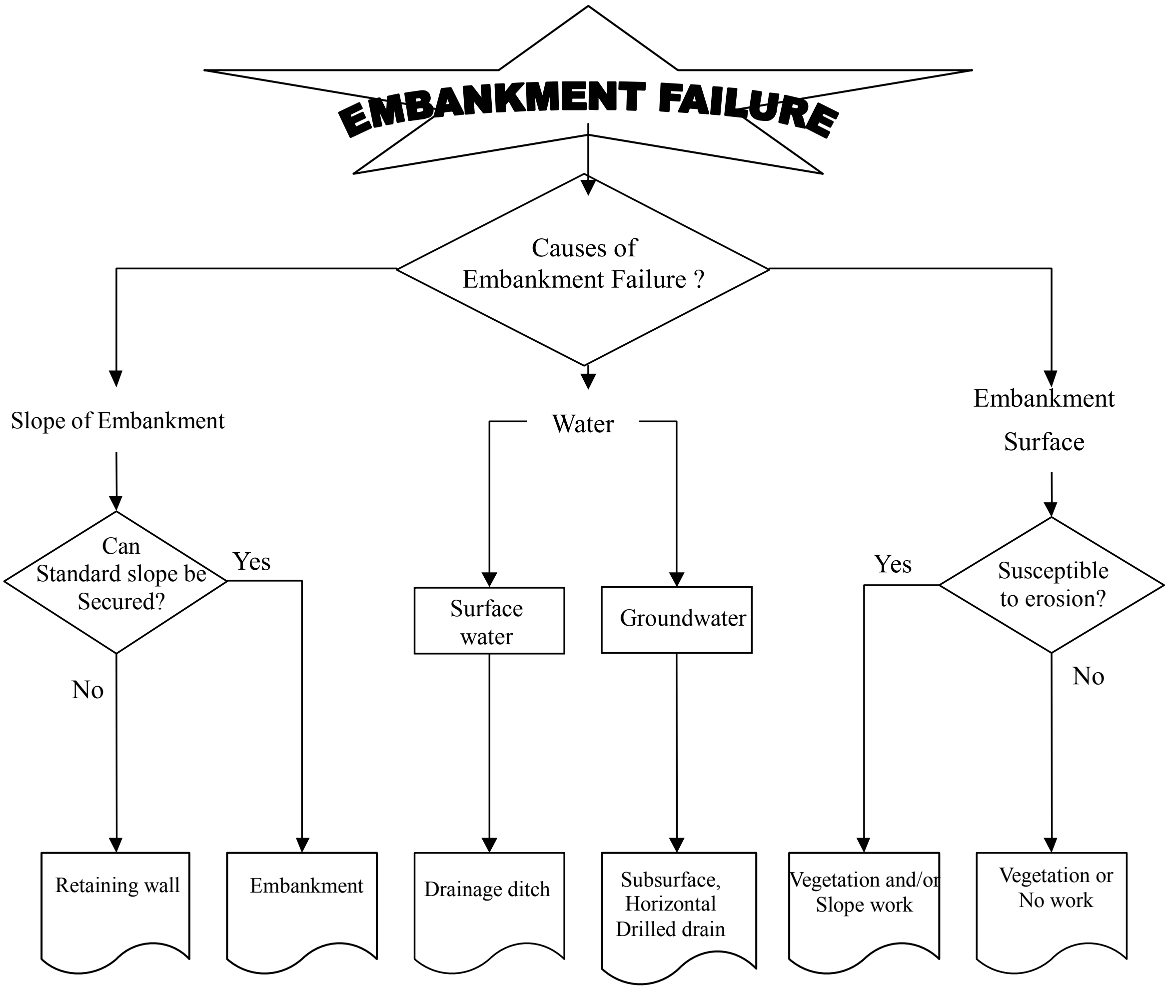


Figure 2.7: Flow Chart for Selection of Countermeasure for Embankment Failure

27 Countermeasure Selection for Debris Flow

27.1 Features of Debris Flow

Debris flows generally involve a source area, transport zone, and a deposit area. Debris flow countermeasures are different for each of these areas and they should be considered separately.

2.7.2 Countermeasures for Debris Flow

Debris flow countermeasure plans should be formulated rationally and effectively with respect to frequency of occurrence and scale of debris flow. For stabilizing the source area of debris flow the range of possible countermeasures are basically same as for landslides and slope collapse. As the area involved is generally wide vegetation and cutting works are effective, however it may be costly. According to their functions and locations the countermeasures for debris flow are classified as

1) Debris Flow Capture Structure

Check dams (Sabo dams) are typical example of this kind of structure which may be impermeable or permeable structure. Their main functions are to reduce the volume of sediment discharge, and to prevent the movement of sediments on streambeds.

2) Debris Flow Depositing Work

Check dams and consolidation works are the main examples for reducing and depositing the debris flows.

3) Debris Flow Training Work

Typical works are revetment, training levee and channel These measures are use d to direct debris flows to a safe place.

A general classification of countermeasures for debris flow is shown in Table 2.7

Table 2.7: Classification of Countermeasures Against Debris Flow

Category/ Group		Countermeasure Works	
CONTROL MEASURES	**Earth Work**	Earth Work	Removal
			Cutting
			Embankment
	Vegetation	Vegetation	Hydro seeding
			Re-Vegetation
	Water Management	Surface Drainage	Drainage Ditch (Channel)
		Water Way	Stone Pitching, Stone riprap
			Concrete Pitching
RESTRAINT MEASURES	**Slopework**	Shotcrete Work	Shotcrete (mortar)
			Shotcrete (concrete)
		Frame Work	Frame Work
	Wall and Resisting Structures	Retaining Wall	Gabion Wall
			Stone Pitching
		Catch Wall	Gabion Wall
	Protection Work	Sabo (Check) Dam	Check Dam (Sabo Dam)
ALT. WORK	**Realignment of Road**		Bridge, Culvert, Causeway,
			Route Relocation

4) Debris Flow Prevention Works

Debris flow usually occurs where there is abundant unstable sediments on stream. To prevent debris flow it is useful to check the sediment at the source area. Preventive works such as cutting, vegetation and or small scale engineering works should be carried out at the source area (collapse, landslide, slope failures) in order to prevent debris flow from mountain slopes.

2.7.2 Countermeasure Selection Process for Debris Flow

In planningcountermeasures on a stream , which is prone to debris flow, various types of countermeasures should be reasonably combined in consideration of the likely occurrence frequency, volume (scale), flow characteristics, topography, and the assets to be protected.

For streams with a high frequency of debris flow occurrence calculate the sediment discharge based on probable sediment discharge of debris flow in the past. For hazardous streams with a low frequency of debris flow occurrence calculate the sediment discharge on the basis of surveys of deposits within the streambed. A combination of countermeasure works comprising of debris flow capture structures, debris flow depositing works, debris flow training works and debris flow preventive works should be planned at right location and scale. A flowchart for selection of countermeasures for debris flow is shown in Figure 2.8.

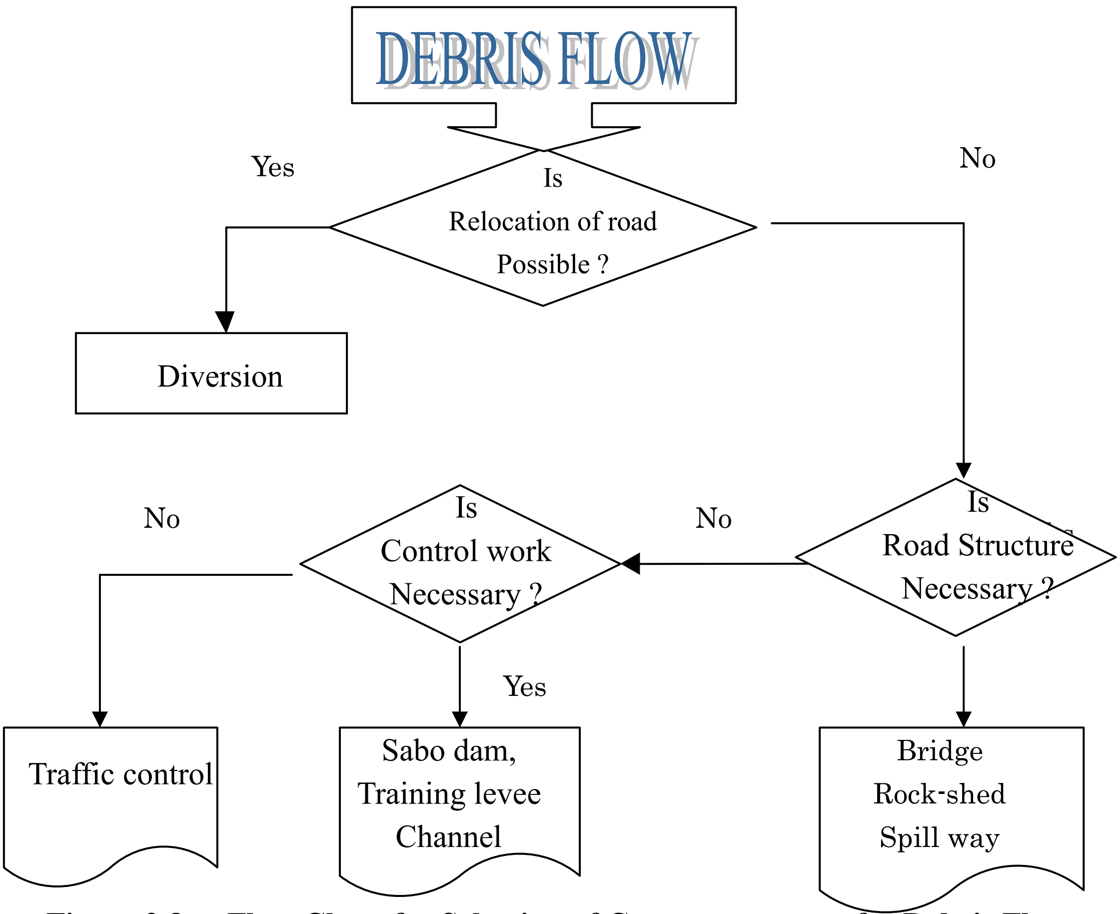


Figure 2.8: Flow Chart for Selection of Countermeasures for Debris Flow

CHAPTER 3: OPTIONS FOR ROAD SLOPE PROTECTION

3.1 Introduction

Countermeasures for the slope failure on road slopes are classified into three categories and nine groups depending upon its purpose and application (refer Table 2.2). A suitable combination of these measures should be applied after assessment of slope failure and its mechanism, importance of the assets to be protected, and the cost-effectiveness.

1) Earthwork
Reducing shear or destabilising force by removing the unstable materials from the upper part of the unstable slope and increasing shear strength or stabilising force along the rupture surface by adding weight at the toe of unstable slope.

2) Bioengineering
Protection from erosion, shallow seated instabilities and weathering of the slope surface by application of vegetative and small-scale engineering works.

3) Water Management
Reducing pore-water pressures in the slope by surface and subsurface drainage.

4) Slope Work
Protection from small collapse, erosion and weathering by application of frame work, shotcrete or pitching work.

5) Anchor Works
Supporting the unstable slope by application of rock bolts, soil nails, and ground anchors.

6) Wall and Resisting Structures
Supporting the slope by construction of retaining walls and similar structures.

7) Gully Protection Work
Protection or reduction of the damages from slope failures by wire net and catch wall. Series of suitable Check (Sabo) dams are applied to check the Debris Flow.

8) Pile Work
Pile works with steel H section piles, steel pipe piles, and reinforced concrete piles are desirable to carryout to support or withstand the moving soil mass if the bed rock is strong. The effect of piles on landslide movement will be less in cases where the motion of landslide is vigorous (exceeding 1 mm per day).

9) Alternative Works
Avoiding the unstable area by relocating a route or by the construction of bridge, tunnel and similar structures.

3.2 Earthworks

Earthwork consisting of cutting and removal of soil mass from upper part of unstable slope and filling or loading at toe (lower portion) is one of the basic and primary control measure.

3.2.1 Cutting

1) Purpose

Cutting work and removal of unstable soil or rock mass at the upper part or head of an unstable or potentially unstable slope is carried out to reduce the load and the shear force. Removal of whole soil mass or part of it is performed in the upper half portion of landslide.

2) Design Considerations

The slope gradient and length of cut slope should be determined on the basis of the geological, hydro geological conditions, and soil parameters. The cut slope gradient should be between 1:0.3 (V:H) and 1:1.5 depending on subsurface conditions and other characteristics. Berms of 1 to 4 m width should be constructed at interval of 5 to 10 m in the vertical direction (height). Attention shall be paid to the geological condition of the slope prior to cutting of the slope. The gradient of the cut slope should be based on the results of the investigation and as approved by the engineer. In designing a cut slope, the following geological conditions should be considered with the utmost care.

a) Colluvial Deposit Slope
Colluviums such as talus and debris flow deposits, being poorly consolidated, usually form a slope with a critical angle of stability. When excavated, the cut slope formed will become unstable. Therefore a wide berm near the boundary between the bedrock and the upper colluvial deposit should be designed.

b) Erosive Sandy Soil
Sandy soils, such as decomposed granite, pit sand or terrace gravel are easily eroded by surface water, which may result shallow collapse.

c) Erodable Soft Rocks
Cut slopes in soft rocks such as mudstone and tuff with low degree of solidification becomes unstable after the completion of cutting because of the weak internal shear strength of the rock and stress release.

d) Fissured Rock Slope
The stability of fissured rock slopes is governed by the degree of fissure development and their distribution.

As a rule, cutting and removal of soil mass should be performed from upper to lower portion to maintain the slope stability. Cutting work should be carried out during dry season. The final cut slopes should be treated with adequate drainages, slope protection works and/or bioengineering works to increase stability against effects of rainfall and infiltration of water.

Protection of the cut slope and itsfoot should be considered in order to prevent erosion and instabilities. Slopes must be protected by means of walls and resisting structures if it is unavoidable to implement steeper slope gradient than the standard gradient. Proper cutting work is effective to safeguard the probable cut slope failures. The recommended standard slope gradient for cut slopes for different soil characteristics are shown in Table 3.1

Table 3.1 Recommended Standard Slope Gradient for Cut Slopes

Soil classification		Cutting Height (m)	Slope Gradient (V:H)
Hard rock			1:0.3 ~ 1:0.8
Soft rock			1:0.5 ~ 1:1.2
Sand	Not dense (loose), poorly graded		1:1.5 ~
Sandy soil	Dense, or well graded	Less than 5 m	1:0.8 ~ 1:1.0
		5~10 m	1:1.0 ~ 1:1.2
	Not dense (loose)	Less than 5 m	1:1.0 ~ 1:12
		5~10 m	1:1.2 ~ 1:15
Sandy soil mixed with gravel or rock mass	Dense, well graded	Less than 10 m	1:0.8 ~ 1:1.0
		10~15 m	1:1.0 ~ 1:1.2
	Not dense (loose), or poorly graded	Less than 10 m	1:1.0 ~ 1:1.2
		10~15 m	1:1.2 ~ 1:1.5
Cohesive soil		Less than 10 m	1:0.8 ~ 1:12
Cohesive soil mixed with rock masses or cobble stones		Less than 5 m	1:1.0 ~ 1:1.2
		5~10 m	1:1.2 ~ 1:1.5

Note1: Recommended standard gradient is only indicative and detailed assessment and design of cut slopes should be carried out by an engineer. Silt is to be classified as cohesive soil.

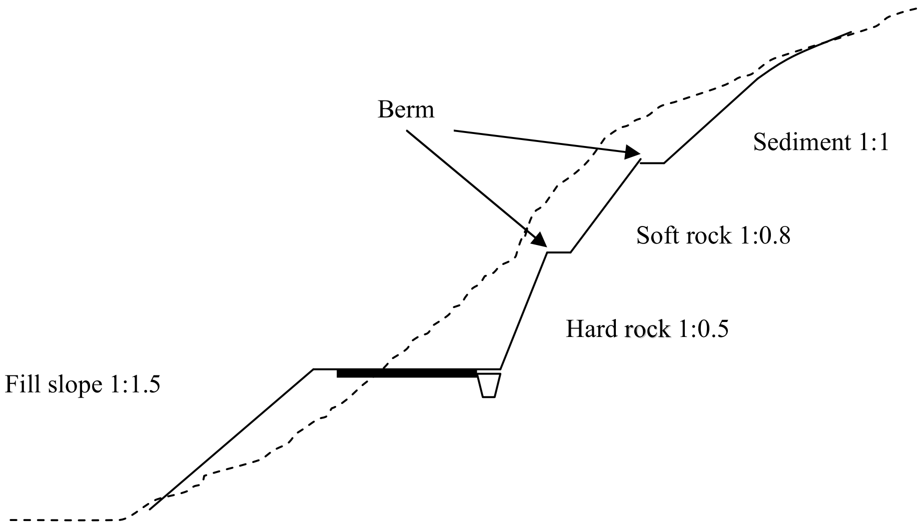


Figure 3.1: Ground Conditions and Shape of Cut Slope

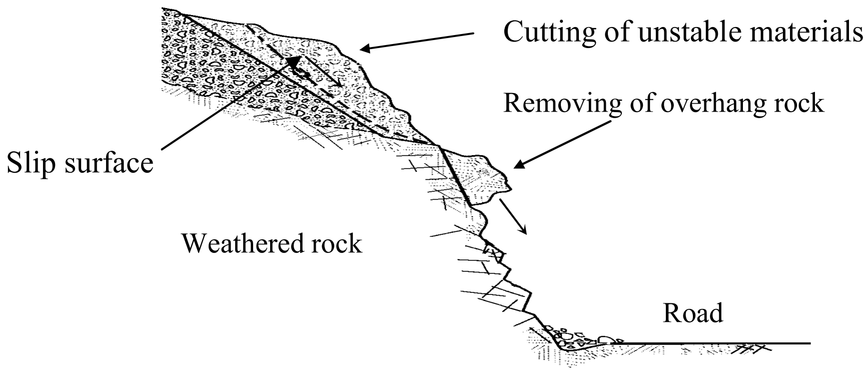


Figure 3.2: Treatment for Cut Slope Failure of Rock Mass

3.2.2 Filling

1) Purpose

Filling work is carried out at the toe of existing or potentially unstable slopes to balance the driving force of loadingfrom top . It is not just a disposal of cutting material from the upper part but should be of proper gradation, compaction and gradient.

2) Design Consideration

The main considerations for design of embankment concerns stability analysis of the existing ground and properties of fill materials. The ground for embankment loading should be able to support the weight of embankment and associated structures without causing any instability. Prior check on natural ground conditions with respect to stability and settlement is recommended before construction of embankment.

In selecting fill materials, their strength and deformation characteristics should be considered. The suitability of fill materials is mainly judged from the classification test and its strength such as CBR test for subgrade and unconfined compressive strength test. The fill slope gradient is also function of characteristics of fill materials. Standard fill slope gradient is shown in the Table 3.2. For high embankment consisting of different layers of fill materials respective standard gradient should be applied for the fill slope of each layer. In high fill construction it is recommended to provide berms of about 1 to 2 m width every 5 to 7 m of height interval with proper drainage considerations in the berms.

As the conditions of ground water also plays stability of embankment slopes the surface and subsurface water management is essential for designing the large embankment slopes. The filling slopes should be treated with sufficient drainages, surface protection works and/or bioengineering works to increase stability against effects of rainfall and infiltration of water.

Table 3.2 Recommended Standard Gradient for Fill Slope

Fill Materials	Fill Height (m)	Slope Gradient (V:H)
Well graded sand, gravels and sand or silt mixed with gravels	Less than 5 m	1:1.5 ~ 1:1.8
	5 ~ 15 m	1:1.8 ~ 1:2.0
Sand with Poorly grading	Less than 10 m	1:1.8 ~ 1:2.0
Rock masses (including muck).	Less than 10 m	1:1.5 ~ 1:1.8
	10 ~ 20 m	1:1.8 ~ 1:2.0
Sandy soils, hard clayey soil and hard clay	Less than 5 m	1:1.5 ~ 1:1.8
	5 ~ 10 m	1:1.8 ~ 1:2.0
Soft clayey soils	Less than 5 m	1:1.8 ~ 1:2.0

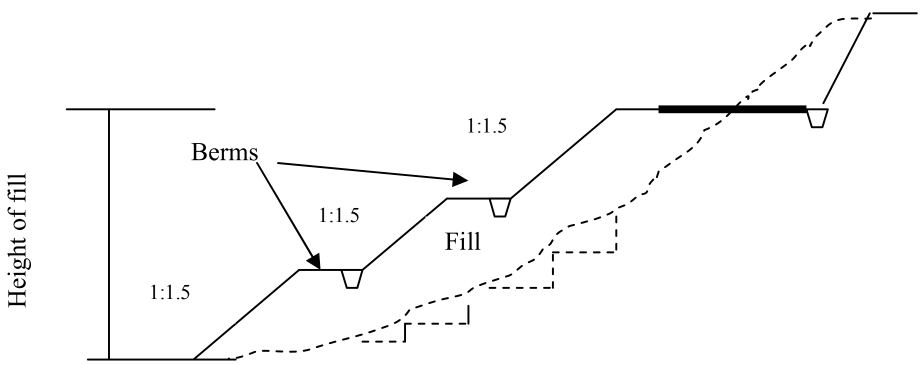
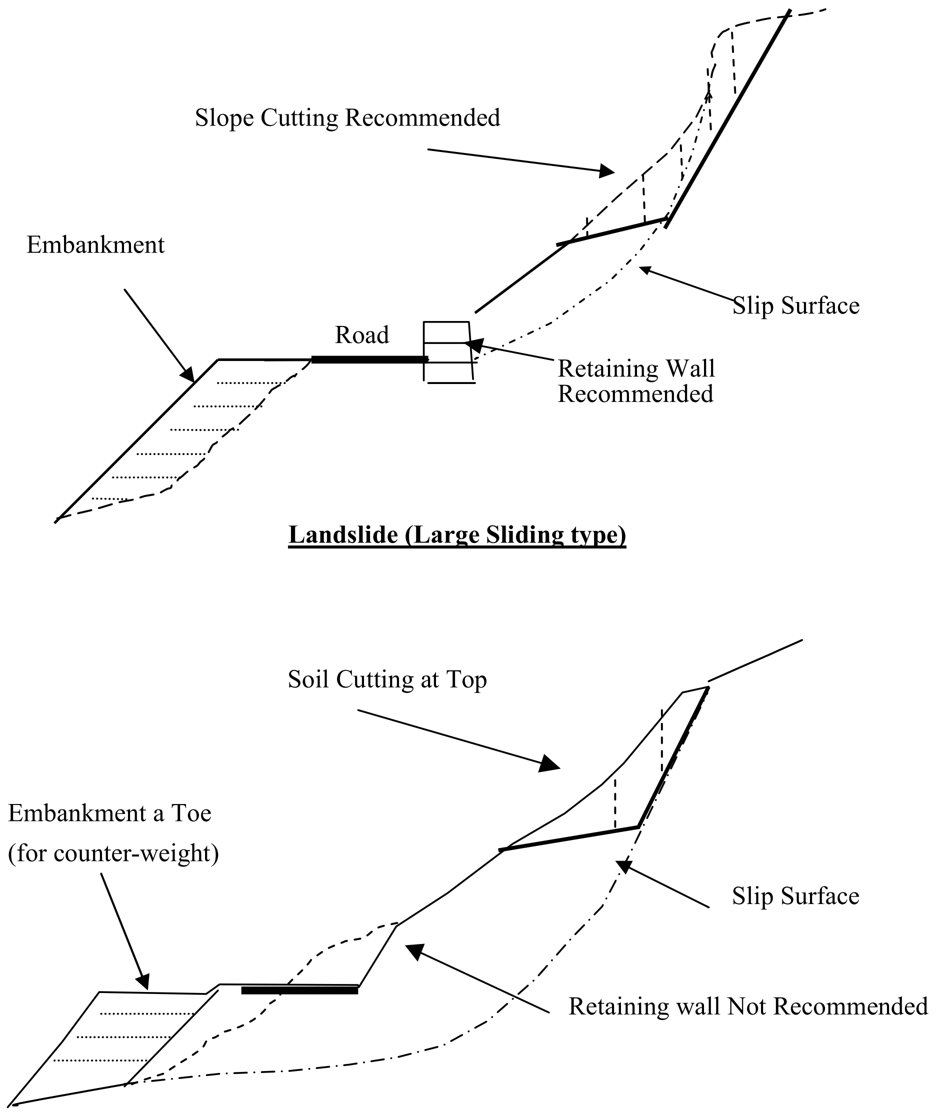


Figure 3.3: Typical Fill Slope with Berms



Landslide (Large Sliding type)

Landslide (Creeping type)

Figure 3.4 Typical Cutting and Filling Works in Landslide

3.3 Bio-engineering

Vegetation cover, as a part of bio-engineering works, protects the slope from erosion in bare slopes and reduces the possibility of shallow seated instabilities. This method is one of the most suitable countermeasures and is normally cost effective.

1) Purpose

The main engineering functions of vegetation on the slopes are;

a) Catch: eroding materials moving down the slope,

b) Armour: the slope against surface erosion from both runoff and rain splash,

c) Reinforce: the soil by providing network of roots that increases the soil's resistance to shear,

d) Anchor: the surface material by extending roots through potential failure plane into firmer strata below,

e) Support: soil mass by buttressing and arching,

f) Drain: excess water from the slope.

2) Design Consideration

Generally, unstable bare slopes are unsuitable for vegetation due to frequent surface failures. There is little possibility of achieving success in developing vegetative cover on unstable slopes without supporting measures. Therefore, vegetation on the slope should be carried out when the slope is stabilized by itself or through implementation of countermeasures.

For selection of vegetative countermeasures, species, and detail design considerations for implementation and maintenance of bio-engineering works reference should be made to **"Roadside Bio-engineering Site Hand Book"** and **"Reference Manual"**, and other relevant publications of DOR.

Figure 3.5: Example of Turfing in Cut Slope (Banepa- Sindhuli- BardibasRoad)

3.4 Water Management

Water management in both the cut and fill slopes is important to protect the slopes from erosion and shallow depth instabilities due to surface water and consequent increase in pore water pressure. In general, water management in slopes consists of surface and subsurface drainages that are capable to take away the water to the natural drainage system safely and as quick as possible. Studies regarding the rainfall, topography, catchment area, ground surface conditions, soil parameters, ground water conditions and existing natural and artificial drainage system should be carried out and assessed to determine the required drainage discharge. Combination of both the surface and subsurface drains could be effectively used to manage the surface and ground water conditions. Water management, being a quick and effective stabilizing measure on landslides and unstable areas, shall be considered as primary control measure. In case of distinctly visible cracks in slope, water infiltration in the ground is to be prevented by sealing cracks using clay or cement, and or polyethylene sheet. A typical example of water management in landslide stabilization is shown in Figure 3.9, which consists of surface and subsurface drainage system together with necessary structures.

3.4.1 Surface Drainage

Surface run off water from springs and rainfall should be prevented from infiltrating the slopes and/or landslide area to avoid increase in pore water pressure. In case of landslides, which are closely related to short-term rainfall, surface drainage works should be immediately executed without loosing time for the results from detail stability analysis. Surface drainage system comprises of catch drain, berm drain, toe drain, drainage channels, and cascades. U-shaped gutter, reinforced concrete, corrugated half pipe drain could be used to construct the drainage ditch. It should be checked that the surface water is properly collected in the ditch and once collected it should not infiltrate the slopes again. To improve the drainage function the drains are to be placed at lowest points of the slopes with proper lining and gradient.

1) Purpose

The main purpose of surface drainage system is collection of surface water due to rainfall and/or spring, and its safe discharge to the nearest natural drainage. Collection is done through catch drain and or numbers of collectors or tributary drains, and the collected water is quickly discharged through drainage channel or main drains.

2) Design Consideration

The design for the sizes of catch drain and the collector drains in the slope is based on the amount of surface runoff it has to cater. The amount of surface water could be estimated based on the intensity of rainfall, catchment area and characteristics of surface conditions. The drainage channel works, main drain and cascades (gabions/ masonry) are designed to remove the collected water out of the landslide zone as quickly as possible. The design of surface drainage system works are often combined with subsurface drains of up to 3 m depth depending upon the necessity of drainage below the ground.

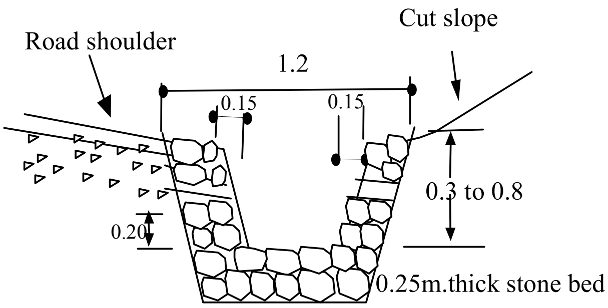
Considering the importance of drainage structures, potenial damages to the road pavement, retaining structures, and slope failures from concentrated runoff; it should be designed according to hydrological and hydraulic considerations. Hydrology such as frequency, intensity, and duration of rainfall, runoff peaks and their frequencies, ground water table and its fluctuation are the most important concerns to the road engineers. Run off could be estimated using the standard methods such as Rational Formula, US Soil Conservation Service Curve Number Method, and California Culvert Practice for Estimating Discharge. Flow in the drainage facilities such as side drain, catch drain, chutes, cascades and culverts that flowing partly full are designed according to principle of flow in open channel. The drainage channels are designed as uniform flow channels considering the flow to be uniform in the constant cross section, roughness and gradient. Most widely used equation for the uniform flow is Manning's Equation with standard coefficient for different materials. Based on the estimation of design discharge from the vicinity and velocity of water in the drainage channel the discharge capacity of channel can be established. Based on the different bed materials in the drainage channel the safe velocity of water is shown in the Table below.

Table 3.3: Safe Velocities in Different Materials

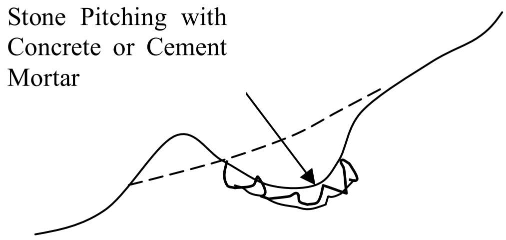
Bed Materials	Safe Velocity (m/sec)
Loose Clay or Fine Sand	Up to 0.50
Coarse Sand	0.50 to 1.00
Fine Gravel, Sandy or Stiff Clay	1.00 to 1.50
Coarse Gravel, Rocky Soil	1.50 to 2.50
Boulders, Rock	2.50 to 5.00

Source: MRE

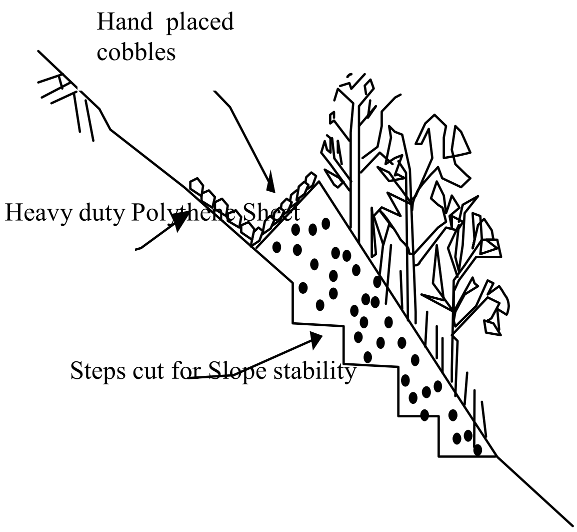
Collector or tributary drains are designed to collect surface water flow by installing corrugated half pipes or lined U-ditches along the slopes, which are then connected to a drainage channel or main drains. To prevent the infiltration of collected surface water the bed of drain is to be lined and or protected with polyethylene sheet. For cleaning and maintenance purpose suitable size of collection chambers should be designed and installed at the junction of collector or tributary drains and drainage channel, and also at points where the gradient and or direction of drain changes remarkably. In case of drain active area of a landslide, drainage ditches should have the required strength and also be easy for maintenance. The drainage channel or main drain along the steep slope should be considered for design of appropriate keying or anchoring structure in frequent intervals in order to prevent sliding of drain. Interval of such keying structure basically depends upon the horizontal force created due to dead load of drain and the gradient of slope.



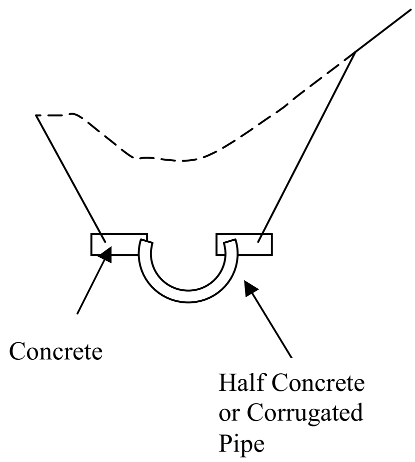
Trapezoidal Cement Masonry Side Drain



Stone Pitching Collector Channel



Catch Drain Lined with Heavy Duty Polythene Sheet



Half Pipe Drainage Channel

Figure 3.6: Typical Surface Drains

3.4.2 Horizontal Drilled Drain

Groundwater conditions in a slope affect the stability of slope. Ground water table usually rises in the rainy season causing saturation of soil mass and may result in the landslides Groundwater table can be at shallow or in depth. Shallow groundwater table (0 to 5 meters below the ground surface) is mainly due to short-term rainfall, which frequently causes a localised shallow failure or toe failure in a large-scale unstable slope. Shallow groundwater is usually drained using the subsurface drains construction which is discussed in separate chapter.

When lowering of groundwater table is required from a depth higher than 5 m, construction of subsurface drains are almost impossible and risky due to excavation problem. In such case the deep groundwater table should be drained out by installation of horizontal drilled drains, drainage wells or drainage tunnels or their combination. Lowering of groundwater table through horizontal drilled drains and drainage wells are one of the most effective methods of stabilizing landslides where the fluctuation of groundwater table is major cause for activating landslides.

1) Purpose

Horizontal drilled drain is used to lower both the shallow (to certain length) and deep groundwater table in a slope to help stabilization of the landslide. The reduction in ground water table in turn helps to;

- decrease the pore water pressure within soil mass,
- increase the shear strength along the slip surface,
- reduce the seepage force and erosion due to seepage,
- reduce the unit weight of soil mass by preventing it from soaking.

2) Design Consideration

Before designing the horizontal drilled drains, it is necessary to carryout geological and geophysical investigations to find out whether the landslide or instability is caused by high seepage problems. It is also necessary to explore the depth and extent of groundwater table, its fluctuation and effect on movement of landslide. Permeable layers of soil mass, springs and aquifers are also to be checked for the necessity of horizontal drilled drains.

Based on the assessment and requirement of the slope conditions the horizontal drilled drains are designed with 20 to 50 meters in length. The diameter of bore holes vary from 50 to 100 millimeters depending upon availability of drilling equipment and are drilled at a gradient of 5 to 10 degrees. After drilling the drain hole suitable size of semi perforated HDP pipe (usually 50 mm dia.) is installed in the whole length of drainage hole. The perforation in the pipe is made on the upper half with 3 mm dia. holes at the rate of 10 to 15 mm distance and in zig-zag pattern. Wrapping of the pipe with geotextile with suitable fixtures, and support at the outlet end is required to make sure the pipe is not clogged and displaced quickly. At the drain outlet suitable support with cement masonry, concrete or gabion structure, and construction of open channel drain to discharge the collected groundwater to the nearest drainage system is required.

The numbers of horizontal drilled drain in the slope mainly depend on the wet area of slope that has to be drained. Usually the drains are made in fan shape and of shorter length. For drains with greater length there will be high risk of non-functioning due to possibility of distortion due to movement.

For the ground water to flow in the horizontal drilled drain pipes the slope should not be of impervious materials or have lot of fines or clay. Typical sketches of horizontal drain are shown in the figure below.

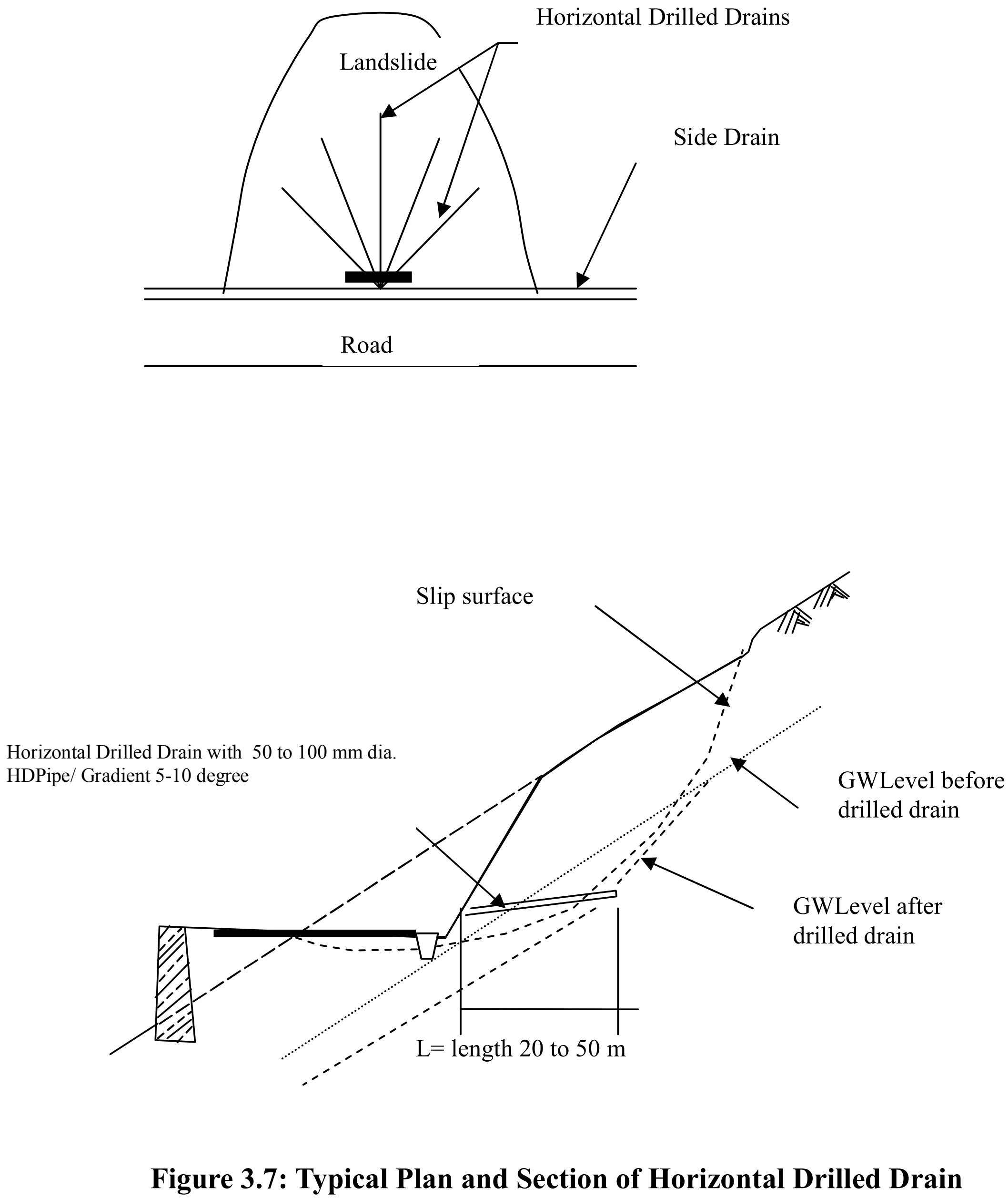


Figure 3.7: Typical Plan and Section of Horizontal Drilled Drain

Figure 3.8: Horizontal Drilled Drain

3.4.3 Sub-surface Drains

Sub-surface Drains (SSD) are effectively used to drain out the shallow groundwater within 0 to 5 m below the ground surface. SSD collects the seepage water from surface runoff and avoids the increase in the groundwater table.

1) Purpose

The main purpose of the SSD construction is to collect and drain out groundwater of shallow depth of up to 3 m depth. By removing such groundwater it is possible to stabilize the shallow failures and also to reduce the ground water table, hence reducing the risk oflandslide due to pore water pressure.

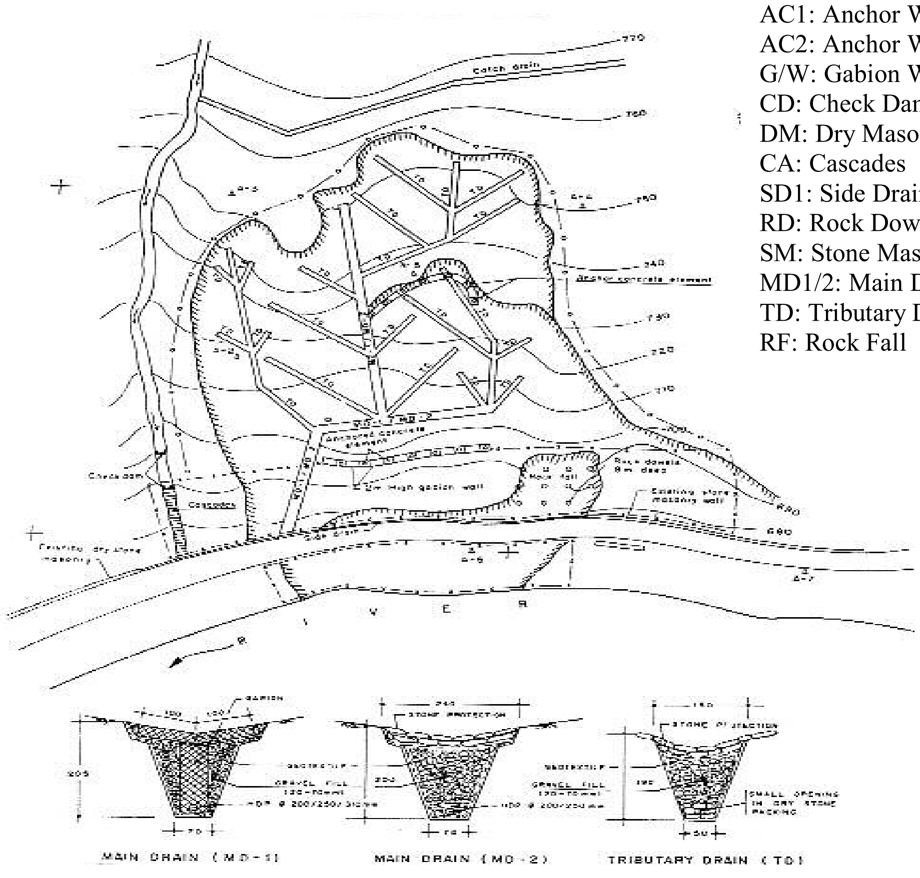
2) Design Consideration

For the design of SSD it is necessary to carryout geological and geophysical investigation to find out whether the landslide or instability is caused by high seepage problems. SSD are designed in the slope if the water seepage and sub-surface water are one of the main causes of instabilities. The SSDs are placed quite similar to surface drains consisting of collector/ tributary drains and main drains. In many cases the surface and sub surface drains are combined for effective drainage purpose.

The size and depth of collector and main drains basically depends upon the area of slope to be covered by the SSD, rainfall intensity, and infiltration characteristics of the ground. Suitable sizes of perforated pipes with filter materials and or together with gabions/ dry stone packing and geotextile materials are used to design the SSD. HDP pipes are recommended at bottom of SSD where amount of collected water is large. At bends, junctions of collector and main drain, and where the length of SSD are long it is recommended to make intermittent catch basin or manhole for clearing purpose. Care should be taken for prevention of infiltration of the collected water as it will be more dangerous to the slope stability. In many cases a polyethylene sheet are also used at the bottom of the SSD to stop the infiltration.

When constructed along the slopes, the SSD may require construction of anchors or support structures at frequent intervals to prevent the drain from sliding. Design of such anchor or support structure depends upon the slope angle, and size and construction of SSD.

Figure 3.9 shows the network of subsurface drains consisting of tributary and main drains together with various drainage and retaining structure that used to stabilize one of the active and large scale landslide in Arniko Highway. Typical design of tributary and main drains are shown using gravel, dry stone packing and gabions.



Legends
D1: Catch Drain
AC1: Anchor Wall
AC2: Anchor Wall
G/W: Gabion Wall
CD: Check Dam
DM: Dry Masonry
CA: Cascades
SD1: Side Drain
RD: Rock Dowels/Bolts
SM: Stone Masonry
MD1/2: Main Drain
TD: Tributary Drain
RF: Rock Fall

Figure 3.9: Landslide Stabilization by Sub-surface Drains

SLOPE INSPECTION SHEET

FORM A: GENERAL IINFORMATION

General Information

Road Name		Road Link	
Chainage of Slope Failure	*Start* ..+… *km* *End* ..+… *km*	Type of Slope	*Cut / Embankment / Natural*
Side of Road	Hill / Valley Right / Left	Effect on Traffic Flow	*High / Low / No*
Slope ID		Inspected Date	
Division Road Office: District: Location:		Inspected by	
		Checked by	
Historical Disaster Record			
Most Likely Failure Type			

Location Map (Show in available Topographical Map (1:25,000)

Slope ID: Road Link/ Chainage at Mid of Slope/ Side of Road

SLOPE INSPECTION SHEET

FORM B: SKETCH

Slope ID	Chainage : *Start* ..+… *km* *End* ..+… *km*	Side of Road: Hill / Valley Right/ Left	Date:

Plan

Section

Note: Sketch with dimensions.

SLOPE INSPECTION SHEET

FORM C: PHOTOGRAPH

Slope ID	Chainage : *Start* ..+… *km* *End* ..+… *km*	Side of Road: Hill / Valley Right/ left	Date:

SLOPE INSPECTION SHEET

FORM D: SLOPE FEATURE

Slope ID	Chainage : *Start* ..+… *km* *End* ..+… *km*	Side of Road*:* Hill /Valley Right/ Left	Date:

GEOMETRY	Length of Slope Failure	*m*	Width of Slope at Toe	*m*
	Angle of Slope (range)	- *deg*	Average Angle of Slope	*deg*
GEOLOGY	Soil type	*Gravel / Sand / Silt / Clay / Peat / other (……………………………...)*		
	Geological Name – Soft Rock	*Siltstone /Phylite / Slate/ Clay stone/ Schist/ Others (………………………………)*		
	Geological Name – Hard Rock	Quartzite/ Granite/ Gneiss / Lime stone/ Sand stone/ Dolomite/ *Others (……………..)*		
EROSION	Sheet Erosion	*Severe (>40% of slope area) / Moderate (10% - 40%) / Minor (<10%)*		
	Rill Erosion	*Severe (0.2 – 0.5m depth) / Moderate (0.05 to 0.2m depth) / Minor (< .05 m)*		
	Gully Erosion	*Severe (>one berm) / Moderate (one berm) / Minor*		
EXISTING COUNTERMEASURE DATA	**Bio-engineering Works**	*Trees / Shrubs / Grass / Gunite / Dental Concrete / Others…….* Percentage covered ………………%		
	Engineering Works		Percentage covered	*%*
	Gabions	*H= m, L= m*	*Rock Bolts*	m^2
	Crib Wall	*H= m, L= m*	*Netting*	m^2
	Concrete Wall	*H= m, L= m*	*Soil Nail*	m^2
	Cement Masonry	*H= m, L= m*	*Piles*	*m*
	Others……..		*Comments*	

DARAINAGE	Roadside Drains	*Good Condition / Needs Clearing / Needs Repair / Not Present*		
	Cascade Drains	*Good Condition / Needs Clearing / Needs Repair / Not Present*		
	Berm Drains	*Good Condition /* Needs Clearing */ Needs Repair / Not Present*		
	Cut-Off Drains	*Good Condition /* Needs Clearing */ Needs Repair / Not Present*		
	Horizontal Drilled Drains	*Good Condition / Needs Clearing / Needs Repair / Not Present*		
	Culvert Chainage			
	Culvert Inlet	*Good Condition / Needs Clearing / Needs Repair / Not Present*		
	Culvert Outlet	*Good Condition / Needs Clearing / Needs Repair / Not Present*		
	Culvert Wing walls	*Good Condition / Needs Clearing / Needs Repair / Not Present*		
	Culvert Passageway	*Good Condition / Needs Clearing / Needs Repair / Not Present*		
	Hydrological Condition	Seepage from Slope Face or Ground : *Yes / No*		
		Natural Surface Runoff : *Yes/ No*	Ponding Water Nearby : *Yes/No*	
	Comments			
PAVEMENT	Cracks :	*Yes / No*	Cause of Cracks :	*Pavement / Slope failure*
	Cracks Sealed :	*Yes / No*	Depression :	*Yes / No*
SHOULDER	Shoulder Cracks:	*Yes / No*	Shoulder Depression :	*Yes / No*
MONITORING (Instrument used, if any)				

SLOPE INSPECTION SHEET

FORM E: Slope Hazard Assessment

Slope ID	Chainage : *Start* ..+... *km* / *End* ..+... *km*	Side of Road: Hill / Valley Right/ Left	Date:

Landslide/Collapse

Hazard Level	Condition	Assessment
High(A)	- A large number of clear deformations such as scarps, bulges, side cracks , and -Visible movements of cracks, subsidence, upheaval, and toe erosion.	
Medium(B)	- Obvious landslide topography such as bulge, stepped land, but - No deformation is found	
Low(C)	- Suspicious of landslide topography , but no evidence . of deformation at present	

Debris Flow

Hazard Level	Condition	Assessment
High(A)	-Occurrence Frequency: Within every two years	
Medium(B)	-Occurrences of Frequency: Over three years	
Low(C)	- Suspicious of landslide topography , but no evidence . of deformation at present	

Embankment Failure

Hazard Level	Condition	Assessment
High(A)	- A large number of obvious clear deformations such as scarps, bulges, side cracks , and - Visible movements of cracks, subsidence, upheaval, and toe erosion.	
Medium(B)	- Obvious landslide topography such as bulge, stepped land, but - No deformation is found	
Low(C)	- Suspicious of landslide topography , but no evidence . of deformation at present	

<u>Remarks</u>: *Identify the Slope Failure Type and Assess the Slope Hazard Level accordingly.*

SLOPE INSPECTION SHEET			
FORM F: Consequence /Risk Level Assessment			
Slope ID	Chainage : *Start* ..+… *km* *End* ..+… *km*	Side of Road: Hill/ Valley Right / Left	Date:

1) Assessment of Consequence

Assessment Criteria	a	✓	b	✓	c	✓
1) AADT	A≧8,00		150≦A＜800		A＜150	
2) Public Asset	Very Important		Important		Less Important	
3)Number of Private House	H≧10		3＜H≦10		H＜3	
4)Time for Road Opening (P in days)	P≧3		1＜P≦3		P＜1	

Note: In overall assessment of Consequence the highest among the four criteria will be considered.

2) Assessment of Risk Level

Hazard Level \ Consequence		Consequence of the Road Slope failure					
		a	✓	b	✓	c	✓
Slope Hazard Level	A	I		I		II	
	B	I		II		III	
	C	II		III		IV	

3) Risk Level and Solutions

Risk Level	Combination Consequence and Slope Hazard	Recommended Solution
I	Aa, Ab, Ba	Implementation of Countermeasures (1st Priority)
II	Ac, Bb, Ca	Monitoring (monitoring by instrument and/or Regular Inspection)
III	Bc, Cb	Bi-annual Inspection (before and after monsoon)
IV	Cc	No more follow-up until some changes occur

Remarks

Form R-A: SLOPE INSPECTION RECORD

Road Name		Road Link	
Slope Failure Chainage	*Start* ..+… *km* *End* ..+… *km*	Type of Slope	*Cut / Embankment / Natural*
Side of Road	Hill / Valley Right / Left	Effect on Traffic flow	High/ Low/ No
Slop ID		Inspected Date	
Division Road Office: District: Location:		Inspected by	
		Checked by	

Pavement	Depression, longitudinal or transversal cracks or any defects ? *(newly found or progressing ?)*	
	Fallen rocks or debris on the road from upper slope ?	
Shoulder	Depression, opened cracks or any defects ? *(newly found or progressing ?)*	
Drain & Culvert	Fallen rocks or debris inside, mal function due to blockade or break, or any defects	
Wall	Fallen material in pocket, breaking, deformation, cracks, tilting, depression, ill-interlocking, or any defects ?	
Slope	Rock fall or slope failure*: (newly found or progressing ?)*	
	Depression, swelling, opened cracks, or any defects ? *(newly found or progressing ?)*	
	Marked erosion of Gully type *(newly found or progressing ?)*	
	Spring water or running water on slope or in drains: *(any change of volume, turbidity ?)*	
	Fall or tilting of tree on the slope *(newly found ?)*	
On-slope works	Breaking deformation, cracks, tilting, depression, ill-interlocking, or any defects ? *(newly found or progressing ?)*	
Any other Comments: (points for careful follow up)		

Lope ID: Road Link/ Chainage at Mid of Slope/ Side of Road

Form R-B: SLOPE DISASTER RECORD

Road Name		Road Link	
Chainage	*Start* ..+… *km* *End* ..+… *km*	Type of Slope	*Cut / Embankment / Natural*
Side of Road	Hill / Valley Right/ Left	Effect on Traffic Flow	High/ Low/ No
Slope ID		Inspected Date	
Division Road Office: District Name: Location:		Inspected by	
		Checked by	

Date and Time of Occurrence	Date : / Time : am / pm
Type of Failure (may be more than one)	1. Landslide 2. Collapse 3. Rock Fall 4. Rock Mass Failure 4. Debris Flow 5. Embankment Failure 6. Others (specify)………….
Dimension of Slope Failure	Length m in longitudinal direction of road Height m (both approximate figures)
Volume of Fallen Debris/ Rocks	m^3 (Approximately)
Damage and loss	Road/ Road Structures/ Vehicles / Other Assets : Death or Injury :
Emergency Operation	Scope of Operation : Traffic Blockage Duration (Yes or No)………………/ …………………… (hours / days / months)
Rainfall (before the failure)	24 hours Rainfall of the Day mm (Date : / / Maximum hourly Rainfall : mm (Date : / / Time:…………….. (am/ pm) Total for proceeding 3 days : mm (Date : from…………………..to ………………………….
Data Source	
Remarks (Related causes, Proposed conceptual countermeasure and others)	
Rough Sketch of Failure	

Slope ID: Road Link No./ Chainge at Mid of Slope/ Side of Road

Form R-C: SLOPE COUNTERMEASURE RECORD

Road Name		Road Link	
Chainage	*Start* ..+… *km* *End* ..+… *km*	Type of Slope	*Cut / Embankment / Natural*
Side of Road	Hill / Valley Right / Left	Effect on Traffic	High/ Low/ No
Slope ID		Inspected Date	
Division Road Office: District: Location:		Inspected by	
		Checked by	

Date of Last Failure Event	**Month:** **Year: 200 __**		
Type of Failure (may be more than one)	1. Landslide 2. Collapse 3. Rock Fall 4. Rock Mass Failure 5. Debris Flow 6. Embankment Failure 7. Others (Specify)…….		
Date for Implementation of Countermeasures	**Month:** **Year: 200 __ (Completion)**		
Objective of Countermeasure Implementation	Control/ Restraint/ Alternative works/ others …………..		
Details of Countermeasure	**Type of work**	**Quantity**	**Remarks**
1)			
2)			
3)			
4)			
5)			
Remarks			
Summary of Contract [Reference Data]	Contract No: Contracting Office: Headquarters / Regional Office/ Division Road Office/ ………… Supervising Office / Officer: Name of Contractor : Total Contract Amount: Construction Period : to Amount of Expenditure on Slope Works: NRs. Chainage of Works : from to Number of Slopes to Work : Remarks:		
Rough Sketch of Implemented work			

Slope ID: Road Link / Chainage at Mid of Slope/ Side of Road

Form R-D: SLOPE INSPECTION SUMMARY

(For Regular, Bi-annual and Emergency Inspection)

Road Name		From (M/Y)	/ 200__
Chainage	*km-* *km*	To (M/Y)	/ 200__
Division Road Office		Checked by	(date:)

Slope ID	Date of Inspection: ……………… Name of Inspector: ………………………	Date of Inspection: ……………… Name of Inspector: ………………………	Date of Inspection: ……………… Name of Inspector: ………………………	Date of Inspection: ……………… Name of Inspector: ………………………	Date of Inspection: ……………… Name of Inspector: ………………………
	Marked Findings, if any	**Marked Findings, if any**	**Marked Findings, if any**	**Marked Findings, if any**	**Marked Findings, if any**

Form R-E: SLOPE DISASTER SUMMARY

(To be prepared at each time of filling-in of SLOPE DISASTER RECORD)

Road Name		From (M/Y)	/ 200__
Chainage	From ..+…. To ..+… *km*	To (M/Y)	/ 200__
Division Road Office		Checked by	(date:)

Slope ID	Disaster Occurrence Data			Name of Inspector	Comments (Blockage duration, Treatment measure etc.)
	Date	Type of Disaster	Causes of Disaster		

Form R-F: SLOPE COUNTERMEASURE SUMMARY

(To be prepared at each time when of filling-in Slope Countermeasure Record)

Road Name		From (M/Y)	/ 200__
Chainage	From .. +… *km to* …+… *km*	To (M/Y)	/ 200__
Division Road Office		Checked by	……………… (date:)……..

Slope ID	Countermeasure Data			Name of Inspector	Comments
	Countermeasure Type	Completion Date	Location of Countermeasure		

Format 5,02

ROAD CLOSURE REPORT FORM

LOCATION

Division Road Office

Highway ☐ Feeder Road ☐ Urban Road ☐

Name of the Road

Chainge (or any description allowing the closure to be located along the road or, location in available topographical map (1: 125,000)

DATE AND DURATION

Road closed on (date) / / at : hrs.

Road reopened to trucks/buses on / / at : hrs.

CAUSE

Slide ☐ Wash-out ☐ Flood ☐ Others

RESOURCES USED FOR REOPENING

Approximate cost (mapower, fuel,materials,etc.) NRs.

Equipment used	Equipment Available on-site (in days)	Equipment Working Hours
1. Tipper		
2. Loader (Make, capacity)		
3. Dozer (Make, capacity)		
4. Backhoe (Make, capacity)		
5. Others (Specify)		

REMARKS