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

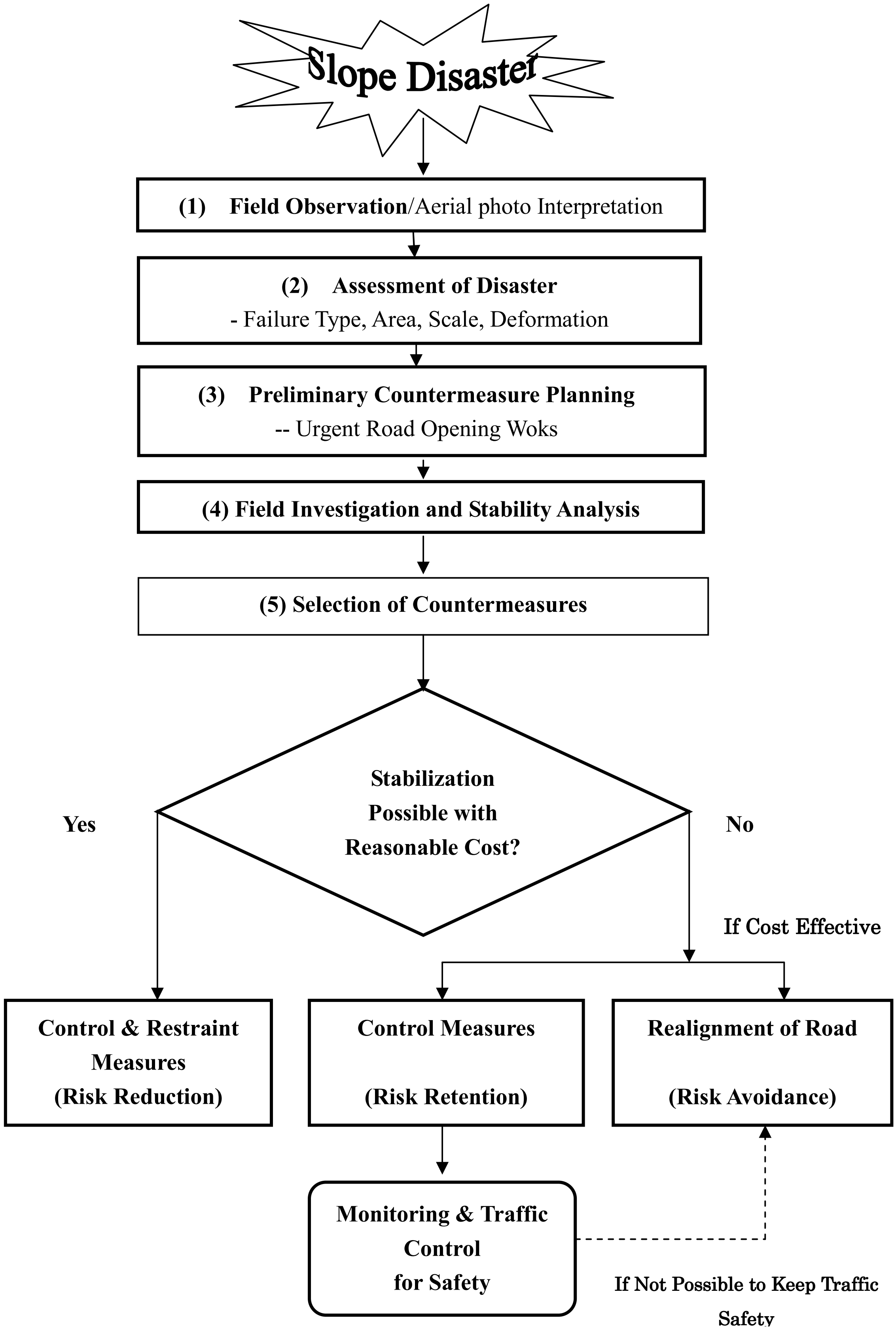


Figure 2.1: Countermeasure Planning Procedure

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)

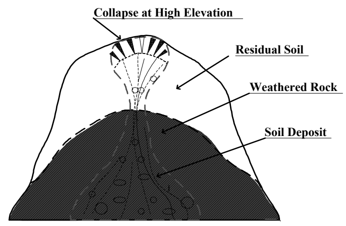
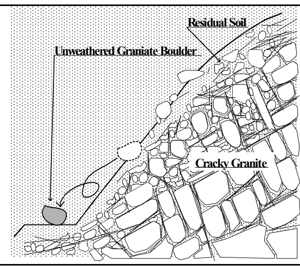
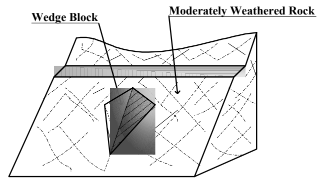
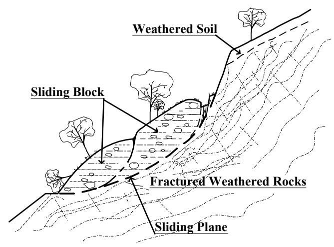
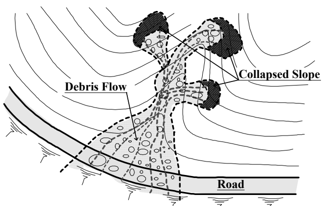
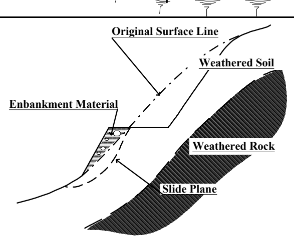
Source of debris flow is located in the upstream of the road slope. Debris flow consisting of rapid flow of boulder, gravel, sand, silt and clay mixed with a large quantity of water is mainly generated by slope collapse and heavy rainfall. It flows down the riverbed with gradient of over 20-degrees and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

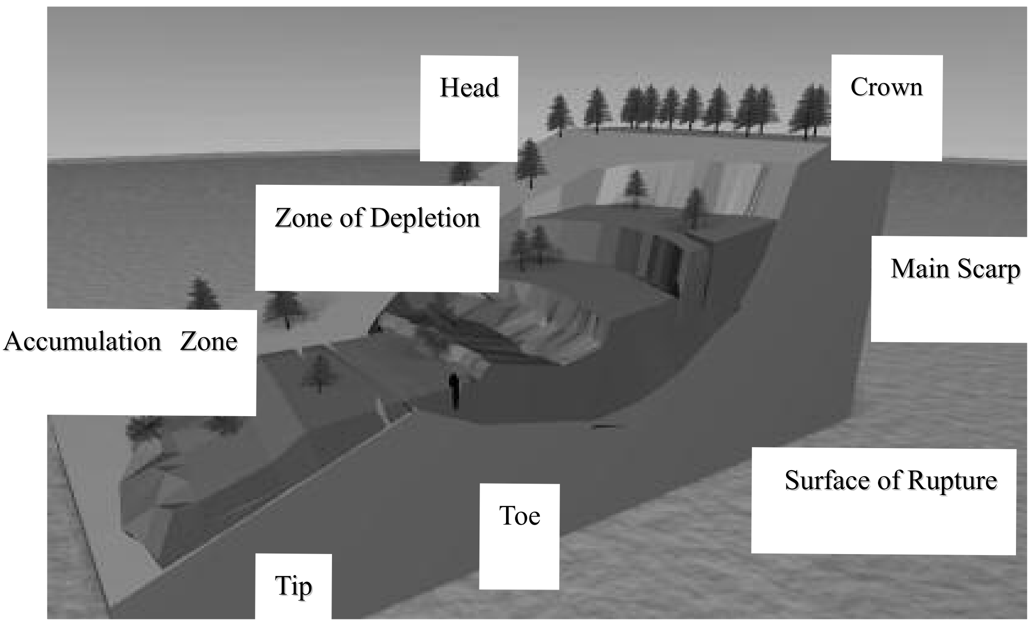
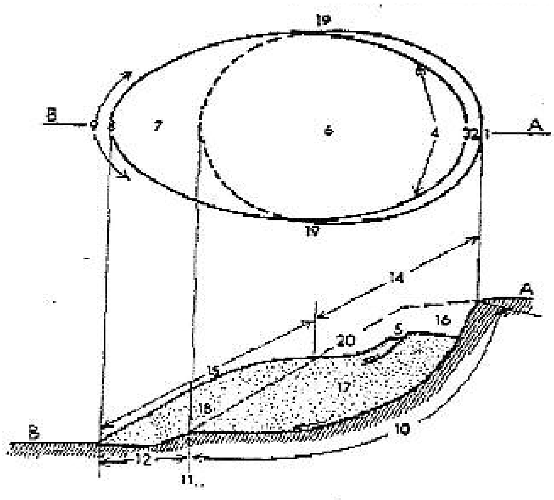


Figure 2.2: Diagram of Complex Landslide (after Varns 1976; modified)



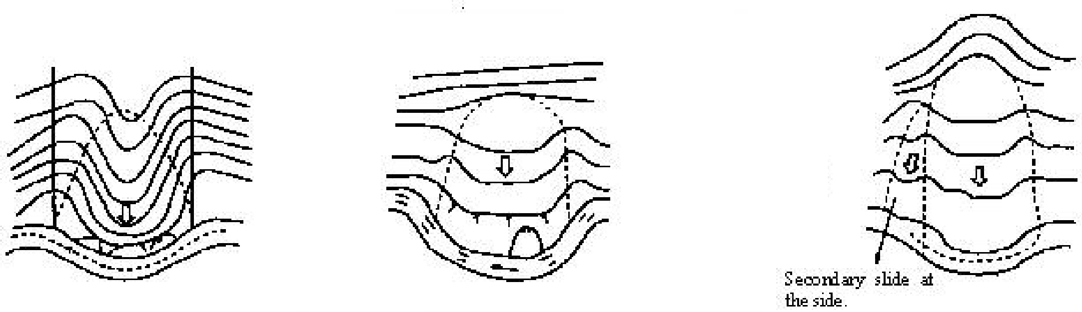
Idealized Landslide Diagrams (1990 IAEG Commission on Landslide)

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.

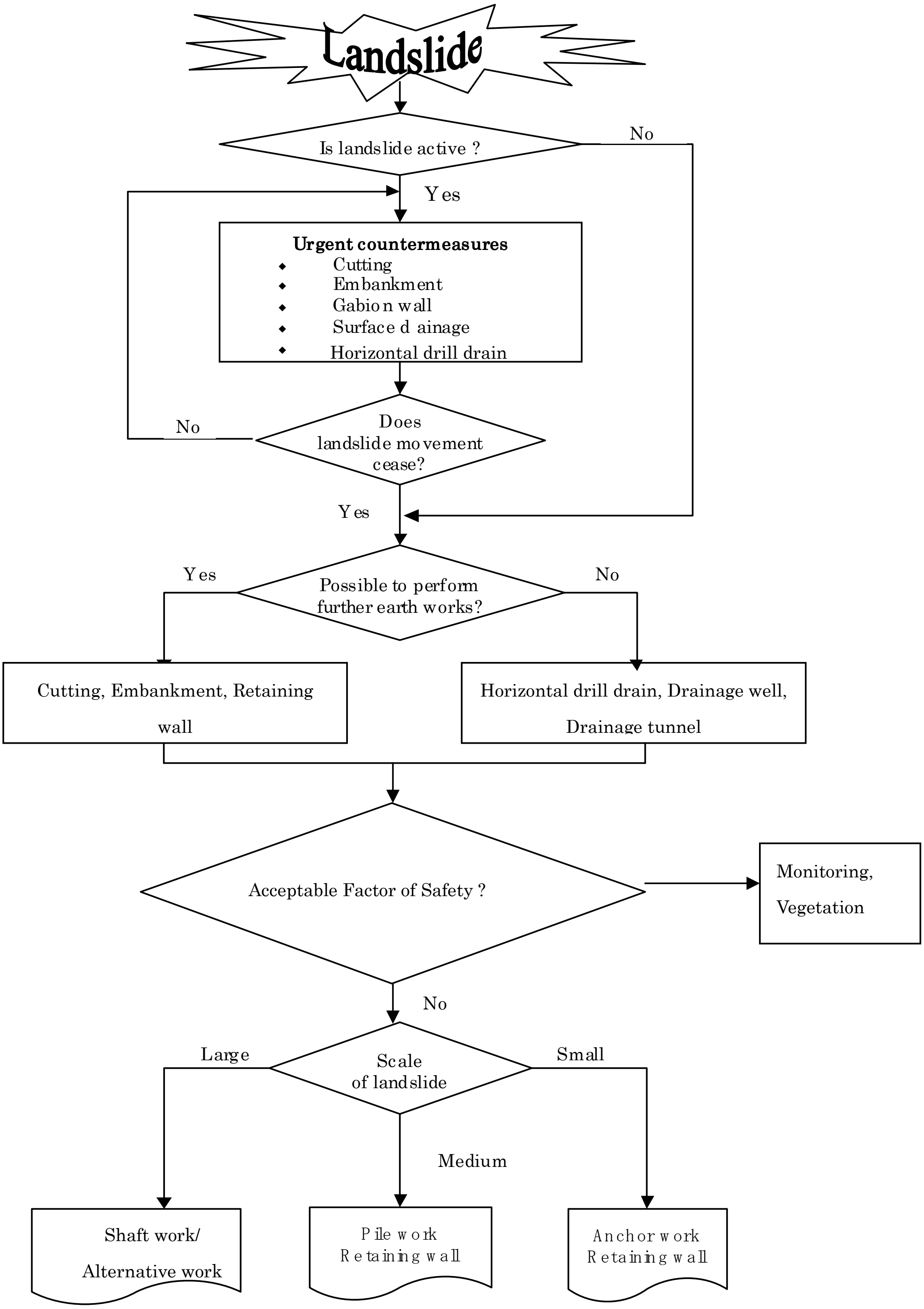


Figure 2.5: Flow Chart for Selection of Countermeasures Against Landslides

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.

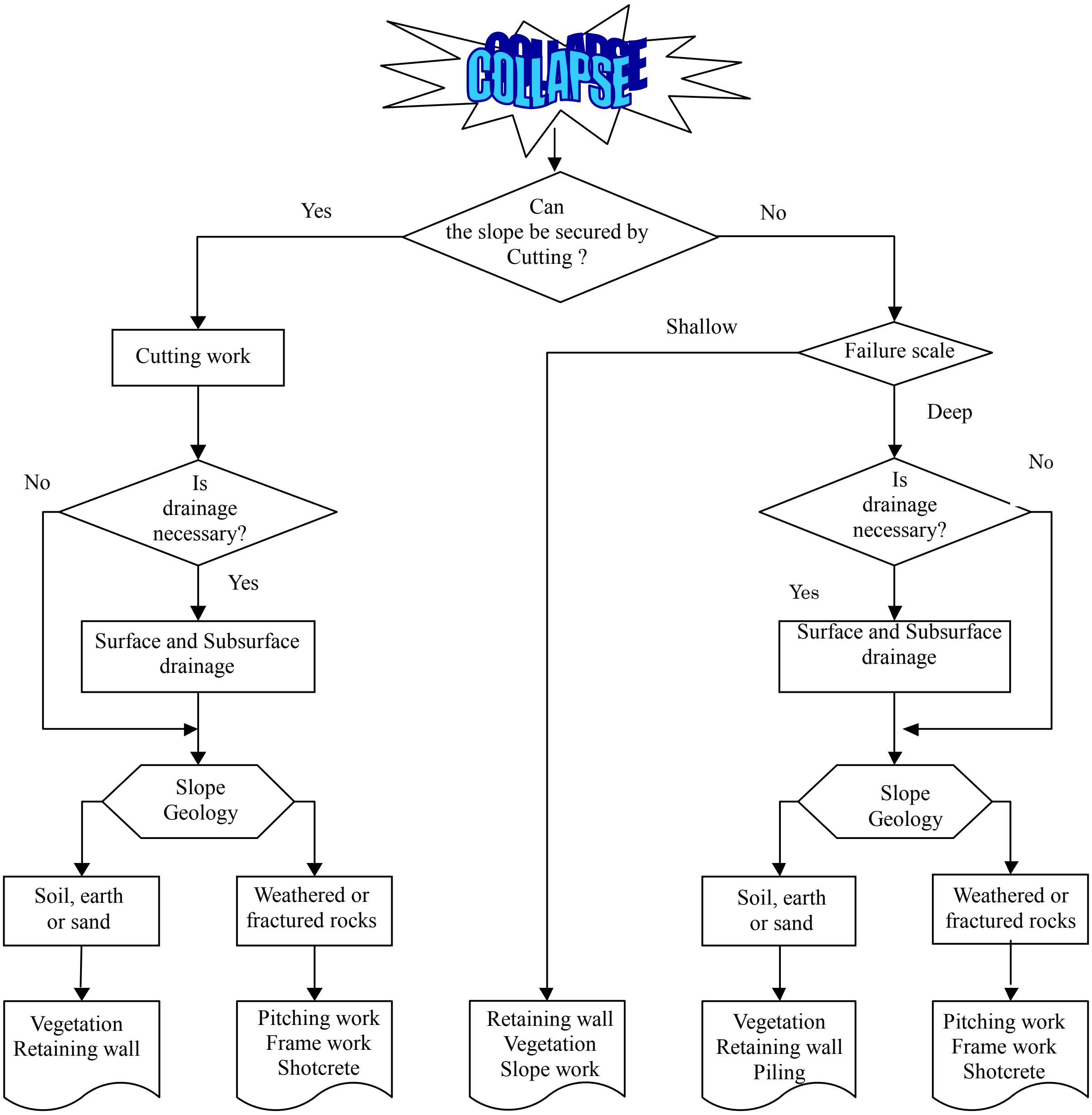


Figure 2.6: Flow Chart for Selection of Countermeasures Against Collapse

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.

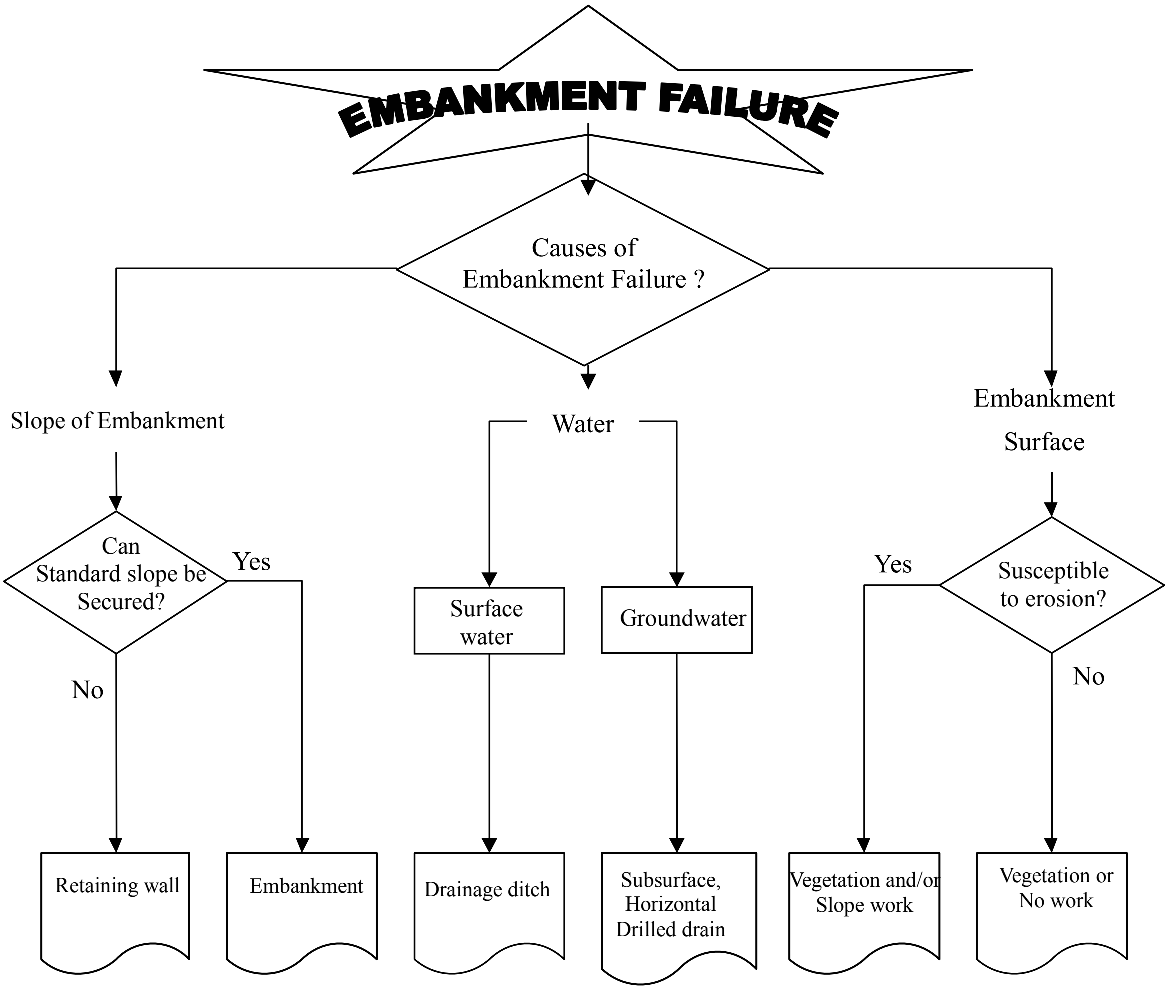


Figure 2.7: Flow Chart for Selection of Countermeasure for Embankment Failure

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

<table>
<tr><th colspan="2">Category/ Group</th><th colspan="2">Countermeasure Works</th></tr>
<tr><td rowspan="8">CONTROL MEASURES</td><td rowspan="3">Earth Work</td><td rowspan="3">Earth Work</td><td>Removal</td></tr>
<tr><td>Cutting</td></tr>
<tr><td>Embankment</td></tr>
<tr><td rowspan="2">Vegetation</td><td rowspan="2">Vegetation</td><td>Hydro seeding</td></tr>
<tr><td>Re-Vegetation</td></tr>
<tr><td rowspan="3">Water Management</td><td>Surface Drainage</td><td>Drainage Ditch (Channel)</td></tr>
<tr><td rowspan="2">Water Way</td><td>Stone Pitching, Stone riprap</td></tr>
<tr><td>Concrete Pitching</td></tr>
<tr><td rowspan="7">RESTRAINT MEASURES</td><td rowspan="3">Slopework</td><td rowspan="2">Shotcrete Work</td><td>Shotcrete (mortar)</td></tr>
<tr><td>Shotcrete (concrete)</td></tr>
<tr><td>Frame Work</td><td>Frame Work</td></tr>
<tr><td rowspan="3">Wall and Resisting Structures</td><td rowspan="2">Retaining Wall</td><td>Gabion Wall</td></tr>
<tr><td>Stone Pitching</td></tr>
<tr><td>Catch Wall</td><td>Gabion Wall</td></tr>
<tr><td>Protection Work</td><td>Sabo (Check) Dam</td><td>Check Dam (Sabo Dam)</td></tr>
<tr><td rowspan="2">ALT. WORK</td><td rowspan="2" colspan="2">Realignment of Road</td><td>Bridge, Culvert, Causeway,</td></tr>
<tr><td>Route Relocation</td></tr>
</table>

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.

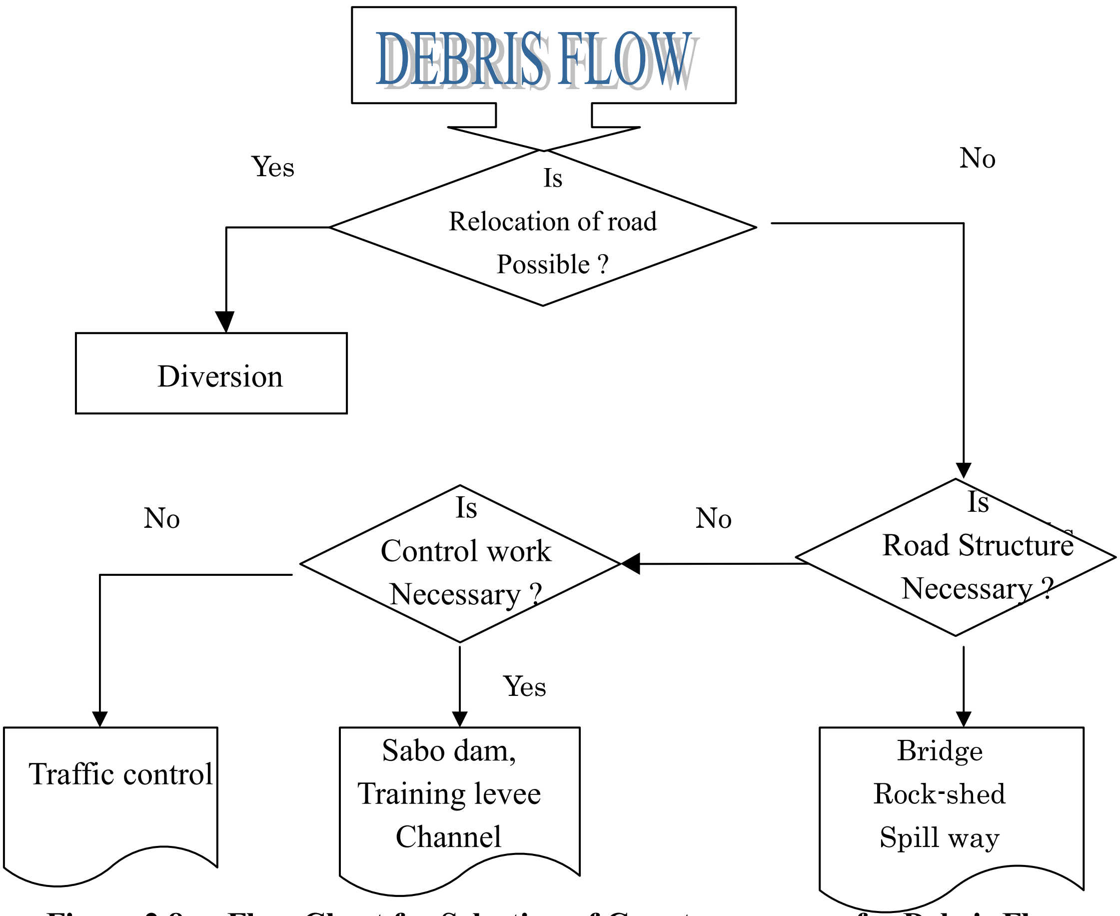


Figure 2.8: Flow Chart for Selection of Countermeasures for Debris Flow