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.

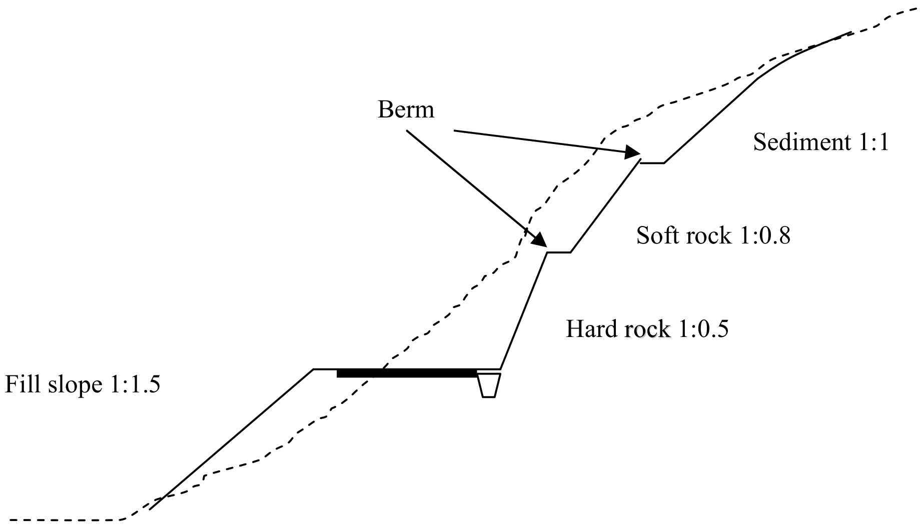


Figure 3.1: Ground Conditions and Shape of Cut Slope

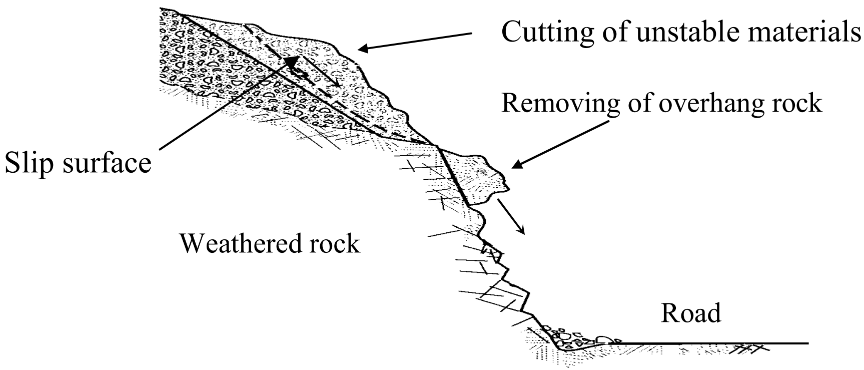


Figure 3.2: Treatment for Cut Slope Failure of Rock Mass

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

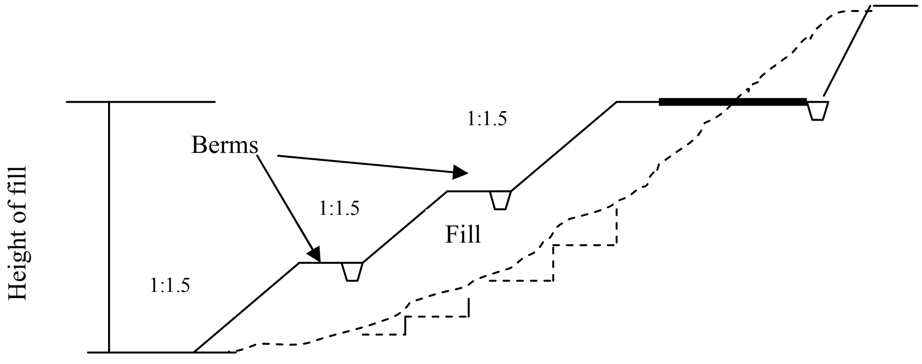
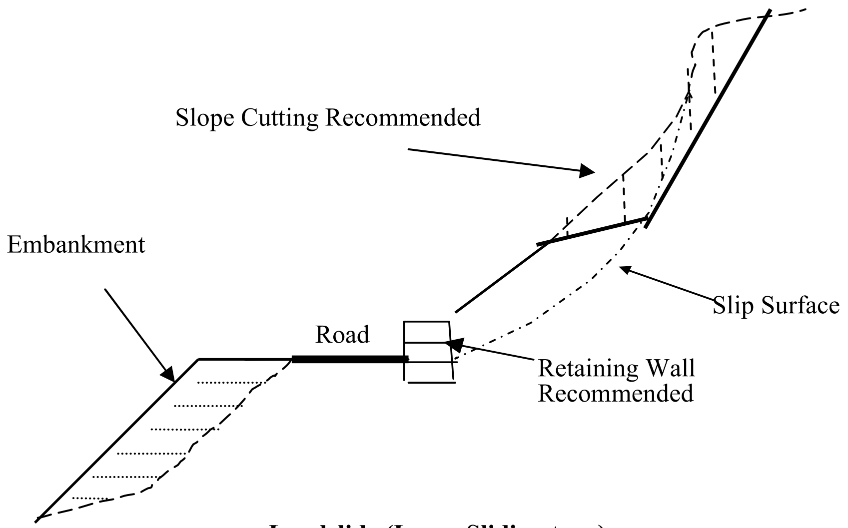
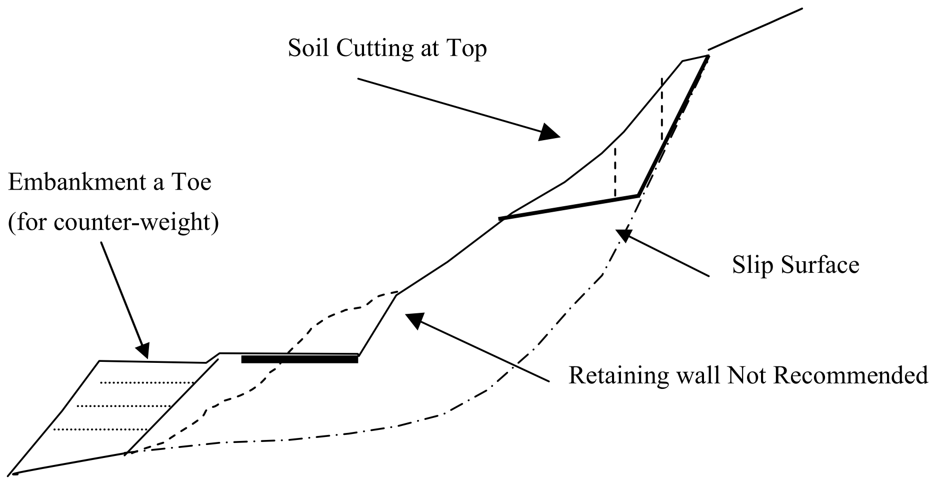


Figure 3.3: Typical Fill Slope with Berms



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.

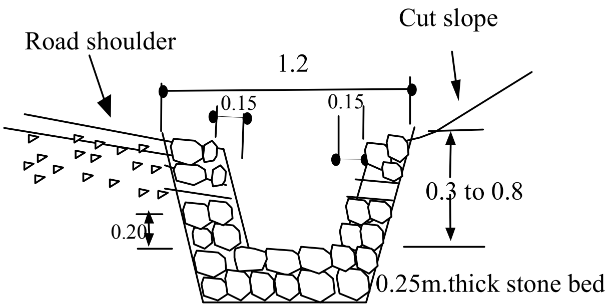
Considering the importance of drainage structures, potenial damages to the road pavement, retaining structures, and slope failures from concentrated runoff; it should be designed according to hydrological and hydraulic considerations. Hydrology such as frequency, intensity, and duration of rainfall, 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

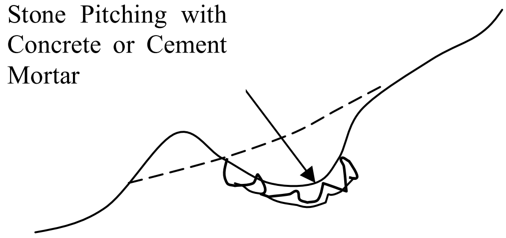
Bed Materials	Safe Velocity (m/sec)
Loose Clay or Fine Sand	Up to 0.50
Coarse Sand	0.50 to 1.00
Fine Gravel, Sandy or Stiff Clay	1.00 to 1.50
Coarse Gravel, Rocky Soil	1.50 to 2.50
Boulders, Rock	2.50 to 5.00

Source: MRE

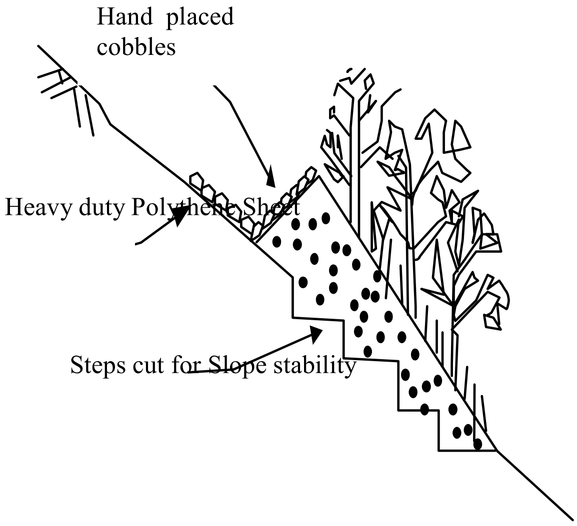
Collector or tributary drains are designed to collect surface water flow by installing corrugated half pipes or lined U-ditches along the slopes, which are then connected to a drainage channel or main drains. To prevent the infiltration of collected surface water the bed of drain is to be lined and or 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.



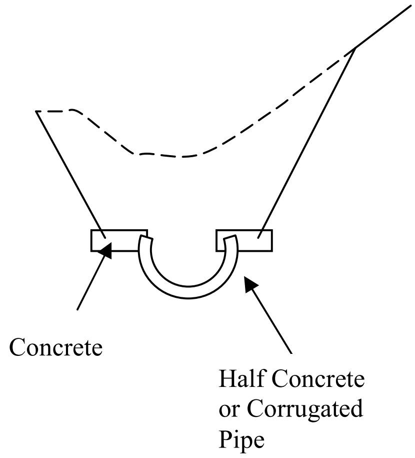
Trapezoidal Cement Masonry Side Drain



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.

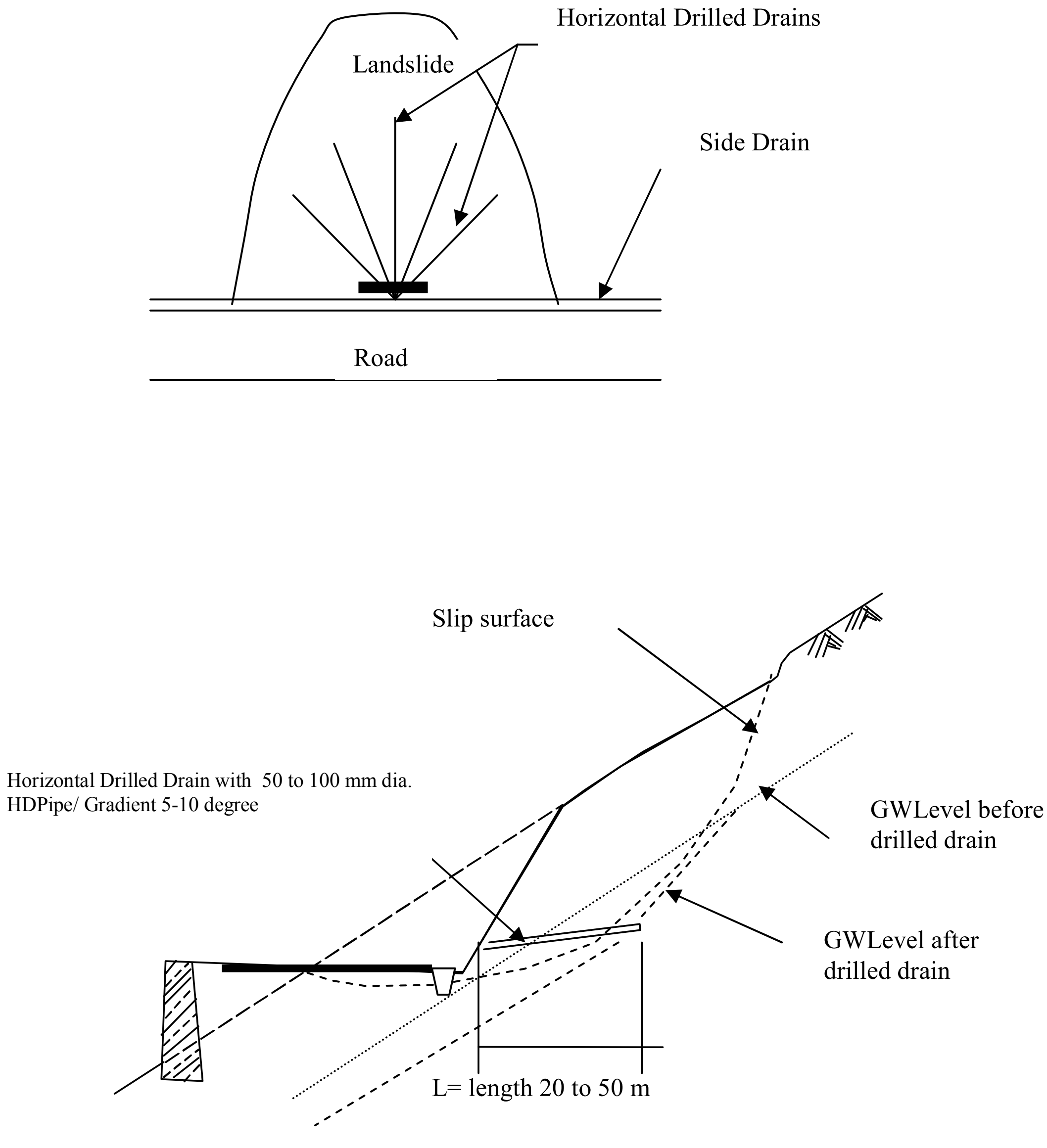


Figure 3.7: Typical Plan and Section of Horizontal Drilled Drain

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

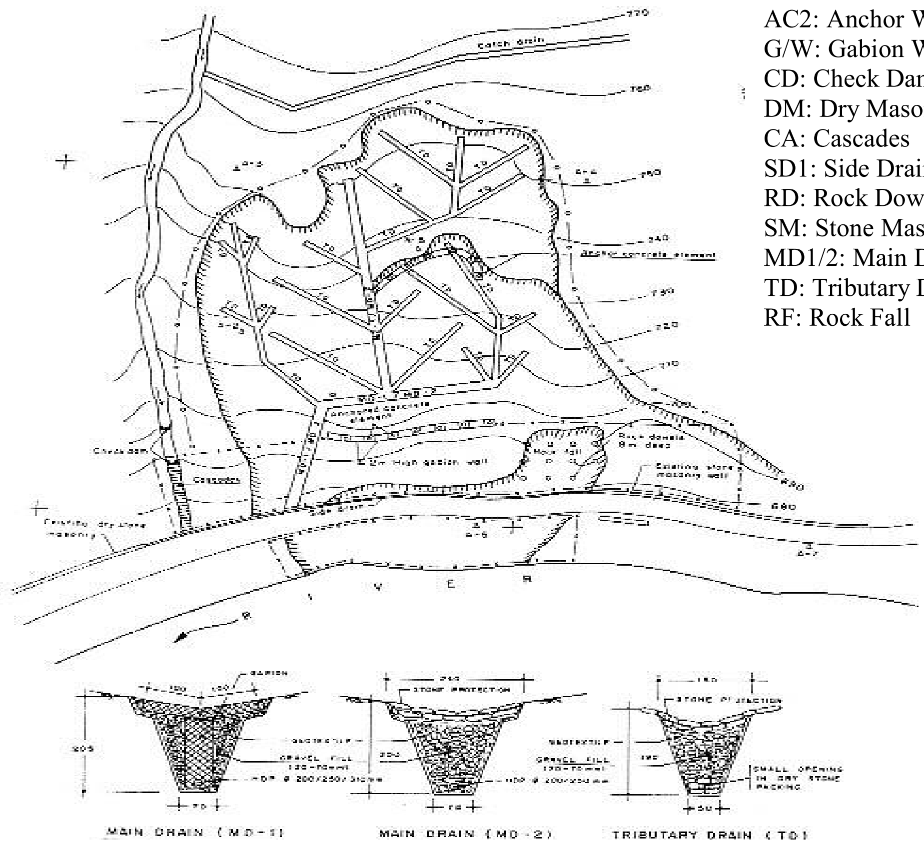


Figure 3.9: Landslide Stabilization by Sub-surface Drains