TRANSPORTATION ENGINEERING - I

(HILL ROADS)

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Hill Roads

5.1 Introduction

A hill road may be defined as the one which passes through a terrain with a cross slope of 25% or more. There may be sections along hill roads with the cross slope less than 25%, especially when the road follows a river route. Even then these sections are also referred to as hill roads. Hence, to establish a hill road overall terrain must be taken into account.

The hilly regions generally have extremes of climatic conditions, difficult and hazardous terrains, topography and vast high altitude areas. The region is sparsely populated and basic infrastructural facilities available in plain terrain are absent. Hence, a strong stable and feasible road must be present in hilly areas for overall development of other sectors as well.

Design and Construction Problems

Design and Construction of roads in hills and mountain are more complex than in plain terrain. It is due to several factors associated in the region. They are:

- A hilly or mountainous area is characterized by highly broken relief with vastly differing elevations and steep slopes, deep gorges etc. which may unnecessarily increase road length.
- The geological condition varies from place to place.
- Hill slopes stable before construction may not be as stable due to increased human activities.
- There may be variation in hydro-geological conditions which may easily be overlooked during design and construction
- Due to highly broken relief construction of special structures should be done at different places. This increases the cost of the construction.
- Variation in the climatic condition such as the change in temperature due to altitude difference, pressure variation, precipitation increases at greater height etc.
- High-speed runoff occurs due to the presence of high cross slopes.
- Filling may overload the weak soil underneath which may trigger new slides.
- The need of design of hairpin bends to attain heights.

5.2 Special Consideration in Hill Road Design

Alignment of Hill Roads

Selecting an alignment in the hilly region is a complex task. The designer should attempt to choose a short, easy, economical and safe comforting route.

General considerations

When designing hill roads the route is located along valleys, hill sides and if required over mountain passes. Due to complex topography, the length of the route is automatically increased. Due to harsh geological conditions, special structures also have to be provided.

Apart from the highly broken relief which has a fixed role in determining the alignment and location of special structures, climatic and geological conditions are also important. In locating the alignment special consideration should be made in respect to the variations in:

1. Temperature
2. Rainfall
3. Atmospheric pressure and winds
4. Geological conditions

Temperature

- Air temperature is in the hills is lower than in the valley. The temperature drop being approximately 0.5° per 100 m of rising.
- On slopes facing south and southwest snow disappears rapidly and rain water evaporates quickly while on slopes facing north and northeast rain water or snow may remain for the longer time.
- Unequal warming of slopes, sharp temperature variations and erosion by water are the causes of slope facing south and southwest.

Rainfall

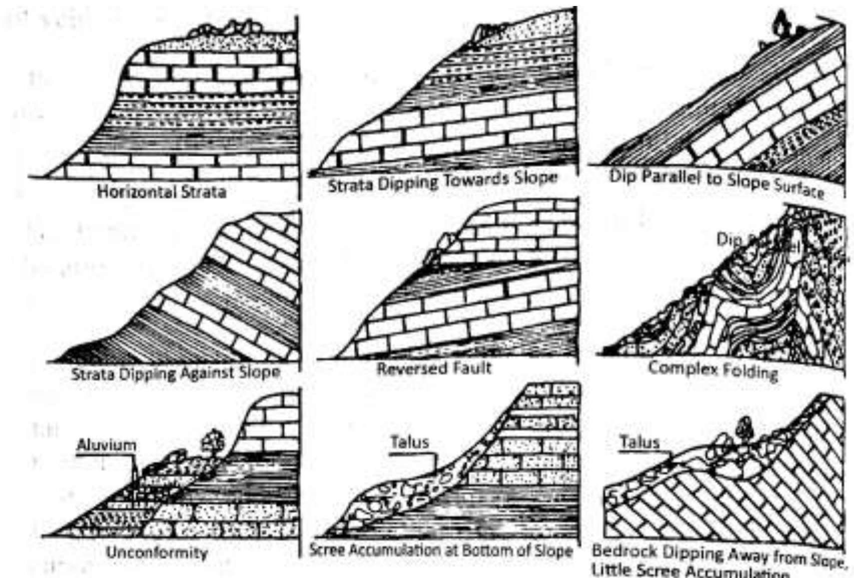
- Rainfall increases with increase in sea level.
- The maximum rainfall is in the zone of intensive cloud formation at 1500-2500 m above sea level. Generally, the increase of rainfall for every 100 m of elevation averages 40 to 60 mm.
- In summer very heavy storms may occur in the hills and about 15 to 25% of the annual may occur in a single rainfall. The effects of these types of rainfall are serious and should be considered well.

Atmospheric pressure and winds

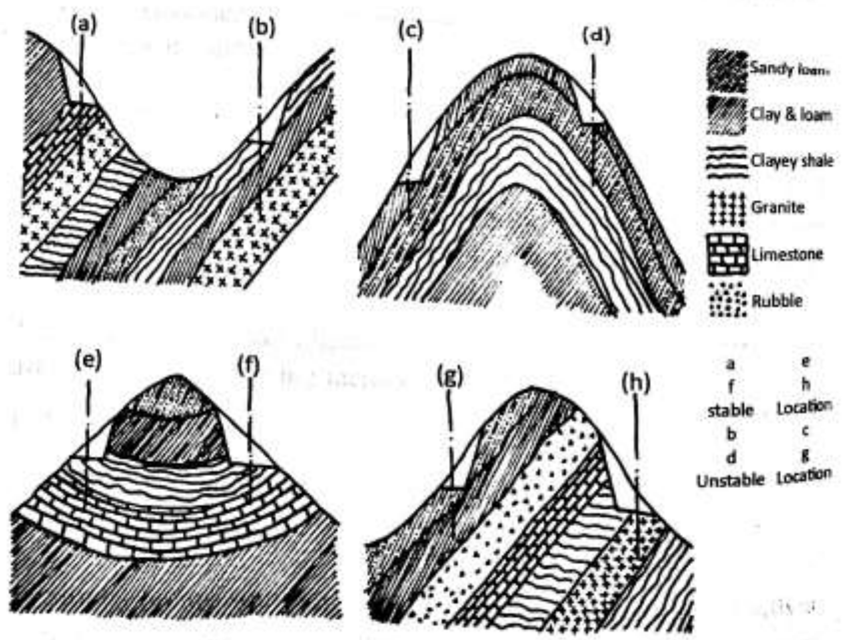
- It decreases with increase in elevation.
- At high altitudes, the wind velocities may reach up to 25-30 m/s and depth of frost penetration is also 1.5 to 2 m.
- Intensive weathering of rocks because of sharp temperature variations which cause high winds.

Geological conditions

- The inclination of folds may vary from horizontal to vertical stratification of rock. These folds often have faults. Limestone or sandstone folds may be interleaved with layers of clay which when wetted may cause fracturing along their surface. This may result in shear or slip fold.
- The degree of stability of hill slopes depends on types of rock, degree of strata inclination or dip, occurrence of clay seams, the hardness of the rocks and presence of ground water.



Various Structures of Slopes



When locating the route an engineer must study the details of geological conditions of that area and follow stable hill slopes where no ground water, landslides, and unstable folds occur.

Route location in Hills

Hill roads may follow different path according to the feasibility of the road. However, a hill road alignment varies for the sections along the valley bottom and along the mountain pass. The first is called **river route** and the second is called **ridge route**.

River route

The location of a route along a river valley is the most frequent case of hill alignment as there is a great advantage of running a road at a gentle gradient. Also, there is a benefit of low construction cost and operation cost.

However, a river valley may run through numerous horizontal curves. Requirements for the construction of large bridges over tributaries also may occur. It may also be necessary to construct special retaining structures and protection walls on hill side for safe guarding the road against avalanches.

Some important considerations

- Road bed should be located sufficiently above and away from the maximum water level.
- When the road bed is near to the waste water course embankment slope should be well protected and stabilized.
- More care should be given to geological and hydrological structures.
- Best alternatives should be selected for crossing water sources.
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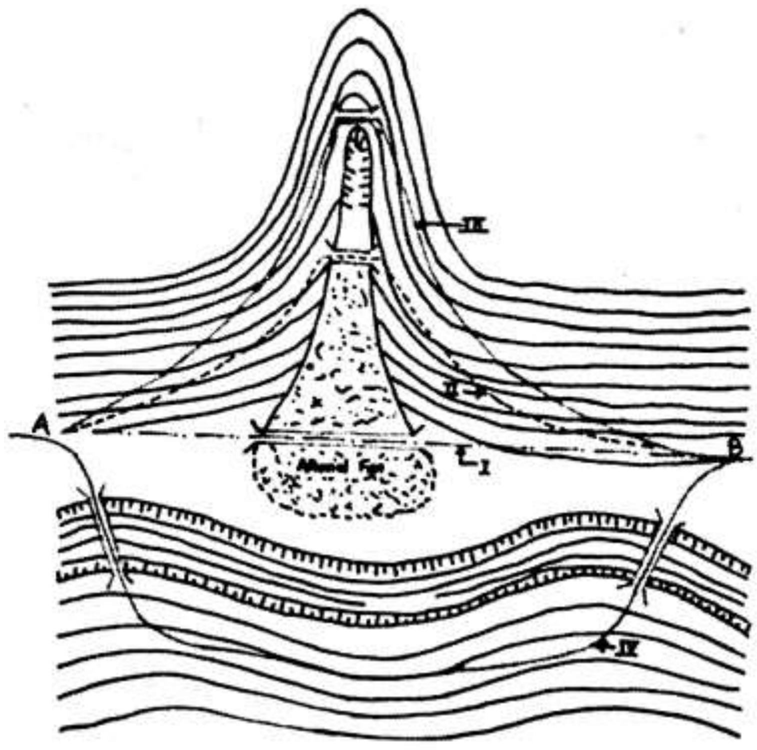
For example, as shown in figure a road is to be connected from A to B.

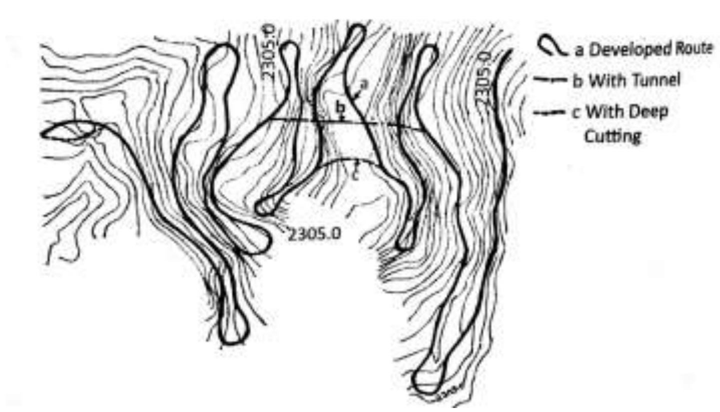


The first alternative runs through alluvial making a bridge. However, it may not be feasible unless there are strong foundations which may increase construction cost greatly.

The second alternative is located above the alluvial fan through which the bridge length is greatly reduced

Similarly, other options like route III or IV may also be chosen depending upon the economic comparison.

Ridge route



- It is characterized by the very steep gradient.
- A large number of sharp curves occurs on the road with hair pin bends.
- Extensive earthwork is required.
- The requirement for the construction of special structures.
- The necessity of long length away from the air route.

Gradient

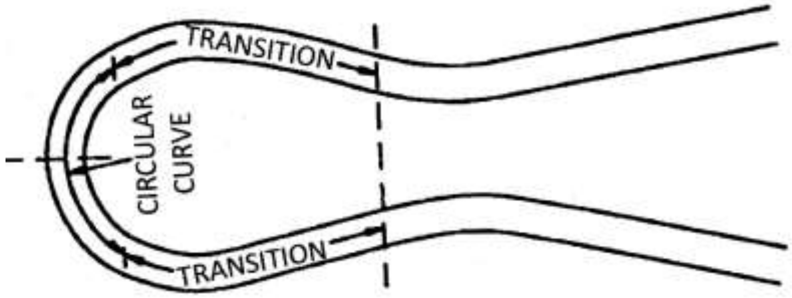
In hill roads, a heavy amount of earthwork is required. So to reduce the earthwork for reducing construction cost the gradients selected are close to maximum. Although steep gradients help in reducing earthwork and length of road, it also causes increased fuel consumption and reduction in operating speed as the vehicles will be on low gears which will use more energy. So both these factors must be taken into account and a suitable solution should be chosen.

The cumulative rise or fall in elevation should not exceed 100 m in mountainous terrain and 120 m in steep terrains. Vertical curves are designed as the square parabola. The curves should be provided at all grade change exceeding those indicated in the table below:

Design speed	Maximum grade change not requiring a vertical curve	Minimum length of vertical curve
Up to 35kmph	1.5%	15m
40kmph	1.2%	20m
50kmph	1.0%	30m

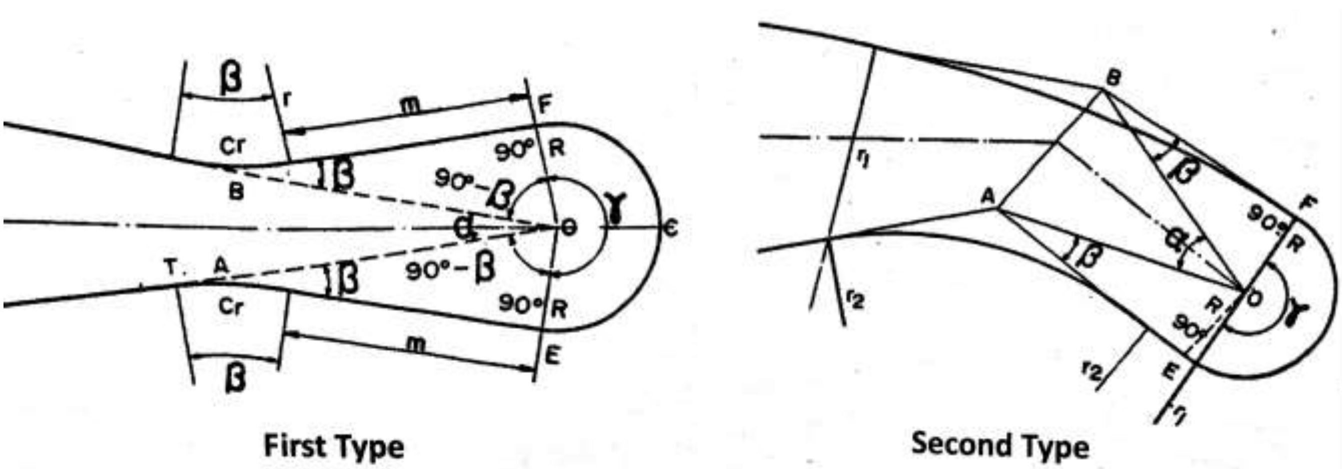
Design of Hair Pin bends

When inscribing a curve inside a turning angle the length of the route will be substantially reduced, which result in steep gradients. In such circumstances, it is preferred to round off the route by circumscribing the curve rather than inscribing the curve around the turning point. Such compound curves are called hairpin bends or reverse loops. A hairpin bend is located on the hill section having the minimum cross slope and maximum stability. It must be safe against landslide and ground water seepage.



According to NRS-2070 the design criteria is as follows:

Minimum design speed	20 kmph
Minimum radius of curve	15 m
Minimum length of transition curve	15 m
Minimum longitudinal gradient	4%
Maximum superelevation	10%



The figure shows two different kinds of symmetrical hair pin bends consisting of main curve ‘C’ reverse curves ‘Cr; and tangents ‘m’. The acute angle of the bend is α. The main curve with radius R has a total length C and subtends and angle γ at the center. Points A and B are located at the apices of reverse curves. Between the ends of reverse curves and main curve of the bend, tangents must be introduced for the transitions of super-elevation and extra-width of the curve.

For the design and layout of hairpin bends, elements such as radii of the main and reverse curves (R and r), the length of tangents m are selected. The design of hairpin bends then basically consists of establishing the value of turning angle β at point A and B which satisfies the preselected parameters of the bend.

Deriving simple expressions (with respect to the first type)

Tangent length of reverse curve

T = r Tan β/2

where,

T - Length of the tangent

r - Radius of the Reverse Curve

β - Deflection Angle

The distance from the apex of the reverse curve angle to the commencement of the main curve is given by: (See side image)

Calculating these parameters hair pin bend can now be plotted on a contour map or set out on the ground. The bends described so far which have reverse curve situated on their convexities in opposite direction are called hair pin bends of the first type.

In the bends of the second type, which may also be either symmetrical or asymmetrical, the convexities of curve face on the same side. These bends are introduced at places with contours representing shallow drainage basin or flat hill nose.

$AE = BF = T + m$

From ΔAOE or ΔBOF if will be found that

$$\tan\beta = \frac{0E}{AE} = \frac{R}{T+m} = \frac{R}{r\tan\frac{\beta}{2} + m}$$

Where,
R is the radius of main curve.

From trigonometry, it is also be known that:

$$\tan\beta = \frac{2\tan\frac{\beta}{2}}{1-\tan^2\frac{\beta}{2}}$$

Substituting this expression for tan β in proceeding expression, solution for $\tan\frac{\beta}{2}$ becomes:

$$\tan\frac{\beta}{2} = \frac{-m+\sqrt{m^2+R(2r+R)}}{R+2r}$$

Hence, the angle β to correspond to 'R', 'r' and 'm' can be easily determined.

The distance from the apex of the reverse curve to the centre of the main curve is determined by:

$$AO = 0B = \frac{T+m}{\cos\beta} = \frac{R}{\sin\beta}$$

The centre angle γ corresponding to the main curve of the bend is:

$$\gamma = 360° - 2(90° - \beta) - \alpha = 180° + 2\beta - \alpha$$

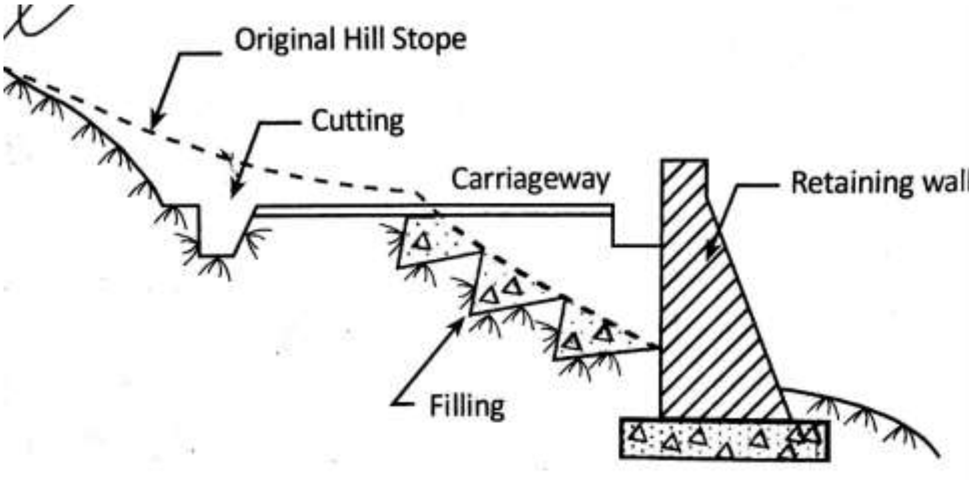
And the length of the main curve is $C = \frac{\Pi R\gamma}{180}$

Hence the total length of the bend is

$$S = 2(Cr + m) + C$$

Where Cr is the length of the reverse curve.

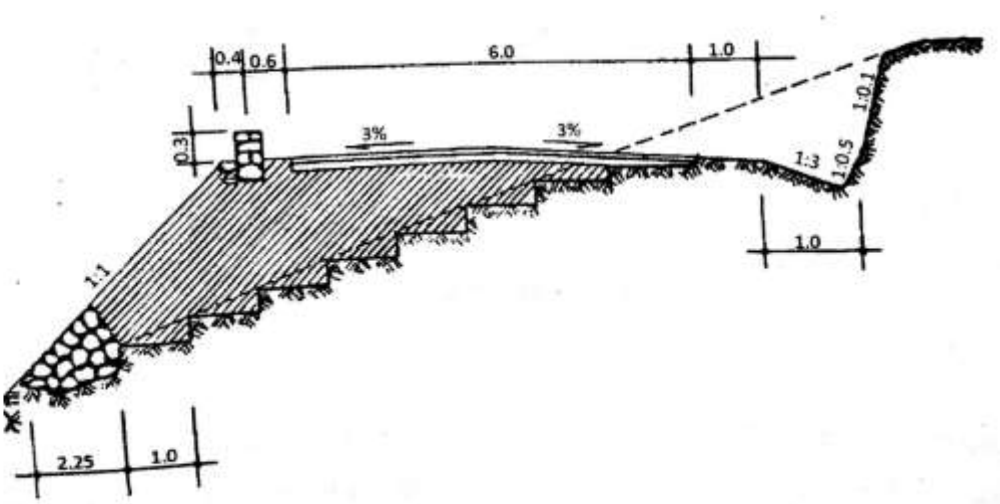
Typical Cross Sections of Hill Road



The cross section of a road in a hilly terrain is determined by the original ground slope of the site, the slope of the road formation, width of roadway, side drain size, and shape and so on. Various types of road cross-section are:

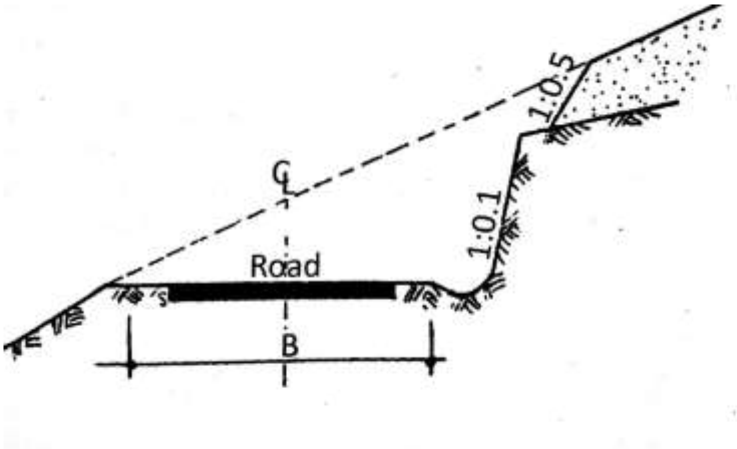
1. Cut and fill
2. Bench type
3. Box cutting
4. Embankment with retaining walls
5. Semi bridge
6. Semi tunnel
7. Platforms

Cut and fill



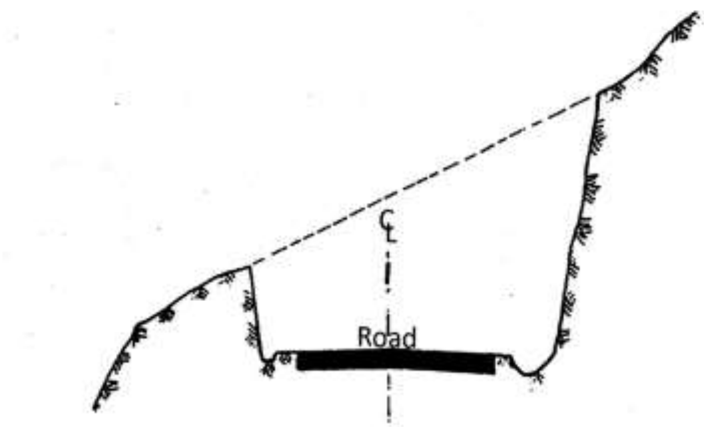
When roadbed slope has a gradient 2% or more a cut and fills road bed is cheaper and environmentally friendly as well. The fill mass is generally balanced by the cut mass. For adequate stability, benches are made on the surface of the hill side with a height of 0.5 m and length varying from 1.5 to 3.0 m depending upon the slope.

Bench type



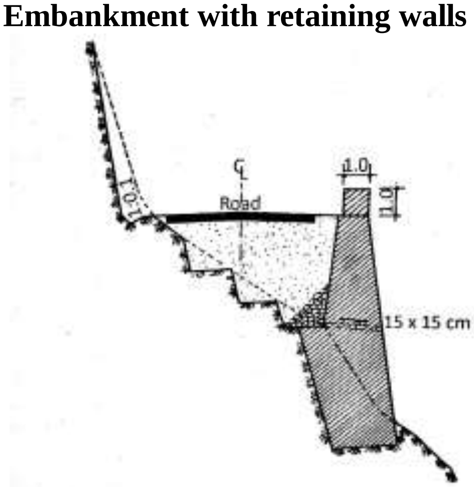
A cross section of the bench type although entails some increase in earthwork but ensures the complete stability of the road bed, if hill side is itself stable.

Box cutting



When the location of road bed is unstable or unsuitable along the hillside due to one or other reasons, the road bed is designed as trench type of cross section. It increases earthwork to a large extent. It is introduced to meet the geometric design standards for a given category road.

Embankment with retaining walls



On steep slopes of about 30-35°, the earthwork involved in constructing the embankment increases substantially. The retaining wall is sometimes provided to reduce earthwork's cost and to increase stability. Also, the retaining wall is provided when embankment soil on steep grounds itself need support. They may also be constructed on a less steep ground slope to increase the stability of road bed.

Semi Bridge

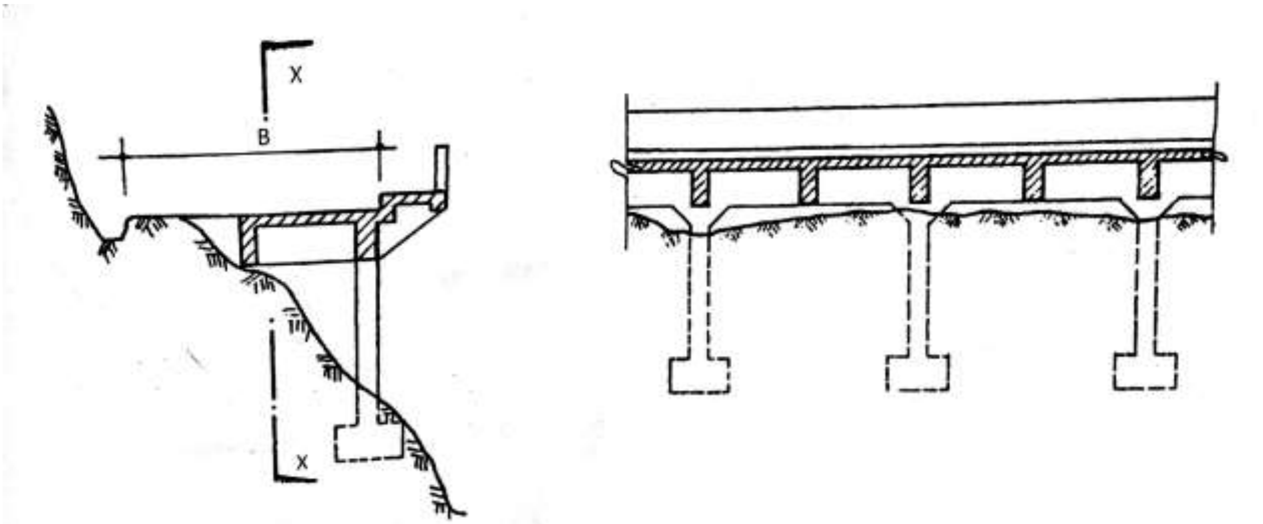


Fig: Cross Section and L-Section (X-X) of a Semi-Bridge.

If the road is located on a hill slope the retaining wall needs to be at a substantial height. In such cases, to reduce quantities of work, road bed with a semi-bridge type of structure may be constructed.

Semi tunnel

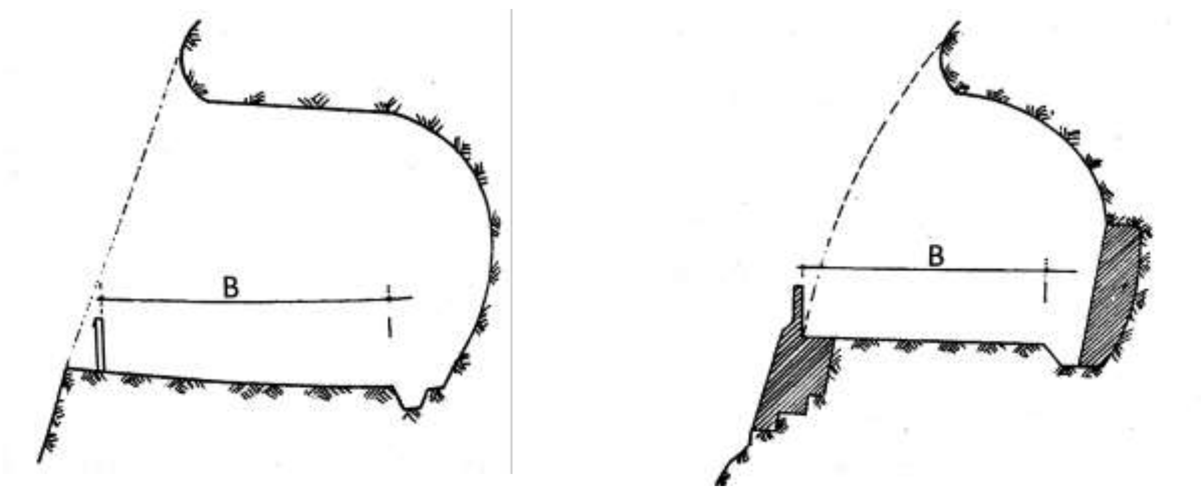
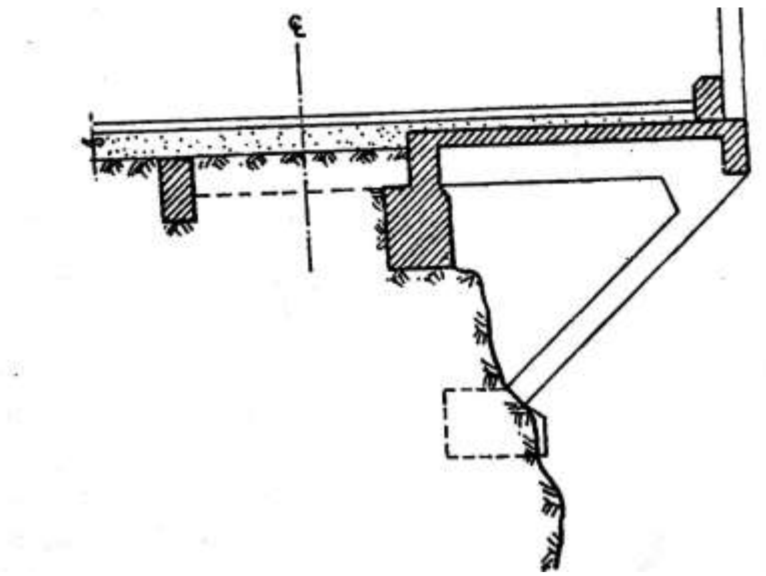


Fig: With Accommodating Road-Way Only and With Retaining and Breast Walls

When inscribing is to be cut into steep hills in stable rock faces, the rock may be permitted to overhang the road to reduce rock works. Such a cross section is called a semi-tunnel.

Platform



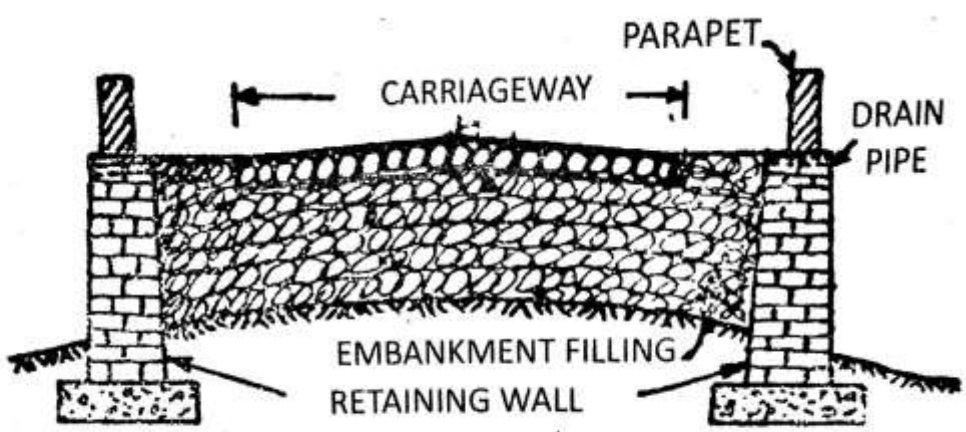


Fig: Fully In Embankment

On the precipitous slopes, where shifting of the route into the hillside will lead to enormous rock works which eventually increases the cost and where semi-tunnel cannot be constructed, platforms are usually cantilevered out of the rock on which road way is partially located.

5.3 Special Structures in Hill Roads

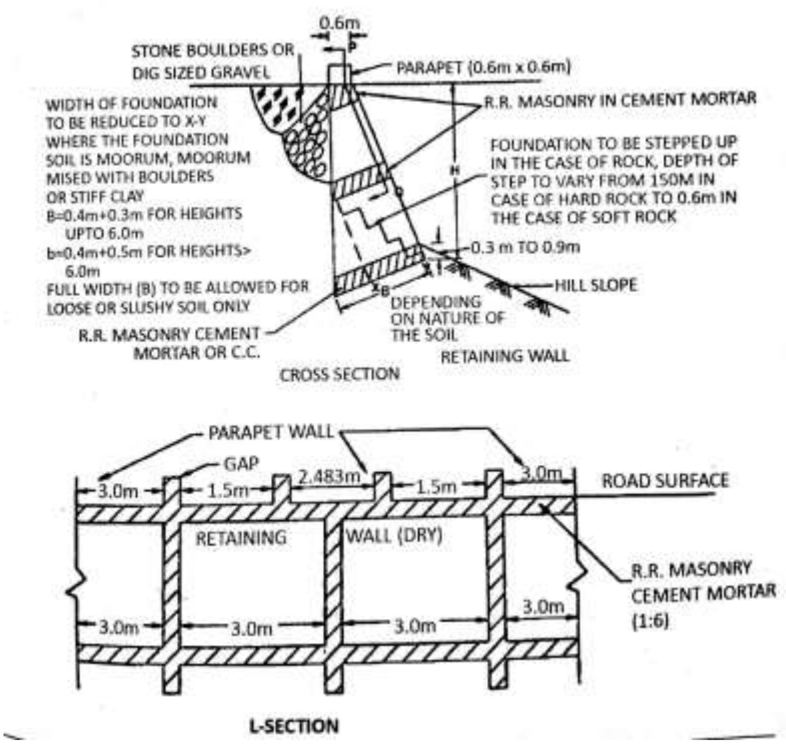
When constructing hill roads a lot of special structures are required owing to harsh geological and hydrological conditions as well as highly broken relief.

The following types of structures are mostly used in the hill roads for strength durability and stability:

1. Retaining structures
2. Drainage structures
3. Slope protection structures

Retaining structures

A retaining structure is usually a wall constructed for supporting vertical or nearly vertical earth bank. Retaining walls are constructed on the valley side on the cut hill side to prevent the the slide towards the roadway. Situations where construction of retaining walls is required:



- Places where the valley side surface gets saturated in the monsoons and is likely to result in slip taking a part of the the road with it.
- Places where undercutting by a stream or other water course causes damage to the valley side and the road.
- In valley point where water flows over the road
- To achieve roadway width, where cutting into the the hill is not economical or has to be restricted due to other reasons.

Types of retaining walls

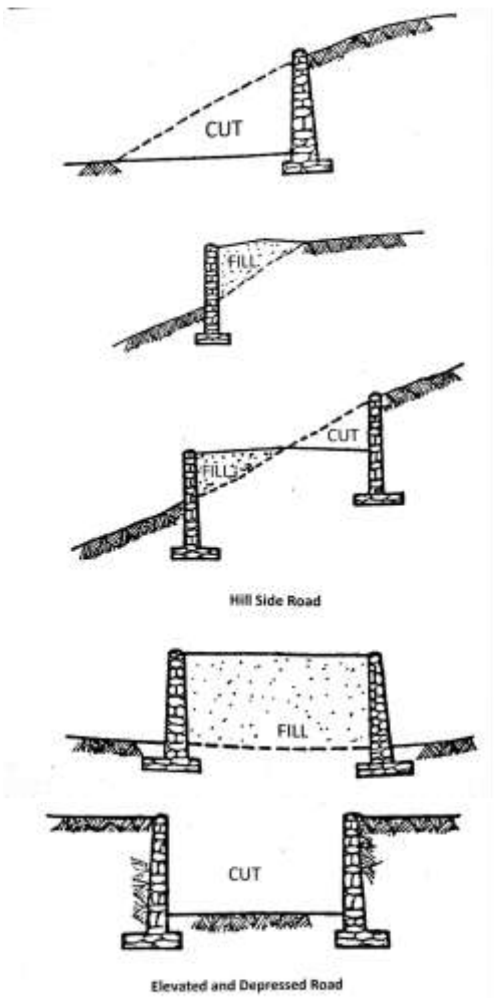
Retaining walls can be classified according to:

1. **Materials used:** based on materials used in constructing retaining walls in hill road may be made of dry stone masonry, stone filled gabion wire crates, stone masonry with cement sand mortar, plain or reinforced concrete wall, steel or timber.
2. **Structural location:** based on where the walls are constructed, retaining walls may be:
3. Gravity wall
4. Semi-gravity wall

- Cantilever wall

1. Counterfort wall
2. Buttressed wall
3. Crib wall

- Reinforced soil wall



Design of retaining walls

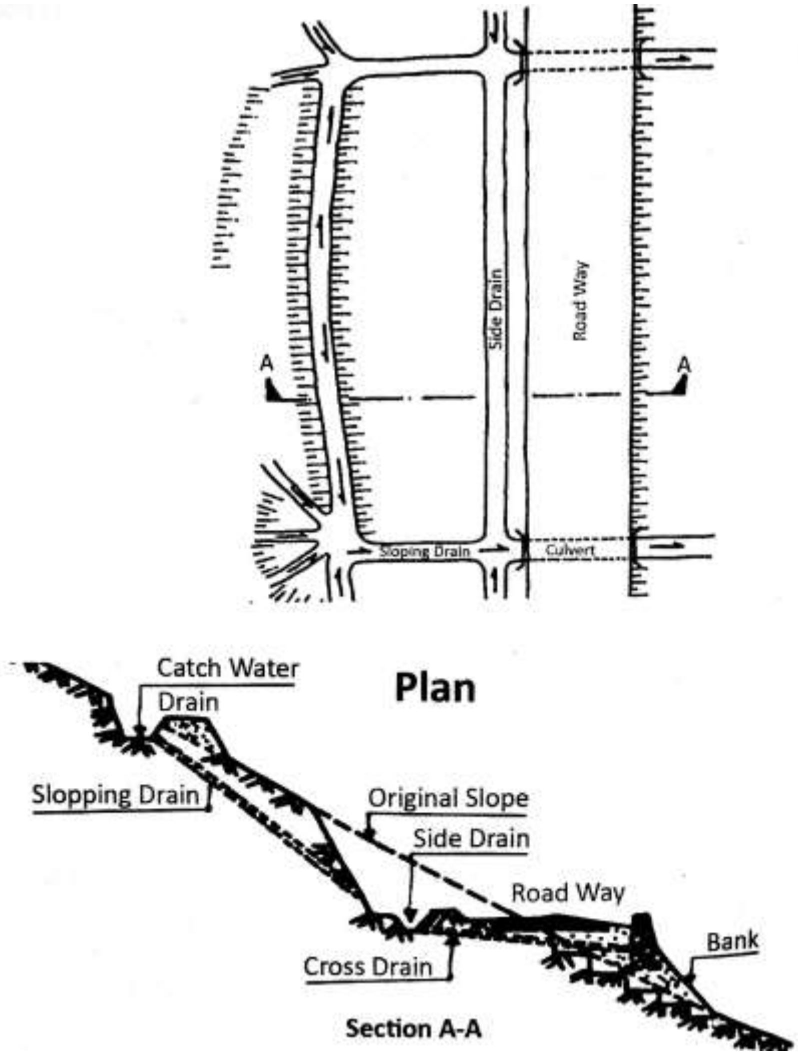
1. Assemble the general information- topographical and physical surveys.
2. Analyze the subsoil condition.
3. Establish surcharge load- highway, building, and other loads
4. Select the type and tentative proportion of the wall.
5. Compute the earth pressure and surcharge pressure.
6. Analyze the structural stability.
7. Analyze foundation stability.
8. Design structural elements.
9. Select drainage in backfill.
10. Predict settlement and movement of the wall.

Drainage Structures

The main problems that hill roads face are the harmful effect of water. Water may come from different sources to the parts of the road. This water must be drained using any means necessary. Drainage of hill roads can be studied under following sub-topics:

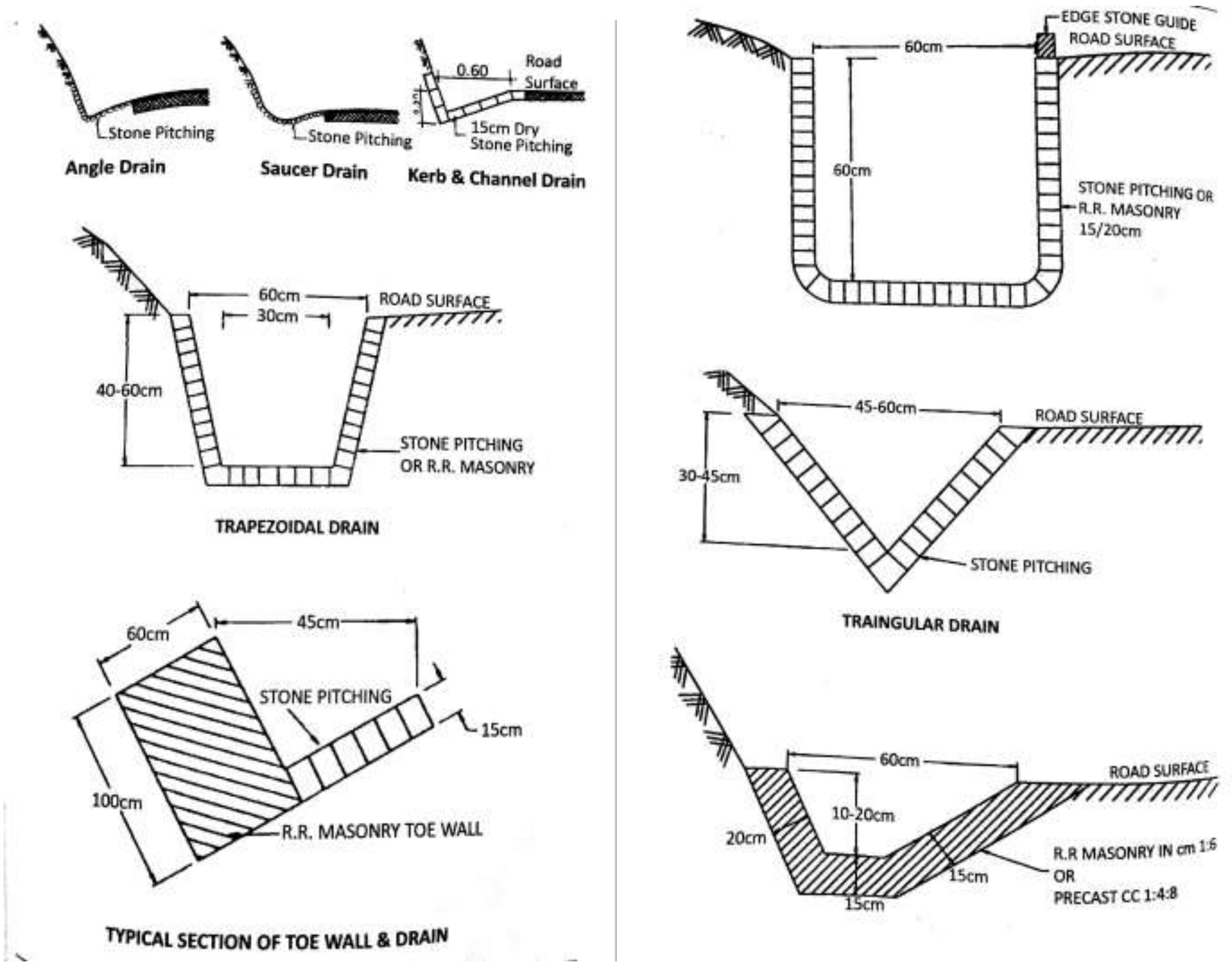
1. **Drainage of water from hill slope**

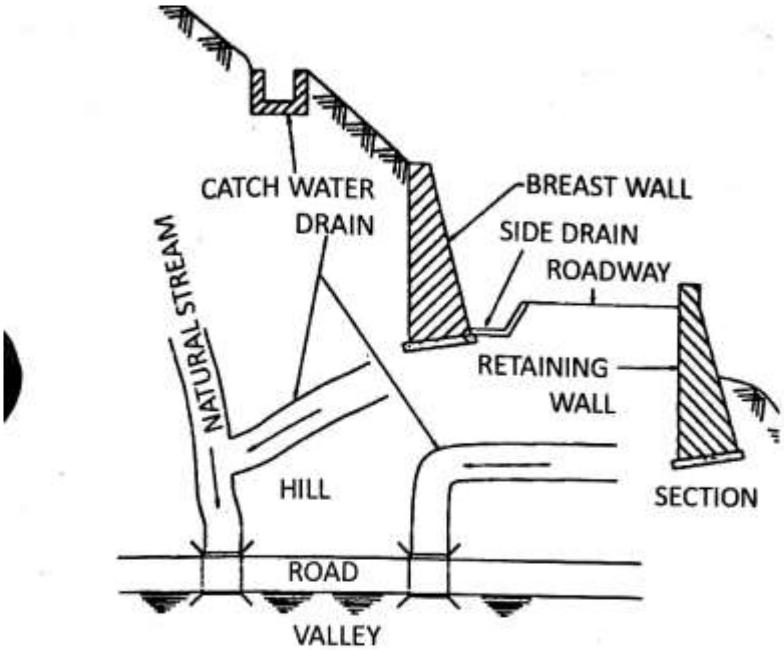
Surface water flowing from the hill towards the roadway is one of the main problems in the drainage of hill roads. Since a large amount of water flows along with debris from the hill slopes during heavy storms, a catch drain is generally provided to catch the water in the middle of the slope. Water intercepted in catch water drains are then diverted by sloping drains and carried to the nearest watercourse or to culvert to cross the roadway. The figure below shows a layout for drainage from hill slopes.

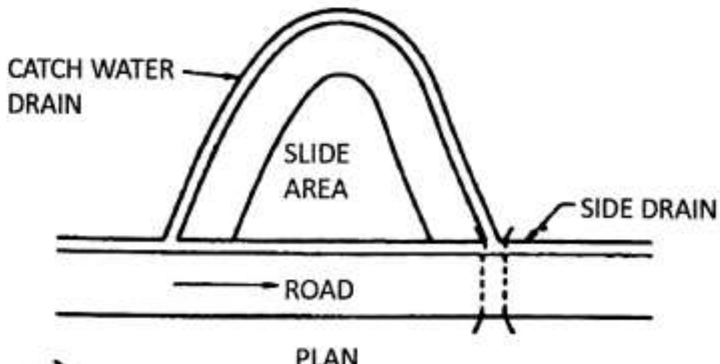


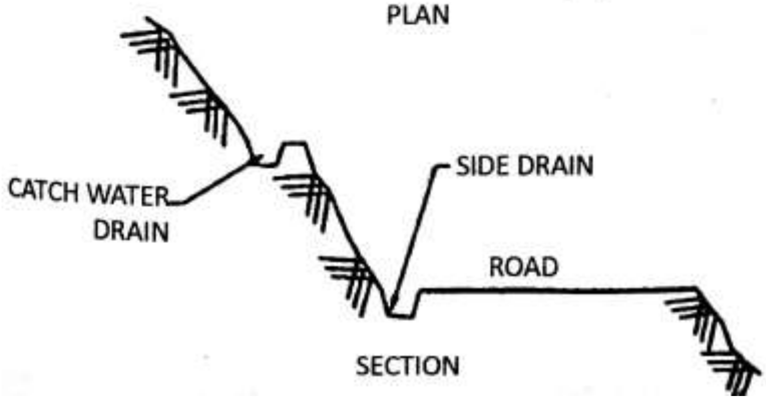
2. **Roadside Surface Drainage**

Side drains are provided all along the hill side of the road. Due to the limitation in the formation width side drains are usually constructed to such a shape that at emergency the vehicles could utilize this space for crossing. The shapes may be angular, saucer or kerb and channel drains.



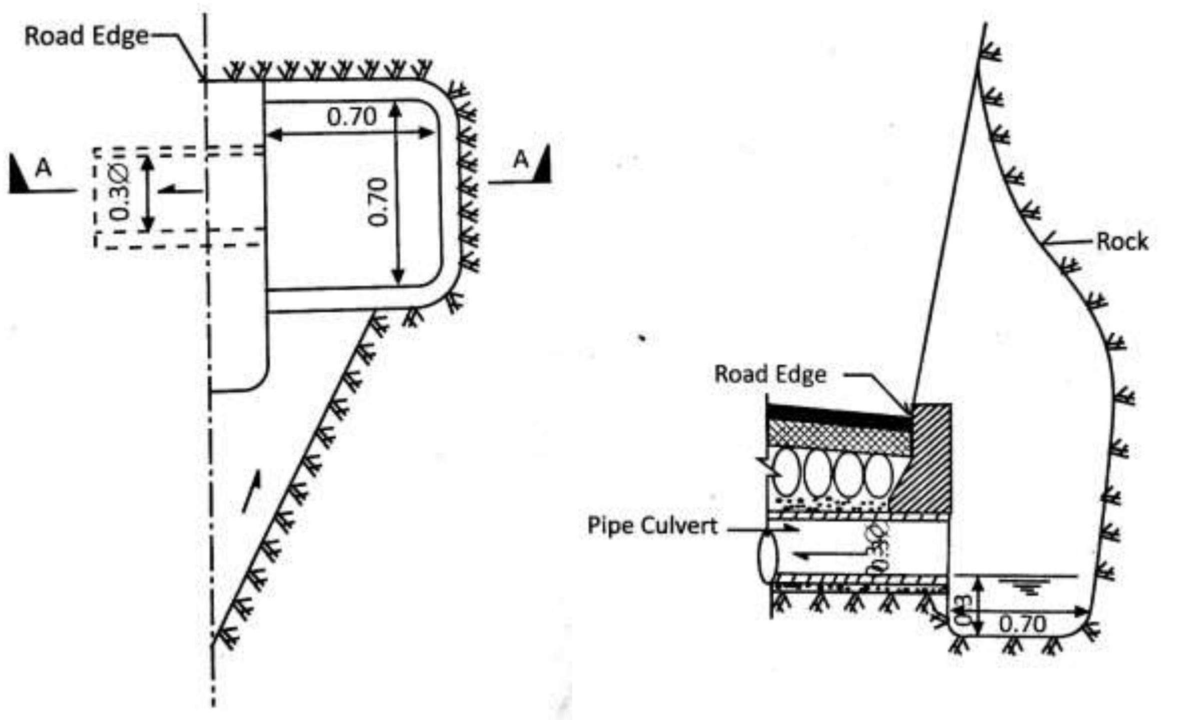

CATCH WATER
DRAIN
BREAST WALL
SIDE DRAIN
ROADWAY
NATURAL STREAM
RETAINING
WALL
HILL
SECTION
ROAD
VALLEY


CATCH WATER
DRAIN
SLIDE
AREA
SIDE DRAIN
ROAD
PLAN


CATCH WATER
DRAIN
SIDE DRAIN
ROAD
SECTION

3. **Cross drainage**

A cross drainage is always required on a hill road. The drainage must be taken under the road as far as possible. At the heads of the small cross drains, catch pits must be provided to collect debris and to prevent scouring.



4. **Subsurface drainage**

Seepage flow is one of the major problems in hill road. Ground water may seep across hillside above or below the road level depending upon several factors such as nature and depth of hard stratum, its inclination, the quantity of ground water etc. sub-surface drainage control may be done by methods in the previous chapter.

Slope Protection Structures

In hill roads, landslides are very common due to steep slopes. The basic cause of landslide is the development of shear stresses more than the shear strength of the soil. Fresh unturfed embankment and cut slopes are the least stable part of the road bed since the soil on the surface of the slopes is subjected to the direct action of sun, rain, and wind**.**

Causes of landslides

- Increase in moisture content of the soil in hill slopes which increases the pore water pressure.
- Alternate swelling and contracting of the soil mass.
- Seepage pressure of percolating groundwater.
- Steeper slopes.
- Human activities like blasting and using heavy vehicles at unstable zones.

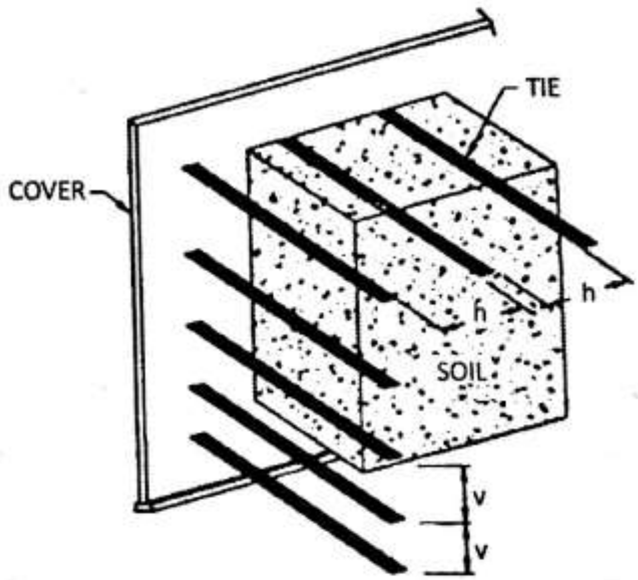
Preventive measures

- The highway may be realigned at areas more prone to landslides.
- Construction of retaining walls must be done at places where required
- Adopting easy slopes during design and construction of the road.
- Treatment of slopes to increase stability conditions.

Reinforced retaining walls

This is a type of retaining wall of composite construction material in which strength of fill is enhanced through the addition of inextensible tensile reinforcement in the form of strips, sheets, grids, or geotextiles.

It is suitable for hill roads because:

- The fill material is readily available at cheaper cost.
- The land required for embankment is less.
- Cost effective, easy to construct and environmentally friendly.
- It causes less alteration in natural slope.
- 

River training structures

River training refers to the structural measures which are taken to improve a river and its banks.

River training is an important component in the prevention and mitigation of flash floods and general flood control, as well as in other activities such as ensuring the safe passage of a flood under a bridge. Hill roads along the river may also be in danger due to different problems created by it.

Problems created by river

- Frequent changes in river course.
- Avulsion of one river into another.
- Development of natural cut-off.
- Landslides in catchment -rise in silt load.
- Aggradation of river bed -high flood levels –Flooding
- River instability -change in bed slopes (seismic activity).
- Degradation of river bed downstream of a dam or a barrage.
- Effects of flood embankment on the regime of rivers.
- Effects of extraction of sand and boulders.
- Effects of heavy urbanization along the river banks.

River training structures

River training structures can be classified into two main categories:

- Transversal protection structures

Installed perpendicular to the water course:

Check dams, Spurs, Sills, Screen, bands, Porcupines, Bank protection as a bar.

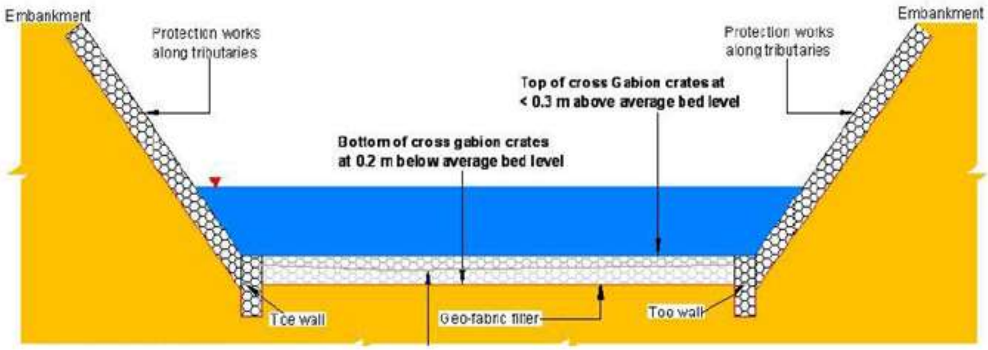
- Longitudinal protection structures.

Installed on river banks parallel to the river course:

Levees or earth fill embankments, Concrete embankments, Revetments and rock riprap, sheet piles, etc

- Other Protection Structures.

Sandbagging, Channel lining, Bamboo piles



Damaged approch road, falling retaining wall and water supply line as on 27-06-2013

Gullies

Gullies are a highly visible form of soil erosion, with steep-sided, incised, drainage lines greater than 30 cm deep. In lay terms, the word 'gully' is often used to describe any drainage line flowing towards a stream. These drainage lines may pass through hill roads and often destroys the layers of the road.

Roads, fences, and firebreaks should be situated in locations that do not readily divert overland runoff and concentrate it to areas that lead to gully erosion. The best place for a road is to follow a ridge line. An examination of satellite imagery in seriously eroded paddocks in the Burdekin catchment shows that graziers being aware of this consistently use ridge lines for access. Roads that run directly up and down the slope will divert or concentrate less runoff than those diagonal to the slope.

Roads should have a profile that does not concentrate overland runoff. Roads that are below normal ground level through constant use or inappropriate maintenance should be re-profiled to a form that does not concentrate overland runoff; alternatively, they should have drainage works incorporated to ensure runoff is dispersed onto stable areas. Associated table drains and mitre drains should have a trapezoidal shape with a flat bottom and not a triangular shape that is more conducive to eroding.

Gully control structures

Weir:

The durability of a weir depends on the construction materials used. Weirs can be made from wire netting, rock, gabions, logs, tyres, concrete, steel sheet piles or hay bales. Strips of suitable vegetation can also be used to act like a pervious weir. Where the vegetation has a relatively short life, the intention is that the weirs will retain some sediment and promote vegetative growth before the weir decays.

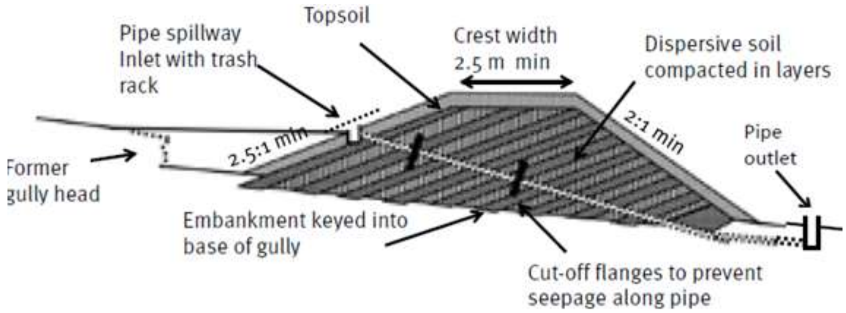
Types of weirs

- Wire netting weirs
- Hay bale weirs
- Rock and gabion weirs
- Tyre-rock weirs
- Concrete and log weirs
- Sand bag weirs

Gully Control Dams

One option for controlling an advancing gully is to ‘drown’ the gully head by building a dam just downstream. The dam submerges the gully head and the subsequent reservoir of water removes the erosive force of water flowing over the head and prevents it from further erosion.

Due to the cost of building a dam, this option should only be considered if it is an asset other than for gully head control purposes. If the dam spillway requires a chute to return runoff safely to the gully floor then the more practical and lower cost option maybe to simply build the chute to control the gully head.



Chutes

Gully control chutes are formed by battering gully heads to an acceptable slope depending on the method used to stabilize them. As well as for controlling gullies, chutes are used as by-washes in farm dams. They are also used to convey water over steep road batters, to control bed erosion in streams, and for urban developments such as sports fields.

Chutes require some form of energy dissipation at the outlet to help dissipate the energy gained when runoff flows down the chute.

Chute failure often occurs when runoff fails to enter the chute properly. It is critical to control potential leaks and flow bypassing, especially at the chute entrance, and also to ensure suitable side walls contain the flows within the chute.

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