4. Highway Drainage (4 hrs)

4.1 Introduction and Importance of Highway Drainage System

- Bearing capacity of soil foundation gets decreased when the moisture content in its get increased and is lowest when the same gets saturated.
- Water standing on the carriageway is danger to high speed traffic.

Highway Drainage may be defined as the process of interception and removal of water from over, under and vicinity of the road surface.

Destruction of highways by water:

- Softening the road surface constructed of soil or sand-clay or gravel or water bound macadam.
- Erosion of side slopes forming gullies, erosion of side drains, etc.
- Softening the subgrade soil and decreasing its bearing power.
- Chances of landslides and slips.

Ways of Protecting above effects:

- Interception and diversion of the surface water which would otherwise flow across the road or along it and cause erosion.
- Interception and rapid removal of seepage of subsurface water.
- Proper soil treatment
- Change of the water course

Importance of Highway Drainage:

Highway Drainage is required to mitigate the effects due to water and moisture variation that are listed below as:

- Road surface becomes soft and loses its strength.
- Road subgrade may be softened and its bearing capacity is reduced.

- Variation in moisture content in expansive soil causes variation in the volume of subgrade and thus failure of road.
- Presence of moisture at freezing temperature may damage road due to frost action.
- Erosion of side slopes, side drains and formation of gullies may result if proper drainage conditions are not maintained.
- Flexible pavement's failure by formation of waves and corrugations is due to poor drainage.
- Formation of pot holes.
- Failure of rigid pavement by mud pumping.

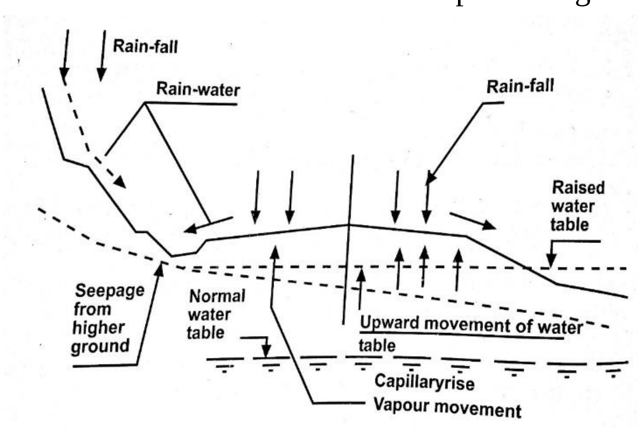
Requirements of Highway Drainage System:

- Surface water from the carriageway and shoulder should be effectively drained off without allowing it to percolate to the subgrade.
- Surface water from the adjoining land should be prevented from entering the roadway.
- The side drain should have sufficient capacity and longitudinal slope to carry away all the surface water collected.
- Seepage and other sources of underground water should be drained off by the sub-surface drainage system.
- Highest level of ground water table should be kept well below the level of subgrade, preferably by at least 1.20m.

4.2 Causes of Moisture Variation in Subgrade Soil

Moisture variation in subgrade soil can be grouped as:

1) By free water
    - Seepage of water from higher adjacent land to the road.
    - Penetration of water through the pavement.
    - Transfer of moisture from the shoulders and pavement edges.
2) By ground water
    - Rise and fall of water table.
    - Capillary rise from lower soil level.
    - Transfer of water vapor through soil.



The amount of water in subgrade soil at any point of time can be viewed as given by the equation,

$W = A + B + C - (D + E + F)$

Where, W = amount of water contained in subgrade soil at any time of the year

A = amount of water infiltrated into the subgrade soil during rainfall

B = amount of water seeping towards the subgrade from the adjacent higher ground

C = amount of water coming to the subgrade due to any or all of the following reasons:

1. Capillary rise
2. Rise of water table
3. Transfer of water vapor due to differences of temperature in upper and lower soil layers

D = loss of water from the subgrade due to flow away towards lower adjacent ground

E = loss of water due to evaporation, transpiration, etc.

F = loss of water due to percolation downward

Components of Highway Drainage System

a) Surface Drainage System
b) Subsurface Drainage System

4.3 Surface Drainage System

A part of rainwater falling on the road surface and adjoining area, is lost by evaporation and percolation. The remaining water is known as surface water. Removal and diversion of this surface water from highway and adjoining land is known as surface drainage. The water from the pavement surface is immediately removed by providing camber and cross slope to the pavement. The camber and slope depend upon the type of the pavement and the intensity of rainfall. The road surface is made impermeable to prevent infiltration of water.

Collection of Surface Water

The surface drainage may be divided into three categories as:

a) **Drainage in rural highway**
   There is the provision of side drains in these areas which are generally open, unlined and trapezoidal cut to suitable cross section and longitudinal slopes. Camber is applied to the pavement to drain the surface water and has to drain across the shoulders which are provided with more cross slope. Usually, drains are provided on one or both sides in embankments while drains are provided on both sides in case of roads with cutting. Open drains are dangerous in the places where space is restricted in cutting and hence covered drains are used with layers of coarse sand gravel.

b) Drains in Urban Street

In urban roads, underground longitudinal drains are provided due to the limitation of land width, the presence of foot path, dividing island and other road facilities. This is provided where there is lesser number of natural water courses and in the presence of impervious surfaces. Water is collected in the catch pits at suitable intervals and lead through underground drainage pipes.

c) Drainage in hill roads

In hill roads, there are complex drainage problems. Water flowing down the hill has to be efficiently intercepted and disposed of downhill side by constructing suitable cross drainage works. Catch water drains at the upper hill side, sloping drains and cross slopes are provided to drain out the water whereas side drains are provided only at the hill side. If hill roads are not properly drained, rockslides and slips may occur blocking the road during monsoon season. The shape of the side drains is made in such a way that vehicles can park at that space during emergency, crossing or parking.

4.3.1 Different types of road side drain

On the basis of the shape of drain, the road side drain may be rectangular, trapezoidal, triangular or semi-circular. The type of drain may be angle drain, saucer drain or kerb and channel drain as mentioned earlier.

4.3.2 Cross Drainage Structures

Cross drainage structures are those structures which are provided whenever streams have to cross the roadway facility. The water from the side drains is also often taken across these structures in order to divert the water away from the road to a water course or a valley.

Culverts

A closed conduit placed under the embankment to carry water across the roadway is termed as culverts. In NRS 2070, culverts are the bridging structures of linear waterway span less than about 6m. It is extensively used in road drainage system. In fact, more than 75% of the cross-drainage structures are culverts. A culvert is more hydraulically efficient than minor bridge and discharge through a culvert is more than a minor bridge

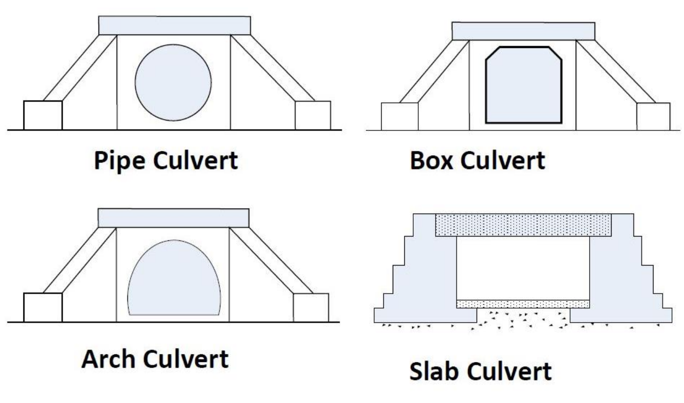
Functions of culverts

The functions of culvert are:

- Collection and transport of water across the road so as to not cause damage to the road bank or the stream bed by scouring.
- To provide sufficient waterway to prevent heading up of water above the road surface.

Types of Culvert

Pipe Culvert



- Used in non-perennial or at very small stream (Surface runoff from side drain).
- Minimum of 50cm cover of soil should be provided so that traffic load transmitted on pipe is of small intensity.
- Minimum diameter of pipe – 600mm.
- Pipes may be made of stone ware, concrete, RCC, etc. with standard sizes of 0.5m, 0.75m, 1m, 1.25m and 2m in diameter.
- For large areas, multiple pipes are used joined to each other by joints because the length of a single pipe is limited to 2.5m.

Box Culvert

- Suitable for large flow where the boulder movement may occur.
- Constructed where the nature of the soil below the foundation is not suitable for individual footing under piers and abutments.
- The size of rectangular passage should not be less than 60cm*60cm.
- The height of such culverts rarely exceeds 3m.
- These culverts have larger life spans, greater hydraulic efficiency, superior durability for worst environmental conditions and greater resistance to damage due to debris.

Slab Culvert

- They are used in stream with boulder movement and debris flow.
- These culverts are used where the water opening is less than 15 m^2 and road crosses the waterway on a relatively high embankment.
- Free board of generally 0.5m is seen in this type of culvert thus, no pressure flow occurs in this culvert.

Arch Culvert

- These culverts are suitable in high discharge areas and low debris flow areas.
- These culverts are constructed when high fillings are involved and there is heavier loading on the culvert.
- Span of each arch should be kept less than 3m.

Bridge

A bridge is a structure constructed over water course to carry traffic over it. In NRS 2070, bridges are the structures having linear waterway span more than about 6m.

On the basis of construction materials

- Steel bridges
- Concrete bridges
- Timber bridges, etc.

On the basis of structural point of view

- Cantilever bridges
- Suspension bridges
- Moving bridges, etc.

On the basis of span length

- Minor bridge (up to 30m)
- Major bridge (above 30m)
- Long bridge (above 120m)

On the basis of load carrying capacity

- Class 70 (Corresponding to class AA)
- Class 40 (Corresponding to class A)
- Class 30 (Corresponding to class B)

- Class 9
- Class 3
- Class 1

Parts of bridge

Bridge is divided into the following three parts structurally:

1. **Foundation:** Since bridges take very heavy loading upon them, the foundations should be carefully designed. If rocky strata are available for the abutments and piers at the location of bridge site it becomes very easy to construct bridge but if they are not available then well sinking may have to be done or caisson type piers or abutments may have to be constructed in the foundation site location.
2. **Substructure:** Substructure is that portion of the bridge which lies between the decking and the foundation. The various components in the substructure are wing walls, piers, abutments, etc. The choice of the type of abutment is done according to the site condition concerning the soil classification which can be made of brick masonry, stone masonry, PCC or RCC.
3. **Superstructure:** Superstructure is the portion which lies above the decking and can be made of material like: timber, steel, RCC or pre-stressed cement concrete.

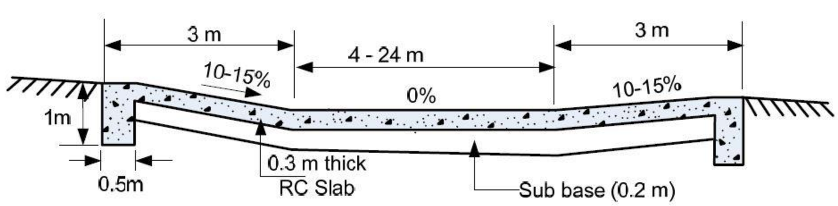
Causeway

They are constructed instead of culverts on less important roads where the maximum flow of depth does not exceed 1.5m which saves the construction cost. During the flood, the water flows over the road and traffic on both sides is stopped but as soon as the flood recedes, the traffic flow is resumed.

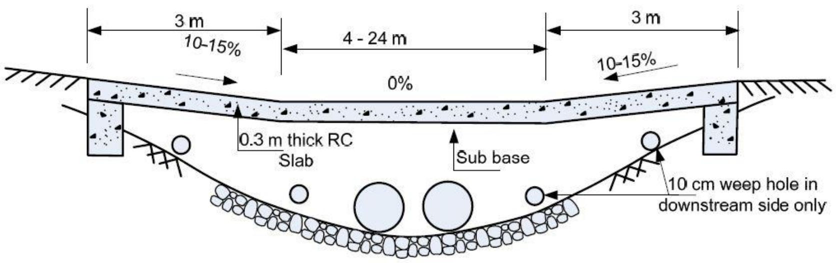
Bed slope of the causeway in estimating the span should not generally exceed (4-5) % in order to prevent the vehicles from skidding and overturning downstream. The depth of flow in most of the period of the year should not exceed 30cm.

There are two types of causeway:

1. **Low level causeways/Flush Causeway/Irish Bridge of Ford:** The causeway which is constructed at the bed level of the stream which allows flood to pass over the road surface at any time is termed as low-level causeway. It remains dry for most of the time.

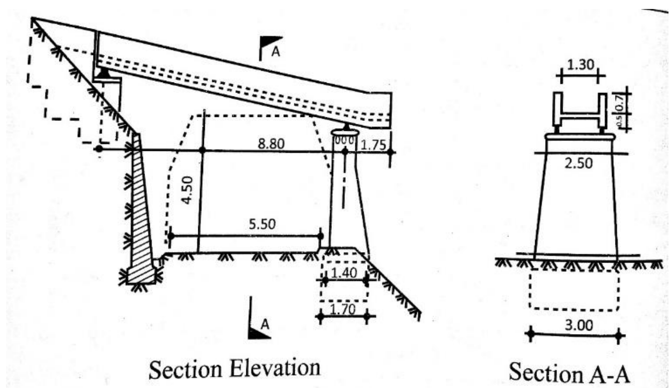


2. **High level causeways/Submersible Causeway/Vented Causeway:** The causeway which is provided with vents below to pass regular flow under the road and flood across the road surface at any time is termed as high-level causeways. It is constructed quite above the stream bed and is also termed as submersible bridge.



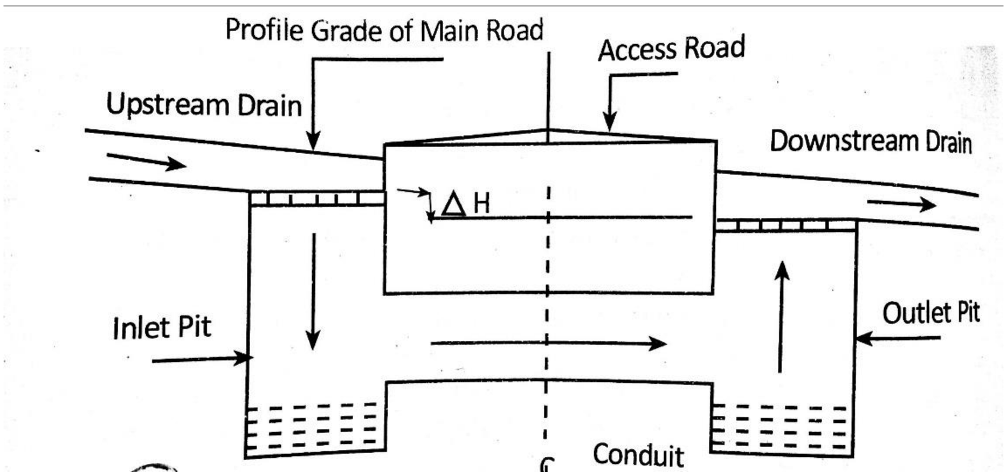
Aqueduct

Aqueduct is an open or closed conduit sufficiently above the roadway to drain water across the road with the provision of pillar supports on either side of the road. These structures can be advantageously used in hill roads where culverts are not feasible.



Inverted Siphon

The inverted siphon is a structure which lowers the invert level of the conduit to the desired level and both inlet and outlet pits are provided to receive flow from the drain and discharge water to the downstream drain respectively. . It is generally provided when the provision of culvert and aqueduct is not possible.



Sub-Surface Drainage System:

- Stability and strength of the road surface depends upon the strength of subgrade.
- With increase in moisture content the strength of the subgrade decreases.

The variation in moisture content of subgrade is caused by the free water and the ground water. Every effort is needed to reduce the moisture content to a minimum. From usual drainage system, only gravitational water can be drained by the provision of subsoil drainage.

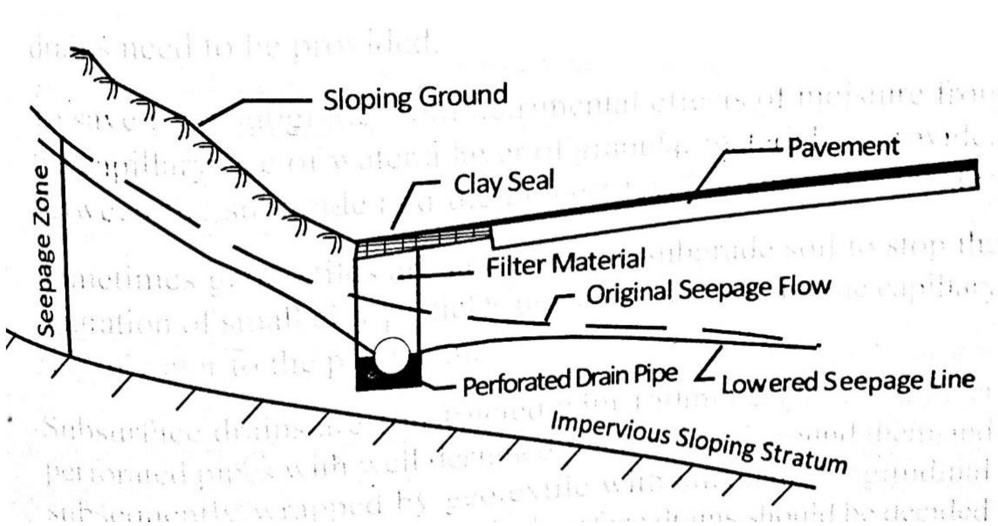
<u>Drainage of infiltrated water</u>

- During rainy season and snow melting season, water will find its way to the subgrade soil through the permeable surface of the adjoining land, carriageway, shoulder, side slope and cracks.
- Removal of such infiltrated water from the subgrade may be accomplished by the arrangements shown in figures below. The control of subsurface water is classified under three headings:

1. Control of seepage flow
2. Lowering of water table
3. Control of capillary rise

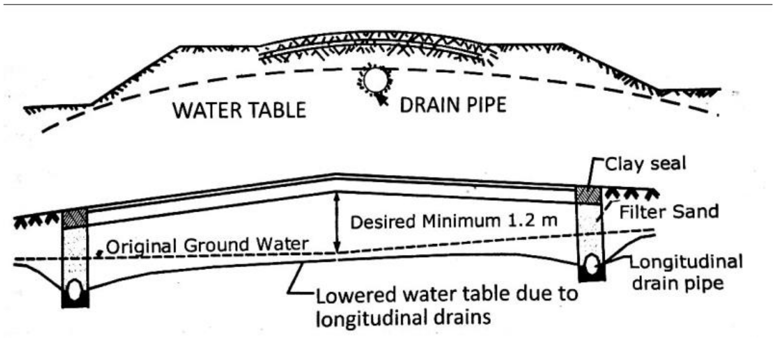
<u>Control of seepage flow</u>

- Seepage may occur from the higher ground in hilly topography or in road cuttings where a layer of permeable soil overlies an impermeable stratum which affects the strength characteristics of the subgrade.
- The best solution to this type of problem would be to intercept the seepage water on the uphill side of the road.
- If the seepage level reaches a depth less than 60-90 cm from the road subgrade, it should be intercepted to keep seepage line at a safe depth below the road subgrade.

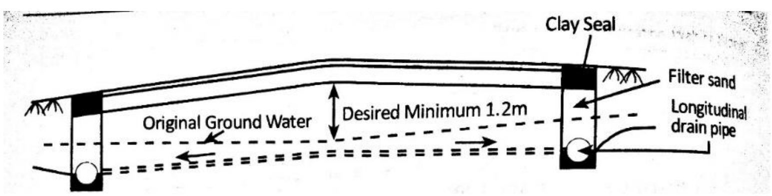


Lowering of water table

- The water table may rise and may come up to the pavement layers in low-lying areas during rainy seasons which becomes very harmful to the pavement and the subgrade especially when the subgrade is made of fine-grained soils. Therefore, it becomes necessary to lower the water table safely below the pavement.



- If the underground water table is more than 1.2m below the surface of the road, it does not require any subsurface drainage but when it is less than 1.2m the best measure would be to raise the road formation.
- The water table is lowered to the desired depth by providing sub drains on either side of the road. It may be possible to lower the water table by merely constructing longitudinal drainage trenches with drain pipes and filter sand if the soil is relatively permeable.
- But if the soil is relatively less permeable, the water table lowered at the center of the pavement or between the two longitudinal drains may not be adequate. Thus, transverse drains may have to be provided in order to effectively drain off the water and lower the water table.



- The depth to which the drains should be laid depends upon the width of the roadway, amount of water table to be lowered, type of subgrade soil and lateral distance between the trenches.
- The pipe in the drainage system should be laid such that silting and scouring do not occur.
- For maintenance of these systems, manholes and inspection chambers can be provided.

Control of capillary rise

In water logged sections, there will be possibility of rising of water to the subgrade level due to the phenomenon of capillary action which affects the strength of the subgrade. Thus, capillary cut off measures needs to be provided to free the subgrade from the excessive moisture. If the subgrade soil is of permeable type, the lowering of water table is economical but in case of retentive type of soil, drainage becomes very difficult and costly. In these cases, capillary cut offs become more economical. There are two types of capillary cut off:

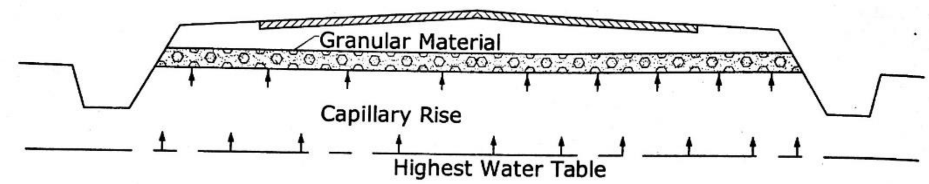
1. **Granular capillary cut off:**

   - Provision of granular material of suitable thickness between the subgrade and the highest level of subsurface water table during the construction of embankment.

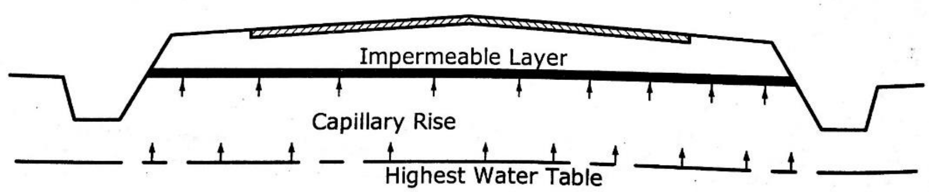
- The granular capillary cut off layer's thickness should be sufficiently higher than the anticipated capillary rise within the granular layer so that the capillary water cannot rise above the cut off the layer.
- Suitable sand blanket and gravel blanket can be used for cut off.

2. **Impermeable capillary cut off:**

- Provision of impermeable membrane such as prefabricated bituminized surfacing is used instead of granular blanket.
- Bitumen stabilized soil, heavy duty tar felt or heavy-duty polythene envelope can also be used.



Granular Capillary Cut-Off



Impermeable Capillary Cut-Off

Design of Surface Drainage System

Two Phases:

Hydrological Analysis

- The main objective of this analysis is to estimate the maximum quantity of water expected to reach the drainage system under consideration.
- Some portion of the rain water gets evaporated and infiltrated and the rest is called runoff which flows over the surface.
- The various factors which affect the run off are the rate of rainfall, type of soil, topography, vegetation, etc.
- The surface drainage to be designed should drain away all the surface water. For such analysis, initially, the details of the average intensity of the area for a selected frequency and duration equal to the time of concentration are required. Then the total and peak rainfall based on the predetermined intensity for the area under consideration is determined.

Then rational formula is used to estimate the peak run off water for the highway drainage given by:

$Q = c*i*A_d$

Where,

Q is the discharge in m^3/s,
c is the run off coefficient which is expressed as the ratio of run off to the rate of rainfall,
i the rainfall intensity in mm/sec and
A_d is the drainage area in $1000m^2$.

The value of the runoff coefficient (c) is dependent on the type of the soil surface and slope. The drainage area consists of different areas with different values of runoff coefficients c_1, c_2, c_3 with their respective areas of A_1, A_2, and A_3. Then the weighted value of the runoff coefficient for the drainage area is given by,

Therefore, $c = (A_1*c_1 + A_2*c_2 + A_3*c_3 + \ldots\ldots) / (A_1 + A_2 + A_3 + \ldots\ldots.)$

The intensity of rainfall is calculated from the rainfall data obtained initially which are the frequency and the expected duration of the rainfall. From the data, the inlet time and the time for the flow of water from the farthest point to the drainage are calculated which gives the time of concentration and the intensity of rainfall.

The drainage area is determined to study contour map and topographic maps. The estimated maximum quantity of water calculated for the drainage element now helps in the design of the drainage structures.

Hydraulic Analysis

The side drains and the culverts are now designed on the principles of flow through open channels once the maximum discharge has been calculated.

Then, $Q = A * v$

Where, Q is the quantity of the surface water in m^3/s to be removed from side drains, v is the velocity of the water in the channel and A is the required area of the drain.

The velocity is calculated using Manning's equation assuming uniform and steady flow through a uniform cross section and slope,

Or, $v = (1/n) * R^{2/3} * s^{1/2}$

Where,

v is the average velocity in m/s,
n is the Manning's coefficient which depends upon the type of soil,
R is the hydraulic radius in meters and
s is the longitudinal slope of the channel.

The design procedure is as follows:

1. The hydraulic radius is calculated for a permissible non-scouring velocity from Manning's equation,

$R = [(n*v) / s^{1/2}]^{3/2}$

2. The minimum cross-sectional area is calculated from the permissible non-scouring velocity and the maximum discharge,

$A = Q / v$

3. The wetted perimeter is calculated,

$P = A / R$

4. Determine the dimensions of the drain i.e. the breadth and width by relating the area and perimeter.
5. The depth of flow found should be greater than the critical depth $[v^2 /g]$
6. If depth is less than the critical depth, erosion may occur at the downstream end and therefore process should be revised or special measures should be provided at the downstream.

Design of subsurface drain

Design of subsurface drain consists of the following steps:

1. **Depth of the drainage trench:** The depth of the trench at which the subsurface flow has to be intercepted is determined on the basis of impervious stratum level, soil type and the requirement at which the subsurface flow has to be maintained.
2. **Selection of the backfill filter material for the trench:** The back-fill's purpose is to improve the interception ability of the drain and to provide effective water collecting space adjacent to the pipe. Such materials should be coarse enough to allow water to have easy access to the pipe but also should be fine enough to act as a filter material to prevent base soil from intruding into the pipe.
3. **Size and number of perforations in the drain pipe:** The size and the number of holes per meter length of the pipe is determined in such a way that:

- The pipe should be able to intercept all the water entering the drain without causing a high head in the filter material as this will reduce both the depth to which the water table can be lowered and its rate of lowering
- The holes should be sufficiently small enough to prevent the filter material from being washed into the pipe and plug the holes.

- The following criteria have been recommended with respect to the size of the pipe perforations. Maximum size of circular holes = d_{85} (filter)

  Maximum width of slotted holes = 0.83*D_{85} (filter)

4. **Diameter of the drainage pipe:** The diameter of the pipe for a given length should be selected in such a way that the pipe will not run full near its outlet and flood the surrounding filter material. It must also be big enough so that all the intercepted water can be discharged through the pipe.

   Currently no authoritative single recommendation is available with regard to the diameter and length of the pipe. But in practice 150mm diameter pipe are commonly used. The design of these factors is the function of the amount of water to be drained off, soil type, filter, underground flow, etc. and the above recommendations may not always be followed.