Highway Drainage

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4. Highway Drainage

4.1 Introduction and Importance of Highway Drainage System

4.2 Causes of Moisture Variation in Sub grade Soil

4.3 Surface Drainage System

- 4.3.1 Different types of Roadside Drain
- 4.3.2 Cross drainage structures (Culverts and others)
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4.4 Subsurface Drainage System

- 4.4.1 Drainage of infiltrated water
- 4.4.2 Control of seepage flow
- 4.4.3 Lowering of water table
- 4.4.4 Control of capillary rise

4.1 Introduction and Importance of Highway Drainage System

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

- 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.

- 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.

4.1 Introduction and Importance of Highway Drainage System

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

- Highway Drainage is to direct surface and subsurface flow away from elements of a roadway and dispose it safely without damage to the highway or adjacent property.
- It is the process of **interception, removing and controlling** surface and sub surface water within right of way.
- Integrated measures oriented towards the safe drainage of excessive surface and subsurface water.

4.1 Introduction and Importance of Highway Drainage System

- Importance of Highway Drainage
  - 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 and potholes.
  - Failure of rigid pavement by mud pumping.

4.1 Introduction and Importance of Highway Drainage System

- 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

- Causes of Moisture Variation in Subgrade Soil
  - 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.
  - By ground water
    - Rise and fall of water.
    - Capillary rise from lower soil level.
    - Transfer of water vapor through soils.

4.2 Causes of Moisture Variation in Subgrade Soil

- Causes/Sources of Moisture Variation in Subgrade Soil

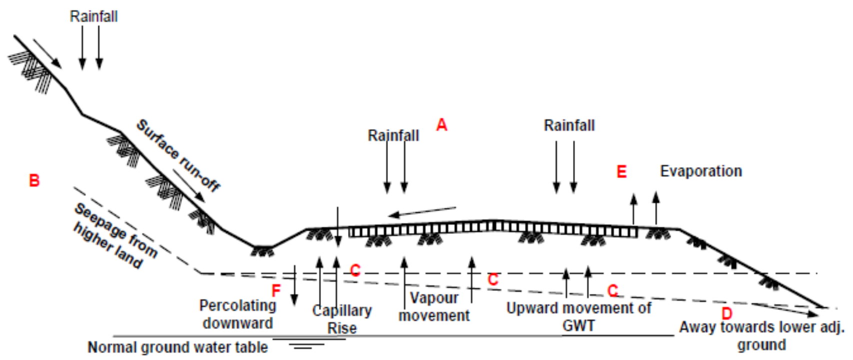


Fig. Sources of moisture variation in sub-grade

4.2 Causes of Moisture Variation in Subgrade Soil

- Causes/Sources of Moisture Variation in Subgrade Soil

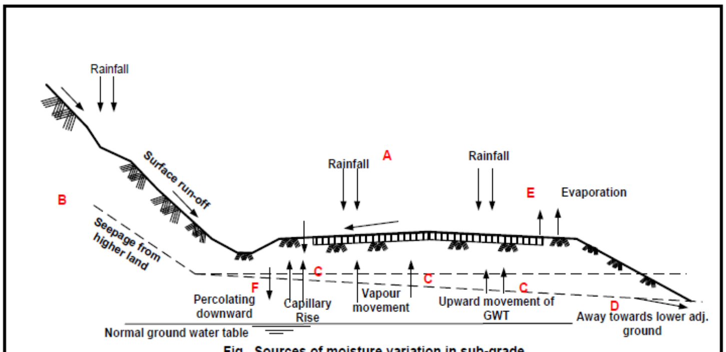


Fig. Sources of moisture variation in sub-grade

The total amount of water in the subgrade soil at any point of time can be given by:

W = (A+B+C) – (D+E+F)

Where,

A = Amount of water infiltrated into subgrade soil due to rainfall

B = Amount of water seeping towards subgrade from adjacent higher ground

C = Amount of water coming to the subgrade due to capillary rise

D = Loss of water from 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

4.3 Surface Drainage System

- Components of Highway Drainage System

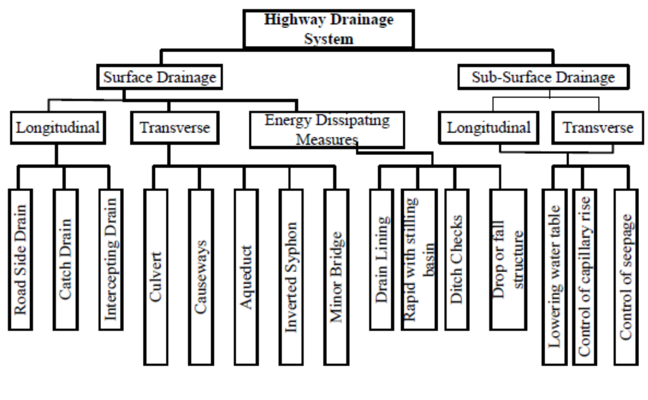


Fig. Highway Drainage System

- Drainage Types
  - Surface Drainage
  - Subsurface Drainage

4.3 Surface Drainage System

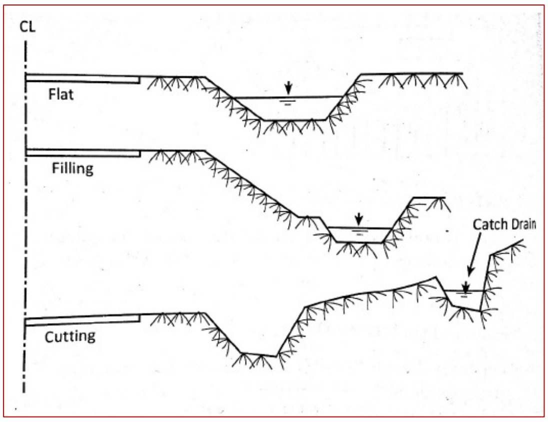
- Surface Drainage
  - A part of rainwater falling on the road surface and adjoining area, is lost by evaporation and percolation. The remaining water is known as surface water.
  - A means by which surface water is removed from pavement and Right of Way.
  - Redirects water into appropriately designed channels.
  - Eventually discharges into natural water systems.
  - Surface drainage system consists of:
    - Camber
    - Longitudinal drain (Side drain, catch drain)
    - Cross (transverse) drain
    - Energy dissipating structure

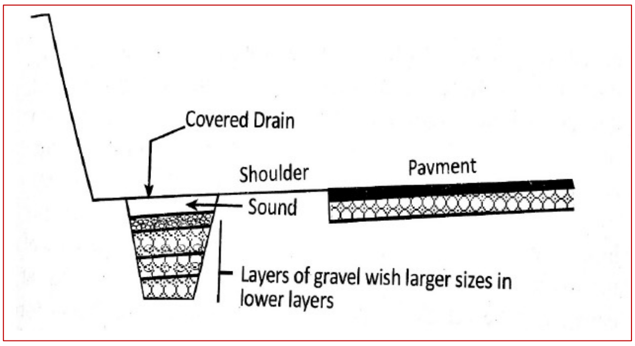
4.3 Surface Drainage System

- Drainage System in Rural Highways
  - 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.
  - Catch drains are provided to collect water before reaching side drains.
  - Open drains are dangerous in the places where space is restricted in cutting and hence covered drains are used with layers of coarse sand and gravel.
  - Cross drains (Culverts, bridges, etc.) are provided to cross the water to valley side.

4.3 Surface Drainage System

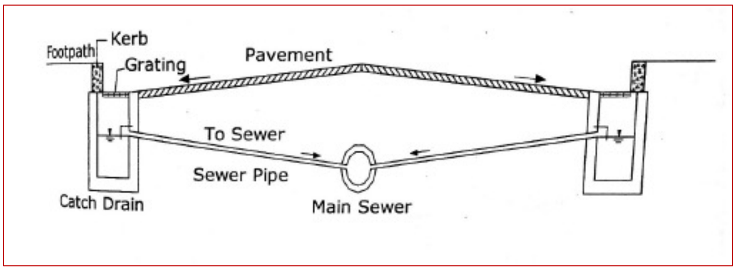
- Drainage System in Rural Highways





4.3 Surface Drainage System

- Drainage System in Urban Highways
  - Cambers are provided to drain water from the pavement.
  - Water is collected in catch pits/drains. Curbs and gutters are provided.
  - Underground longitudinal drains are provided due to the limitation of land width, the presence of foot path, dividing island and other road facilities.
  - Water leads to sewer line through underground drainage pipes.

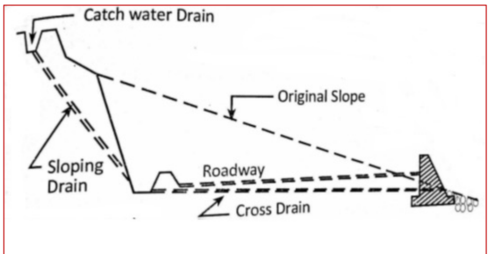


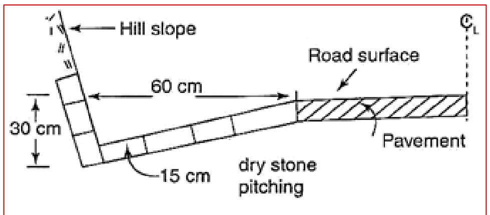
4.3 Surface Drainage System

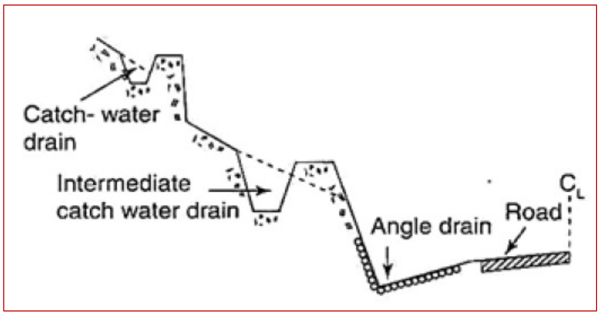
- Drainage System in Hill Roads
  - Water flowing down the hill has to be efficiently intercepted and disposed of downhill side by constructing suitable cross drainage works.
  - Camber are provided to drain water from the pavement and shoulders.
  - Side drains are provided at hill side to collect water from road surface in adjoining land.
  - 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.
  - The shape of the side drains is made in such a way that vehicles can park at that space during emergency, crossing or parking.

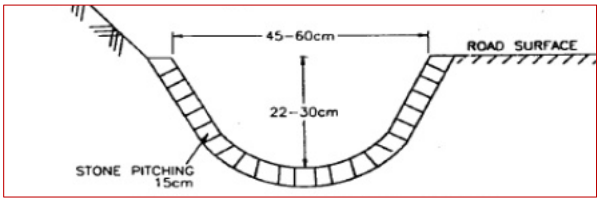
4.3 Surface Drainage System

- Drainage System in Hill Roads









4.3 Surface Drainage System

- Side Drains
  - Ditches along side of road to collect surface water after run-off.
  - Side drains collect water from the carriageway and the batters of cutting or embankments.
  - It also drains water from the abutting developed water.
  - If the cut slopes and hill side slopes are long enough and accumulates more water, the capacity of usual sized drain and if the runoff may erode the slope, then the runoff is intercepted on its way to roadway by providing drains at these slope itself.
  - These drains are known as intercepting drains (catch drains) and are common drainage components in hill roads.

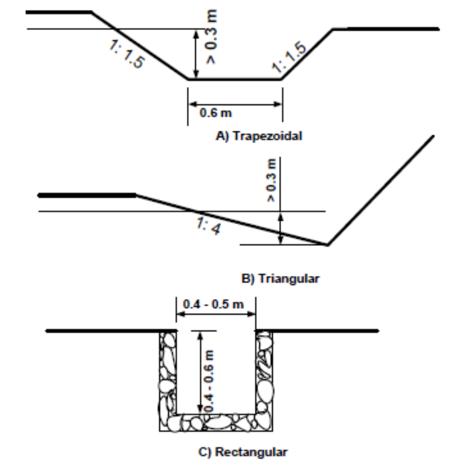
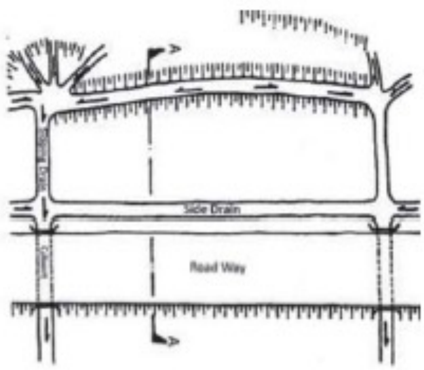
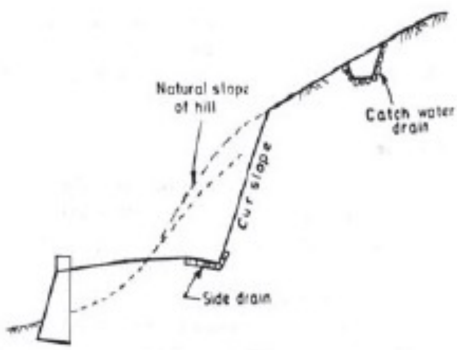


Fig. Typical Side drains

4.3 Surface Drainage System

- Intercepting Drains/Catch Drains





4.3 Surface Drainage System

- Camber (Transverse Slopes)
  - Removes water from pavement surface as quickly as possible.
  - 2% for concrete, 2.5% for bituminous, 3% for gravel, 4% for earthen roads.

4.3 Surface Drainage System

- Cross Drainage Structures
  - Those 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.
  - Quick drainage, prevents water from penetrating the soil in the embankment.
  - Various cross-drainage structures are used – Culverts, Minor bridge, Bridge, Aqueduct, Syphon, Causeway, etc.

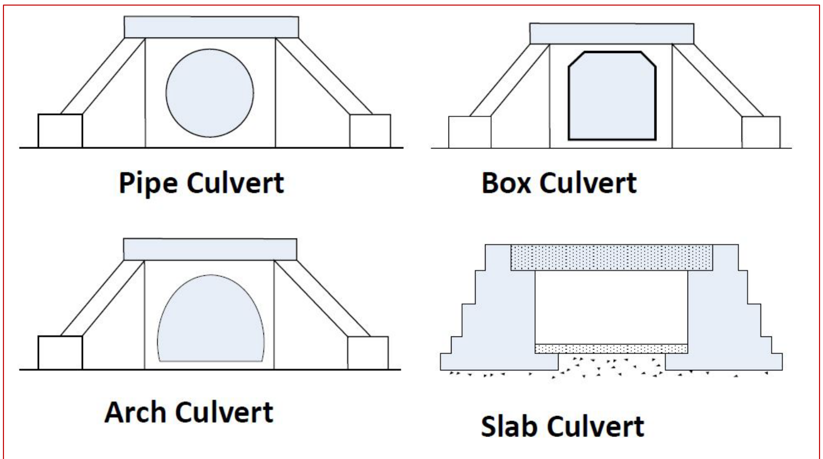
- Culverts – upto 6 m length
- Minor Bridge – More than 6 m and upto 20 m length
- Medium Bridge – Above 20m length and span length less than 20m
- Major Bridge – Bridge with span length greater than 20m
- Causeway – Which allows the water to flow over the roadway

4.3 Surface Drainage System

- 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.
  - Bridges are designed to pass floating debris or vessels while culverts are designed for full flow under certain conditions.
- Functions
  - Collection and transport of water across the road and dispose safely.
  - Provide sufficient waterway to prevent heading up of water above the road surface.
- Importance
  - Culvert are laid beneath embankment
  - Hydraulically efficient
  - Identical discharge through culvert is higher than bridge
- Types
  - Pipe Culvert
  - Box Culvert
  - Slab Culvert
  - Arch Culvert

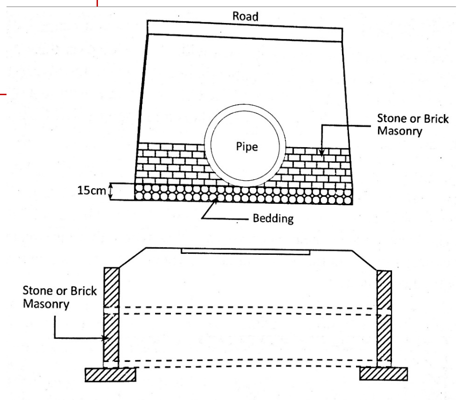
4.3 Surface Drainage System

- Culverts



4.3 Surface Drainage System

- Pipe Culvert
  - Used in non-perennial or at very small stream (Surface runoff from side drain).
  - Minimum of 50 cm cover of soil should be provided so that traffic load transmitted on pipe is of small intensity.
  - Minimum diameter of pipe – 600 mm.

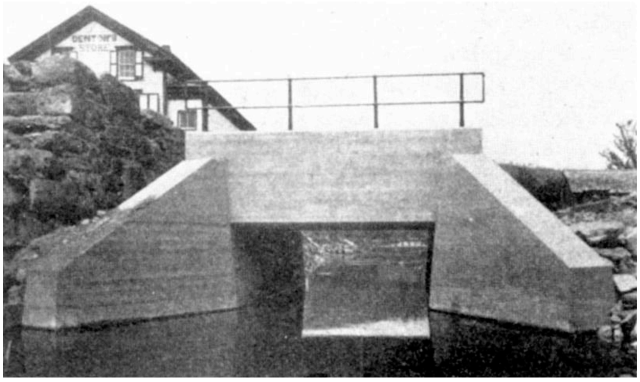


4.3 Surface Drainage System

- 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.

4.3 Surface Drainage System

- Slab Culvert
  - They are used in stream with boulder movement and debris flow.
  - These culverts are used where the water opening is less than $15m^2$ 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.

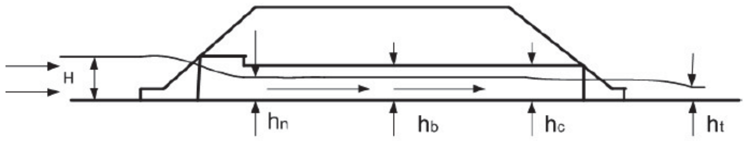


4.3 Surface Drainage System

- Arch Culvert
  - These culverts area 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.

4.3 Surface Drainage System

- Culvert: Hydraulic Classification
  - Culvert with Free flow (Non-pressure flow):
    - Culverts functioning with free flow surface at both entrance and through the entire length of culvert barrel.
    - If $H < 1.2\ h_b$ the culvert will have free flow surface

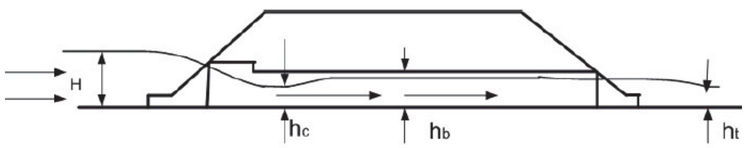


A) Culvert with free flow condition

H- depth of head water; hn - Normal depth of flow at inlet; hb - Height of culvert barrel;
hc - Critical depth of flow; ht - Depth of tail water

4.3 Surface Drainage System

- Culvert: Hydraulic Classification
  - Culvert with Part full flow
    - Culvert with normal inlet, when the head water depth rises above $1.2\ h_b$, the flow is part full flow.
    - $1.4\ h_b \geq H \geq 1.2\ h_b$
    - Culvert has been laid on steep slope.

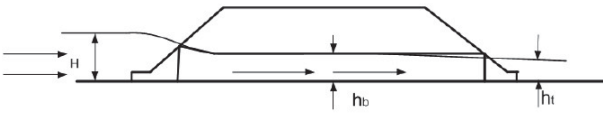


B) Culvert with part full flow condition

H- depth of head water; hn - Normal depth of flow at inlet; hb - Height of culvert barrel;
hc - Critical depth of flow; ht - Depth of tail water

4.3 Surface Drainage System

- Culvert: Hydraulic Classification
  - Culvert with Full flow
    - Both inlet and outlet are in submerged condition
    - Occurs in flat or slightly rolling case
    - Pipe flow case and pressured flow ($H \geq 1.4\ h_b$)

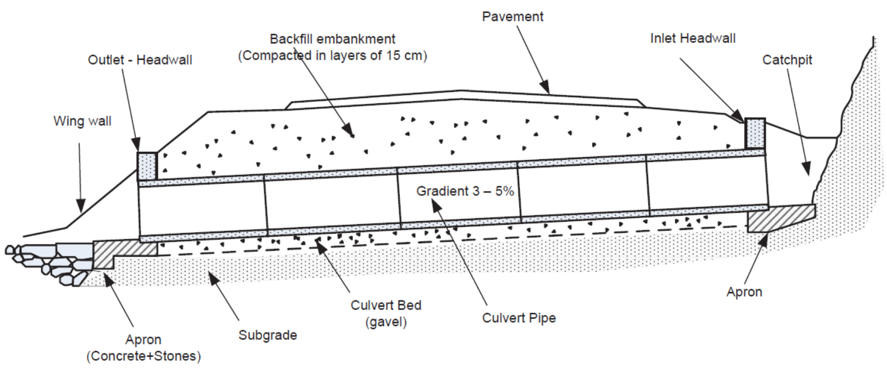


C) Culvert with full flow condition

H- depth of head water; hn - Normal depth of flow at inlet; hb - Height of culvert barrel; hc - Critical depth of flow; ht - Depth of tail water

4.3 Surface Drainage System

- Components of Culvert
  - Culvert barrel
  - Apron
  - Headwall
  - Wingwall
  - Drop inlet
  - Bedding



4.3 Surface Drainage System

- Geometric standards for culverts
  - Culvert width: Equal to the formation width of road
  - Slope: Natural bed slope (1 in 100 in hill, 1 in 1000 in plain roads)
  - Culvert size: min. 60 cm dia.
  - Height of culvert: 1.75m for 1m dia, 2.15m for 1.2m dia pipe. Minimum height of slab culvert is 1.775m.
  - Height of fill: Min. height of fill above pipe is 1m.
  - Jointing: Flush joint or collar joint of width 15 to 20 cm.

4.3 Surface Drainage System

- Culverts Location
  - Bottom of depression where no natural water course exist
  - Where natural stream intersect the roadway
  - Confirm with natural stream
  - Confirm to existing grade of stream

4.3 Surface Drainage System

- Bridge
  - Structure constructed over water course to carry traffic over it.
  - Culverts – upto 6 m length
  - Minor bridge – more than 6m and upto 20m length
  - Medium bridge – above 20m length, span length less than 20m
  - Major bridge – bridge with span length greater than 20m

- On the basis of construction materials
  - Steel bridges
  - Concrete bridges
  - Timber bridges

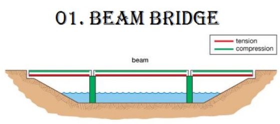
- On the basis of structural point of view
  - Cantilever
  - Continuous
  - Suspension
  - Cable stayed

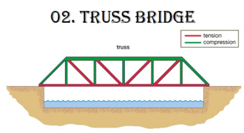
- On the basis of span length
  - Minor bridge (upto 30m)
  - Major bridge (above 30m)
  - Long bridge (above 120m)

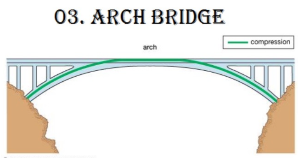
- On the basis of load carrying capacity
  - Class 70 (AA)
  - Class 40 (A)
  - Class 30 (B)

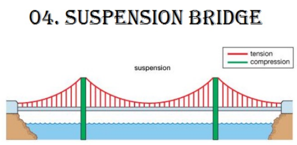
4.3 Surface Drainage System

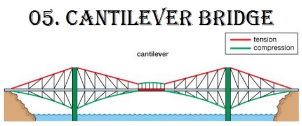
- Based on Loading Characteristics
  - Beam or slab bridge
  - Truss bridge
  - Arch bridge
  - Suspension bridge
  - Cantilever bridge
  - Cable stayed bridge

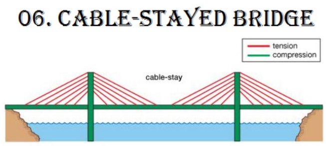












Source: 7 Jenis Jembatan yang dibangun di Dunia – afifnf (wordpress.com)

4.3 Surface Drainage System

- Based on Utility
  - Highway Bridge
  - Railway Bridge
  - Compound Bridge (dual purpose)
  - Pedestrian Bridge

4.3 Surface Drainage System

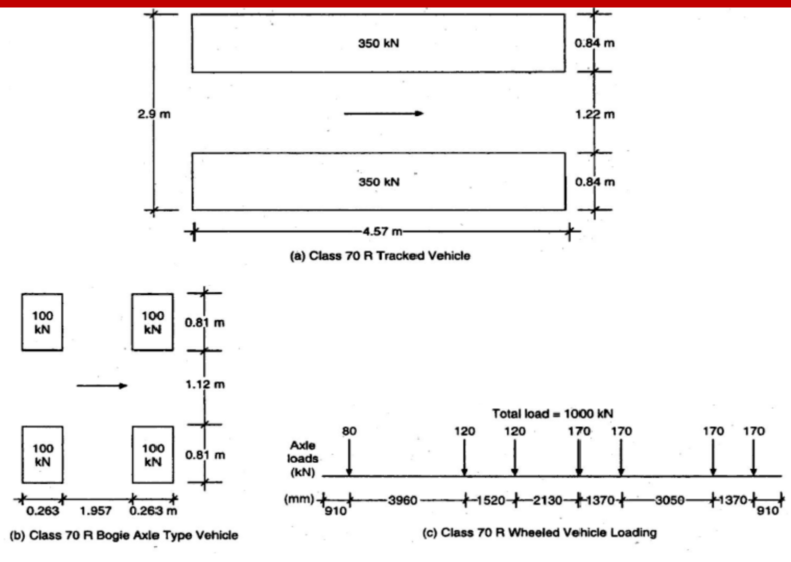
- Based on Construction Material
  - Masonry Bridge
  - PCC Bridge
  - RCC Bridge
  - Steel Bridge
  - Timber Bridge
  - Floating Bridge

4.3 Surface Drainage System

- Based on Loading

Major Bridge: IRC class AA or Class 70 R

In this category, two types of vehicles are specified and they are grouped as tracked vehicle and wheeled vehicles. The tracked vehicle simulating an army tank of 700 KN and wheeled vehicle of 400 KN (a heavy army truck) are standardized for the designing of all the bridges located on National Highways and State Highways.



I.R.C. Class 70 R Tracked and Wheeled Vehicles.

4.3 Surface Drainage System

- Based on Loading

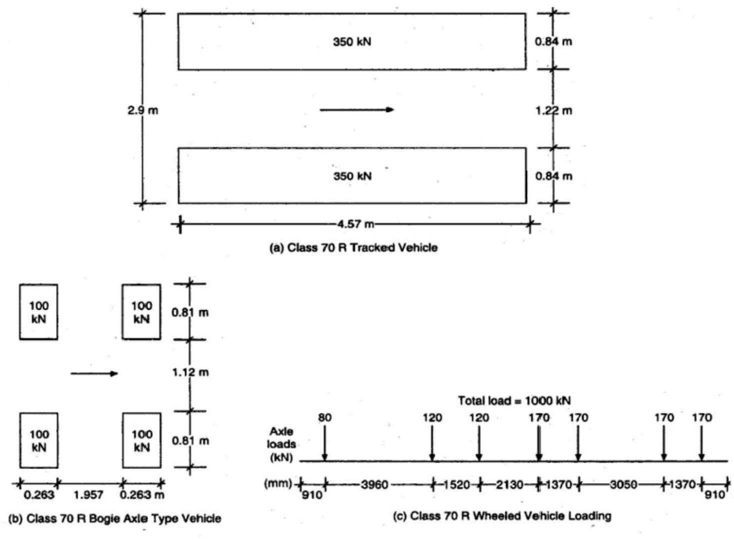
Major Bridge: IRC class AA or Class 70 R

The following vehicles are considered for the design under this category:

(a) The tracked vehicle of the total load of 700 KN with tracks each weighing 350 KN each

(b) Wheeled vehicle of the total load of 400 KN with each wheels weighing 100 KN each

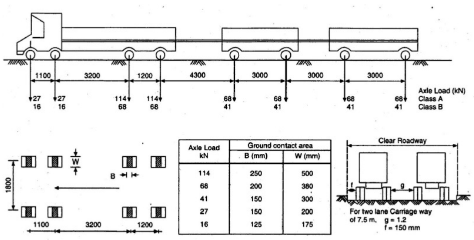
(c) Wheeled vehicle with a train of vehicles on seven axles with a total weight of 1000 KN



I.R.C. Class 70 R Tracked and Wheeled Vehicles.

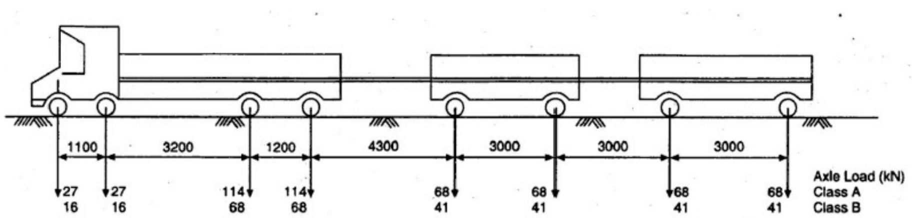
4.3 Surface Drainage System

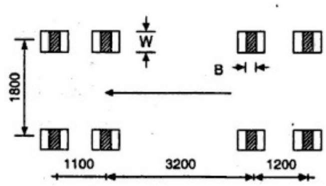
- Based on Loading
- <u>Medium Bridge or minor bridge: IRC Class A</u>
  - The IRC Class A loading is consists of a wheel load train of a total load of 554 KN. It comprises a heavy-duty truck with two trailers that transmit loads from 8 axles varying from a minimum of 27 KN to a maximum of 114 KN
  - This type of loading is recommended for all roads on which permanent bridges and culverts are constructed.
- <u>Temporary bridges: IRC Class B</u>
  - The loading of this class is similar to the Class A loading except that the axle loads are of lesser magnitude. The total axle loads of this Class are 332 KN with a train of wheeled vehicles on eight axles.



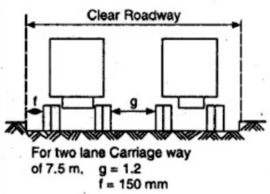
4.3 Surface Drainage System

- Based on Loading





Axle Load kN	Ground contact area B (mm)	Ground contact area W (mm)
114	250	500
68	200	380
41	150	300
27	150	200
16	125	175



4.3 Surface Drainage System

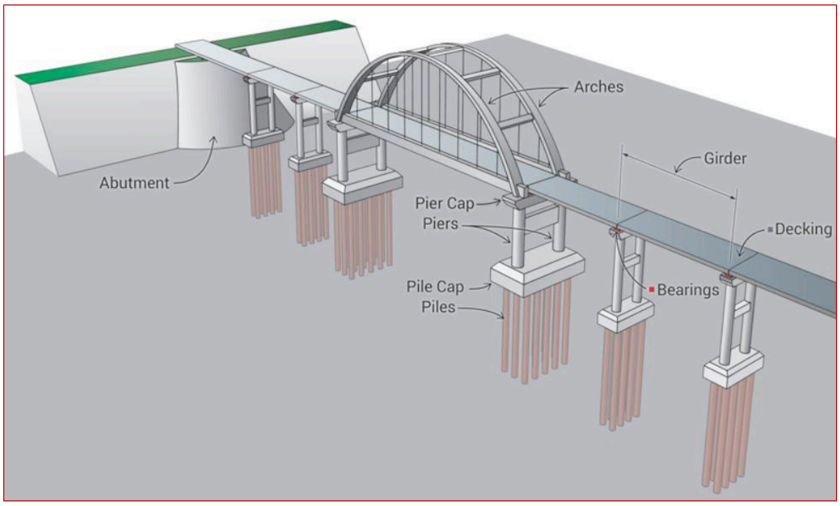
- Based on Obstacle to be Crossed
  - River Bridge
  - Fly over

4.3 Surface Drainage System

- Based on Position of pavement on the carriageway
  - Carriageway at bottom (through)
  - Carriageway at top (deck)
  - Carriageway at middle (semi through)

4.3 Surface Drainage System

- Components of Bridge
  - Superstructure
  - Substructure
  - Foundation

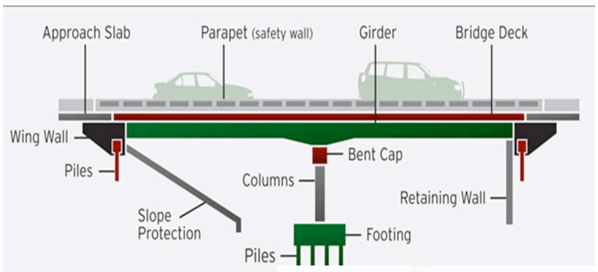


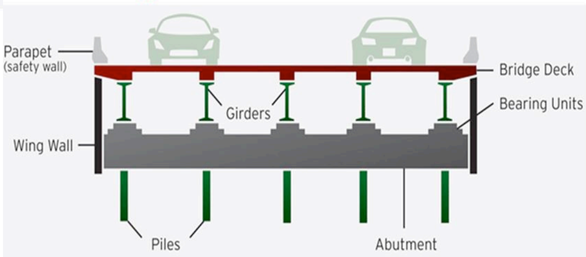
4.3 Surface Drainage System

- **Components of Bridge**

<u>Superstructure</u>

- Structure of a bridge above the bearing.
- Structure above which traffic moves safely.
- Main girders, cross girders, deck slab, parapet, roadway, footpath, kerb stones, etc.





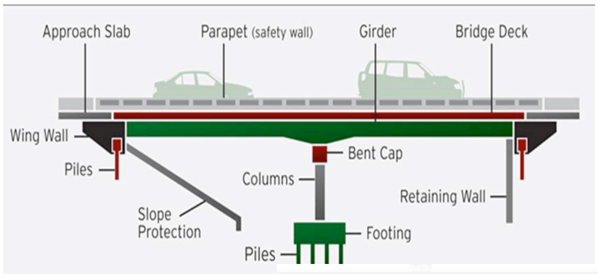
4.3 Surface Drainage System

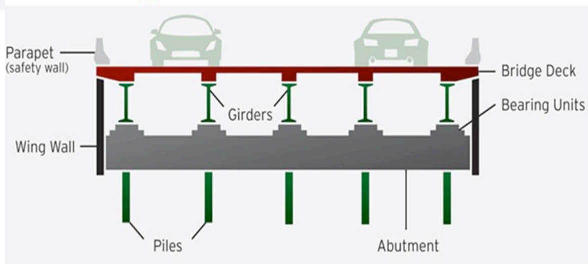
- **Components of Bridge**

  <u>Substructure</u>

  - Supports the super structure and distributes the loads to the soil below through foundation.
  - Abutment and its cap, pier and its cap, foundations for abutments and piers, etc.

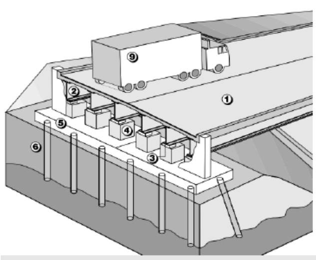
  <u>Foundation may be pile or well foundation.</u>

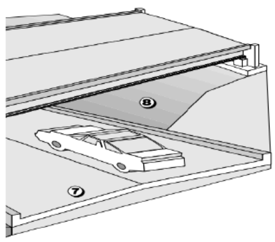




4.3 Surface Drainage System

- **Components of Bridge**
  - Deck – Physical extension of the roadway across the obstruction to be bridged.
  - Pedestals – Short column on an abutment or pier under a bearing which directly supports a superstructure primary member.
  - Abutments – Earth retaining structures which support the superstructure and overpass roadway at the beginning and end of a bridge.
  - Piers – Structures which support the superstructure in intermediate points between the end supports (abutments).





1-Deck and	2- Stringer	3-Bearing
4- Pedestal	5-Footing	6-Piles
7- Underpass	8-Embakment	9- Live Loading

Bearings – Mechanical systems which transmit the vertical and horizontal loads of the superstructure to substructure and adjust movements between them.

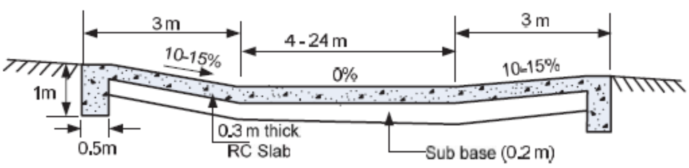
4.3 Surface Drainage System

- Causeway
  - Structure which will enable to drain water laterally by road surface.
  - 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.
  - The depth of flow in most of the period of the year should not exceed 30cm.

- Types of Causeway
  - Low Level Causeways/Flush Causeways/Irish Bridge of Ford
  - High Level Causeways/Submersible Causeways/Vented Causeways

4.3 Surface Drainage System

- Low Level Causeways/Flush Causeways/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.
  - Points to be considered:
    - Maximum depth of water less than 15cm and flood water depth less than 1.5m.
    - The period of interruption < 24 hours for rural roads in hills and 3 days in case of road in plains.
    - Total interruption during a year < 10 days for district roads and 15 days for village roads.

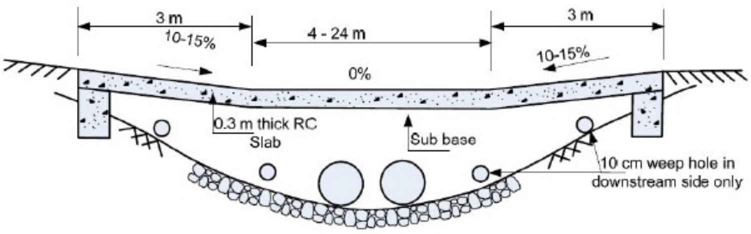


4.3 Surface Drainage System

- Low Level Causeways/Flush Causeways/Irish Bridge of Ford

4.3 Surface Drainage System

- High Level Causeways/Submersible Causeways/Vented Causeways
  - 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.

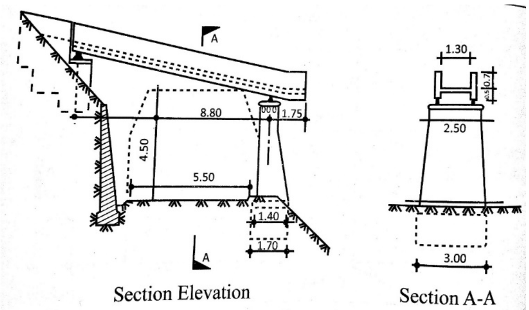


4.3 Surface Drainage System

- High Level Causeways/Submersible Causeways/Vented Causeways

4.3 Surface Drainage System

- Aqueduct
  - 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.
  - If a road cutting exceeding 5 meters, then aqueduct is best option to cross natural drainage course or irrigation canal.

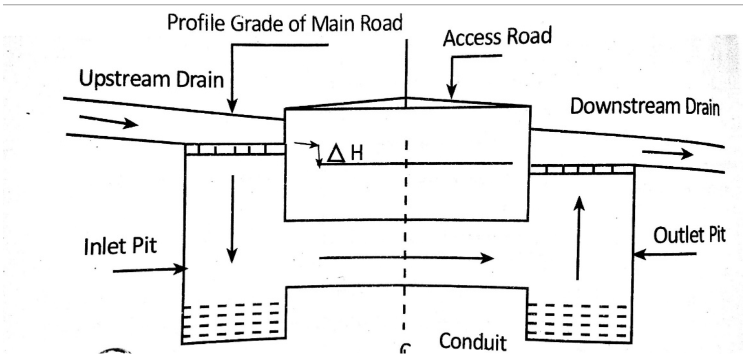


Section Elevation

Section A-A

4.3 Surface Drainage System

- Inverted Siphon
  - A pressure pipeline crossing a depression or passing under highway is called inverted siphon.
  - U-shaped vertical alignment such that they are always running full.

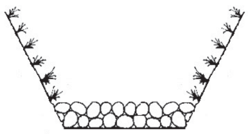


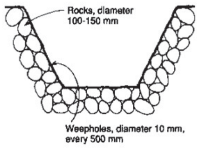
4.3 Surface Drainage System

- Erosion Control and Energy Dissipating Structures
  - High velocity of water may cause
    - Erosion of hill slope
    - Removal of vegetation layer
- Control of the erosion is directly concerned with the dissipation of energy which ultimately means the reduction of velocity.

4.3 Surface Drainage System

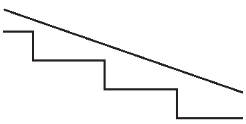
- Energy Dissipating Structures
  - Lining of drains
    - If the mean velocity exceeds the permissible velocity, lining is provided to protect against scouring.
    - The slope of drain is lined with turf and bottom is covered by cobbles and gravels of desired size.
    - For higher velocity, stone or brick masonry or precast blocks are used throughout the perimeter and length of drain.
    - Pre-cast concrete blocks can be used if local stone materials are not available.

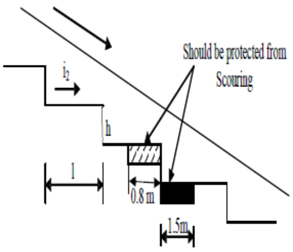




4.3 Surface Drainage System

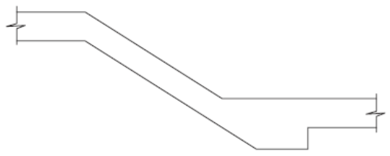
- Energy Dissipating Structures
  - Ditch Checks
    - The energy of flowing water can be reduced by providing falls at certain interval.
    - Used when grade line of side drain is high.





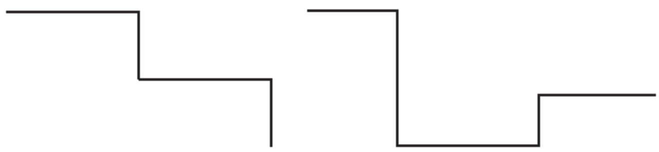
4.3 Surface Drainage System

- Energy Dissipating Structures
  - Road Rapids
    - Road channels having bed slopes generally higher than the critical slope.
    - Provided at the end of the catch drain.
    - Consist of inlet, main conduit, stilling basin and outlet.



4.3 Surface Drainage System

- Energy Dissipating Structures
  - Fall or Drop Structure
    - Where the bed slope of existing drainage is high, drop structures are provided.
    - Such structures are frequently provided in hill roads.



4.3 Surface Drainage System

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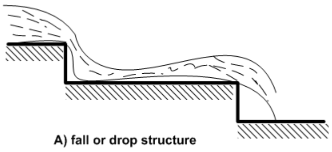
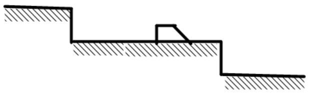
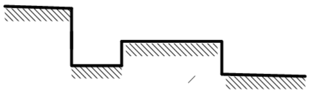


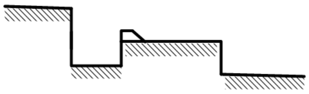
A) fall or drop structure



A) fall or drop structure with friction wall



A) fall or drop structure with stilling basin



A) fall or drop structure with stilling basin and friction wall

4.3 Surface Drainage System

- Reasons of Soil Erosion
  - Formation of new fills and cut slopes
  - Excavation of drainage way
  - Diversion of waterways along new channels
  - Embankment construction
  - Removal of top-soil
  - Increase in human activities on construction site and deforestation

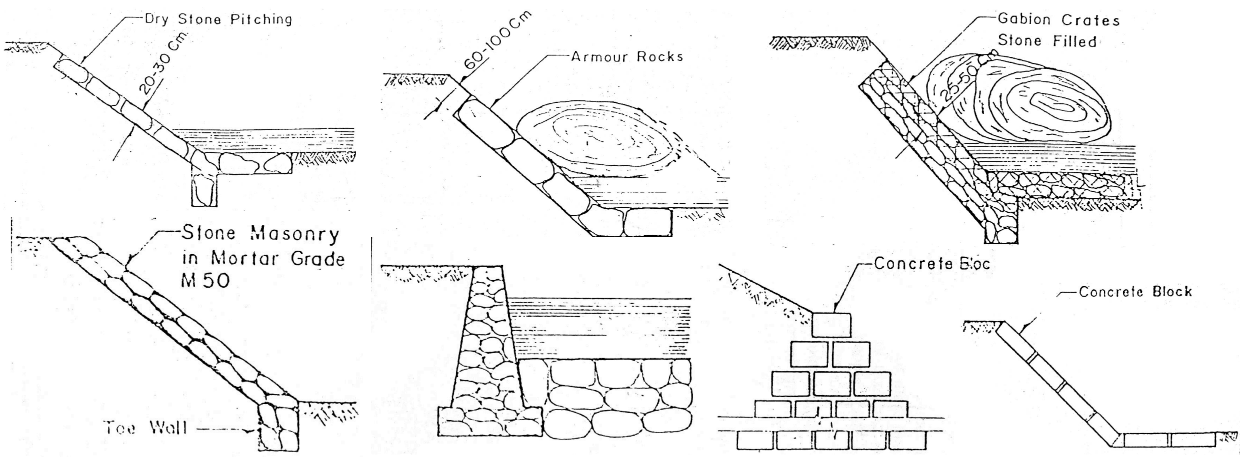
4.3 Surface Drainage System

- Miscellaneous Erosion Control Measures
  - Vegetation
  - Slope pitching, lining and protection walls
  - Bank protection spurs and check dams

- Miscellaneous Erosion Control Measures
  - Vegetation
    - Turf and other ground cover could be rapidly established.
    - Trees and shrubs on steep hill slopes.

4.3 Surface Drainage System

- Miscellaneous Erosion Control Measures
  - Slope pitching, lining and protection walls



4.3 Surface Drainage System

- Miscellaneous Erosion Control Measures
  - Bank protection spur and check dams
    - Spur: Perpendicular structure to the direction of flow to dissipate the water energy and protect the erosion.
    - Check dams: Structures constructed across the stream having high bed slope in a particular section to retain boulder or bed material.

4.4 Subsurface Drainage System

- Subsurface Drainage
  - Stability and strength of the road surface depends upon the strength of subgrade.
  - With increase in moisture content, the strength of the subgrade decreases.
  - Whatever, effective measures for the surface drainage may be considered, water finds its own way to get into the subgrade and further below. The provision of drainage under the ground surface is referred as sub-surface drainage.

4.4 Subsurface Drainage System

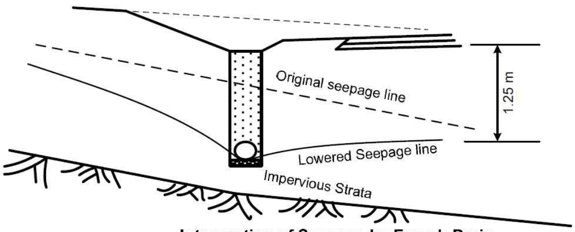
- Subsurface Drainage
  - Drainage of Infiltrated Water
    - Water enters to subgrade soil through permeable surface of adjoining land, shoulder, side slope and cracks on the pavement surfaces.
    - The water infiltrated is collected at the side drain with the function of sand blanket.
    - The water infiltrated from side drain is collected in perforated pipe just below the side drain and is disposed off with the help of cross-drainage structure.

4.4 Subsurface Drainage System

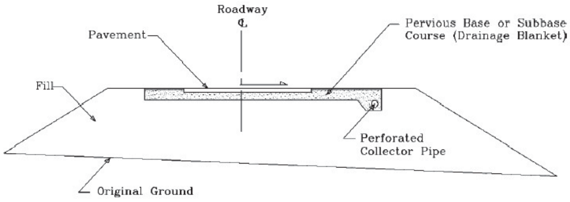
- Subsurface Drainage
  - Control of Seepage Flow
    - Seepage may occur from the higher ground in hilly topography or in road cuttings where a layer of permeable soil overlies an impermeable stratum which affects the strength characteristics of the subgrade.
    - The best solution to this type of 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 surface, it should be intercepted to keep seepage line at a safe depth below the road subgrade.

4.4 Subsurface Drainage System

- Subsurface Drainage
  - Control of Seepage Flow



Interception of Seepage by French Drain

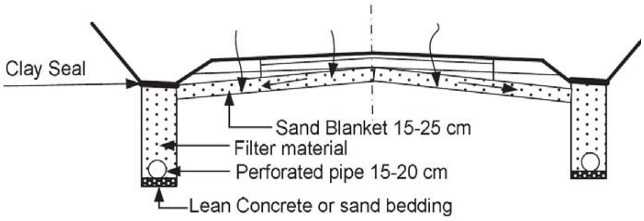


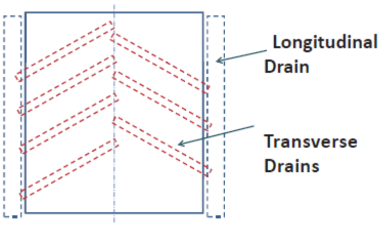
4.4 Subsurface Drainage System

- Subsurface Drainage
  - Lowering of Water Table
    - The water table may rise and may come up to the pavement layers in low-lying areas during rainy seasons. Therefore, it becomes necessary to lower the water table safely below the pavement.
    - For relatively permeable soil, longitudinal drains at slope of 0.5 – 1% parallel to the center lines are mainly used.
    - For impermeable soils, transverse drains are used in addition to longitudinal drains.
    - The depth to which 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.

4.4 Subsurface Drainage System

- Subsurface Drainage
    - Lowering of Water Table



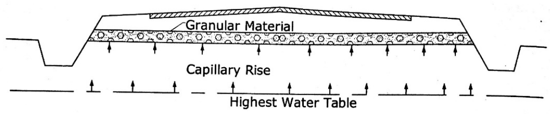


4.4 Subsurface Drainage System

- Subsurface Drainage
    - Control of Capillary Rise
        - In water-logged areas, there will be possibility of rising of water to the subgrade level due to capillarity.
        - 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.
        - There are two types of capillary cut off:
            - Granular Capillary Cut off
            - Impermeable Capillary Cut off

4.4 Subsurface Drainage System

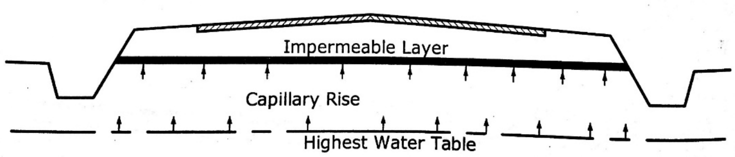
- Subsurface Drainage
  - Control of Capillary Rise
    - Granular Capillary Cut off
      - Provision of granular material of suitable thickness between the subgrade and the highest level of subsurface water table during the construction of embankment.
      - The granular capillary cut off layer's 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.
      - Suitable sand blanket and gravel blanket can be used for cut off.



Granular Capillary Cut-Off

4.4 Subsurface Drainage System

- Subsurface Drainage
  - Control of Capillary Rise
    - 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 or heavy-duty polythene can also be used.



Impermeable Capillary Cut-Off

Design of Surface Drainage System

- Design of Surface Drainage
  - Hydrological Analysis
  - Hydraulic Design

- Hydrological Analysis

$$Q = CIA$$

Where, Q = runoff (m^3/secs), C = runoff coefficient, I = intensity of rainfall (mm/secs), A = drainage area (1000 sq.m.)

- Runoff Coefficient: Fraction of rainfall that becomes runoff. Depends upon characteristics of soil, shape of drainage area, existing moisture conditions, slope of watershed, amount of impervious soil, land use, duration and intensity of rainfall.

$$C = \frac{C_1 A_1 + C_1 A_1 + \dots \quad \dots \quad \dots + C_n A_n}{A_1 + A_1 + \dots \quad \dots \quad \dots + A_n} = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_i}$$

Design of Surface Drainage System

- Design of Surface Drainage
  - Hydrological Analysis
  - Hydraulic Design

- Hydrological Analysis

$$Q = CIA$$

Where, Q = runoff (m^3/secs), C = runoff coefficient, I = intensity of rainfall (mm/secs), A = drainage area (1000 sq.m.)

- Watershed (Drainage) Area: Area that contributes to the runoff at the point where the channel capacity is to be determined. Determined from: Topographic maps, aerial photos, digital elevation models, drainage maps, field reviews.

- Rainfall: Factors usually considered in making decision includes: the improvement of the highway, the volume of traffic on the highway and the population density of the area.

Design of Surface Drainage System

- Design of Surface Drainage
  - Hydrological Analysis
  - Hydraulic Design

- Hydrological Analysis

$$Q = CIA$$

Where, Q = runoff (m^3/secs), C = runoff coefficient, I = intensity of rainfall (mm/secs), A = drainage area (1000 sq.m.)

- Rainfall intensity: Average intensity for a selected frequency and duration over drainage area for duration of storm. Based on values of: time of concentration and recurrence interval or design frequency.

- Time of concentration: Inlet time for storm water to flow from most remote point in drainage area to the drain inlet is estimate by using chart. Depends on: size and shape of drainage area, type of surface, slope of drainage area, rainfall intensity, whether flow is entirely overland of whether some is channelized.

Design of Surface Drainage System

- Hydrological Analysis

$$Q = CIA$$

Where, Q = runoff (m^3/secs), C = runoff coefficient, I = intensity of rainfall (mm/secs), A = drainage area (1000 sq.m.)

- Design Rain Fall (IRC SP13 Method)
  - The rainfall intensity is

$$I = F\frac{\left(1+\frac{1}{T}\right)}{t_c+1}$$

where, F = the rainfall in cm dropped by severest storm over a period of T hours and t_c is the time of concentration in hours.

$$t_c = \left(\frac{0.87L^3}{H}\right)^{0.385}$$

where, L is the distance from the critical point to the culvert in km, and H is the fall in level from the critical point to the culvert in m.

Design of Surface Drainage System

- Hydraulic Design
  - Cross sectional area of the side drain may be determined with the help of the following formula.

$$Q = AV$$

Where, V = allowable velocity in m/secs, Q = Quantity of surface water in m^3/secs, A = Area of cross section of the channel in m^2

- Once discharge is known, open channel principle can be used.
- Manning's formula assumes steady flow in a uniform channel.

$$V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

Where, V = mean velocity in m/secs, R = hydraulic radius in m, S = slope of the channel (m/m), n = Manning's roughness coefficient

Design of Subsurface Drainage

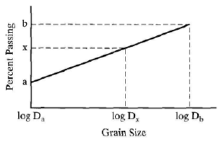
- Design of Subsurface Drainage
  - Depth of the drainage trench
    - On the basis of impervious stratum level, soil type and requirement at which the subsurface flow has to be maintained.
  - Selection of the backfill filter material for the trench
    - Clogging Criteria
    - Permeability Criteria
    - Additional Criteria
  - Size and number of perforations in the drain pipe
  - Diameter of the drainage pipe

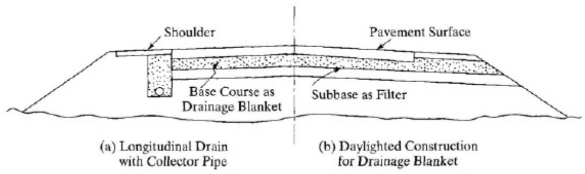
Design of Subsurface Drainage

- Design of Subsurface Drainage
  - Selection of the backfill filter material for the trench
    - Clogging Criteria
      - The filter material should be fine enough to prevent the adjacent finer material from piping or migrating into the filter material as indicated by

$$\frac{D_{15} filter}{D_{85} Soil} \leq 5$$

Where, D_{15} and D_{85} are the grain size corresponding to 15 and 85% passing respectively, and can be obtained from the grain size curves of each materials.





Design of Subsurface Drainage

- Design of Subsurface Drainage
  - Selection of the backfill filter material for the trench
    - Permeability Criteria
      - The filter material must be coarse enough to carry water without any significance resistance, as indicated by

$$\frac{D_{15} filter}{D_{15} soil} \geq 5$$

    - Additional Criteria

$$\frac{D_{50} filter}{D_{50} soil} \leq 2.5$$

      - To minimize segregation, the Corps of Engineers specified that filter materials should have a coefficient of uniformity not greater than 25.
      - To prevent the fines in the filter from infiltrating into the drainage layer, Moulton (1980) recommended that the amount of sieves passing sieve No. 200 be not greater than 5% or D_5 of filter ≥ 0.074mm.

Design of Subsurface Drainage

- Design of Subsurface Drainage
  - Size and number of perforations in the drain pipe
    - The holes should be sufficiently small enough to prevent the filter material from being washed into the pipe and plug the holes.
    - Maximum size of circular holes = D_{85} (filter)
    - Maximum width of slotted holes = $0.83*D_{85}$ (filter)
  - Diameter of the drainage pipe
    - Selected such that the pipe will not run full near its outlet and flood the surrounding filter material.
    - Must be big enough so that all the intercepted water can be discharged through the pipe.
    - 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.

Highway Drainage

Thank You!

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