SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING

HIGHWAY ENGINEERING I
CENG 3202

Chapter V
Highway Drainage

2012EC (2019/20) 2nd Sem

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Highway Drainage

- **Provision of sufficient drainage is an important factor in the location and geometric design of highways.**
- **Drainage facilities used for the flow of water away from the surface of the pavement to properly designed channels.**
- **Inadequate drainage will eventually result in serious damage to the highway structure.**
- **In addition, traffic may be slowed by accumulated water on the pavement, and accidents may occur as a result of loss of visibility from splash and spray.**

Drainage

- **Surface drainage:** **for surface water which occurs as rain**

- **Subsurface drainage:** **for absorbed water into the soil**

Surface drainage

- **Encompasses all means by which surface water is removed from the pavement and right of way of the highway.**

Surface drainage system

- **Transverse slopes: crown or camber**
- **Longitudinal slopes: minimum 0.5%**
- **Longitudinal Channel: ditches**
- **Curbs**
- **Gutters: are drainage usually located on the pavement side of a curb**
- **Drainage Structures**
  - Culverts and Bridges

Highway Sub drainage Systems

- **Subsurface drainage systems are usually classified into five general categories:**
    - Longitudinal drains
    - Transverse drains
    - Horizontal drains
    - Drainage blankets
    - Well systems

Effects of water on the pavement structure

- **Presence of moisture causes:**
  - reduction in the stability of the soil mass.
  - considerable variation in volume of subgrade in clayey soils.
  - Waves and corrugations failure in flexible pavements.
  - Stripping failure in flexible pavements.
  - Mud pumping failure in rigid pavements.

DESIGN OF SURFACE DRAINAGE SYSTEMS

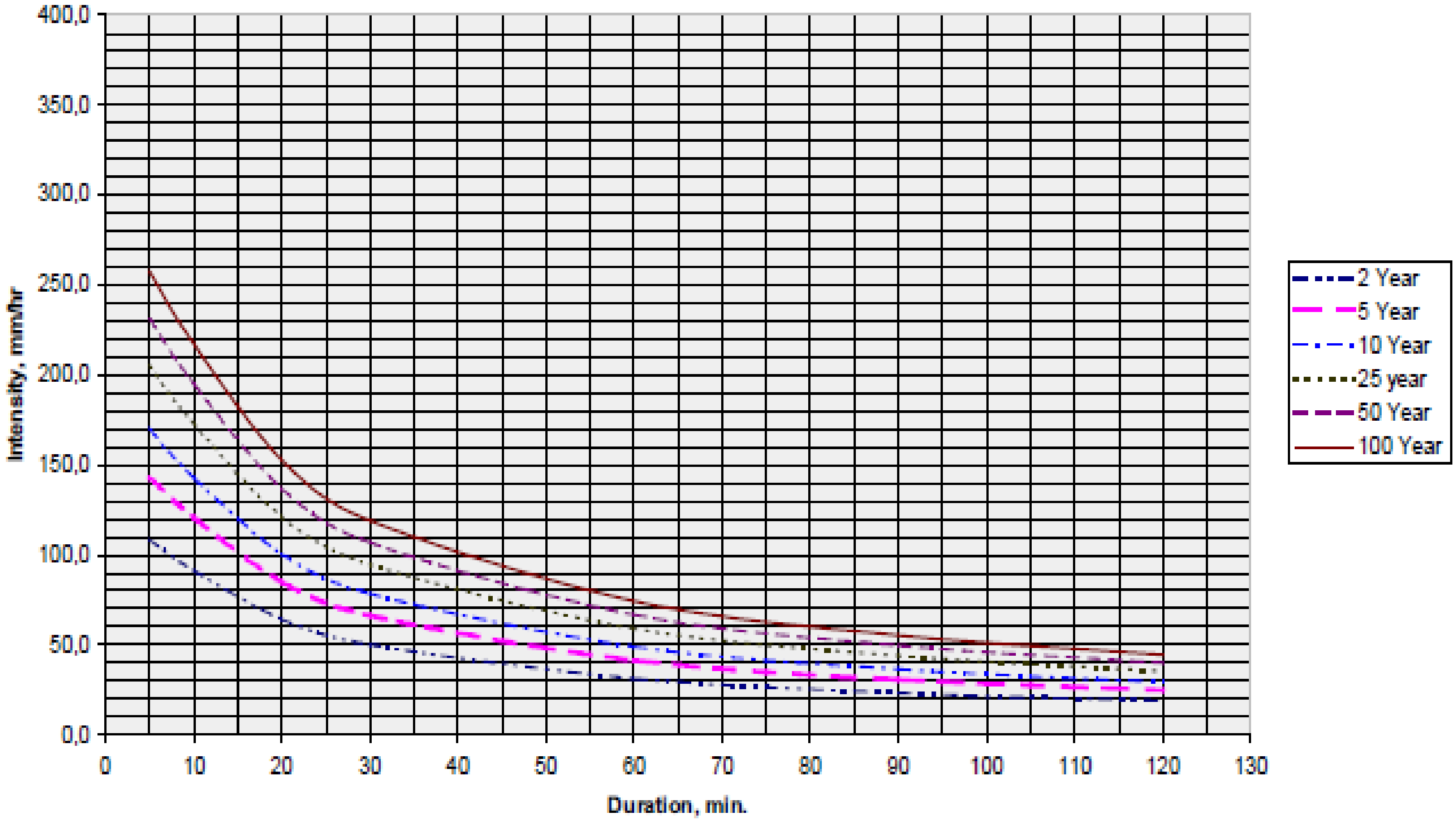
- **Can be divided into three phases:**
    i. Estimation of the quantity of water that can reach any element of the system.
    ii. Hydraulic design of each element of the system.
    iii. Comparison of alternative systems and materials
        - Criteria-Lowest annual cost alternative

DESIGN OF SURFACE DRAINAGE SYSTEMS

1. Rainfall Intensity

- **Runoff is obtained by considering expected sever storm.**
  - Return period of 5, 10, 20, 25, 50, and 100 years
- **Quantity of runoff depends on intensity and duration.**
- **Duration= Time of Concentration**
  - The time required for water from the remotest place to reach a specific point on the drainage system.
  - $T=T_1+T_2$
    - T_1= over land flow time
    - T_2= time of flow in the longitudinal drain

DESIGN OF SURFACE DRAINAGE SYSTEMS



Intensity duration graph (Source: ERA Manual)

DESIGN OF SURFACE DRAINAGE SYSTEMS

2. Computation of Runoff

- **Rain water expelled from the road surface**

    i. Infiltration

    ii. Runoff

    iii. Evaporation- insignificant

i. Infiltration depends on:

- Type and gradation of soil
- Soil covers, moisture content of the soil
- Presence of impervious layers near the surface.

DESIGN OF SURFACE DRAINAGE SYSTEMS

Infiltration contd.

- Rate of infiltration on bare soil is less than on a turfed soil.
- Frozen soil is impervious
- Rate of infiltration is assumed to be constant during any specific design storm.

ii. Runoff depends on:

- Nature of the ground, degree of saturation, and slope of the surface
- Rate of runoff greater on smooth surfaces.

DESIGN OF SURFACE DRAINAGE SYSTEMS

- **Rational Formula- accurate way of estimating runoff up to areas of 0.5 km^2**

$$Q = 0.00278 \cdot CIA$$

$$C = \frac{C_1 A_1 + C_2 A_2 + \ldots}{A_1 + A_2 + \ldots}$$

- **If the water shade is made up of different surfaces**

- Q= runoff (m3/sec)
- C=coefficient, representing ratio of runoff to rainfall
- I= intensity of rainfall (mm/hr) for a duration equal to the time of concentration
- A= catchment area tributary to the design location, ha

Design of Surface drainage system

Table 5-4 Recommended Runoff Coefficient C for Various Selected Land Use

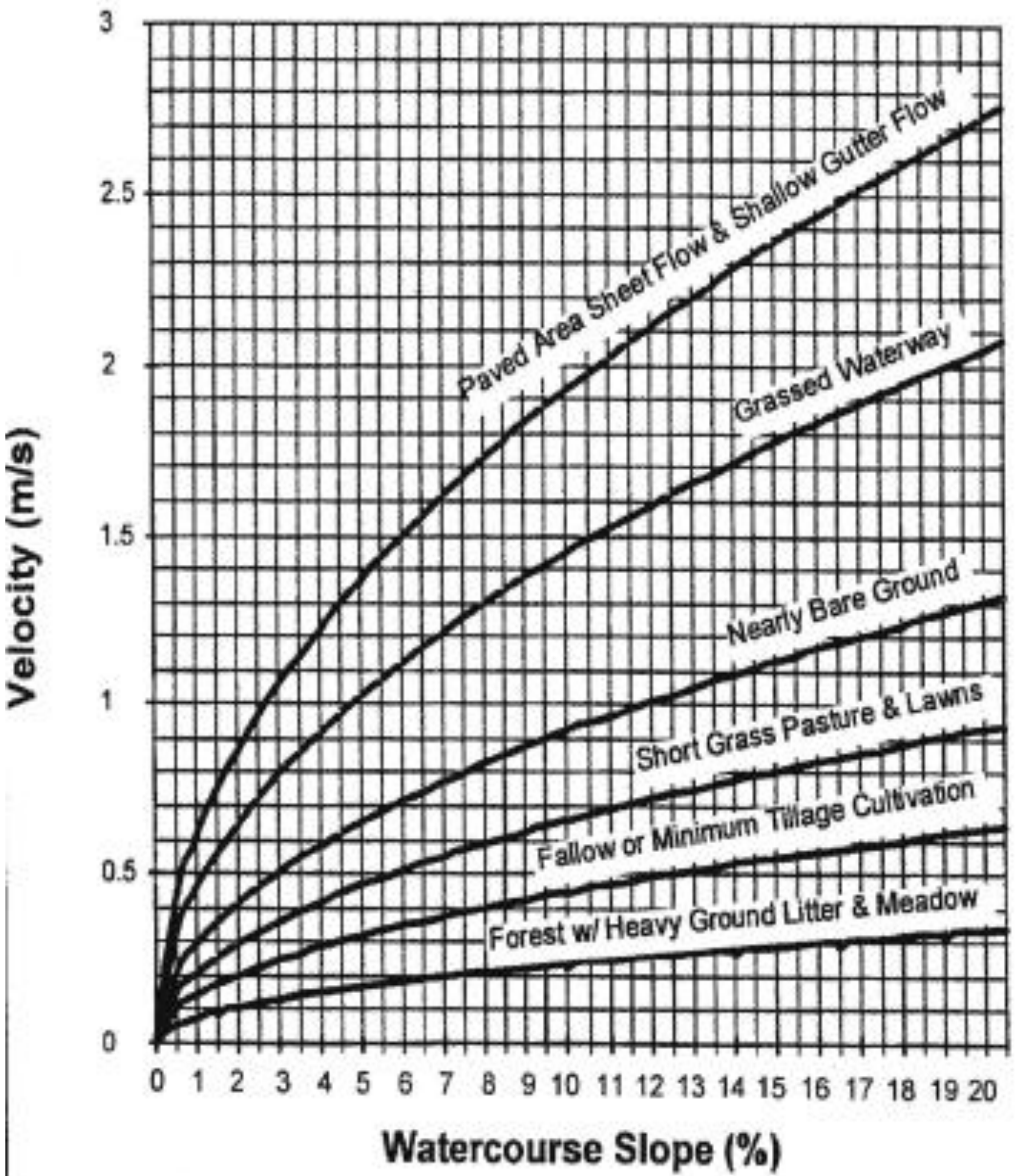
Description of Area		Runoff Coefficients
Business:	Downtown areas	0.70-0.95
	Neighborhood areas	0.50-0.70
Residential:	Single-family areas	0.30-0.50
	Multi units, detached	0.40-0.60
	Multi units, attached	0.60-0.75
	Suburban	0.25-0.40
Residential (0.5 hectare lots or more)		0.30-0.45
Apartment dwelling areas		0.50-0.70
Industrial:	Light areas	0.50-0.80
	Heavy areas	0.60-0.90
Parks, cemeteries		0.10-0.25
Playgrounds		0.20-0.40
Railroad yard areas		0.20-0.40
Unimproved areas		0.10-0.30

Source: Hydrology, Federal Highway Administration, HEC No. 19, 1984

Table 5-5 Coefficients for Composite Runoff Analysis

Surface		Runoff Coefficients
Street :	Asphalt	0.70-0.95
	Concrete	0.80-0.95
Drives and walks		0.75-0.85
Roofs		0.75-0.95

Source: Hydrology, Federal Highway Administration, HEC No. 19, 1984



- t_c=distance/velocity of flow
- t_c is then used to determine the rainfall intensity (I)

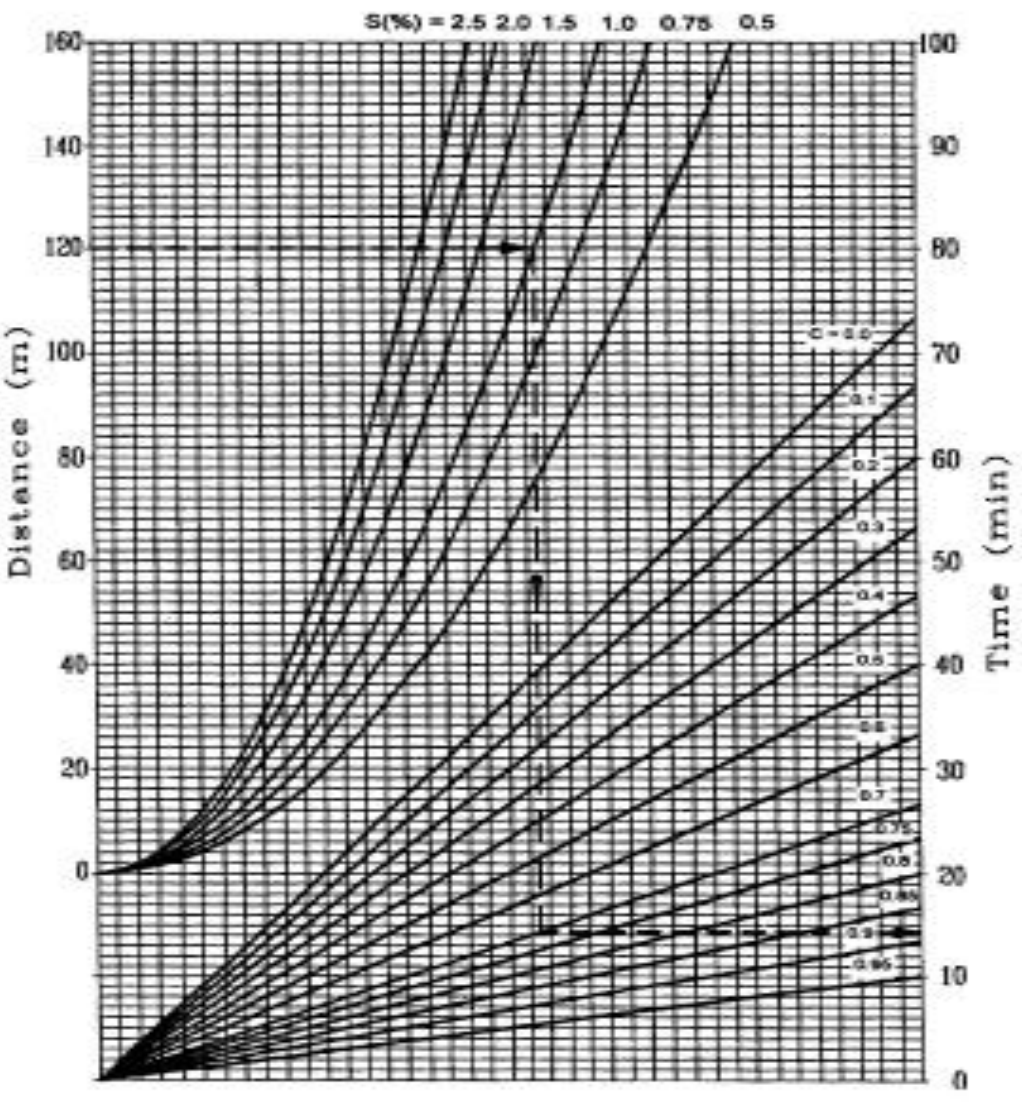


Figure 5-3 Overland Time Of Flow

- This chart can also be alternatively used to determine t_c

Example 1
Runoff determination

- **From a topographic map and field survey, the area of the drainage basin upstream from the point in Region A1 is found to be 35 hectares. The road has a functional classification of a Link Road, with a design standard of DS3 indicating a design storm frequency of 10 years.**
- **Determine the maximum rate of runoff for a 10-year and check a 25-year return period using Rational Method. The following data were measured:**
  - Length of overland flow = 45 m
  - Average overland slope = 2.0%
  - Slope of channel = 0.018 m/m = 1.8 %
  - Time of concentration= 1.5hr
- **Land Use and Soil Data**
  - Residential (multi-units, attached) 40% (C = 0.68)
  - Undeveloped (2.0% slope),with good vegetative cover 60% (C = 0.14)

DESIGN OF SIDE DITCHES AND OPEN CHANNELS

- **The Manning's Formula**
  - **Once the quantity of runoff is known, the design of ditches and similar structures is based on the principles of open channel flow.**
  - **Mannings's formula assumes steady flow in a uniform channel.**

$$V = \frac{1}{n} R^{2/3} S^{1/2} \qquad Q = V \cdot A$$

Where:

- V= mean velocity (m/sec)
- R= hydraulic radius (m)= Area/wetted perimeter
- S=slope of the channel (m/m)
- n=Manning's roughness coefficient

DESIGN OF SIDE DITCHES AND OPEN CHANNELS

- **The Manning's Formula**

TABLE 5.3 Manning's Roughness Coefficient, *n*, for Overland Sheet Flow

Surface description	*n*
Smooth asphalt	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Good wood	0.014
Brick with cement mortar	0.014
Vitrified clay	0.015
Cast iron	0.015
Corrugated metal pipe	0.024
Cement rubble surface	0.024
Fallow (no residue)	0.05
Cultivated soils	
Residue cover ≤ 20%	0.06
Residue cover > 20%	0.17
Range (natural)	0.13
Grass	
Short grass prairie	0.15
Dense grasses	0.24
Bermuda grass	0.41
Woods*	
Light underbrush	0.40
Dense underbrush	0.80

DESIGN OF SIDE DITCHES AND OPEN CHANNELS

- **Capacity of a Trapezoidal Channel**

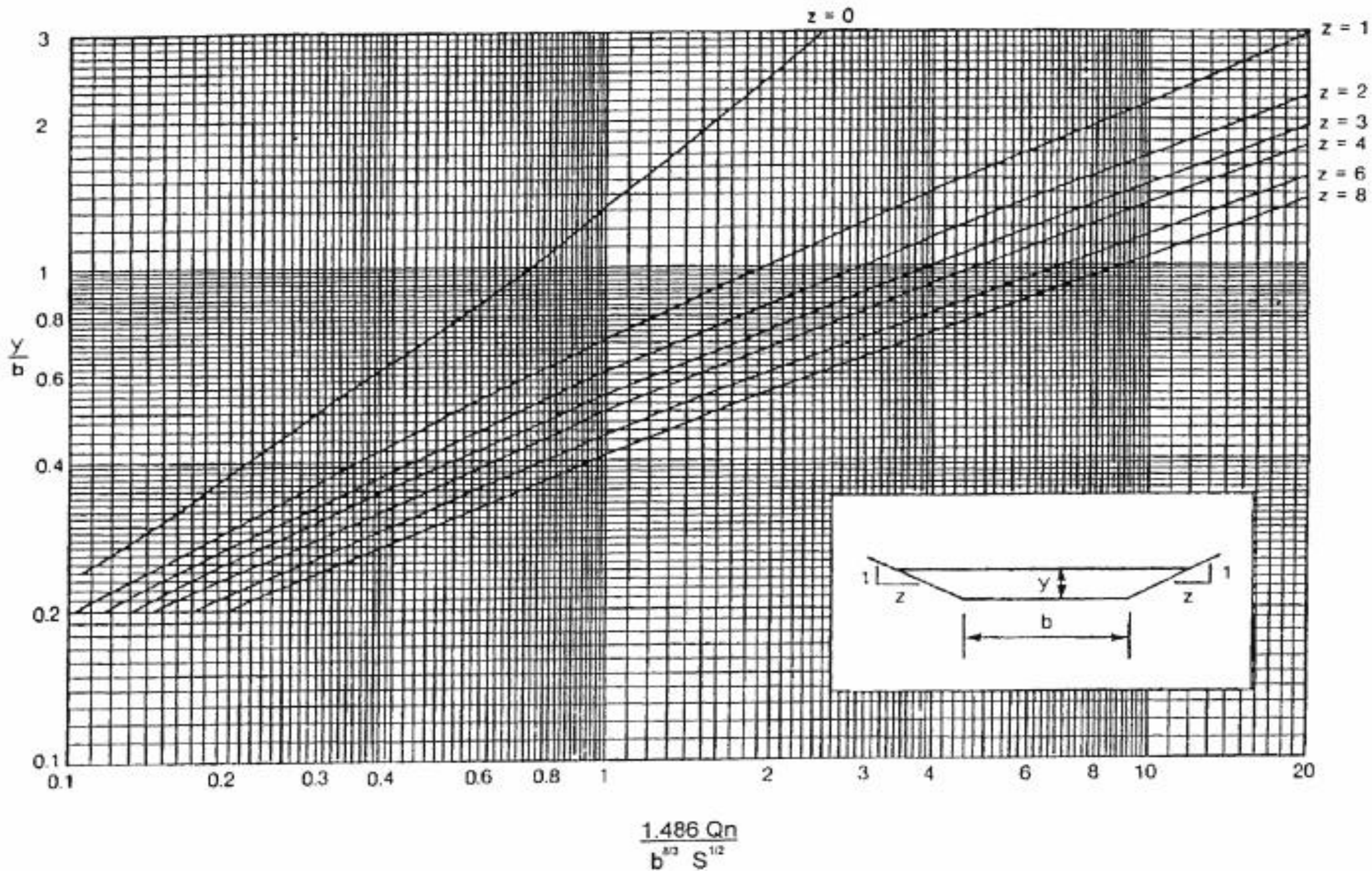


Figure 6-4 Trapezoidal Channel Capacity Chart

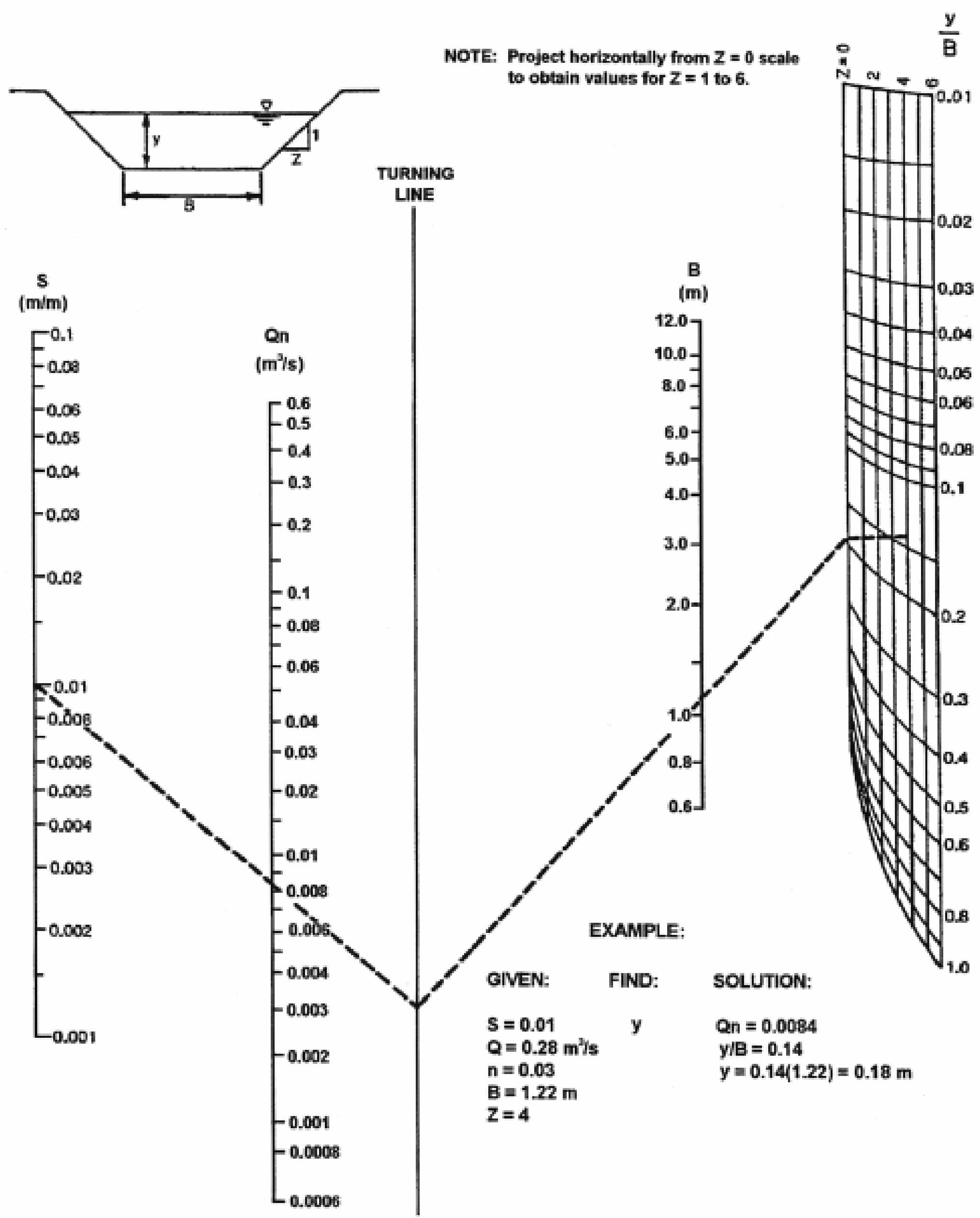
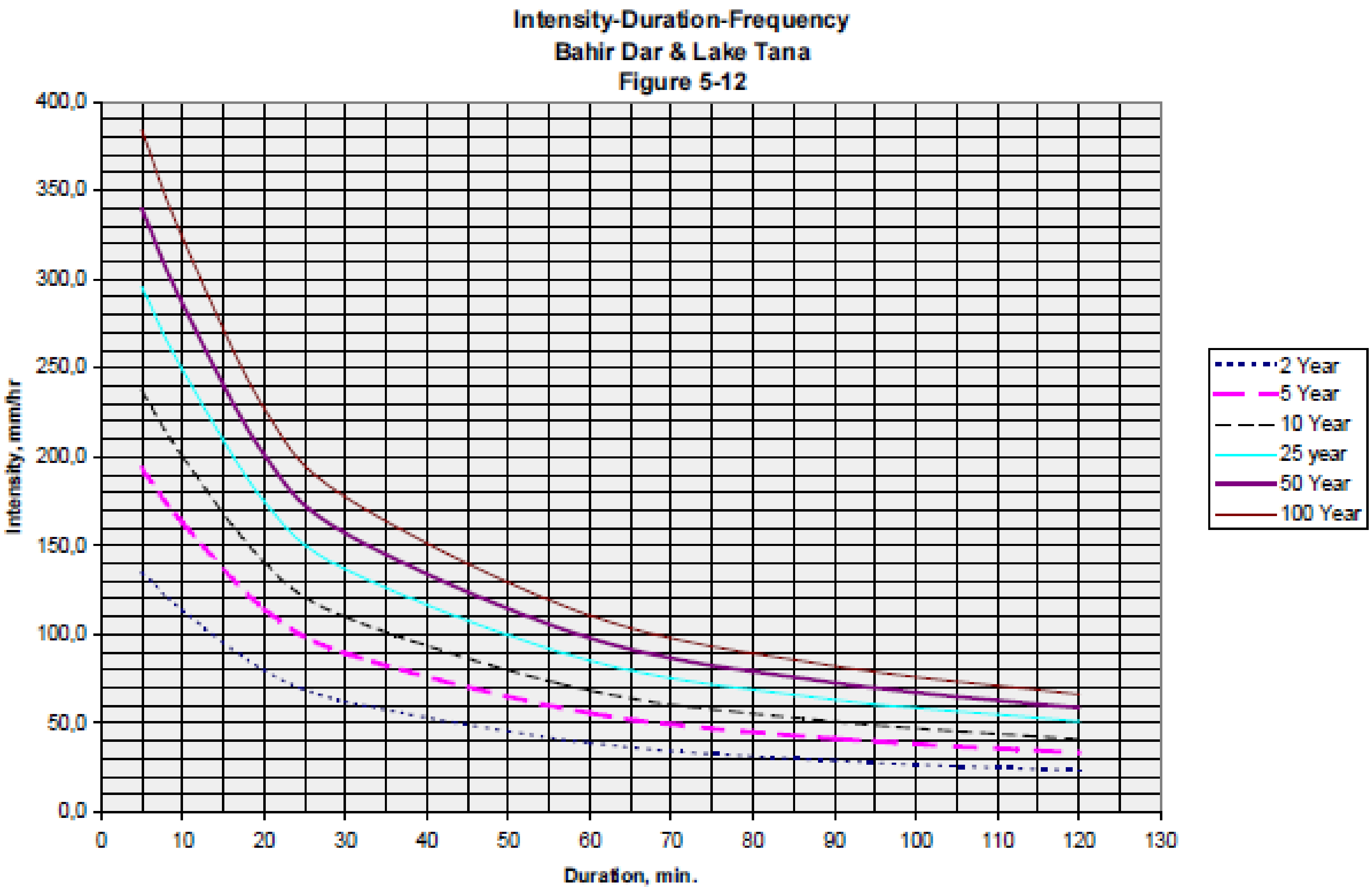


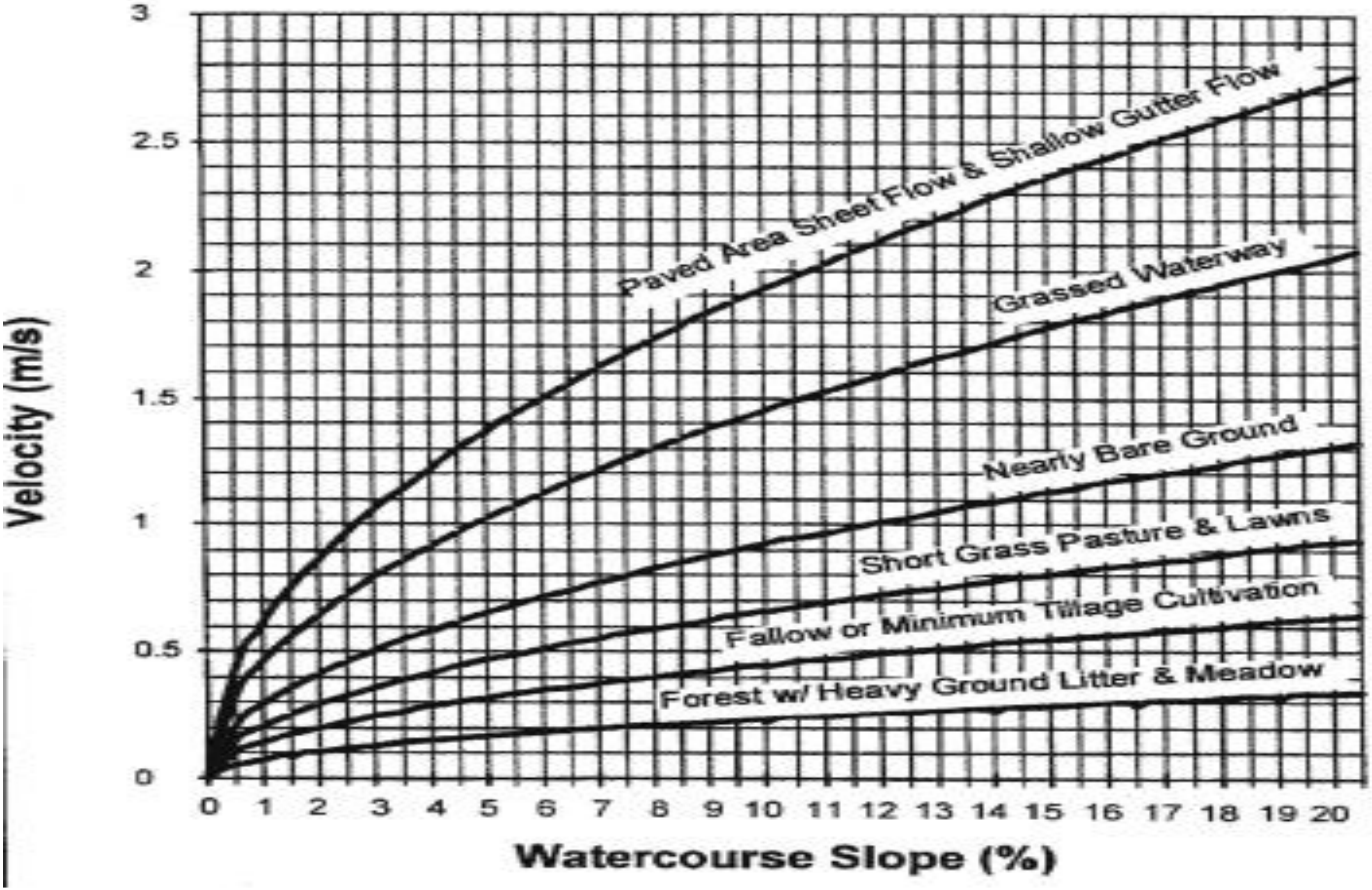
Figure 6-5 Nomograph For Normal Depth

Example 2

The surface water from road side is drained to the longitudinal side drain from across on half a bituminous pavement surface of total width 7.0m, shoulder and adjoining land of width 8.0m on one side of the drain. On the other side of the longitudinal drain, water flows across from reserve land with grass and 2% cross slope towards the side drain, the width of this strip of land being 25m. The run off coefficients of the pavement, shoulder and reserve land with grass surface are 0.8, 0.25 and 0.35 respectively. The length of the stretch of land is about 400m.

a. **Estimate the quantity of run off flowing in the drain assuming 25 years period of frequency.**
b. **Design a rectangular cross section and longitudinal slope of the side drain in loamy soil with Manning's roughness coefficient = 0.022, base width= 0.5m and suitable speed of low = 0.8m/sec.**


Intensity-Duration-Frequency
Bahir Dar & Lake Tana
Figure 5-12
Intensity, mm/hr
400,0
350,0
300,0
250,0
200,0
150,0
100,0
50,0
0,0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Duration, min.
2 Year
5 Year
10 Year
25 year
50 Year
100 Year


Velocity (m/s)
0
0.5
1
1.5
2
2.5
3
Paved Area Sheet Flow & Shallow Gutter Flow
Grassed Waterway
Nearly Bare Ground
Short Grass Pasture & Lawns
Fallow or Minimum Tillage Cultivation
Forest w/ Heavy Ground Litter & Meadow
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Watercourse Slope (%)

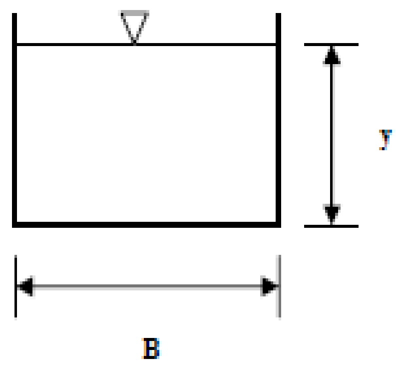
Examples 3

DESIGN OF SIDE DITCHES AND OPEN CHANNELS

The maximum quantity of water expected in one of the open longitudinal drains on clayey soil is 0.9 m3/sec. Design the cross section and longitudinal slope of trapezoidal drain assuming the bottom width of the trapezoidal section to be 0.5 m and cross slopes to be 1V:1.5H. The allowable velocity of flow in the drain is 1.2 m/sec and Manning's roughness coefficient is 0.02.

Example 4

Calculate the best hydraulic rectangular cross-section to convey Q =10 m3/sec discharge with n= 0.02 and S = 0.0009 canal characteristics.



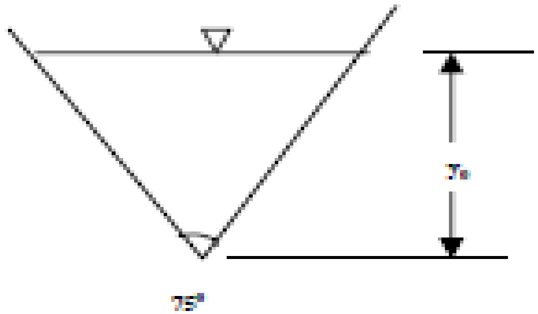
Exercise

DESIGN OF SIDE DITCHES AND OPEN CHANNELS

The surface water from road side is drained to the longitudinal side drain from across one half a bituminous pavement surface of total width 7.0 m, shoulder and adjoining land of width 8.0 m one side of the drain. On the other side of the longitudinal drain, water flows across from reserved land with grass and 2% cross slope towards the side drain, the width of this strip of land being 25 m. The run off coefficients of the pavement, shoulder and reserve land with grass surface are 0.8, 0.25, and 035 respectively. The length of the stretch of land parallel to the road from where water is expected to flow to the side drain is about 400 m. Estimate the quantity of run-off flowing in the drain assuming 25 years period of frequency.

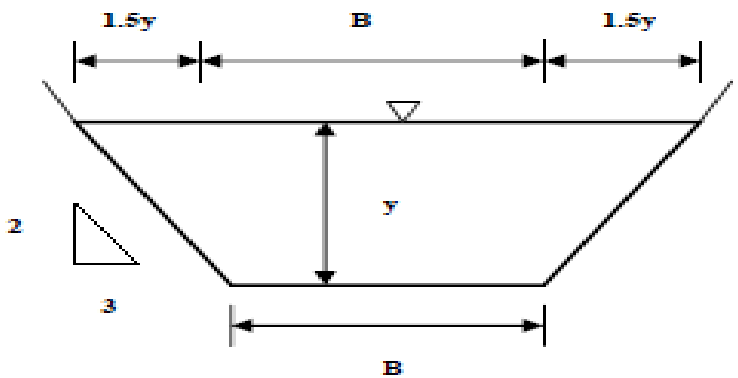
Quiz

A triangular channel with an apex angle of 750 carries a flow of 1.20 m3/sec at a depth of 0.80 m. If the bed slope is $S_0 = 0.009$, find the roughness coefficient **n** of the channel.

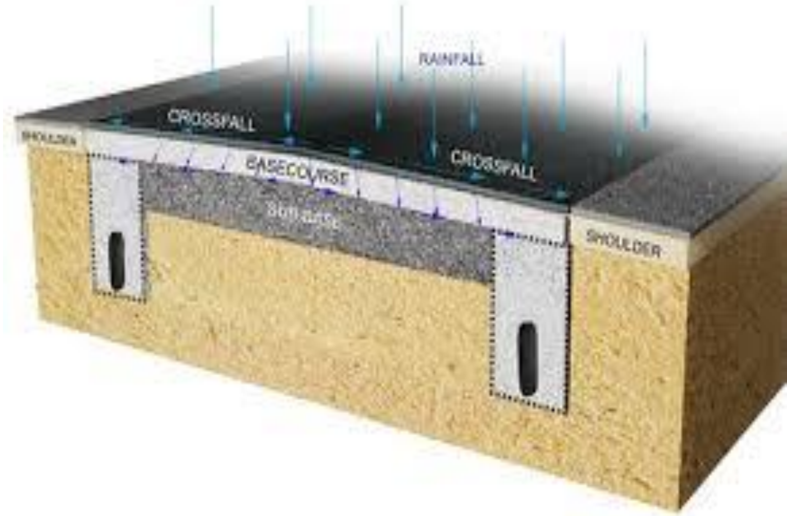


Exercise

Design the trapezoidal channel as best hydraulic cross-section with Q= 10m3/sec, n= 0.014, S0= 0.0004, and m= 3/2.



Design of Subsurface Drainage



SUBSURFACE DRAINAGE

1. Lowering of Water Table

- **Highest level of water table should be below the subgrade.**
    - Practically 1.0 to 1.2 m below subgrade
- **Relatively permeable soil-**
    - Longitudinal drains are mainly used
- **Impermeable soils-**
    - Transverse drains may be necessary in addition to longitudinal drains

SUBSURFACE DRAINAGE

1. Lowering of Water Table cont..

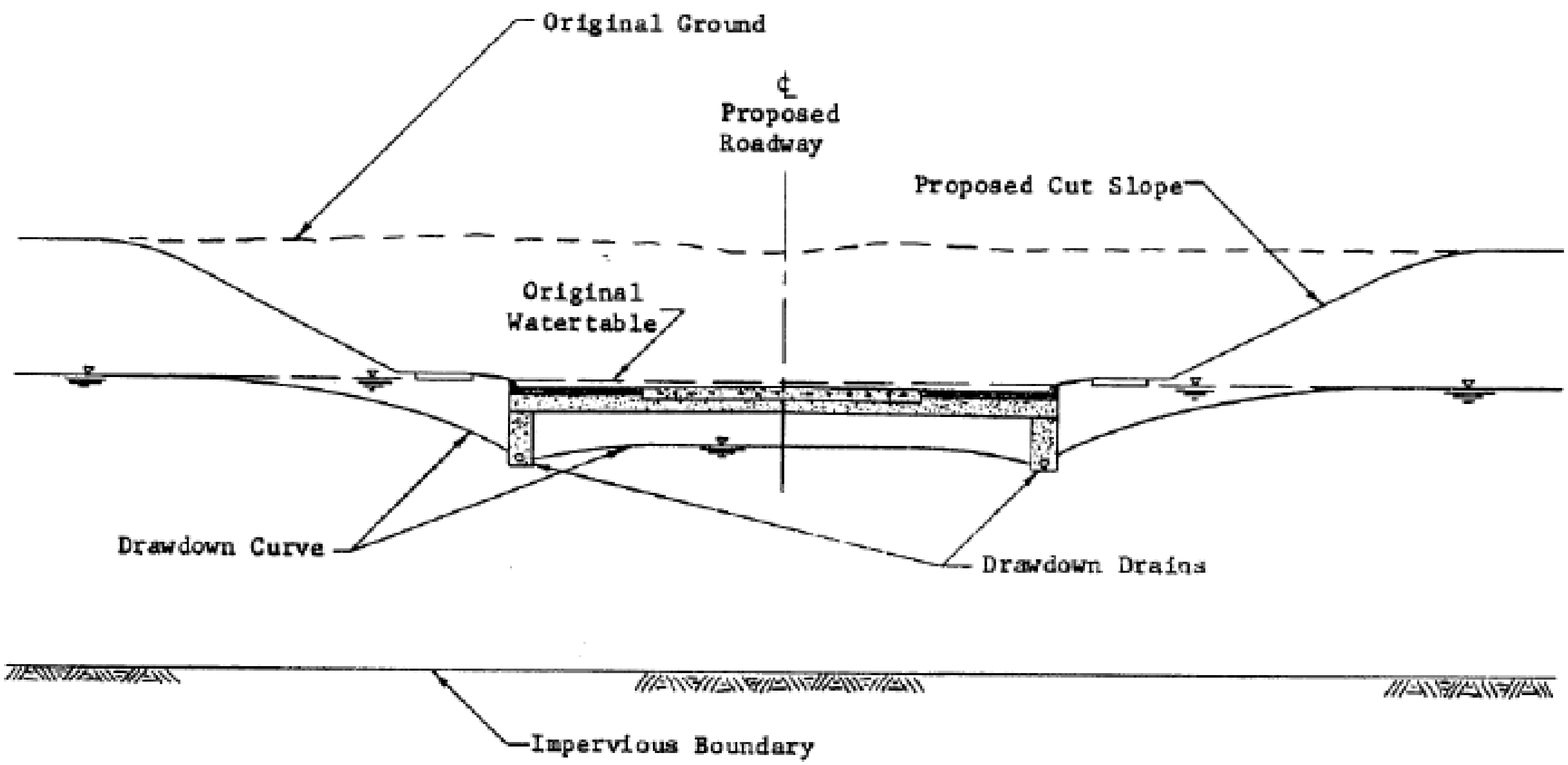


Fig. Symmetrical longitudinal drains used to lower the groundwater table and to collect water infiltrating the pavement.

SUBSURFACE DRAINAGE

Lowering of Water Table

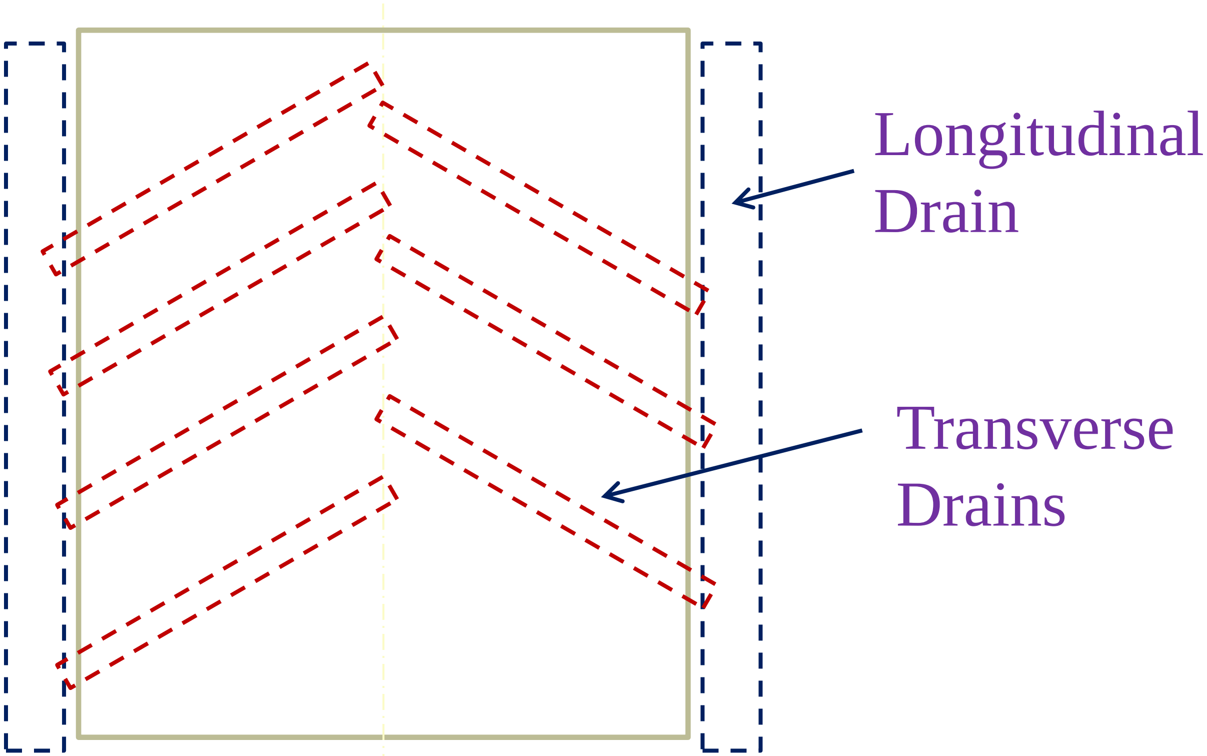
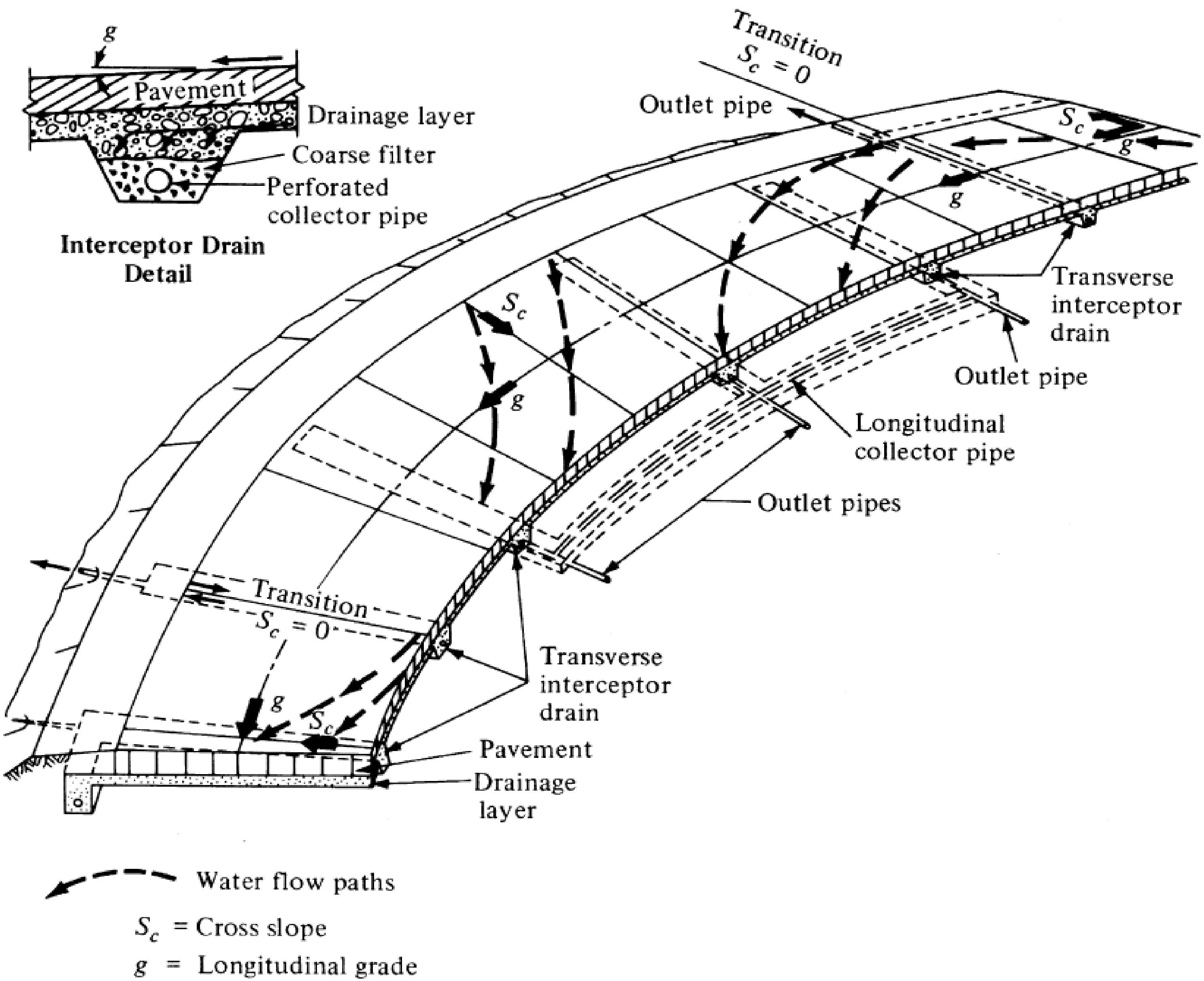


Fig. Lowering of water table using Transverse Drains (Plan View)



Transverse Drains

SUBSURFACE DRAINAGE

2. Seepage Control

- **If seepage zone is at a depth less than 0.6 to 0.9 m below subgrade level,**
  - Use longitudinal pipe drain in trench with filter material to intercept the seepage flow.
  - This phenomenon can be explained using figures.

SUBSURFACE DRAINAGE

Seepage Control cont..

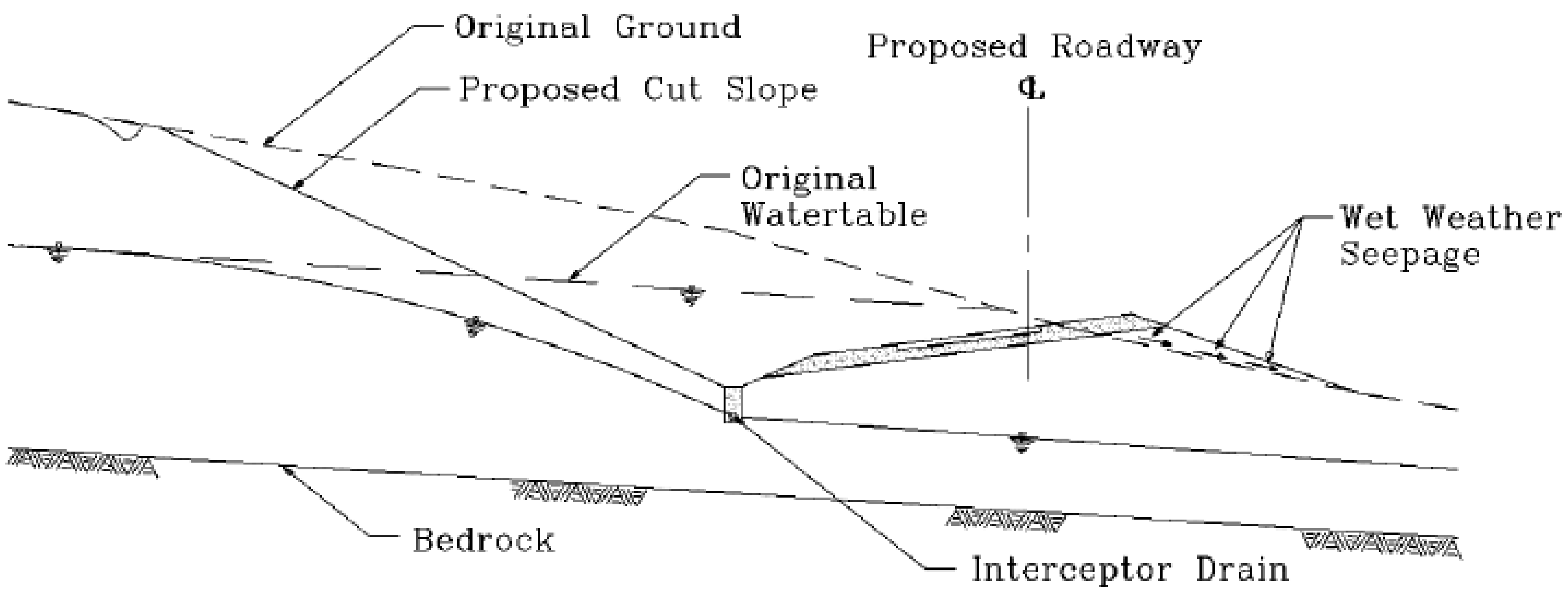


Fig. Longitudinal interceptor drain used to cut off seepage and lower the groundwater table.

SUBSURFACE DRAINAGE

Seepage Control cont..

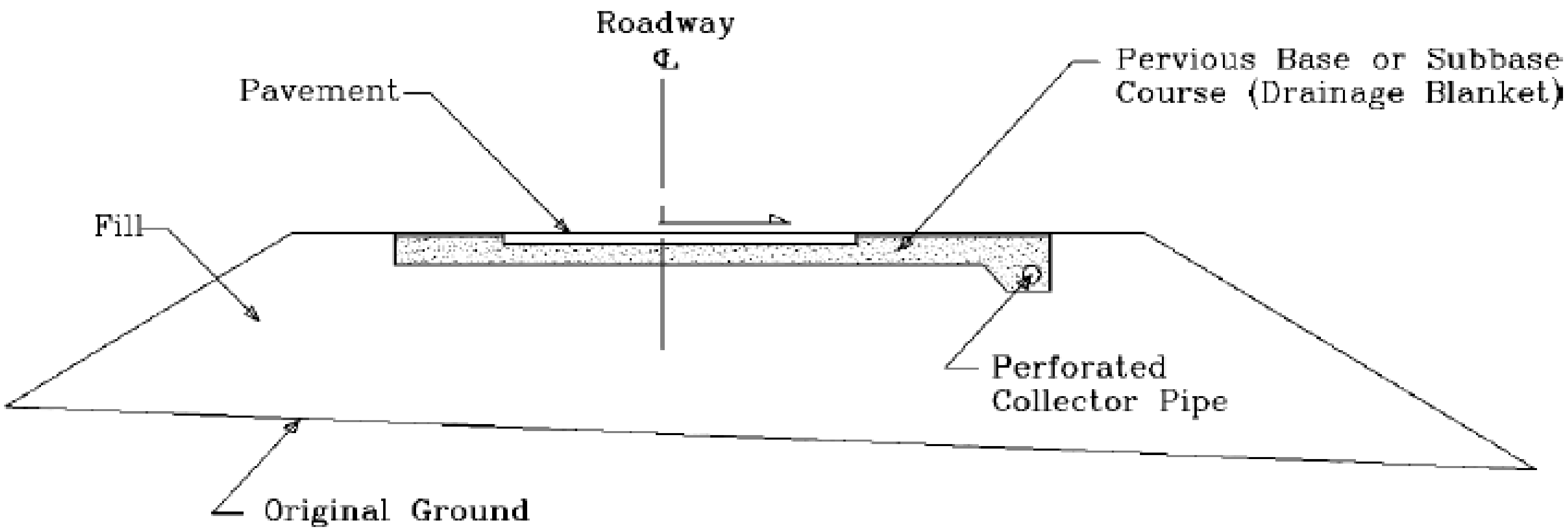


Fig. Longitudinal collector drain used to remove water seeping into the pavement structural section.

SUBSURFACE DRAINAGE

3. Control of Capillary Rise

- **Capillary rise can be controlled by**
  - Using a layer of granular material of suitable thickness.
  - Using a layer of impermeable capillary cutoff.
- **Capillary water should not rise above the thickness of the granular layer**

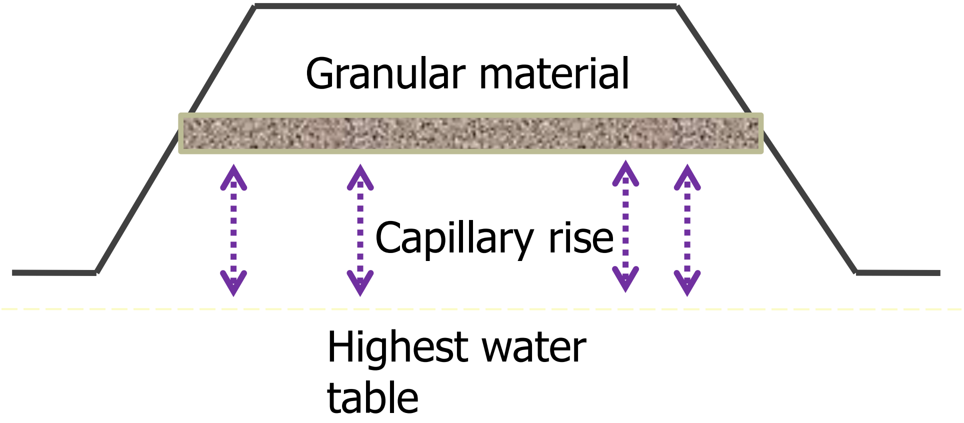


Fig. Granular capillary cutoff

SUBSURFACE DRAINAGE

Control of Capillary Rise cont…

- **Bituminous layer or other geo-textiles can be used as an impermeable layer.**

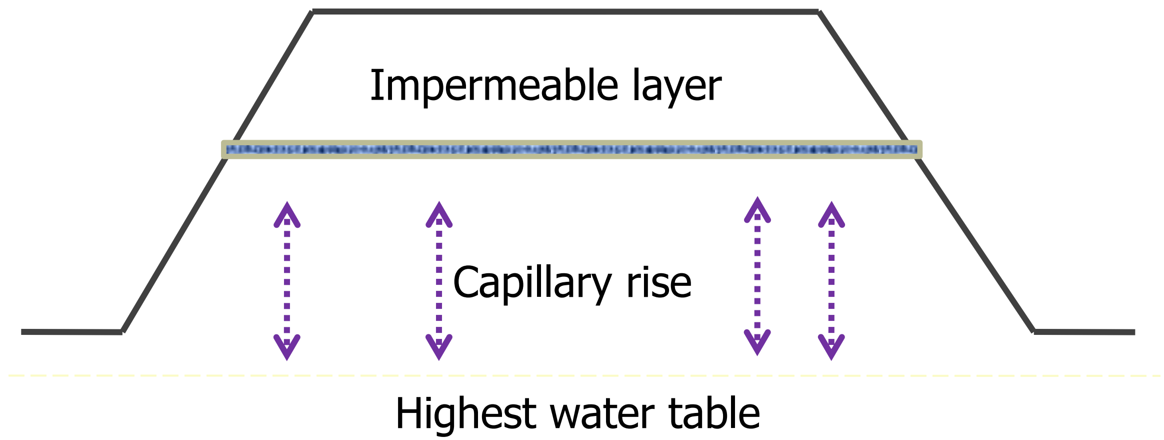


Fig. Impermeable layer capillary cutoff

4. Design of Filter Material

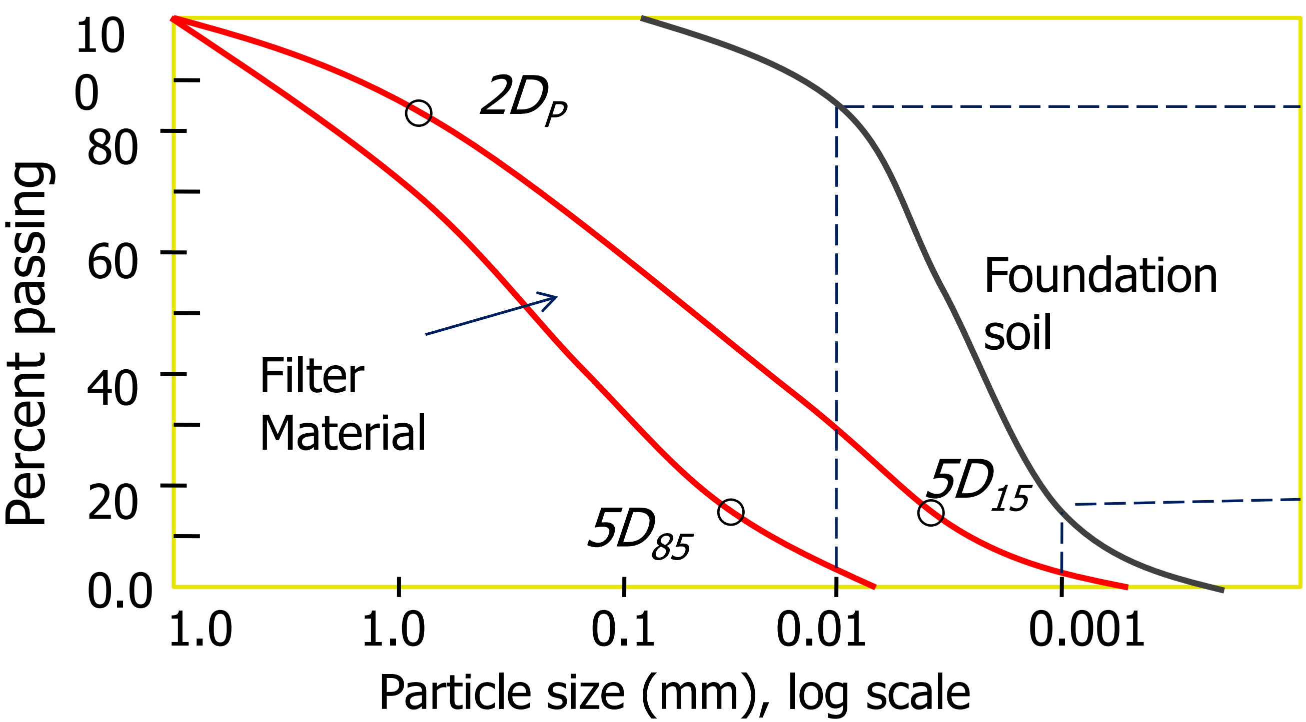
- **Proper filter material should be used for:**
  - Subsurface drainage system and backfilling the drainage trenches
- **Criteria:**
  - Permeability and Piping

$$\frac{D_{15}\ of\ \ filter}{D_{15}\ of\ \ foundation} > 5$$ ← **Permeability criteria**

$$\frac{D_{15}\ of\ \ filter}{D_{85}\ of\ \ foundation} < 5$$ ← **Piping criteria**

Design of Filter Material cont…

- D_P=size of perforation in drain pipe
- D_{85} Filter = $2D_P$



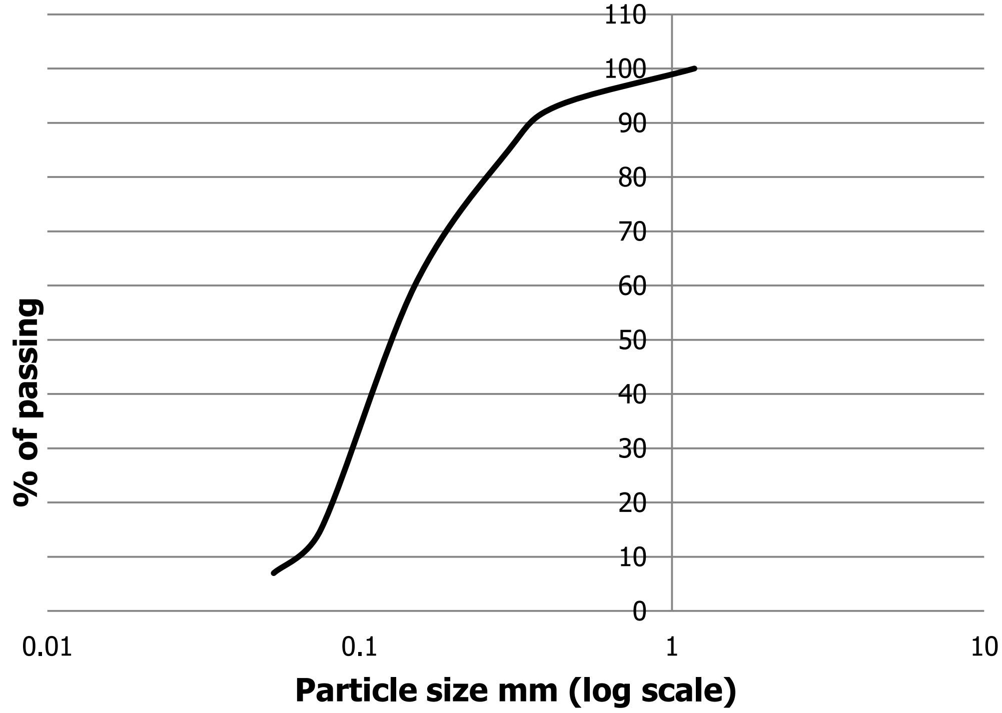
The area between the two red curves represents the filler material.

Fig. Design of Filter Material

Examples 5

A pipe drain with circular perforated holes 10mm dia is to be designed. The soil gradation is given below. Design the filter materials.

Sieve size (mm)	% passing
1.18	100
0.425	93
0.300	85
0.150	60
0.075	15
0.053	7



110
100
90
80
70
60
50
40
30
20
10
0
% of passing
0.01
0.1
1
10
Particle size mm (log scale)

QUESTIONS?