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Drainage Engineering (BTAI3103)

Module 4 Construction of Pipe Drainage Systems (Lecture-13: Design of Pipe Drainage_1)

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Design of Pipe Drainage

While designing the drainage system, the following aspect elements need to be considered and determined,

- Spacing and depth of laterals and collectors pipes – primary factors in the control of ground water;
- Diameters and gradient of laterals and collector pipes – must ensure the proper evacuation of water taken up by the laterals;
- Layout (alignment) of laterals and collectors, adapted to the topographical features of the area and to other conditions



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Spacing and Depth of Laterals

- Theoretically, for deeper drain, wider spacing can be allowed
- Practically, following conditions restrict the depth of drain installation:
 - *Water level that can be maintained in the collector ditch*
 - *Occurrence of less suitable soil layer* – the poorly pervious layers at shallow depth, highly pervious layer and peat soils are not suitable for pipe drains
 - *Increased seepage* – if the hydraulic conductivity of deep layers is considerably higher than in overlying layers, inflow from surrounding area may be quite high and thus affect the efficiency of the drainage system in depressing the water table
 - *Depth that can be handled by available machinery*



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- The calculated drain spacings for a project area may show considerable variations due to variations in hydraulic conductivity
- Therefore, the area should be divided into subareas or blocks of convenient size, for each of which a uniform and representative drain spacing served by one collector is selected



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Diameters and Gradients (Hydraulic Design)

- The following aspects need to be considered while undertaking hydraulic design:
 - ❑ What area can be drained by a pipe line of given diameter laid at a given slope, assuming a certain drain discharge or specific discharge
 - ❑ What pipe diameter is needed for a pipe line of given length, laid at a given slope, with given drain spacing and specific discharge



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- To design the pipe drainage system, the following points should be taken into consideration:
 - Basic flow equation (uniform flow) for different types of drain pipes (clay tiles, corrugated plastic pipes)
 - Flow equations governing non-uniform flow
 - A safety factor to allow for some decrease in capacity due to a certain degree of sedimentation
 - A drain composed of sections of increasing diameter in the directions of flow



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Uniform flow: The head loss in full flowing pipes using Darcy-Weisbach Equation is given by,

$$i = \frac{z}{x} = \frac{\lambda v^2}{d 2g} \dots\dots\dots(1)$$

where,

z = loss in hydraulic head (m)

x = length of pipe section considered (m)

d = inside pipe diameter (m)

v = flow velocity (m/s)

g = acceleration due to gravity (m/s^2)

λ = resistance factor dimensionless



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- The resistance factor depends on the type of flow (laminar or turbulent) and wall roughness k_r

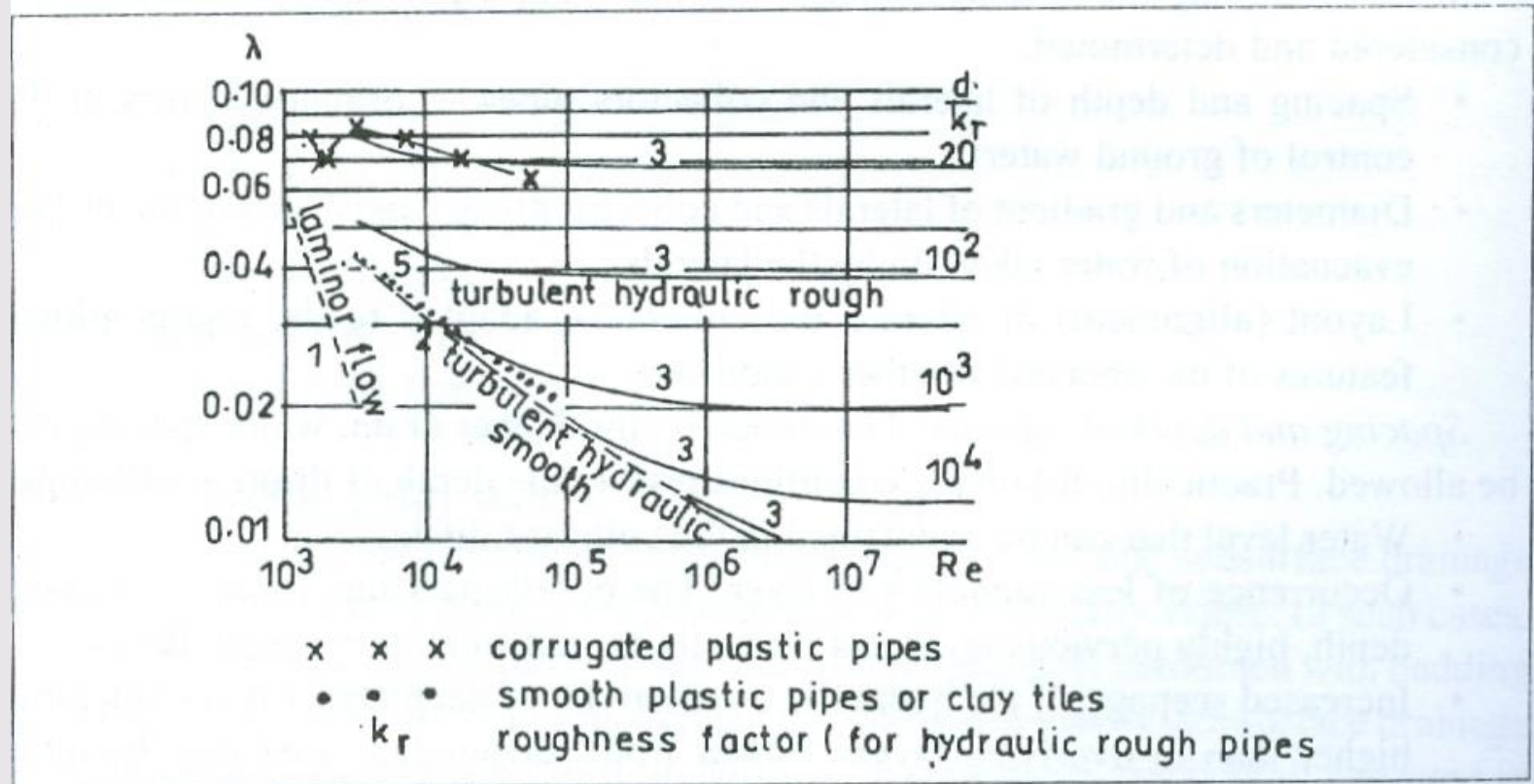


Fig. Relation between resistance factor (λ) and Reynold Number (Re)



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$$R_e = \frac{vd}{\nu} \dots\dots\dots(2)$$

where

ν = kinematic viscosity of the liquid

$$\nu = 1.31 \times 10^{-6} \text{ m}^2/\text{s}$$

For smooth pipes (clay tiles and smooth plastic pipes),

$$\lambda = aR_e^{-0.25} \dots\dots\dots(3)$$

where

a = a measure for the shift of the line as a result of isolated irregularities (e.g., tile joints, saw slits)

The value of 'a' for clean pipes is taken as 0.40



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For full flowing pipes

$$Q = \frac{\pi}{4} v d^2 \dots\dots\dots(4)$$

Substituting equation 2 to 4 into equation 1,

$$i = \frac{z}{x} = 26.3 \times 10^4 a Q^{1.75} d^{-4.75}$$

$$Q = 30 a^{-0.57} d^{2.71} i^{0.57} \dots\dots\dots(5)$$



For corrugated plastic pipes, the relation between λ and R is non linear (Fig. 1)

$$v = K_m R^{2/3} i^{1/2} \dots\dots\dots(6)$$

where

$$K = 70(i/n)$$

n = Manning roughness coefficient

R = hydraulic radius = $1/4$ d with full flowing pipes

$$i = 10.25 K_m^{-2} Q^2 d^{-5.33} \dots\dots\dots(7 a)$$

or $Q = 0.312 K_m d^{2.67} i^{0.50} \dots\dots\dots(7 b)$



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- These equations are applicable to the transport of a quantity of water, which is constant over the entire length of pipe section (Fig. 2)

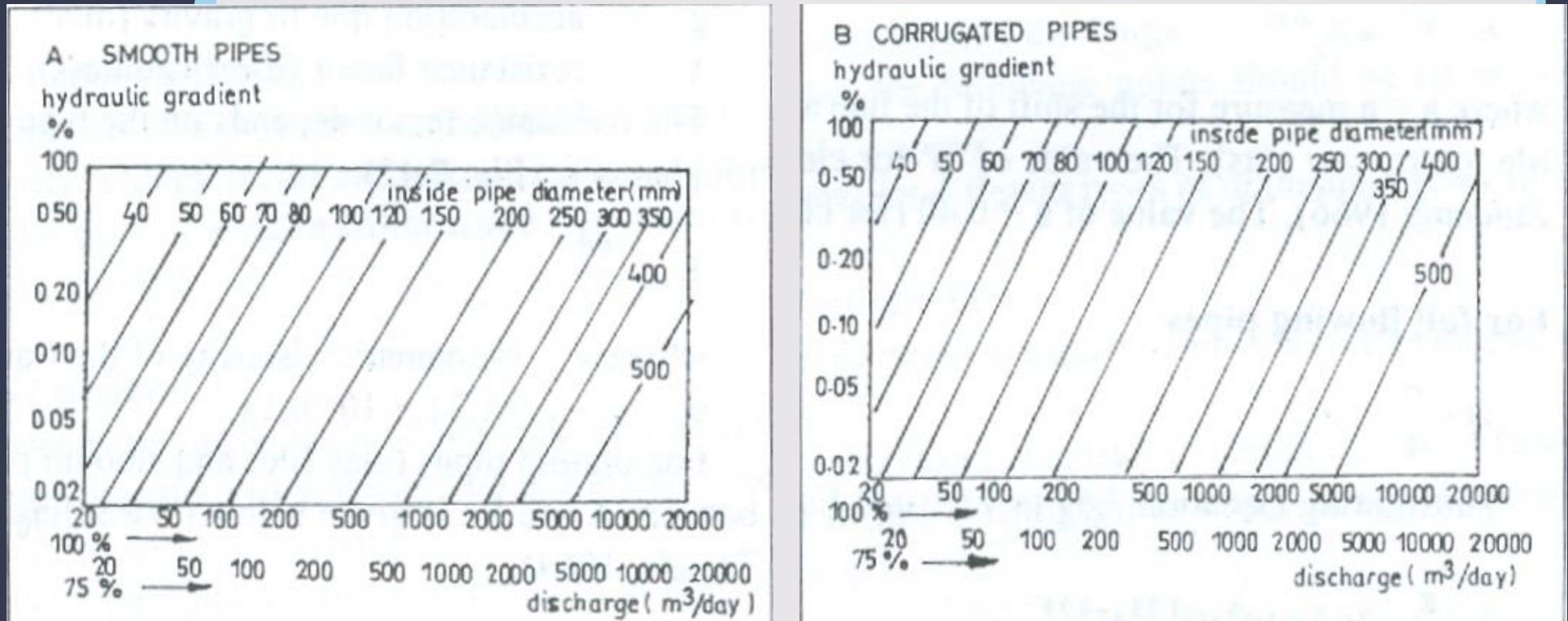


Fig. Diagram for pipe line capacity for smooth pipes (A) and corrugated pipes (B)



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The general equations for uniform flow can be written as,

$$i = Cd^{-\alpha} Q^{\beta} \dots\dots\dots(8 a)$$

or

$$Q = C^{-1/\beta} d^{\alpha/\beta} i^{-1/\beta} \dots\dots\dots(8 b)$$



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Non-uniform flow in pipe drain: In pipe drain the flow is non-uniform as the flow gradually increases from

$$Q = 0 \text{ at the upstream end to } Q = qBL$$

Where

q = specific discharge (m/s)

B = width of the area drained by the pipe line (= drain spacing) (m)

L = length of drain line (m)

The hydraulic gradient increases as the flow increases in the direction of flow



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- The flow in the pipe drain can be derived using uniform flow equations as follows:

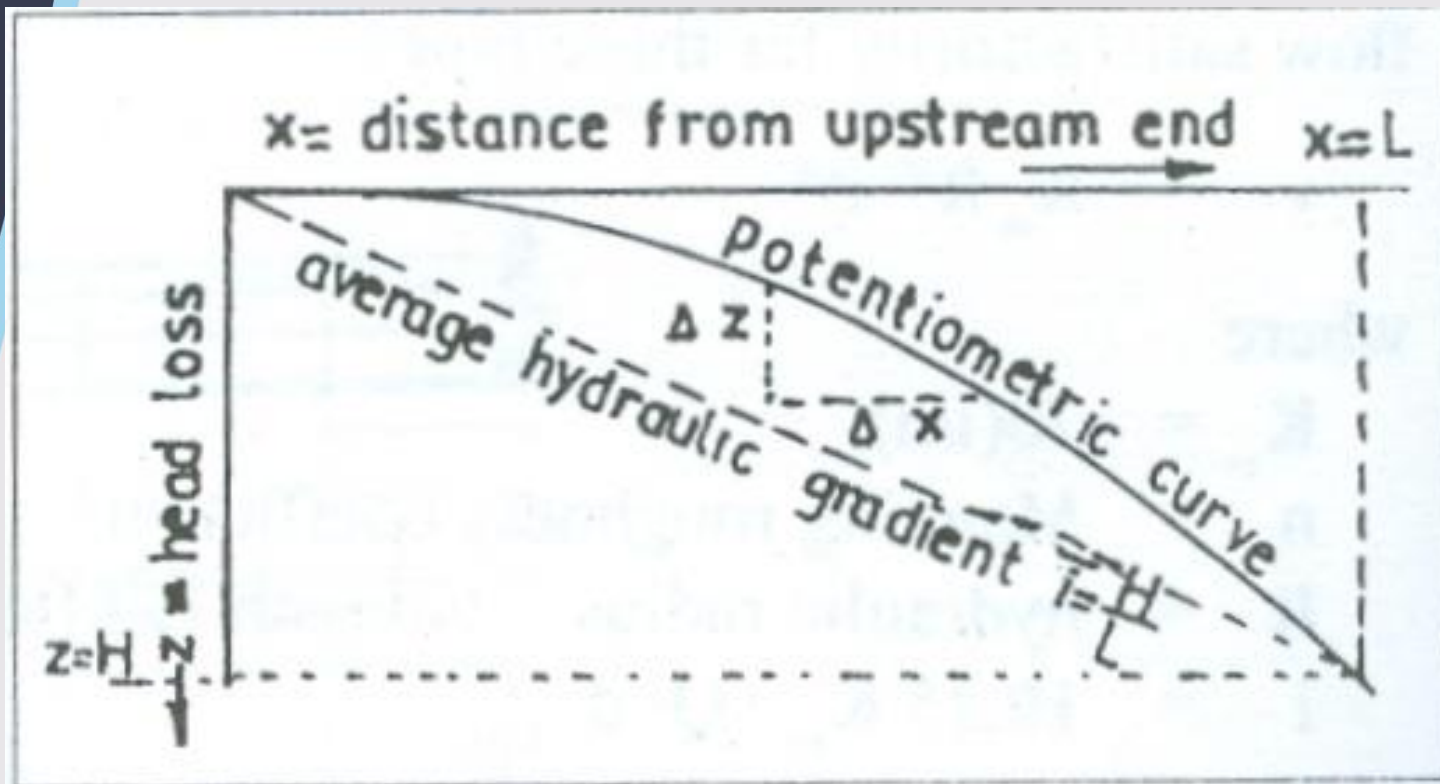


Fig. Head loss in full flowing drain pipe as a function of distance and resulting potentiometric curve



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- The flow rate Q_x at a distance x from the upstream end is equal to

$$Q_x = qBx \dots\dots\dots(9)$$

- Substituting equation 9 into general equation 8a

$$i = \frac{dz}{dx} = cd^{-\alpha} Q^\beta = cd^{-\alpha} (qB)^\beta x^\beta \dots\dots\dots(10)$$



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Integrating equation 10 using the following conditions yields

$$\checkmark z = 0 \text{ for } x = 0$$

$$\checkmark z = H \text{ for } x = L$$

$$H = \frac{1}{\beta + 1} cd^{-\alpha} (qB)^\beta x^{\beta+1} \dots\dots\dots(11)$$



Average hydraulic gradient $\bar{i} = H/L$ and considering
 $Q = qBL$ (total outflow from the drain line),

$$\bar{i} = \frac{H}{L} = \frac{1}{\beta + 1} c d^{-\alpha} Q_L^\beta \quad \dots\dots\dots(12 a)$$

$$Q_L = q\beta L = (\beta + 1)^{1/\beta} c^{-1/\beta} d^{\alpha/\beta} i^{1/\beta} \quad \dots\dots\dots(12 b)$$

- c , α and β values for smooth and corrugated pipes are substituted in the equation and results are shown in fig. 4 and fig. 5



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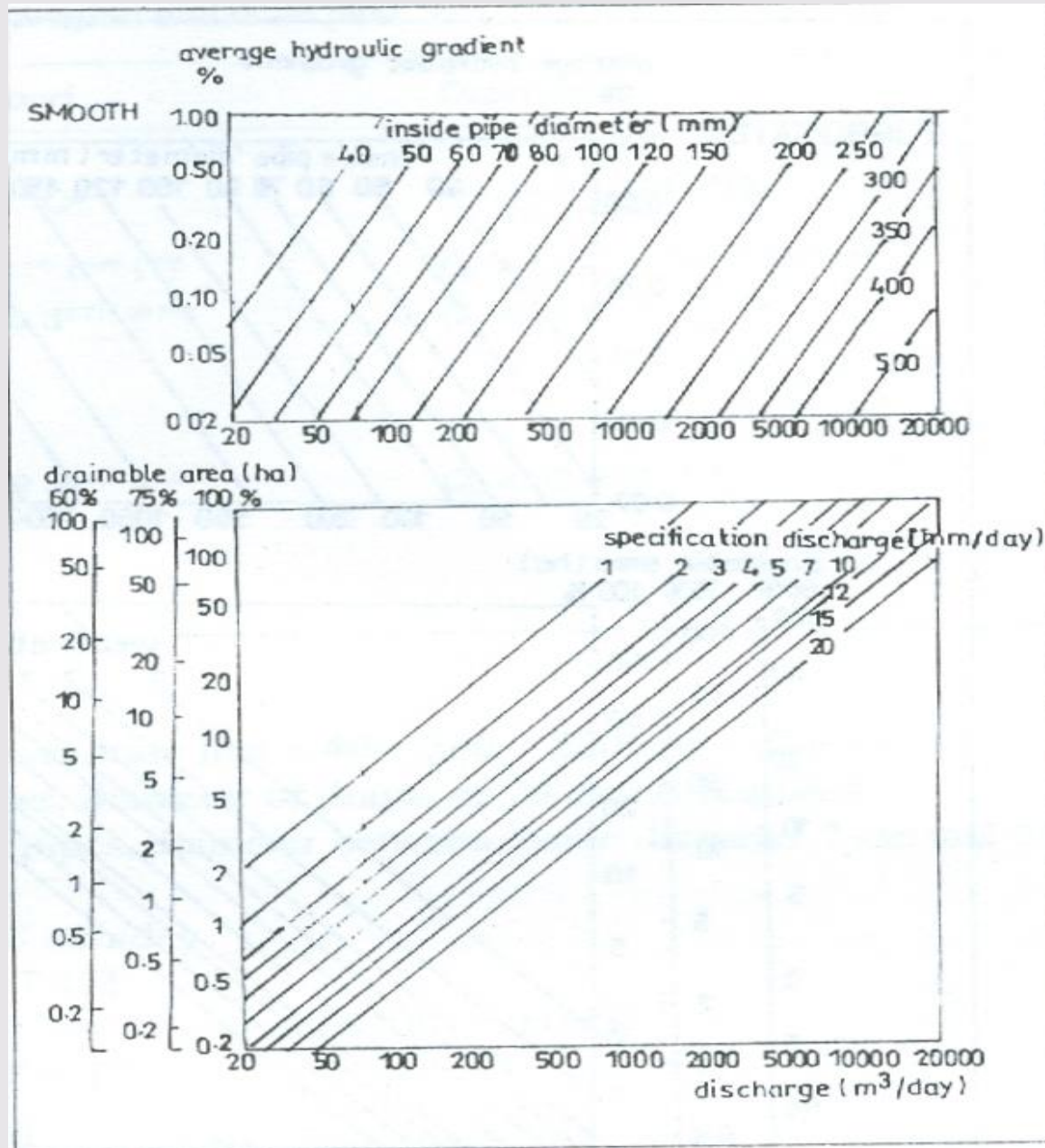


Fig. Diagram for capacity of smooth, full flowing drain pipes



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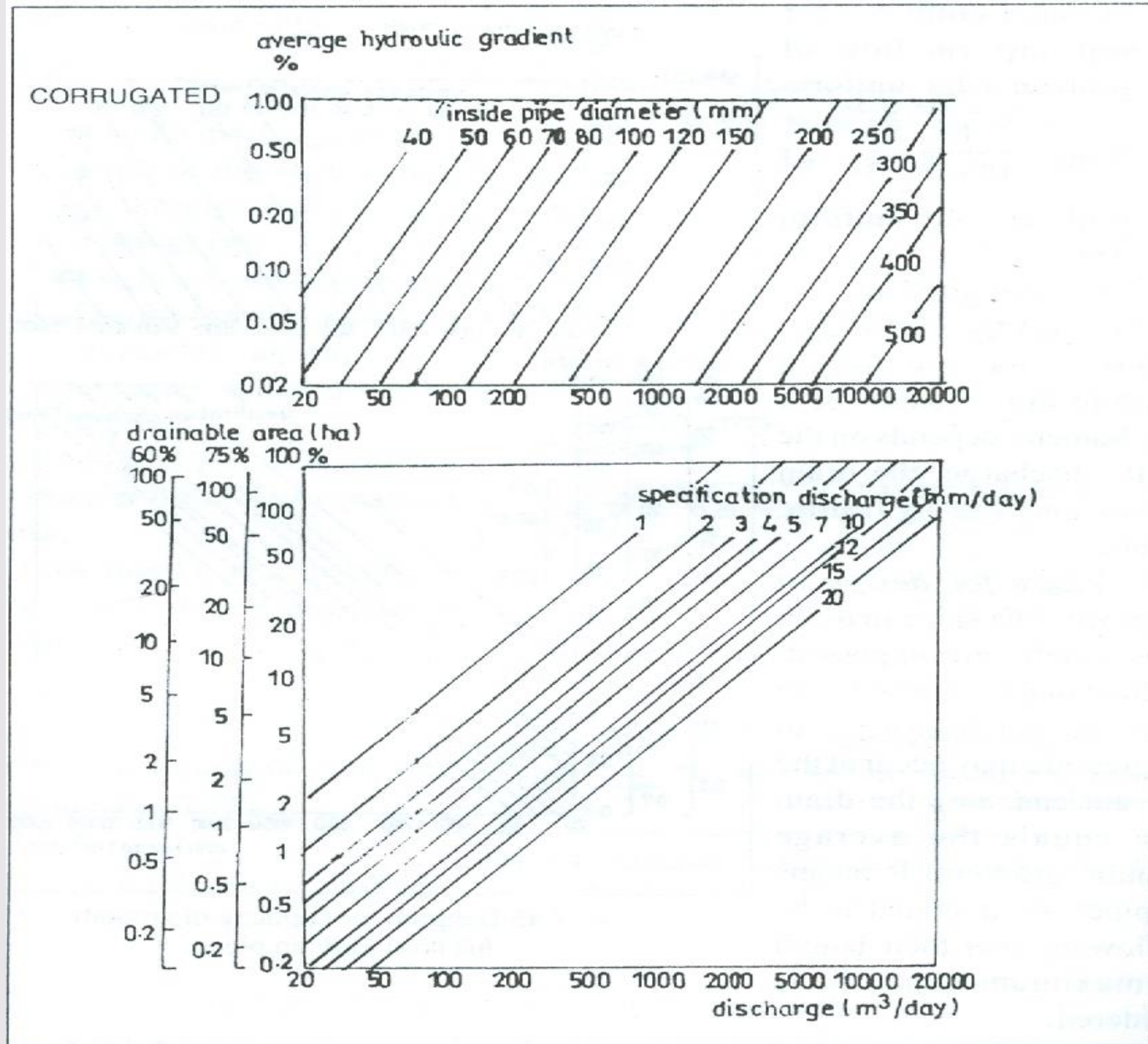


Fig. Diagram for capacity of corrugated full flowing drain pipes



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Thus, the maximum allowable drain length of a given diameter depends on the,

- specific discharge
- drain spacing
- hydraulic gradient

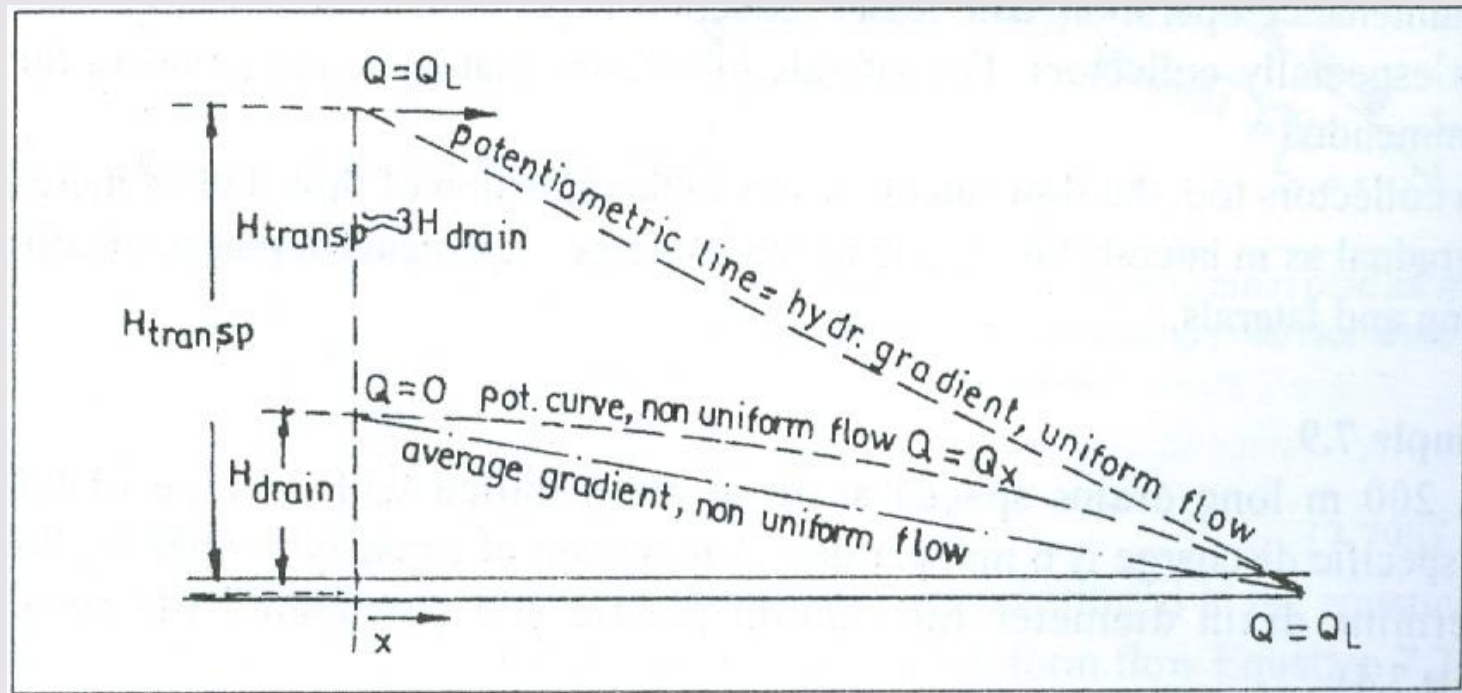


Fig. 7 Hydraulic gradient in a full flowing horizontal line for uniform and non-uniform flow



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Comparing uniform flow equation 7 and non-uniform flow equations, following conclusions are drawn:

- At equal outflow \bar{i} for non uniform flow of gradient i for uniform flow $\frac{1}{(\beta+1)} = \frac{1}{3}$ of gradient i for uniform flow
- For equal gradient

$$(i_u = i_{nu}) Q_u = 0.57 Q_{nu} \dots\dots\dots(13)$$



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