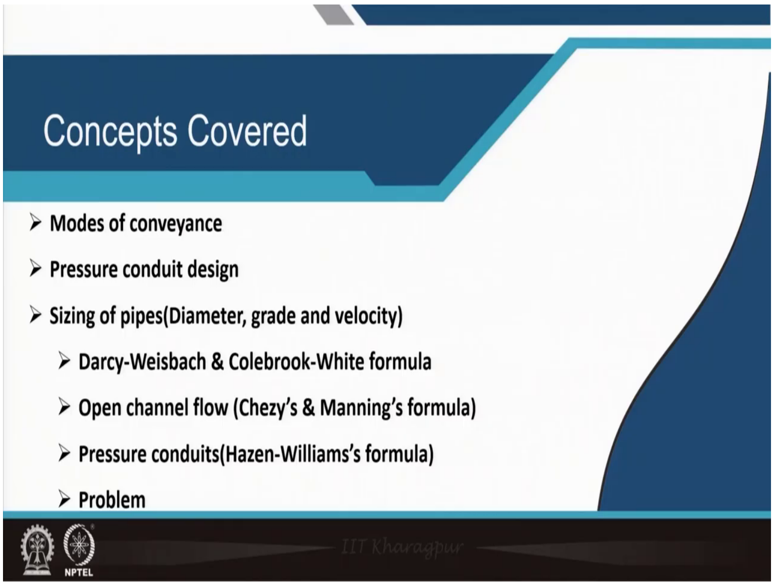
Urban Utilities Planning: Water Supply, Sanitation and Drainage

Prof. Debapratim Pandit
Department of Architecture and Regional Planning
Indian Institute of Technology, Kharagpur

Module - 05
Water supply Distribution system and Plans
Lecture - 22
Conveyance of Water Part I

Welcome back. In lecture 22, the conveyance of water will be considered.

(Refer Slide Time: 00:35)

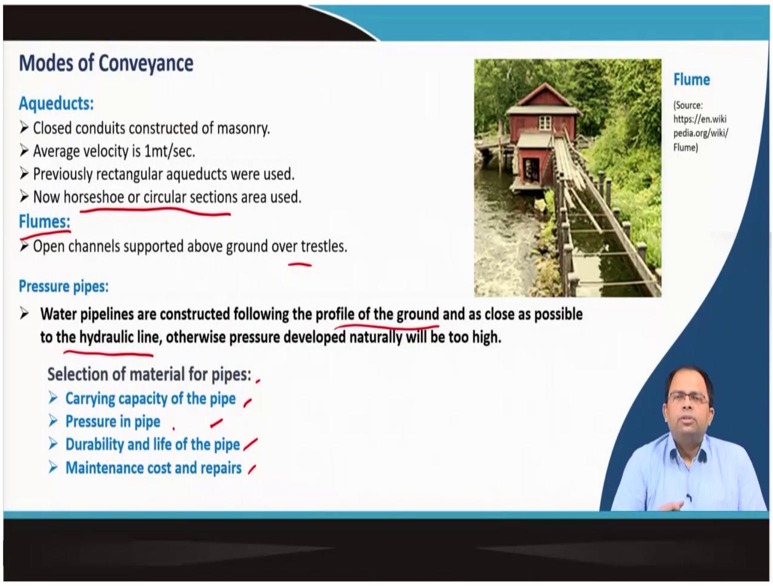


The contents include

- Modes of conveyance
- Pressure conduit design
- Sizing of pipes (diameter, grade and velocity)
- Darcy-weisbach and colebrook-white formula.
- Chezy's and Manning's formula which are used for open channel flow
- Pressure conduit design specific formula which is the Hazen-Williams formula

Modes of Conveyance

(Refer Slide Time: 01:28)



Flumes

Open channels are supported above ground using trestles because of the profile of that particular area. Open channels are generally not employed widely to carry water. It may be used to carry water to the treatment plant.

Aqueducts

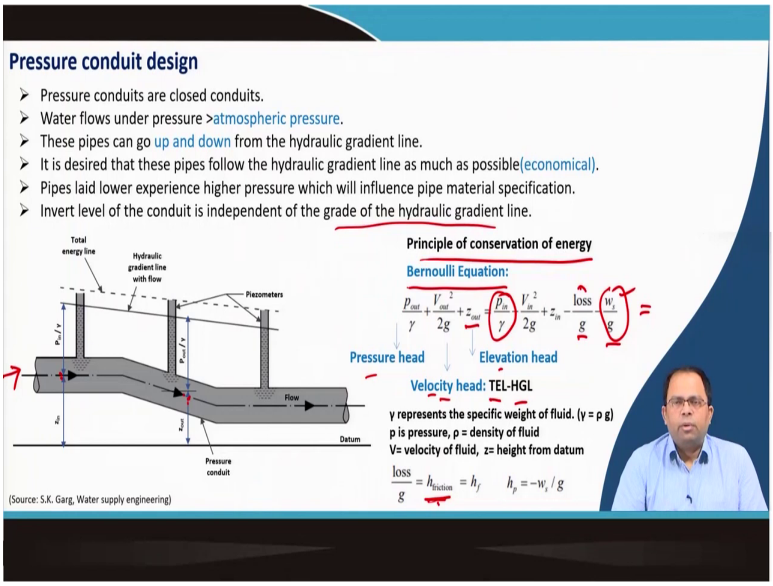
- Closed conduits are made up of masonry.
- The average velocity is around 1 m/s.
- In the olden days, rectangular aqueducts were constructed. But nowadays, if it is constructed, either a horseshoe or circular sections are adopted. There are rarely in use presently.

Pressure pipes

These are constructed following the profile of the ground such that it is as close as possible to the hydraulic line and, if this deviates, such as above or below the hydraulic line, change in pressure occurs. This extra pressure is addressed through pumping or certain other measures. As these are pressure pipes, it can be taken below the ground or above the ground. The selection of material for a pipe depends on the carrying capacity of the pipe, the pressure that is built up in the pipe, the durability and life of the pipe, maintenance cost and repairs etc. Pressure is the most significant in the selection of the pipe, determining the thickness of the pipe, the material used etc.

Pressure conduit design

(Refer Slide Time: 04:17)



- These are closed conduits
- Water flows under pressure which is usually greater than atmospheric pressure
- These pipes can go up and down from the hydraulic gradient line.
- Even then, it is better to follow the hydraulic gradient line as much as possible because it leads to the economy in terms of the pressure, which is lower in that particular case.
- Pipes laid lower experience higher pressure which will influence pipe material specification
- Invert level of the conduit is independent of the grade of the hydraulic gradient line

In the above image, it can be observed that the pipe is laid such that it is at different heights at different points. To determine the pressure in a pipeline, the principle of conservation of energy has to be considered. Bernoulli's equation is used.

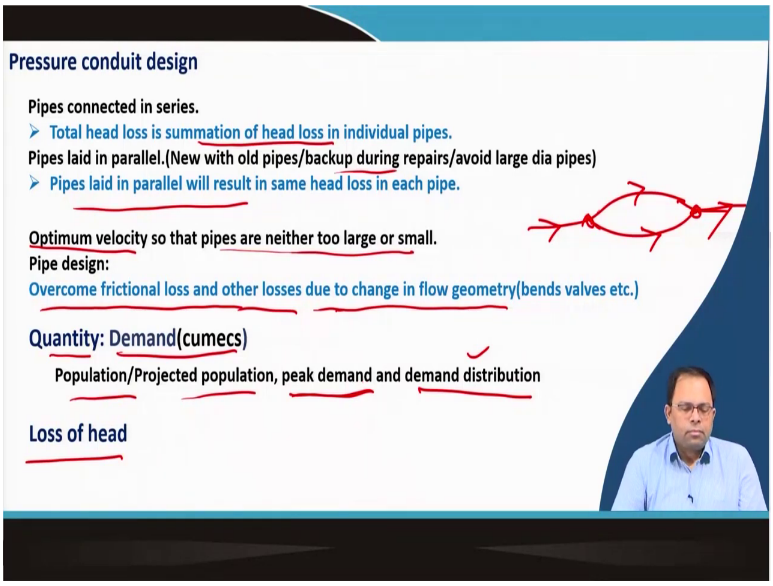
$$\frac{p_{out}}{\gamma} + \frac{V_{out}^{2}}{2g} + z_{out} = \frac{p_{in}}{\gamma} + \frac{V_{in}^{2}}{2g} + z_{in} - \frac{\text{loss}}{g} - \frac{w_s}{g}$$

P_{out}/γ represents pressure head, **$V_{out}^2/2g$** represents velocity head (Kinetic energy), **z_{out}** represents elevation head (potential energy). At every point along the pipeline, this is conserved. If the overall pressure or the total energy is considered at two points along the pipeline (as shown in the figure), the pressure at the second point may be lesser owing to the frictional losses in the pipeline or because of the change in diameter along the pipeline resulting in the loss of energy; Frictional loss is the major cause of loss of energy. **w_l/g**, which is the minor loss, can even be ignored. So, **loss/g** is equal to this head loss due to friction **$h_{friction.}$** Loss is divided by g to convert the energy to head. So, it is assumed that the velocity will remain the same from one point to another, which is also known as steady-state flow; And if the z value or the height of the pipe remains the same; In that case, **P_{out}/γ** becomes equal to **(P_{in}/γ -** head loss). **w_l/g** can be ignored. This leads to the formula derived by Darcy Weisbach.

Velocity head = T E L (Total energy line) **- H G L (**hydraulic gradient line)

So, the head loss in a particular pipeline can be derived by considering the conservation of energy principle and Bernoulli's equation. This helps to derive the diameter of the pipe, slope of the pipe etc.

(Refer Slide Time: 09:30)

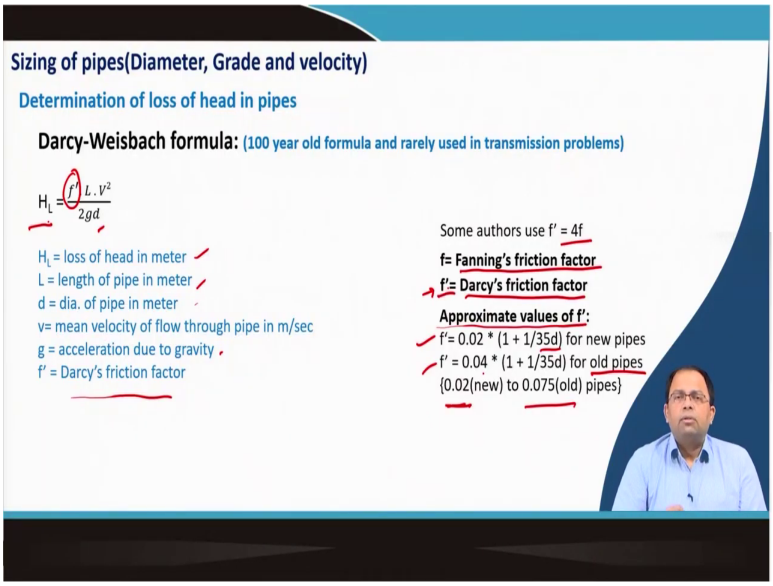


If the pipes are connected in series, the total head loss is a summation of head loss in individual pipes. That is, the frictional loss that happens in a pipeline is a summation of the head loss in individual pipes. If pipes are laid in parallel (which is done in case there is a need to increase supply along the old pipeline or when there is a need for backup or when two smaller diameter pipes are preferred over large pipes) , the headloss resulting in the parallel pipes will be the same. These are the two basic rules to be followed during the design process.

- Optimal velocity is considered so that pipes are neither too large nor too small.
- Frictional losses and other losses (because of the presence of fixture, bend or a valve) due to change in flow geometry has to be overcome.
- Head loss refers to pressure loss. The amount of pressure that has to be present in a pipe is based on the total head loss plus the final residual pressure. This can be achieved by raising the OHT further or based on pumping.
- Either by raising the water to the overhead tank, so that we get that kind of pressure or that kind of head or by putting or using a pump, which could give that kind of a meter head.
- The total quantity or demand (cumecs), is based on the population/the projected population, peak demand and demand distribution.

Sizing of pipes (diameter, grade, velocity)

(Refer Slide Time: 12:49)



▪ <u>Darcy-Weisbach formula</u>

This can be used to determine the loss of head in pipes. This is an old 100 year old formula and is rarely used in transmission or pipe design problems. Head loss (H_L)in metres is given by:

$$\frac{f'.L.v^2}{2gd} \quad \frac{f'.L.v^2}{2gd}$$

Where, H_L = loss of head in meter; L = length of pipe in meter; d = dia. of pipe in meter; v = mean velocity of flow through pipe in m/sec; g = acceleration due to gravity and f' = Darcy's friction factor

This equation can be derived by considering the difference between the incoming and outgoing pressure is equal to the head loss.

Instead of Darcy's friction factor (f^1), some authors choose to use Fanning's friction factor (f)

f' = 4f

The empirical formulas derived are given below. These are not universally applied.

Approximate values of f':

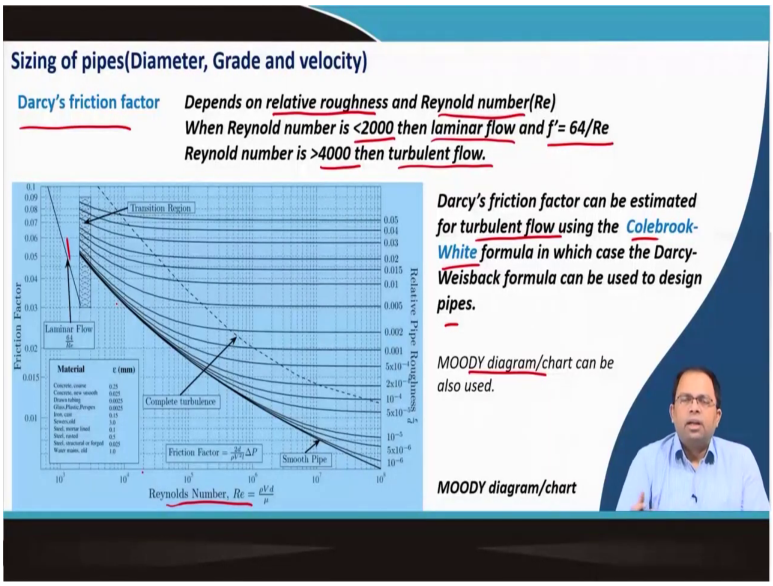
$$f' = 0.02 * (1 + 1/35d) \text{ for new pipes}$$

$$f' = 0.04 * (1 + 1/35d) \text{ for old pipes}$$

{0.02(new) to 0.075(old) pipes}

These values can be derived with complex calculations. It is very important to derive them appropriately for design purposes.

(Refer Slide Time: 15:33)



Darcys friction factor depends on:

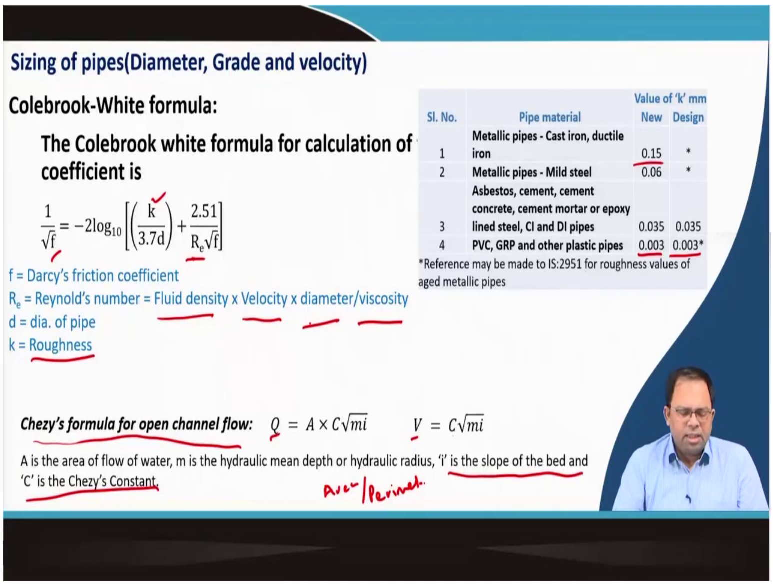
- It depends on relative roughness and Reynold number(Re)

- When Reynold number is <2000, then laminar flow (it is assumed as laminar flow; however it is not) and f'= 64/Re
- Reynold number is >4000, then it is assumed as turbulent flow.

Darcy's friction factor can be estimated for turbulent flow using the Colebrook-White formula, in which case the Darcy-Weisbach formula can be used to design pipes (It is not advised to use the Darcy-Weisbach formula with the empirically derived values). The Colebrook-White formula is solved for different kinds of pipes with different roughness. Along with the Reynolds number, Moodys diagram/chart can be developed. The diagram is shown in the above figure. The friction factor can be determined based on the pipe roughness and the Reynolds number. So, this chart or the Colebrook-White formula can be used for calculation.

- Colebrook-White formula

(Refer Slide Time: 17:53)



The formula is given as

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left[\left(\frac{k}{3.7d}\right) + \frac{2.51}{R_e\sqrt{f}}\right]$$

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left[\left(\frac{k}{3.7d}\right) + \frac{2.51}{R_e\sqrt{f}}\right]$$

Where,

f = Darcy's friction coefficient

R_e = Reynold's number = Fluid density x Velocity x diameter/viscosity

d = dia. of pipe

k = Roughness

Fluid density is 1 in case of water.

Reynolds number determines the type of flow, such as whether it is a turbulent flow or laminar flow; This can be observed from the graph, such as in between the2000 to 4000 part, it is the laminar range, and beyond 4000, it is a turbulent flow. In this way, the head loss in a pipeline can be determined. Roughness values is given in the following chart as:

Sl. No.	Pipe material	Value of 'k' mm	
		New	Design
1	Metallic pipes - Cast iron, ductile iron	0.15	*
2	Metallic pipes - Mild steel	0.06	*
3	Asbestos, cement, cement concrete, cement mortar or epoxy lined steel, CI and DI pipes	0.035	0.035
4	PVC, GRP and other plastic pipes	0.003	0.003*

*Reference may be made to IS:2951 for roughness values of aged metallic pipes

Roughness, as well as Reynolds number, is useful for determining Darcy's friction factor.

- <u>Chezys formula:</u>

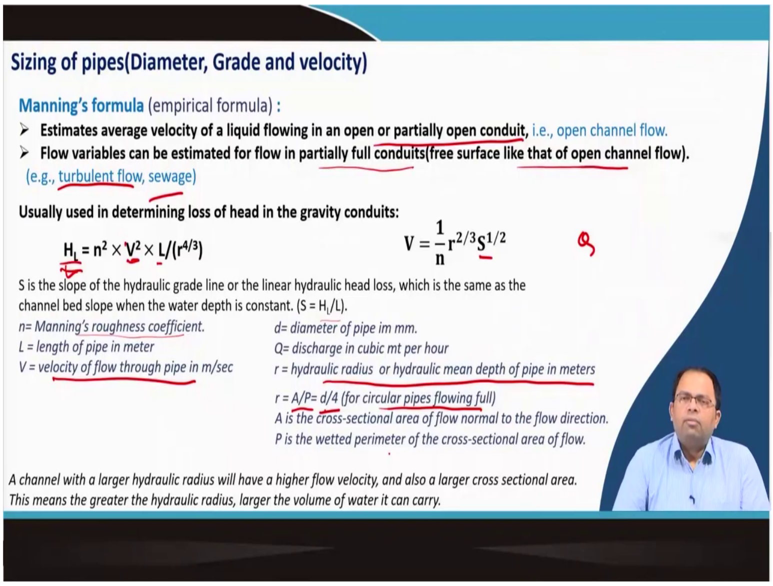
For open channels, there are specific formulas such as the Chezy's formula.

$$Q = A \times C\sqrt{mi}$$
$$V = C\sqrt{mi}$$

Where, A is the area of flow of water, m is the hydraulic mean depth or hydraulic radius (Hydraulic radius is area/perimeter corresponding to the wetted part of the pipe), ‘i’ is the slope of the bed, and ‘C’ is the Chezy’s Constant.

Chezy’s formula is not that commonly used nowadays.

(Refer Slide Time: 21:26)



- Mannings formula (empirical formula):

Manning’s formula is more commonly used. Estimates average velocity of a liquid flowing in an open or partially open conduit, i.e., open channel flow. Flow variables can be estimated for flow in partially full conduits (free surface like that of open channel flow). (e.g., turbulent flow, sewage). Partial flow is considered similar to an open channel flow. Only 2/3rd or half full flow happens in a sewer, and this formula can be efficiently used for estimation. In the case of pressure pipelines, where the channel is almost full, other formulas can be used as discussed above.

$$\mathbf{H_L = n^2 \times x\ V^2 \times x\ L/(r^{4/3}).}$$

It can be rewritten as:

$$V = \frac{\mathbf{1}}{\mathbf{n}} \mathbf{r^{2/3} S^{1/2}}$$

Where,

n= Manning's roughness coefficient.

L = length of pipe in meter

V = velocity of flow through pipe in m/sec

d= diameter of pipe im mm.

Q= discharge in cubic mt per hour

r = hydraulic radius or hydraulic mean depth of pipe in meters

r = A/P= d/4 (for circular pipes flowing full)

A is the cross-sectional area of flow normal to the flow direction.

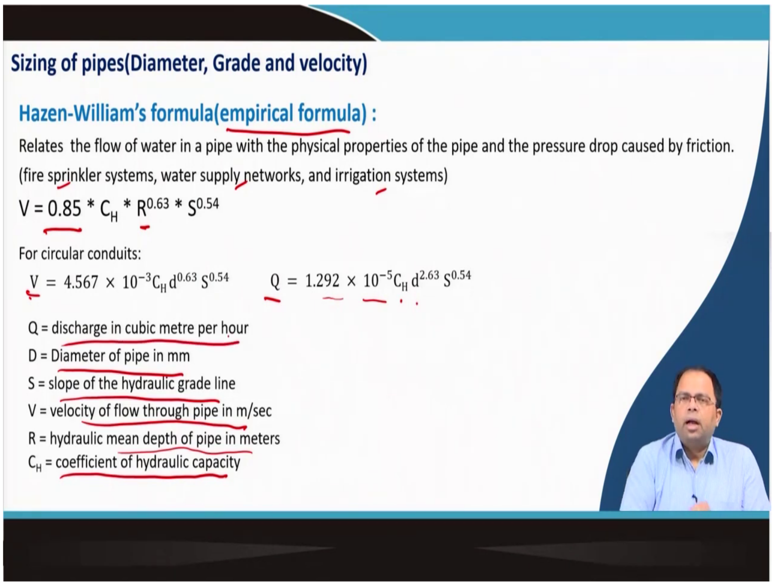
P is the wetted perimeter of the cross-sectional area of flow.

The equation can also be written in terms of Q. There could be different forms in which the equation could be written.

A channel with a larger hydraulic radius will have a higher flow velocity and also a larger cross-sectional area. This means the greater the hydraulic radius, the larger volume of water it will be able to carry.

- Hazen-William's formula

(Refer Slide Time: 26:08)



It is an empirical formula and has certain drawbacks. This formula is commonly used for pipe designs and relates to the flow of water in the pipe with the physical properties of the pipe and the pressure drop caused by friction. It is used to design a pipe sprinkler system, water supply networks, irrigation systems etc.

$$V = 0.85 \times C_H \times R^{0.63} \times S^{0.54}$$

It can be rewritten for circular conduits as:

$$V = 4.567 \times 10^{-3} C_H \, d^{0.63} \, S^{0.54}$$

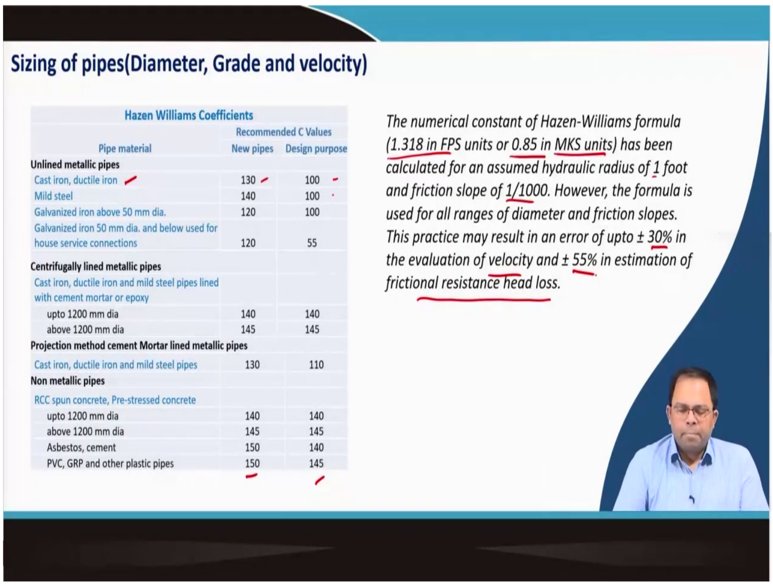
$$Q = 1.292 \times 10^{-5} C_H \, d^{2.63} \, S^{0.54}$$

Where,

Q = discharge in cubic metre per hour
D = diameter of pipe in mm
S = slope of the hydraulic grade line
V = velocity of flow through pipe in m/sec
R = hydraulic mean depth of pipe in meters
C_H = coefficient of hydraulic capacity

The hazen Williams coefficient is given in the following figure and can be referred to.

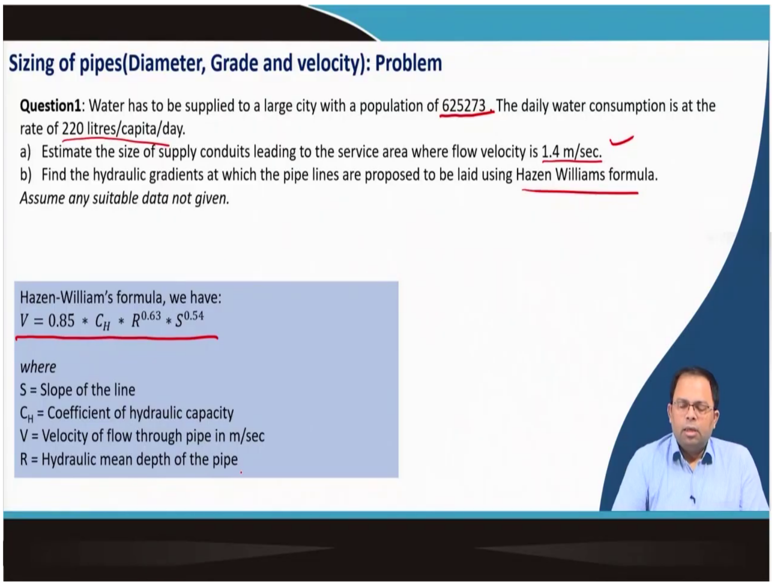
(Refer Slide Time: 28:13)



The numerical constant of the Hazen-Williams formula (1.318 in FPS units or 0.85 in MKS units) has been calculated for an assumed hydraulic radius of 1 foot and friction slope of 1/1000. However, the formula is used for all ranges of diameter and friction slopes. This practice may result in an error of up to ± 30% in the evaluation of velocity and ± 55% in the estimation of frictional resistance head loss.

PROBLEM

(Refer Slide Time: 30:22)



Question: Water has to be supplied to a large city with a population of 625273. The daily water consumption is at the rate of 220 litres/capita/day.

a) Estimate the size of supply conduits leading to the service area where the flow velocity is 1.4 m/sec.
b) Find the hydraulic gradients at which the pipelines are proposed to be laid using the Hazen Williams formula.

Assume any suitable data not given.

Answer:

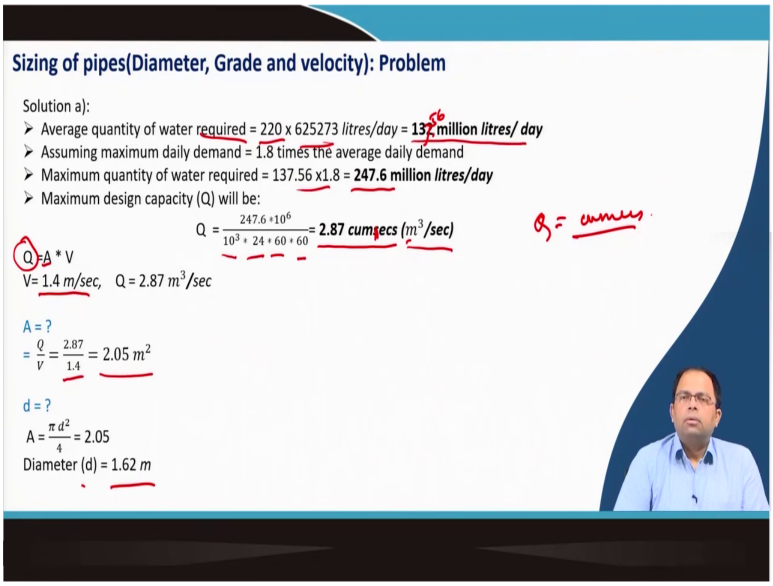
Hazen-Williams formula, we have:

$$V = 0.85 * C_H * R^{0.63} * S^{0.54}$$

where

S = Slope of the line
C_H = Coefficient of hydraulic capacity
V = velocity of flow through pipe in m/sec
R = Hydraulic mean depth of the pipe

(Refer Slide Time: 31:36)



Solution a):

- Average quantity of water required = 220 x 625273 *litres/day* = **132 million *litres/ day***
- Assuming maximum daily demand = 1.8 times the average daily demand
- Maximum quantity of water required = 137.56 x1.8 = **247.6 million *litres/day***
- Maximum design capacity (Q) will be:

$$Q = \frac{247.6 * 10^6}{10^3 * 24 * 60 * 60} \frac{247.6 * 10^6}{10^3 * 24 * 60 * 60} = \textbf{2.87 } \textbf{\textit{cumsecs}} \textbf{ (} m^3\ m^3 \textbf{\textit{/sec)}}$$

Q =A * V

V= 1.4 *m/sec*, Q = 2.87 $m^3\ m^3$ */sec*

A = ?

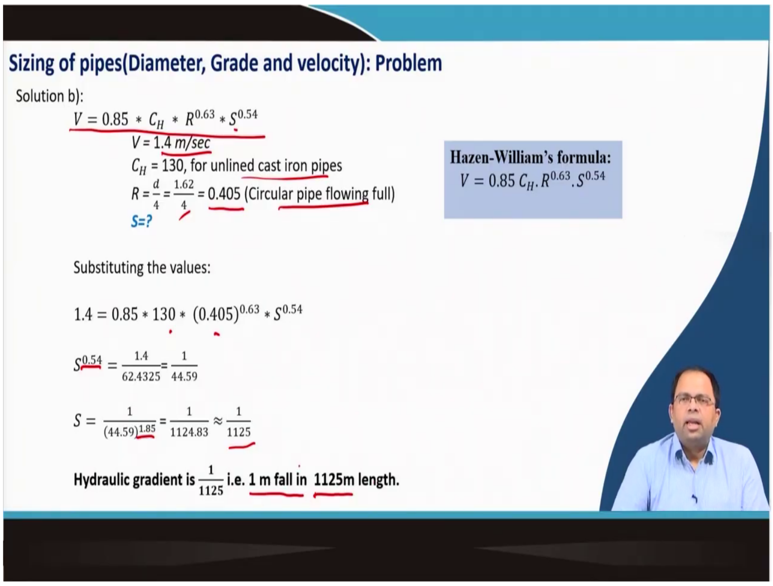
$$= \frac{Q}{V} = \frac{2.87}{1.4} = 2.05\ m^2\ \frac{Q}{V} = \frac{2.87}{1.4} = 2.05\ m^2$$

d = ?

$$A = \frac{\pi\, d^2}{4} \frac{\pi\, d^2}{4} = 2.05$$

Diameter (d) = 1.62 *m*

(Refer Slide Time: 34:21)



(Refer Slide Time: 36:01)

Solution b):

$$V = 0.85 * C_H * R^{0.63} * S^{0.54}$$

V = 1.4 m/sec

C_H C_H = 130, for unlined cast iron pipes

R = d/4 = 1.62/4 = 0.405 (Circular pipe flowing full)

S=?

Substituting the values:

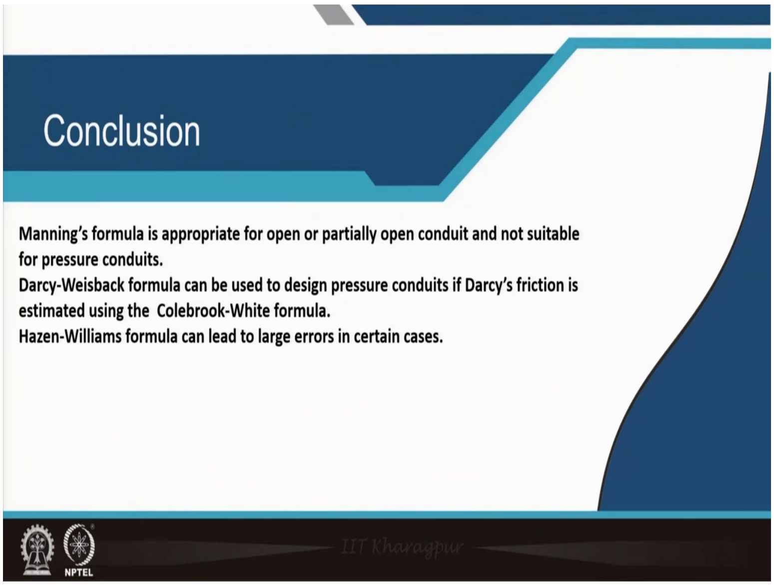
$$1.4 = 0.85 * 130 * (0.405)^{0.63} * S^{0.54}$$

$$S^{0.54} = \frac{1.4}{62.4325}\, S^{0.54} = \frac{1.4}{62.4325} = \frac{1}{44.59}\, \frac{1}{44.59}$$

$$S = \frac{1}{(44.59)^{1.85}}\, S = \frac{1}{(44.59)^{1.85}} = \frac{1}{1124.83} \approx \frac{1}{1124.83} \approx \frac{1}{1125}\, \frac{1}{1125}$$

Hydraulic gradient is 1/1125 i.e. 1 m fall in 1125m length.

Conclusion:



- Manning's formula is appropriate for open or partially open conduits and not suitable for pressure conduits.
- Darcy-Weisbach formula can be used to design pressure conduits if Darcy's friction is estimated using the Colebrook-White formula.
- Hazen-Williams formula can lead to large errors in certain cases.

References:

(Refer Slide Time: 36:25)