Urban Utilities Planning: Water Supply, Sanitation and Drainage

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Module - 09
Sewer Design
Lecture - 41
Sewer Design

Welcome back!

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The different concepts covered in this lecture are sewer sections, sewer design, self-cleansing velocity, limiting velocity, hydrogen sulphide build-up in sewers, design depth and slope of flow, gravity sewer design, and numericals.

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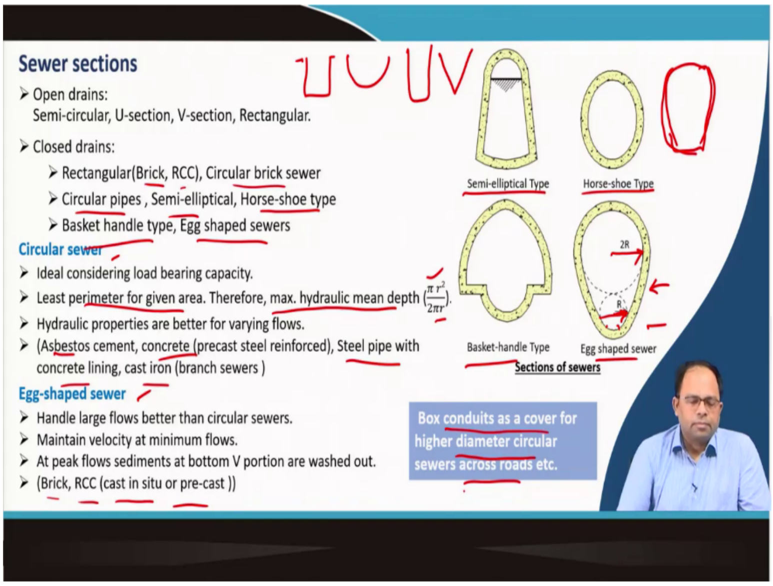

Sewer sections

Sewers can be either open drains or closed drains, the latter being the most common. Open drains are of different profile; semi-circular, U section, V section, or rectangular section. Open drains are used for stormwater.

Closed drains are of different kinds based on the material used for construction; brick or RCC, based on shape; rectangular, circular sewer, semi-elliptical, horseshoe-shaped, basket-handled type, and egg-shaped, the most common being circular and egg-shaped.

The shape of the sewer determines the flow profile and its characteristics. The flow characteristics of an egg-shaped sewer are almost like a circular sewer even when the water quantity is very less.

In the case of circular sewers, the load-bearing capacity is high and it has the least perimeter for a given area and maximum hydraulic mean depth. There are different types such as asbestos cement, concrete, precast with steel reinforcement, steel pipe with concrete lining and cast iron pipes which are used mainly for branch sewers.

The egg-shaped sewers can handle large flows and maintain velocity at minimum flows. At peak flow, sediment at the bottom V-shaped portion is washed out and it is made up of brick or could be made of RCC which could be cast in situ or it could be precast as well. Box conduits are suitable as a cover for higher diameter circular sewers laid across roads and gives additional protection.

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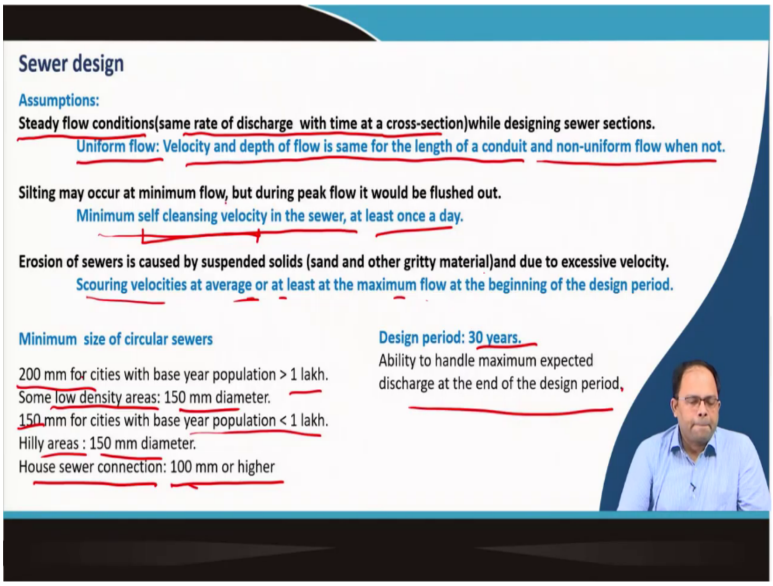

Sewer design

Sewer design can be either partially separate system, separate system, or combined system. There are some basic assumptions we need to follow in sewer design. First, it is assumed that steady flow conditions prevail while designing sewer sections. It means a constant rate of discharge with time at a cross section. The next assumption is of uniform flow that is, velocity and depth of flow are the same for the entire length of a conduit. Silting may occur at minimum flow but we assume that during peak flow, it will be flushed out. Another assumption is of minimum self-cleansing velocity in a sewer at least once a day.

Then, erosion of sewers is caused by suspended solids such as sand and gritty material and due to excessive velocity, which means we also need to keep velocity under control. We should determine the scouring velocities at average flow or at least at the maximum flow at the beginning of the design period, and based on that we will design our sewers.

The minimum size of circular sewers again depends on the use. For house sewer connection, it should be 100 mm or higher which is the least diameter pipe that we use in a sewer network. 200-millimeter is the least diameter sewer for cities with a base year population greater than 1 lakh, and 150-millimeter for cities with a base year population lesser than 1 lakh. In low-density areas, we can go for 150 millimeter diameter sewers.

Hilly areas have 150-millimeter diameter sewers as well. The design period of sewers is 30 years and it would be able to handle maximum expected discharge at the end of the design period.

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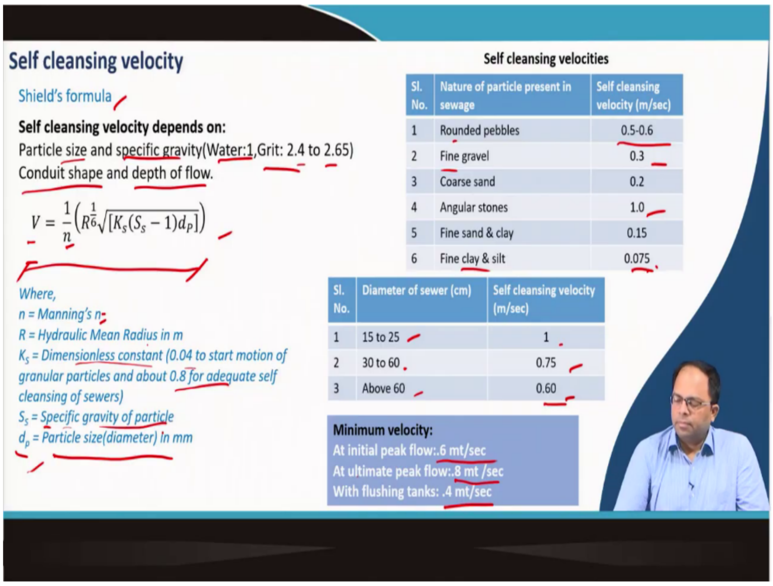

Self-cleansing velocity

Self-cleansing velocity is determined using Shields formula depending on the kind of material in sewage. We need to understand if it contains grit, sand particles, clay, silt, fine gravel, or pebbles based on which we can determine the particle size and the specific gravity.

The formula is as follows:

$$V = \frac{1}{n}\left(R^{\frac{1}{6}}\sqrt{\left[K_s\left(S_s - 1\right)d_P\right]}\right)$$

Where,

n = Manning's n

R = Hydraulic Mean Radius in m

K_S = Dimensionless constant (0.04 to start motion of granular particles and about 0.8 for adequate self-cleansing of sewers)

S_S = Specific gravity of particle

d_p = Particle size(diameter) in mm

Instead of going with the Shields formula, we can also follow standard guidelines based on the nature of particles present in sewage or the diameter of the sewer as shown in the tables given below.

Sl. No.	Nature of particle present in sewage	Self cleansing velocity (m/sec)
1	Rounded pebbles	0.5-0.6
2	Fine gravel	0.3
3	Coarse sand	0.2
4	Angular stones	1.0
5	Fine sand & clay	0.15
6	Fine clay & silt	0.075

Sl. No.	Diameter of sewer (cm)	Self cleansing velocity (m/sec)
1	15 to 25	1
2	30 to 60	0.75
3	Above 60	0.60

When we look into the diameter of pipe sewers, the larger the diameter of the pipeline, the lesser self-cleansing velocity is adequate. The minimum velocity that we usually target is at the initial peak flow. We should target a minimum velocity of at least 0.6 meters per second. At ultimate peak flow it should be 0.8 meters per second, that is at the end of the design period after 30 years. If we use flushing tanks to achieve self-cleansing velocity, we can have 0.4 meters per second as the minimum velocity of design in the sewer pipelines.

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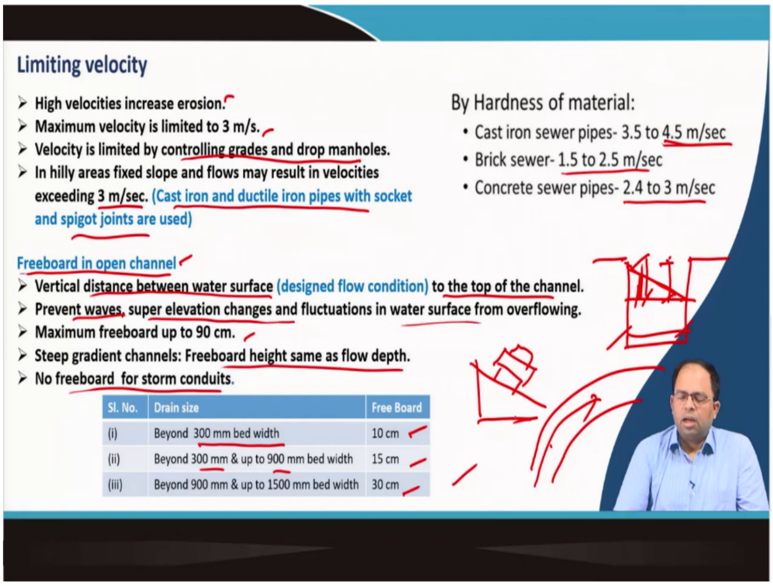

Limiting velocity

Limiting velocity is required because we cannot have too much velocity in the pipeline which will result in erosion. Maximum velocity is limited to 3 meters per second, and this is controlled through drop manholes and by changing the grades. In hilly areas, since the slope is as per the hill slope and flows may result in velocities that are more than three meters per second. For this purpose, we use cast iron and ductile iron pipes which is able to take care of this excess velocity. These are connected with socket and spigot joints, but the limit is 4.5 meters which means, cast iron pipes can take water till 4.5 meters per second, beyond which there will be damage to that particular pipeline.

For brick sewers limiting velocity is within 1.5 to 2.5 meters. For concrete sewer pipes, it is 2.4 to 3 meters per second.

Some amount of freeboard has to be provided in an open channel which is the empty area at the top of the water level in a pipe. It is measured as the vertical distance between the water surface to the top of the channel.

This is provided to prevent waves, superelevation changes, and fluctuations in water surface from overflowing. Superelevation is when a channel takes a turn. In case of roads, we provide banking. Similarly, we have to provide banking in a drain. The freeboard helps in taking care of this. Maximum freeboard is up to 90 centimeters and for steep gradient, channel freeboard is the same as the height of flow of depth. There is no freeboard for storm conduits i.e., there is no need for giving any kind of freeboard within pipelines.

For drain sizes having 300-millimeter bed width, we go for freeboard of 10 centimeters these are as per standards, from 300 to 900-millimeter bed width we go for 15-centimeter freeboard and beyond 900 millimeters up to 1500 millimeter bed width, we go for 30 centimeters of freeboard.

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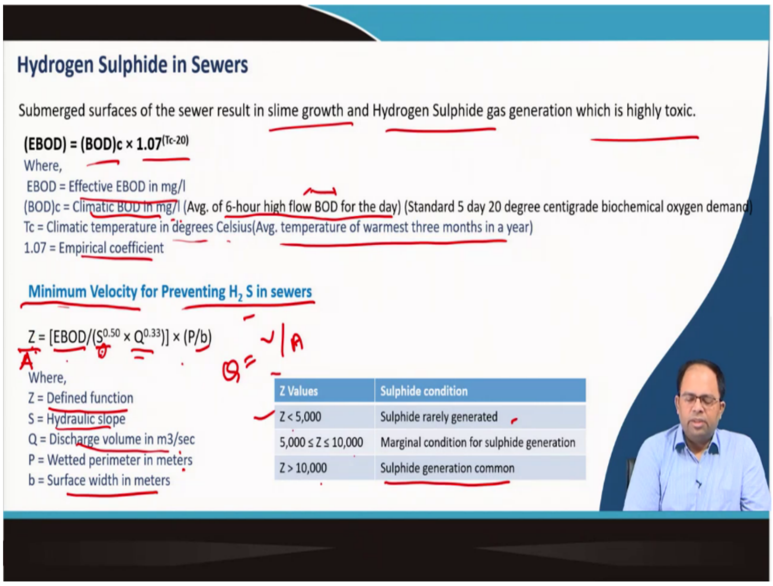

Hydrogen sulphide in sewers

One of the biggest concerns in sewers is the build-up of hydrogen sulphide gas which is pretty toxic. The presence of slime in sewers results in decomposition which results in hydrogen sulphide gas formation. Therefore, we try to provide adequate velocity in the pipeline so that H_2S gas is not formed.

In order to determine the minimum velocity for preventing the same, we have the following formula:

$$Z = [EBOD/(S^{0.50} \times Q^{0.33})] \times (P/b)$$

Where,

Z = Defined function
S = Hydraulic slope
Q = Discharge volume in m3/sec
P = Wetted perimeter in meters
b = Surface width in meters

(EBOD) = (BOD)c × 1.07$^{(Tc-20)}$

Where,
EBOD = Effective EBOD in mg/l
(BOD)c = Climatic BOD in mg/l (Avg. of 6-hour high flow BOD for the day) (Standard 5-day 20-degree centigrade biochemical oxygen demand)
T_c = Climatic temperature in degrees Celsius (Avg. temperature of warmest three months in a year)
1.07 = Empirical coefficient

There may be sulphide generation and if Z is less than 5000. So, our goal is to make Z lesser than 5000. In order to achieve that, we can change the slope and also Q which can be converted into velocity by dividing it by area.

So, in this way, we can actually determine the minimum velocity that is required to prevent the formation of H_2S gas in sewer lines.

EBOD is this effective BOD in milligram per liter. EBOD is estimated from standard BOD or climatic BOD in milligram per liter which is an average of 6-hour high flow BOD for the day i.e., we take the higher flow rates for 6 hours and during that time whatever is the BOD, we take an average of that and we take it in milligram per liter.

From the Z value, we can understand if this particular sewer line laid it at a particular slope with a particular flow will result in sulphide formation or not. We may need to make changes in the sewer profile or in the sewer velocity to actually make sure that sulphide does not form.

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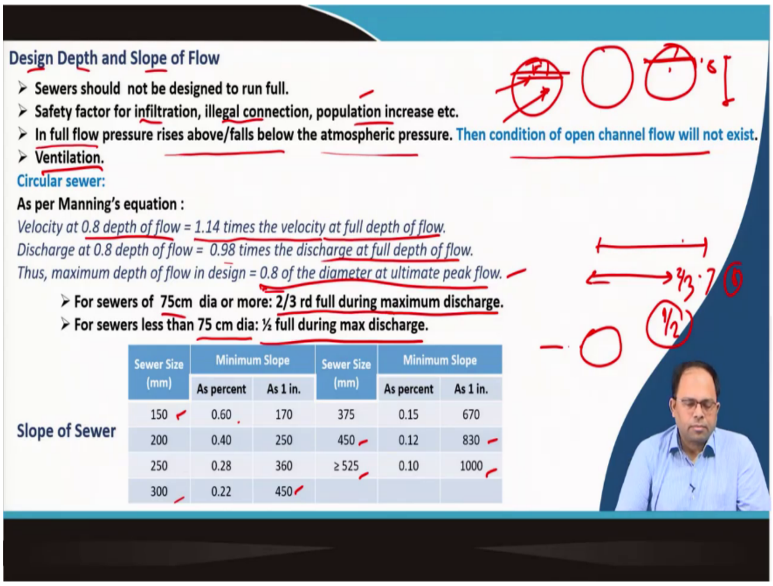

Design depth and Slope of Flow

Sewers should not be designed to run full. We need to consider certain safety factors such as infiltration of water into the sewer pipelines from groundwater, illegal connections and also population increase in future. When the sewer flows and it is totally filled then pressure rises or falls above the atmospheric pressure and the condition of open channel flow will not exist. Thus, we cannot use Manning's equation in that case. Theoretically, we can assume that the sewer is flowing full, but in practical terms always there is some amount of gap. This gap also helps in the ventilation and removal of the gases from the sewer. Considering all this we have to design the depth and the slope of flow for a particular sewer. So, we need to understand the depth at which the sewer could be laid, the slope, and the design of a particular sewer.

Circular sewers are designed as per Manning's equation and the velocity in Manning's equation at 0.8 depth of flow is around 1.14 times the velocity at full depth of flow, so velocity is actually more. And discharge at 0.8 depth of flow is 0.98 times the discharge at full depth of flow.

Whenever, we have a full channel or a 0.8 depth of flow, the discharge rate is almost the same. Whereas, the velocity is higher in the case of partial flow. For sewers of 75-centimeter dia or more we assume it would be two-thirds full during maximum discharge, for sewers less than 75-centimeter dia we assume half full during maximum discharge. So, even though 0.8 will result in the maximum discharge, but for designing sewers we assume two-thirds or half full, because we need to take consider the safety factors.

In addition to that, there are also standards for slopes. There is no point in giving a larger slope because then the excavation depth should be higher and sewage has to be lifted using pumps which is costly. So, we give minimum slope to sewer pipelines. For sewer sizes of 150 mm dia, the minimum slope is 0.6 percent or 1 in 170.

Whereas, for sewer size of 300, we give slope of 1 in 450, for sewer size of 450 we give around 1 in 830 and sewer size greater than 525 we give 1 in 1000.

Considering velocity, there is minimum velocity which is the self-cleansing velocity. Then there is maximum velocity i.e. the scouring velocity. This gives us a range of velocity that we can consider for a particular kind of pipe. For different pipes this velocity range will vary.

Then, the sewer will be not 100 percent filled.

When we put all these values in Manning's equation, we will get diameter for a particular sewer line. If we know the diameter then we can determine slope or velocity. So, we will see how these things are estimated.

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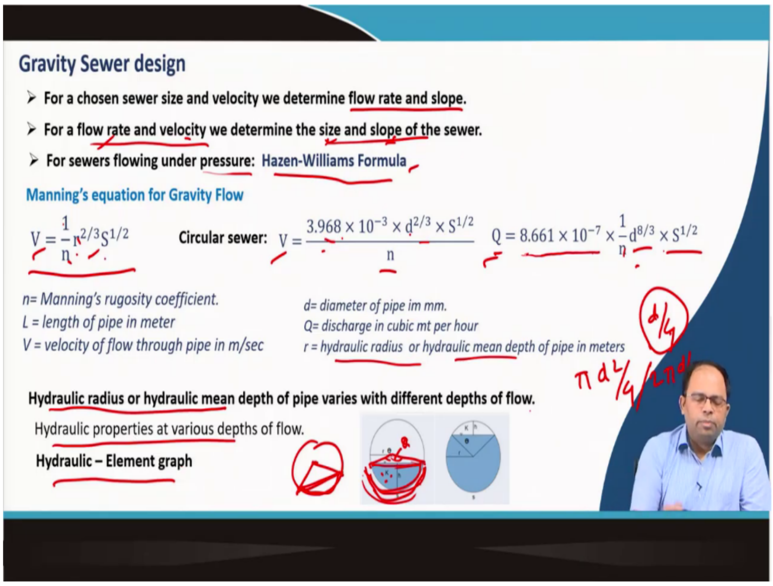

Gravity sewer design

Gravity sewer design: For a chosen sewer size and velocity, we can determine flow rate and slope. For a given flow rate and slope, we can determine the size of the sewer. Flow rate is known because we estimate the quantum of sewage that would be generated (maximum discharge). Then, a suitable range of velocity is considered, and then there is the slope.

The slope could be assumed to a certain extent, but in some cases, we can determine the slope as well. We can assume a certain sewer size and we can determine the slope.

For sewers flowing under pressure, we can also go for using Hazen-William's formula as well. So, for pressure sewers, we can go for Hazen-Williams formula, but for normal sewers, we will go with Manning's equation for gravity flow.

Manning's equation for Gravity Flow:

For circular sewers,

Where,

n= Manning’s rugosity coefficient.

L = length of pipe in meter

V = velocity of flow through the pipe in m/sec

d= diameter of the pipe in mm.

Q= discharge in cubic mt per hour

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

The sewer is designed for varying depths of flow and with varying depths we get different discharges. Hydraulic radius or hydraulic mean depth of pipe varies with different depths of flow and this has to be determined.

When we have depths which is lesser than the radius, then we can assume that ϴ is the angle, and based on that we can determine what is the wetted perimeter and the area of flow. And if this degree is given in radians, we can find what share of that degree is this particular perimeter and from there we can estimate the wetted perimeter. The area of this section could be determined by determining the area of half of the circle minus the area of the triangles in between.

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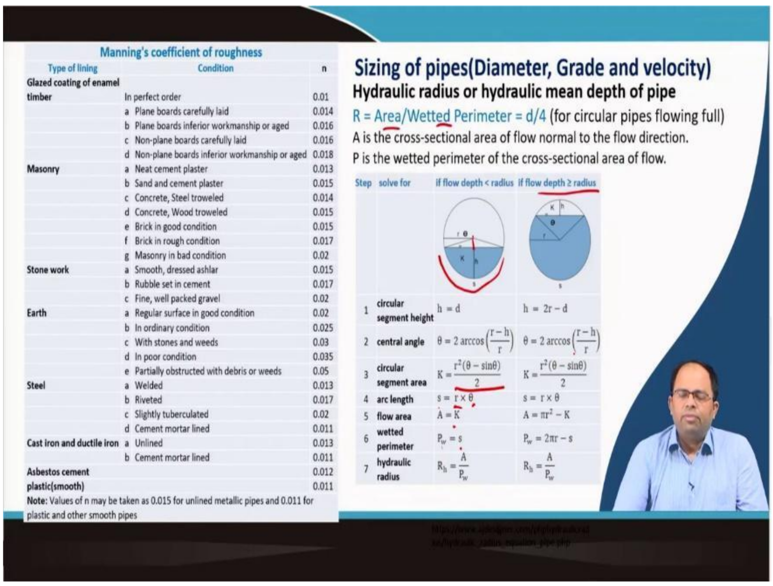


Sizing of pipes (Diameter, grade, and velocity)

Manning's coefficient of roughness or smoothness is based on the type of lining that is used in the pipe and on the condition of the pipeline which is given in the table below.

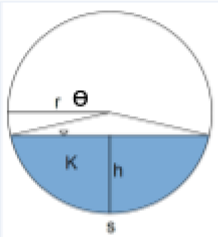
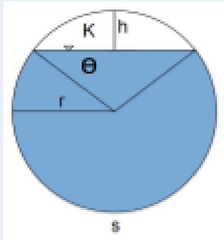
Manning's coefficient of roughness			
Type of lining		**Condition**	**n**
Glazed coating of enamel timber		In perfect order	0.01
	a	Plane boards carefully laid	0.014
	b	Plane boards inferior workmanship or aged	0.016
	c	Non-plane boards carefully laid	0.016
	d	Non-plane boards inferior workmanship or aged	0.018
Masonry	a	Neat cement plaster	0.013
	b	Sand and cement plaster	0.015
	c	Concrete, Steel troweled	0.014
	d	Concrete, Wood troweled	0.015
	e	Brick in good condition	0.015
	f	Brick in rough condition	0.017
	g	Masonry in bad condition	0.02
Stone work	a	Smooth, dressed ashlar	0.015
	b	Rubble set in cement	0.017
	c	Fine, well packed gravel	0.02
Earth	a	Regular surface in good condition	0.02
	b	In ordinary condition	0.025
	c	With stones and weeds	0.03
	d	In poor condition	0.035
	e	Partially obstructed with debris or weeds	0.05
Steel	a	Welded	0.013
	b	Riveted	0.017
	c	Slightly tuberculated	0.02
	d	Cement mortar lined	0.011
Cast iron and ductile iron	a	Unlined	0.013
	b	Cement mortar lined	0.011
Asbestos cement			0.012
plastic(smooth)			0.011
Note: Values of n may be taken as 0.015 for unlined metallic pipes and 0.011 for plastic and other smooth pipes			

We determine the hydraulic radius for different depths of flow: Area / wetted perimeter. This is d / 4 for circular pipes flowing full. But we need to determine the same for other depths.

h is equal to d.

h is the depth and then central angle Θ is basically 2 x arc cos((r – h)/ r).

The circular segment area could be determined based on the share of that Θ. The arc length s equal to r x Θ.

Step	solve for	if flow depth < radius	if flow depth ≥ radius
			
1	circular segment height	$h = d$	$h = 2r - d$
2	central angle	$\theta = 2\arccos\left(\frac{r-h}{r}\right)$	$\theta = 2\arccos\left(\frac{r-h}{r}\right)$
3	circular segment area	$K = \frac{r^2(\theta - \sin\theta)}{2}$	$K = \frac{r^2(\theta - \sin\theta)}{2}$
4	arc length	$s = r \times \theta$	$s = r \times \theta$
5	flow area	$A = K$	$A = \pi r^2 - K$
6	wetted perimeter	$P_w = s$	$P_w = 2\pi r - s$
7	hydraulic radius	$R_h = \frac{A}{P_w}$	$R_h = \frac{A}{P_w}$

Flow area a is equal to K, and wetted perimeter P_w is equal to s, which is given by r x Θ and hydraulic radius is given by A/P_w. Similarly, we can determine the hydraulic radius for the case if the flow radius is greater than equal to the radius.

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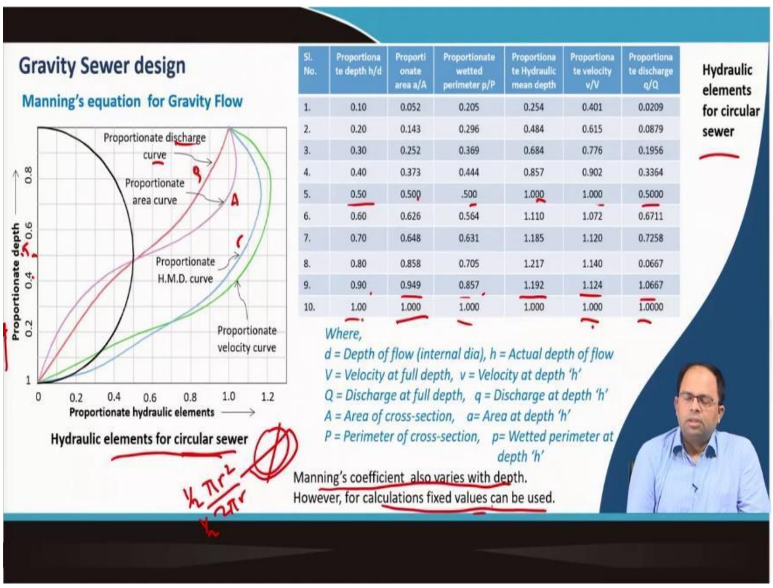

Gravity Sewer Design

A hydraulic elements chart is available for different types of sewers. In this chart, in the y-axis we get the proportionate depth which is given as ratio of the full depth.

And on the x-axis, these are the proportionate hydraulic elements i.e., velocity, hydraulic mean depth, area, discharge. Discharge is Q and HMD is the hydraulic mean depth. Area is the proportionate area of that wetted perimeter.

For proportionate depth, it determines what is the proportionate area or velocity or discharge. When hydraulic mean depth is 1 which means the entire sewer is filled with water. So, everything is one because this is for full depth. When proportionate depth by 0.9, we see proportionate area as 0.949, proprtione wetted perimeter as 0.857.

When we consider a half-filled circular pipeline, the proportionate depth is 0.5, the proportionate area is also 0.5, the proportionate wetted perimeter is also 0.5, so hydraulic mean depth is 1 and then this results in velocity which is also 1, which is same as the full velocity, but of course, the discharge would be half, because we are only utilizing half the area.

In this way, we can determine discharge and velocity at a particular depth easily using hydraulic element chart. Manning's coefficient also varies with depth, but for calculations, we use fixed values. So, we can have another curve for Manning's coefficient which will change for every depth, but again for normal calculations, we will use the fixed values.

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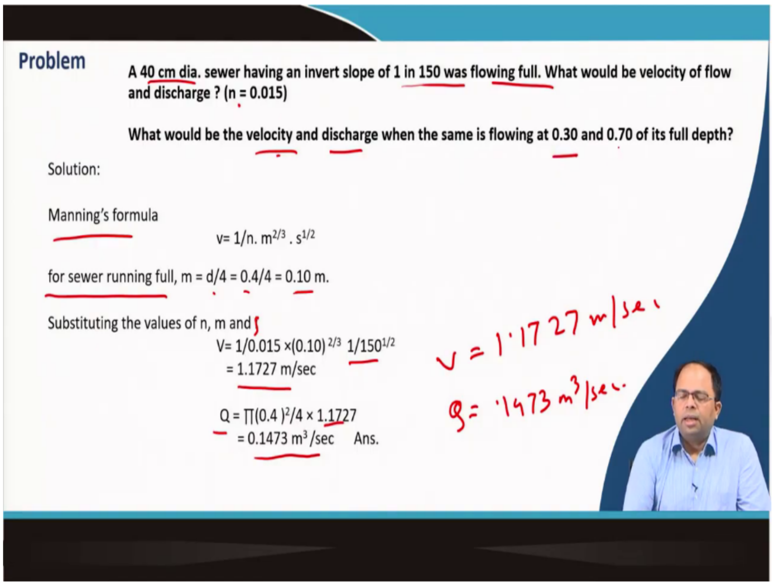

Q. A 40-centimeter diameter sewer having an invert slope of 1 in what 50 was flowing full, what would be the velocity of flow and discharge while flowing full, and then what would be the velocity and discharge when the same is flowing at 0.30 and 0.70 of its full depth?

Solution:

Manning's formula

$$V= 1/n.\ m^{2/3}.\ s^{1/2}$$

for sewer running full, m = d/4 = 0.4/4 = 0.10 m.

Substituting the values of n, m and i

$$V= 1/0.015 \times (0.10)^{2/3}\ 1/150^{1/2}$$

$$= 1.1727 \text{ m/sec}$$

$$Q = \pi (0.4)^2/4 \times 1.1727$$

$$= 0.1473 \text{ m}^3\text{/sec}$$

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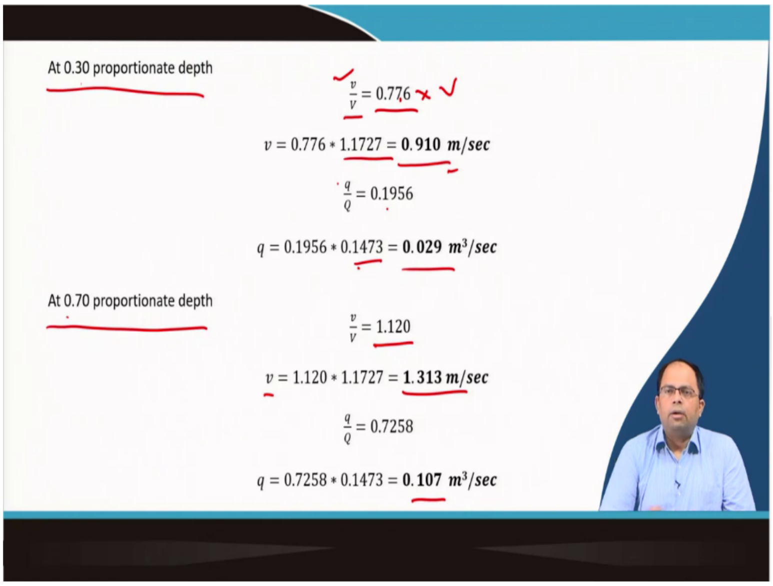

At 0.30 proportionate depth

$$\frac{v}{V} = 0.776$$

$$v = 0.776 * 1.1727 = 0.910\ m/sec$$

$$\frac{q}{Q} = 0.1956$$

$$q = 0.1956 * 0.1473 = 0.029\ m3/sec$$

At 0.70 proportionate depth

$$\frac{v}{V} = 1.120$$

$$v = 1.120 * 1.1727 = 1.313\ m/sec$$

$$\frac{q}{Q} = 0.7258$$

$$q = 0.7258 * 0.1473 = 0.107\ m3/sec$$

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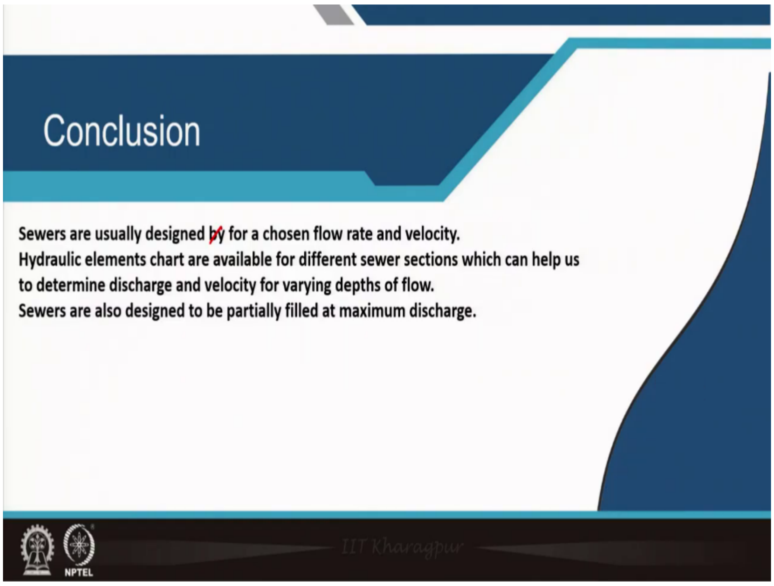

Conclusion

To conclude, sewers are usually designed for a chosen flow rate and velocity. Hydraulic elements chart is available for different sewer sections which can help us to determine discharge and velocity for varying depths of flow and sewers are also designed to be partially filled at maximum discharge.

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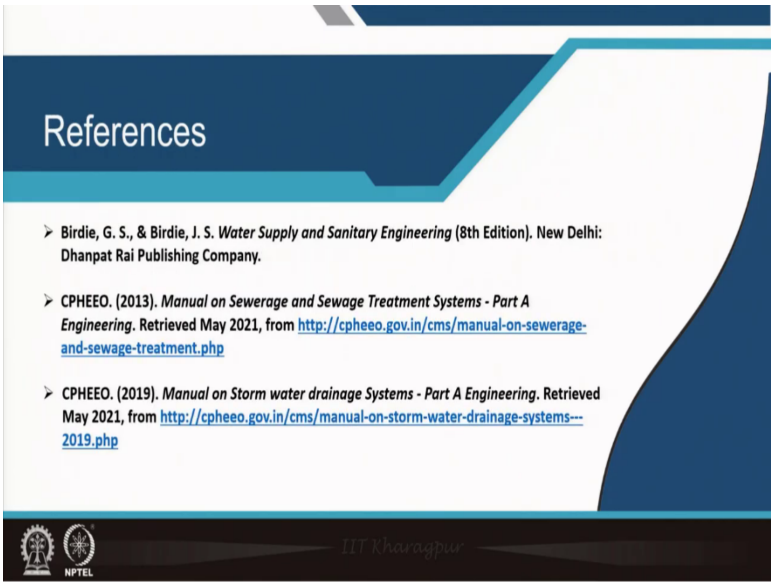

So, these are the references you can use.

Thank you!