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 - 23
Conveyance of Water Part II

Welcome back. In lecture 23, we will continue with Conveyance of Water, this is the part 2 of the lecture.

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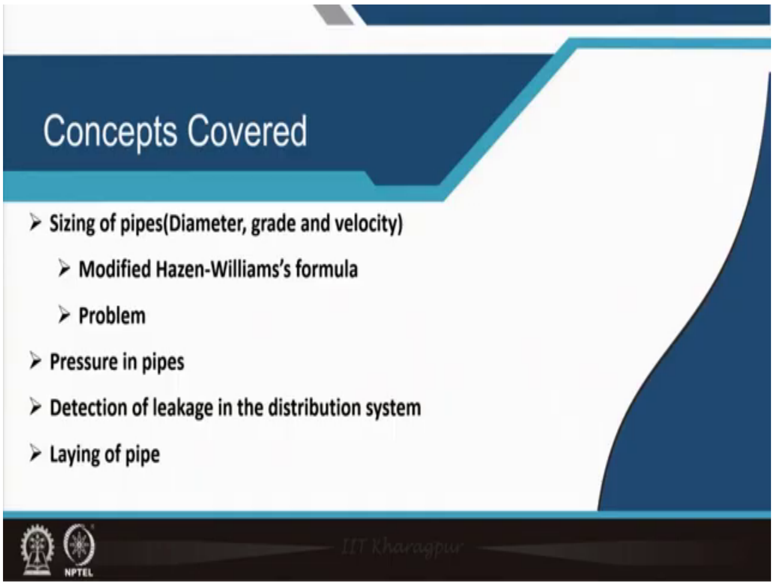

So, the different concepts that we will cover will be on sizing of pipes, and within that we will look into the modified Hazen-William's formula, and we will solve a problem. We will then look into the different kinds of pressure in pipes, and we will also try to see how leakage is detected in a distribution system, and then we will discuss on laying of pipes.

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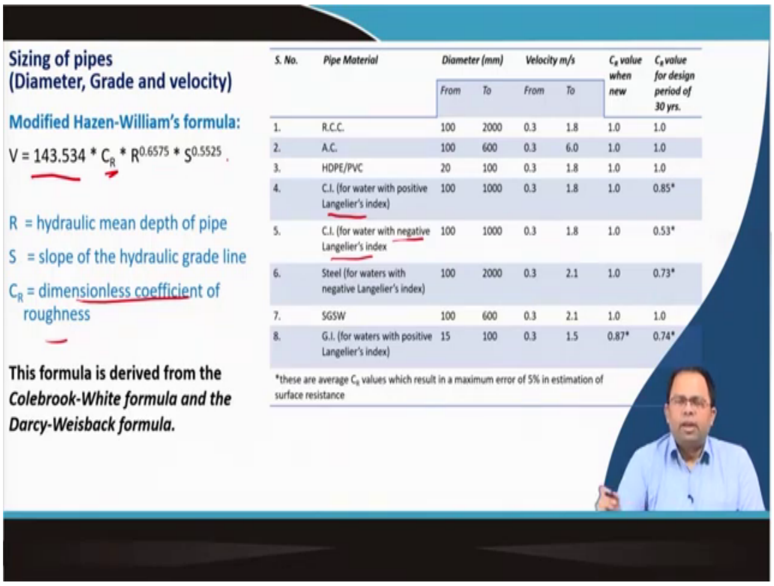

Sizing of pipes (Diameter, grade and velocity)

So, as we discussed in the last lecture that in the Hazen-William's formula, the initial constant value of 0.85 is only good for a particular case as it is based on certain assumptions such as a particular diameter of a pipeline and for a particular slope that has been calculated and that actually leads to lot of errors.

So the constant was modified to a value of 143.534 which was derived from the Colebrook-White formula and the Darcy-Weisbach formula.

So, the modified Hazen-William's formula is:

$$V = 143.534 * C_R * R^{0.6575} * S^{0.5525}$$

where,

R = hydraulic mean depth of pipe

S = slope of the hydraulic grade line

C_R = dimensionless coefficient of roughness

In this equation, C_H values are replaced by C_R values. C_R values for new pipes and a design period of 30 are provided in Table 1 .

Table 1 Coefficient of Roughness values for different pipe materials

S. No.	**Pipe Material**	***Diameter (mm)***		***Velocity m/s***		***C_R value when new***	***C_R value for design period of 30 yrs.***
		From	*To*	*From*	*To*		
1.	R.C.C.	100	2000	0.3	1.8	1.0	1.0
2.	A.C.	100	600	0.3	6.0	1.0	1.0
3.	HDPE/PVC	20	100	0.3	1.8	1.0	1.0
4.	C.I. (for water with positive Langelier's index)	100	1000	0.3	1.8	1.0	0.85*
5.	C.I. (for water with negative Langelier's index	100	1000	0.3	1.8	1.0	0.53*
6.	Steel (for waters with negative Langelier's index)	100	2000	0.3	2.1	1.0	0.73*
7.	SGSW	100	600	0.3	2.1	1.0	1.0
8.	G.I. (for waters with positive Langelier's index)	15	100	0.3	1.5	0.87*	0.74*
***These are average C_R values which result in a maximum error of 5% in estimation of surface resistance**							

For RCC pipes, for different diameters 1000; 100 to 2000 mm and with velocity of 0.3 to 1.8, we go for C_R value of 1. And similarly, for this CI pipes for water with positive Langelier's index, 100-to-1000-millimeter diameter and velocity of 0.3-to-1.8-meter C_R value is 1. These values can be obtained from the above table for calculations.

Langelier's index value maybe positive or negative which depends on the quality of water particularly with presence of carbonates in the water which leads to crustrations. Therefore, depending on that, different values for C_R are chosen.

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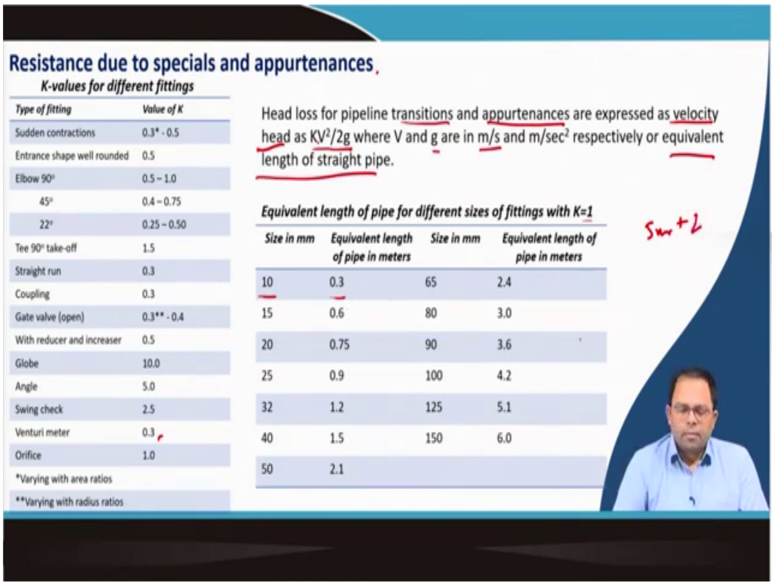

So, in addition to head losses in a pipe, there are other minor losses due to fittings inside the pipe, bends and radar reducers. This is called resistance due to specials and appurtenances. Apart from this, frictional losses arise either from the length of the pipeline, the material of the pipe or the fixtures attached to it.

This head loss can be determined directly for pipeline transitions, i.e., from bigger size to lower size or for lower size to higher size or for the different appurtenances. Using the Bernoulli's equation, the head loss is represented as $\frac{KV^2}{2g}$ where V and g are in m/s and m/sec^2 respectively or equivalent length of straight pipe. K values can be obtained from the Table 2.

Table 2 K-values for different settings

Type of fitting	***Value of K***
Sudden contractions	0.3* - 0.5
Entrance shape well rounded	0.5
Elbow 90°	0.5 – 1.0
45°	0.4 – 0.75
22°	0.25 – 0.50
Tee 90° take-off	1.5
Straight run	0.3
Coupling	0.3
Gate valve (open)	0.3** - 0.4
With reducer and increaser	0.5

Globe	10.0
Angle	5.0
Swing check	2.5
Venturi meter	0.3
Orifice	1.0
***Varying with area ratios**	
****Varying with radius ratios**	

The type of fitting is given and the value of K is given. Based on the type of contractions, angle or appurtenances, K value can be chosen to measure the head loss.

Head loss can also be calculated using the equivalent pipe length method of straight pipe. For different sizes of pipeline like 10-millimeter pipeline, equivalent length of pipe in meters is given and then based on this fitting size, based on K equal to 1 these values are calculated as in Table 3. Based on these values, we can multiply and determine based on these K values for different fittings what would be the actual equivalent head loss.

Table 3 Equivalent length of pipe for different sizes of fittings with K=1

Size in mm	***Equivalent length of pipe in meters***	***Size in mm***	***Equivalent length of pipe in meters***
10	0.3	65	2.4
15	0.6	80	3.0
20	0.75	90	3.6
25	0.9	100	4.2
32	1.2	125	5.1
40	1.5	150	6.0
50	2.1		

For example, we will add a length of 5 meters and due to the presence of fixtures, instead of measuring the fixture separately we just measure another few meters because of the presence of that particular fixture. So, that we will add that as the equivalent length of pipe.

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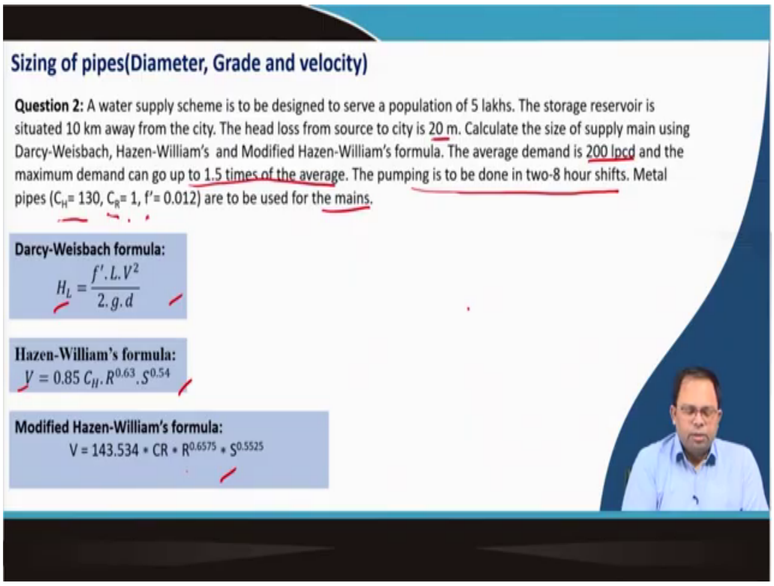

Since we have reviewed three different approaches, the Darcy-Weisbach formula, Hazen-William's formula, and the modified Hazen-William's formula, let's assess the kind of results we obtain using them to solve a particular problem.

Consider the following problem: A water supply scheme is designed to serve a population of 5 lakhs. The storage reservoir is situated 10 kilometers away from the city. The head loss from source to city is 20 meters. Calculate the size of supply main using Darcy-Weisbach, Hazen-William's and modified Hazen-William's formula. The average demand is 200 lpcd and the maximum demand can go up to 1.5 times the average. The pumping is to be done in two-8 hour shifts and metal pipes C_H equal to 130, the corresponding C_R value is 1 and the corresponding f'value is 0.012. f' is used in Darcy-Weisbach, C_R used in modified Hazen-William's, and C_H value is used in Hazen-William's.

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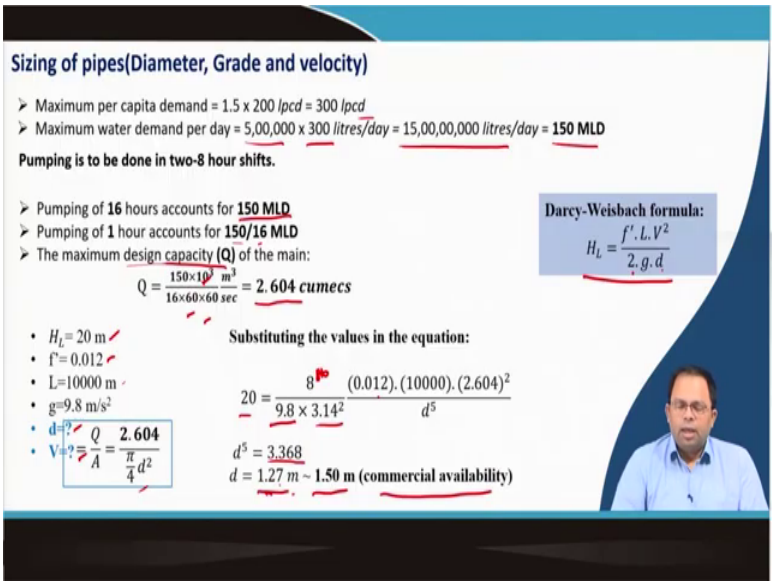

Solution of the problem:

Maximum per capita demand = 1.5 x 200 lpcd = 300 lpcd

Maximum water demand per day = 5,00,000 x 300 litres/day = 15,00,00,000 litres/day = 150 MLD

Since pumping is to be done in two-8-hour shifts, we are not doing 24 hour pumping but for 16 hours, a quantity of 150 MLD of water. So, in 1 hour we have to pump 150/16 MLD

The maximum design capacity **(Q)** of the main:

$$Q = \frac{150\times10^3}{16\times60\times60}\frac{m^3}{sec} = 2.604\ cumecs$$

So, now, let us apply the Darcy-Weisbach formula,

$$H_L = \frac{f'.L.V^2}{2.g.d}$$

Where,

H_L= 20 m, f'= 0.012, L=10000 m, g=9.8 m/s^2 , d=?

$$V = \frac{Q}{A} = \frac{2.604}{\frac{\pi}{4}d^2}$$

Substituting the values in the equation, we get:

$$20 = \frac{8}{9.8 \times 3.14^2} \frac{(0.012).(10000).(2.604)^2}{d^5}$$

$$d^5 = 3.368$$

$d = 1.27\ m$ ~ 1.50 m (commercial availability)

Here d value is equal to 1.27 meters and because we do not have any commercial availability of 1.27 meter pipeline, we may go for a 1.5 meter value or the next commercially available pipeline for this particular type of pipes.

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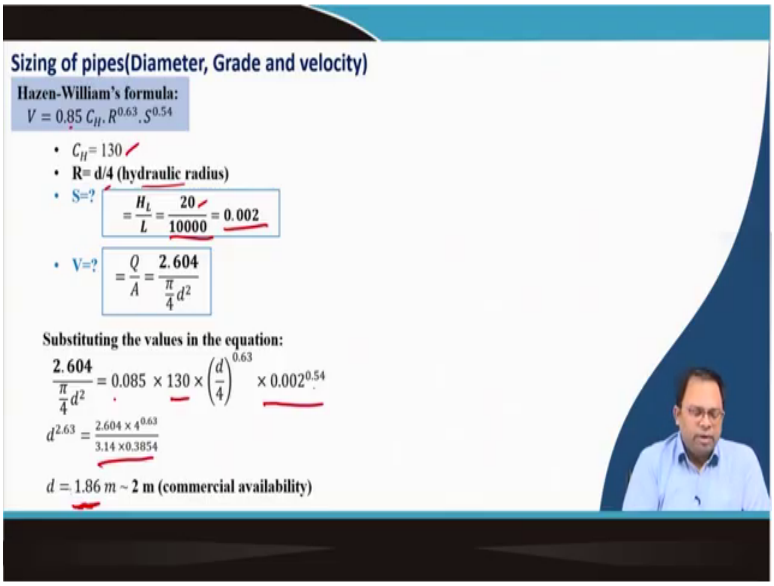

So, let us look at the Hazen-William's formula:

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

C_H= 130

R= d/4 (hydraulic radius)

$$S = \frac{H_L}{L} = \frac{20}{10000} = 0.002$$

$$V = \frac{Q}{A} = \frac{2.604}{\frac{\pi}{4}d^2}$$

Substituting the values in the equation, we get:

$$\frac{2.604}{\frac{\pi}{4}d^2} = 0.085 \times 130 \times \left(\frac{d}{4}\right)^{0.63} \times 0.002^{0.54}$$

$$d^{2.63} = \frac{2.604 \times 4^{0.63}}{3.14 \times 0.3854}$$

$d = 1.86\, m$ ~ 2 m (commercial availability)

Now, we solve we get around d to the power 2.60. This is the value and this roughly comes to around 1.86 which is where the next commercial availability is 2 meters. So, you see this value is much higher than 1.27 meters. In Darcy-Weisbach, we got 1.27, whereas, using this formula we are getting 1.86.

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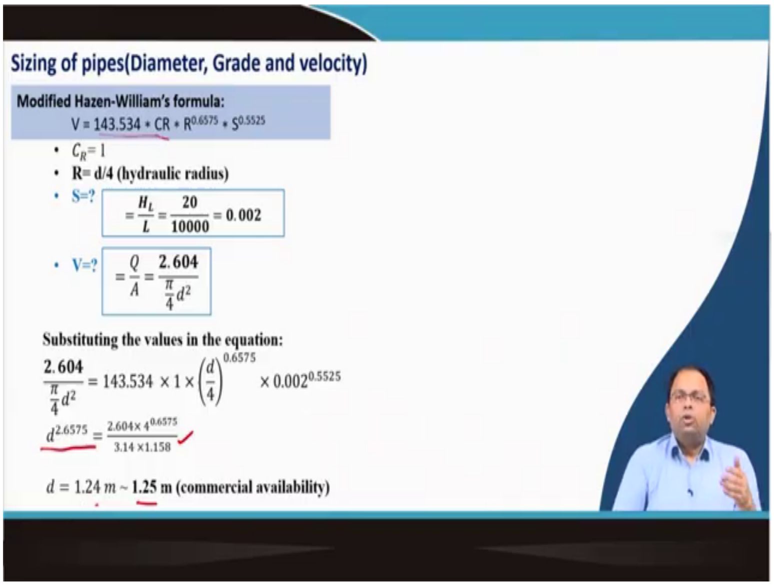

Then, coming back to modified Hazen-William's formula:

$$V = 143.534 * CR * R0.6575 * S0.5525$$

$C_R = 1$

R= d/4 (hydraulic radius)

$$S = \frac{H_L}{L} = \frac{20}{10000} = 0.002$$

$$V = \frac{Q}{A} = \frac{2.604}{\frac{\pi}{4}d^2}$$

Substituting the values in the equation:

$$\frac{2.604}{\frac{\pi}{4}d^2} = 143.534 \times 1 \times \left(\frac{d}{4}\right)^{0.6575} \times 0.002^{0.5525}$$

$$d^{2.6575} = \frac{2.604 \times 4^{0.6575}}{3.14 \times 1.158}$$

$d = 1.24\ m$ ~ 1.25 m (commercial availability)

On solving, we get is equal to 1.24 and the next commercial availability is 1.25. So, you can see the implications of using each formula. There is difference in these 3 computations and you can see that this will lead to a huge change in the cost of laying that pipeline that is a 10-kilometer-long pipeline. You will be able to save a lot of cost if you select the most appropriate formula. And for most cases we go for this modified Hazen-William's formula or we can fall back to the Darcy's formula.

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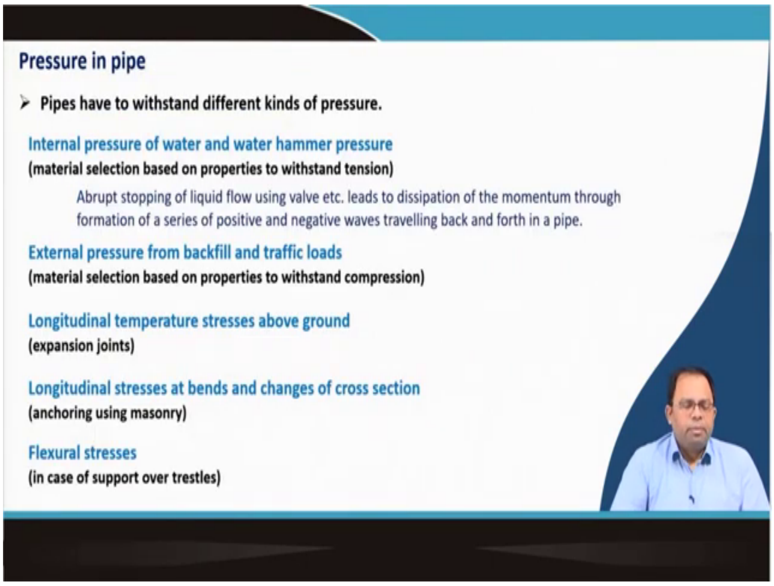

Pressure in pipe

Next, we will talk about the different pressures we find inside a pipe. The first pressure is the internal pressure of water and water hammer pressure. Water hammer occurs whenever there is an abrupt stopping of liquid flow, i.e., whenever we stop a valve immediately the water is stopped which leads to dissipation of the momentum through formation of positive and negative waves traveling back and forth in a pipe. So, suddenly we put in a sluice valve, so immediately the water is stopped and that the momentum is dissipated by the movement of water inside the pipe like that, i.e., it goes forward and backwards inside and that actually leads to this water hammer. So, material selection should be done based on properties to withstand this internal pressure of water.

Then, there is external pressure which comes from the backfill and the traffic load. Once the pipe is laid below the ground and filled up, pressure from this backfill and the load of traffic movement on top constitutes this external pressure. So, material selection must also be based on properties to withstand compression. So, in this case the pipe is compressed because there is load from the top.

Then, longitudinal temperature stresses also exist above the ground. Expansion joints need to be tested for that. There would be temperature stresses because pipes elongate because of temperature change. Then, longitudinal stresses at bends and changes of cross section which can be taken care of by anchoring using masonry. Then, flexural stresses in case of support over trestles where there is a bend when put two pipelines and raise it. So, these are the different kind of pressures that has to be considered.

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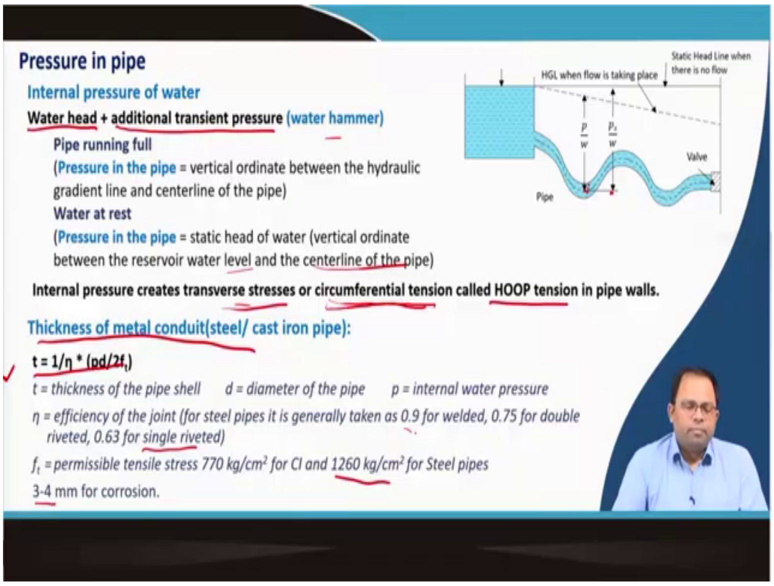

Internal pressure of water

Now, looking into the pressures in details like when we talk about the internal pressure of water. So, there is water head pressure, and the additional transient pressure which is resulting from water hammers

Internal pressure of water = Water head + additional transient pressure (water hammer)

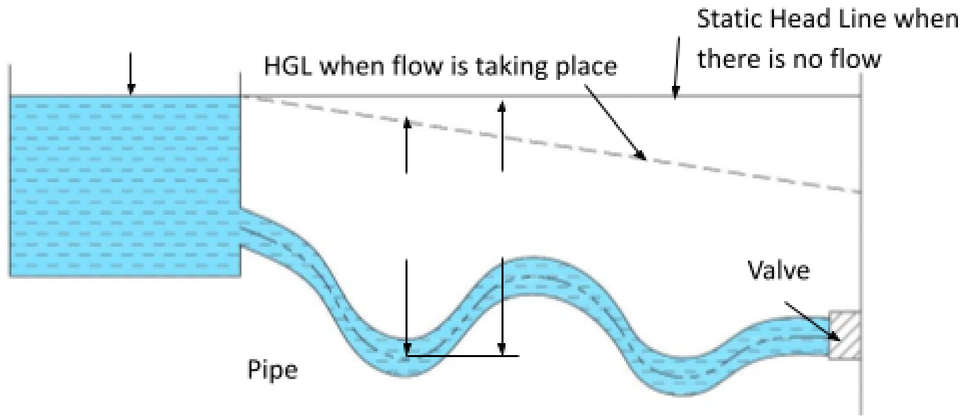

Figure 1 Pressure in pipe

So, when pipes are running full, pressure in the pipe is same as the vertical ordinate between the hydraulic gradient line and the centerline of the pipe as shown in Figure 1. So, the pipe has to withstand this pressure when the water is flowing, and water at rest pressure in the pipeline is equal to static head of the water.

So, internal pressure creates transverse stresses or circumferential tension because there is pressure inside water. So, it will have some pressure on the walls of the pipe which is known as transverse stresses or as circumferential tension along the circumference. And this is called hoop tension in the pipe walls.

Considering the type of tension, the thickness of pipes, metal conduits like steel and cast-iron pipes could be determined using this formula:

$$\mathbf{t = 1/\eta * (pd/2f_t)}$$

where,

t = thickness of the pipe shell   d = diameter of the pipe   p = internal water pressure

η = efficiency of the joint (for steel pipes it is generally taken as 0.9 for welded, 0.75 for double riveted, 0.63 for single riveted)

f_t = permissible tensile stress 770 kg/cm^2 for CI and 1260 kg/cm^2 for Steel pipes

3-4 mm for corrosion.

Therefore, the permissible tensile stress, diameter of the pipeline and the pressure of water determine the thickness of the pipeline pipes. If we do not provide adequate thickness then the pipe may break.

And in addition, whatever we get for thickness, 3 to 4 millimeter have to be added for corrosion consideration because corrosion will eventually happen in the pipeline. So, we usually take a little bit thicker pipe than required and that is thicker by 3 to 4 millimeters.

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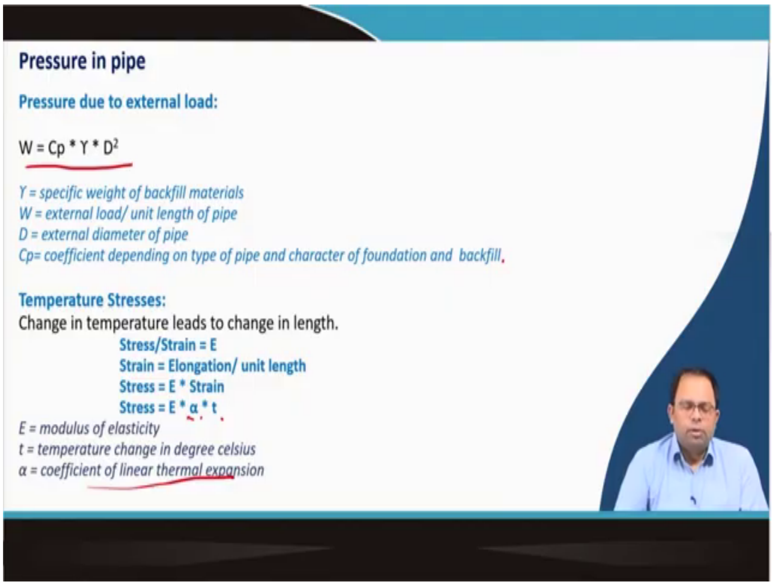

<u>Pressure due to external load</u>

Now, pressure due to external load can be calculated using the formula:

$$W = Cp * \Upsilon * D^2$$

Where,

Υ = specific weight of backfill materials

W = external load/ unit length of pipe

D = external diameter of pipe

Cp= coefficient depending on type of pipe and character of foundation and backfill

The Cp values will be chosen to determine the external load per unit length of pipe from specific tables. And, based on that, we have to choose a particular pipe material which will be able to withstand that kind of external load. And usually, we have seen that concrete pipes can take external load whereas, steel pipes can take more internal loads.

Temperature stresses

There is another pressure that is temperature stresses. As we are aware, change in temperature would change the length of the pipeline. So, this can be explained by the equation:

Stress/Strain = E

Strain = Elongation/ unit length

Stress = E * Strain

Stress = E * α * t

where,

E = modulus of elasticity

t = temperature change in degree celsius

α = coefficient of linear thermal expansion

So, that means, for each degrees Celsius linear thermal expansion will happen. That is why we are multiplying alpha with t and then multiplying with E to get the overall stress in that particular pipe. So, this temperature stress, stress due to external load, stress due to internal load, all these things determine the diameter, type of pipe and thickness of the pipe.

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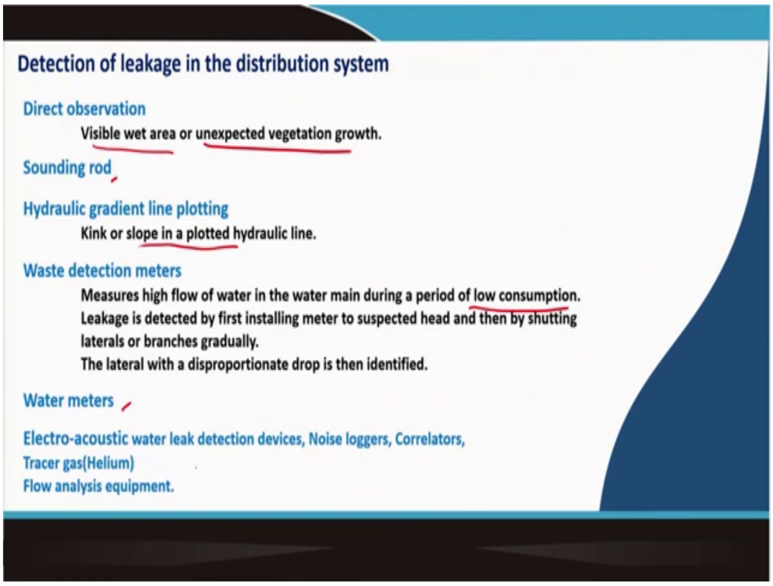

Detection of leakage in the distribution system

Next we will talk about leakage detection in a distribution system. Once we lay the pipeline and once the system is operating, leakages are bound to happen in water supply pipelines, but we need to detect it efficiently and fast. There are different methods to do this.

The first method is a direct observation method. That means, wherever leakage happens the surrounding area will be wet even without any precipitation or where there is unexpected vegetation. These could be some indicators for a leakage nearby.

Another method is to use a sounding rod where we put the device and listen to the sound of water gushing out of a particular pipeline. Another method is hydraulic gradient line plotting in which we check the hydraulic gradient at different points. We have to measure wherever there is a sudden kink in the line or a slope and we can determine that there may be a leakage in between.

Then, waste detection meters is the easiest way or the most common way to detect any leakages. Meters are provided in the main line and then at every branch, and the period of very low consumption is determined. Then along this particular line, if the flow is higher, then it is an indicator of leakage.

We gradually keep on stopping the meters to prevent supply and if there is not much difference then we understand that it is not a leaking line. And if it is found that there is tremendous increase in the flow in the values then probably there is a leakage in that particular direction. To summarize, waste detection meters measures high flow of water in the water main during a period of low consumption. Leakage is detected by first installing meter to suspected head and then my shutting laterals or branches gradually. So, we will put in the meter at the main line where we are detecting and then in all the subsequent laterals and branches that come after that. And based on that the laterals with disproportionate drop is identified by stopping it gradually one after another. And the one where there is a significant drop, we can determine that leakage is happening in that particular lateral and then we can search for it in using the direct observation method or other methods.

We can also opt for an electro acoustic water leak detection device. These are noise loggers or correlators, or we can go for tracer gas helium, we can put in helium and we can detect the leakage where helium is coming out because helium will come out where there is a leakage, and we can also detect using flow analysis equipment. So, these are the different methods of leakage determination in a water supply pipeline.

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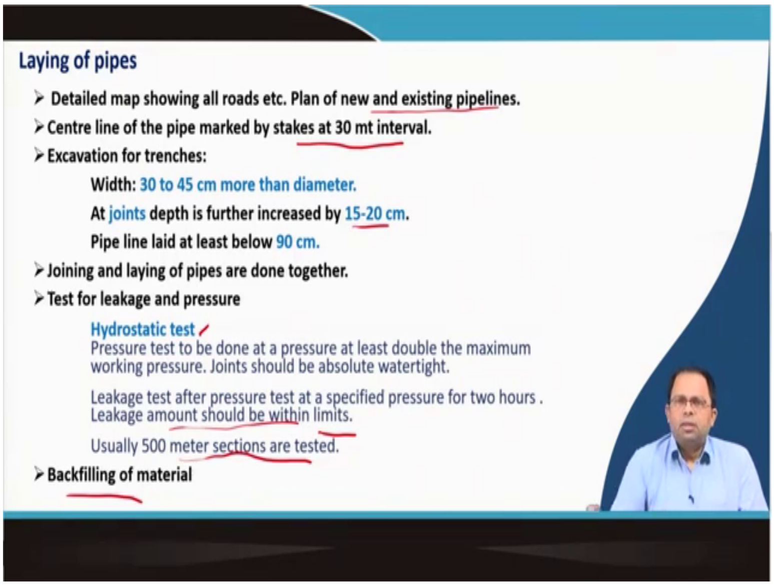

Laying of Pipes

In order to design laying of pipelines, first of all we need a detailed map showing all the roads because most of the utility lines are laid along the major corridors and then from there along the roads, we take our lines to reach the different parts of the city. Usually, roads give the structure of the city. They could be called as a skeleton of the city and the utility pipelines also go along with that.

And then we mark the center line of the pipe by using stakes at 30-meter interval along that particular corridor and then we excavate for trenches. Excavation is usually done which is 30 to 45 centimeters more than the diameter of pipeline. And, at joints because these are a little bit wider, we increase it further by another 15 to 20 centimeters. Pipelines are laid at least below 90 centimeter, 3 feet below ground. And when we are laying the pipelines, we also do joining of the pipelines together.

And once we have laid down the pipelines, then we test it for leakages and if it is able to withstand pressure. These tests are called as hydrostatic tests.

So, the first test is the pressure test which is to be done at pressure at least double the maximum working pressure, and joint should be able to withstand the same i.e., joints should be absolutely watertight, there should be no leakage. So, that means, we are subjecting the pipeline to double the pressure that it is subjected to bear, during normal peak periods and so on.

And the other is the leakage test where we put in water in the pipelines and keep it for 2 hours, and that is at the same pressure that it would be subjected to. And we also determine that what kind of leakage is happening and if it within limits or not. If it is within limits then we accept it, and then we can put in the backfill material and complete the job.

But if it is not the case, then we have to again search for the leakage, replace that segment of pipeline and so on. Usually, 500 meters sections are tested at each go. So, once all these things are done, then backfilling is done.

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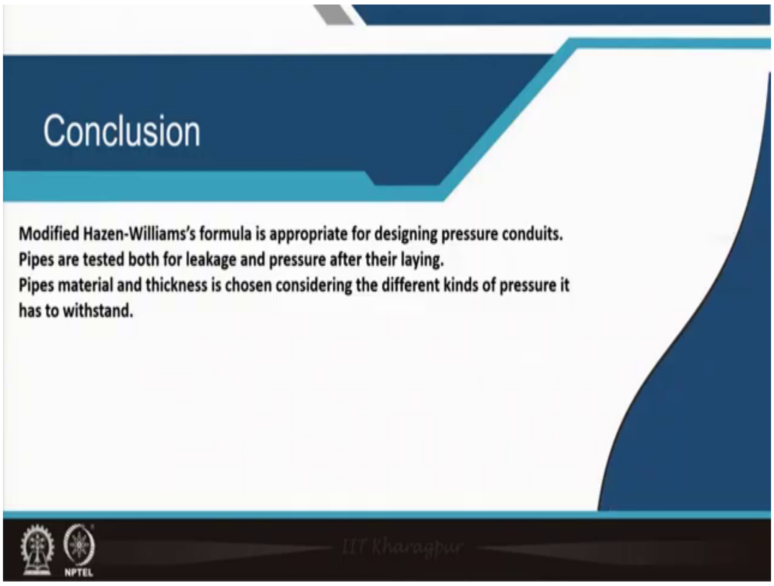

So, to conclude modified Hazen-William's formula is appropriate for designing pressure conduits and we need to test pipes both for leakage and pressure after they are laid. And pipe material and thickness are chosen considering the different kinds of pressure it has to withstand.

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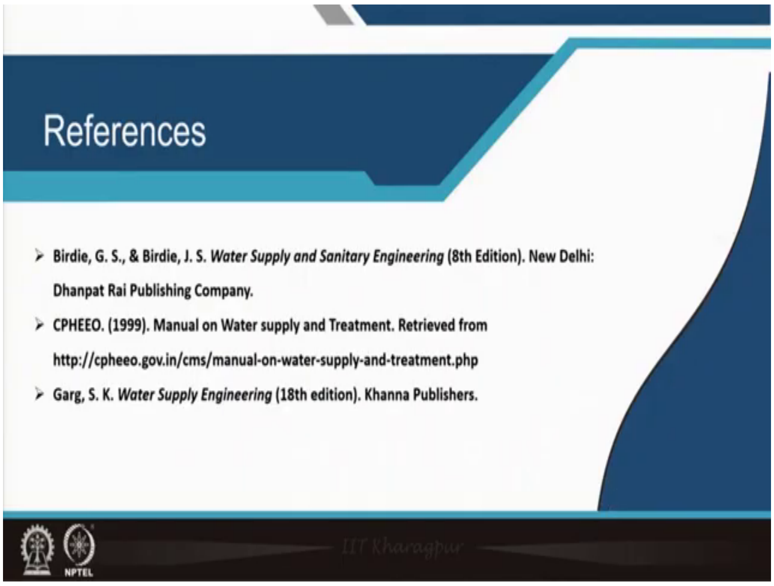

So, these are the references.

Thank you.