Civil Engineering

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Lecture No. # 28

Good Morning everybody!

In this series we are going to discuss about the design of culverts. As you know culvert is generally constructed to drain water and is placed in a highway.

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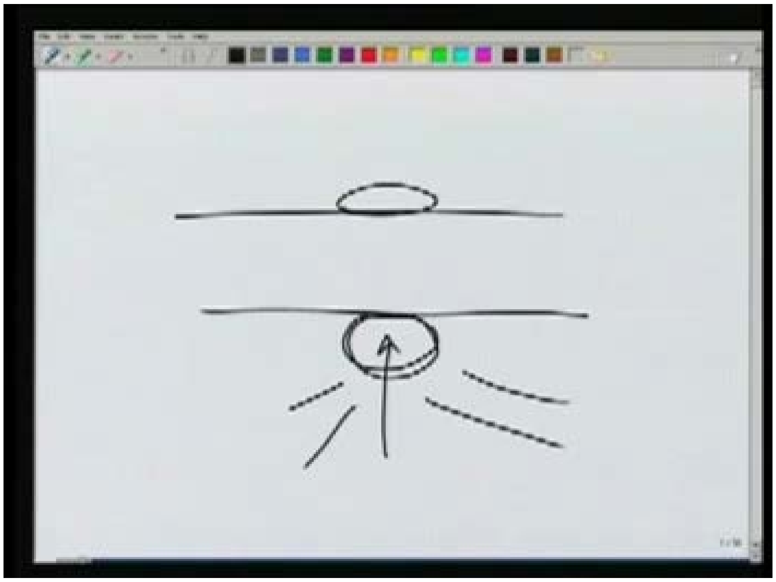

Suppose this is a highway, beneath this, we will have some line so that this water can be drained through this. When it comes to draining of water, this size can be circular or it can be oval or it can be of any shape. Similarly the material will be decided by the engineer (the material of these pipes) and we are we are here to discuss about the design of this. It means how do we know what should be the opening size and what should be the discharge passing through it?

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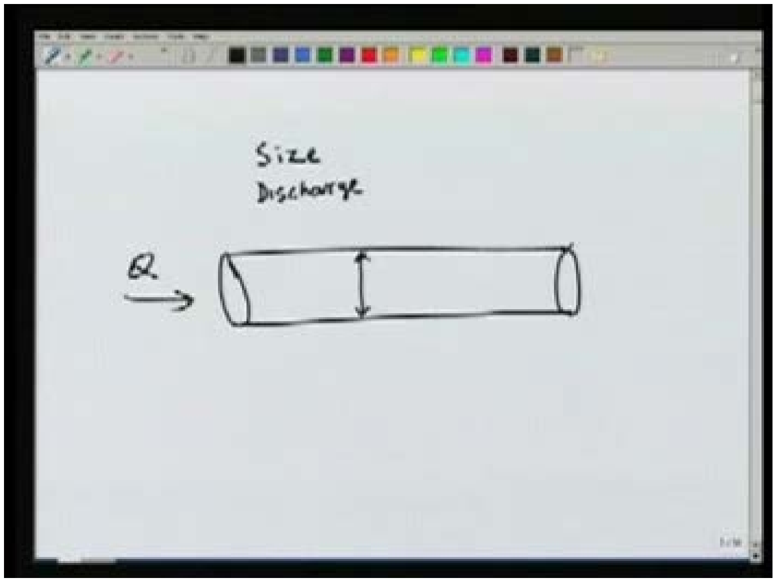

Let us consider a culvert. Let us assume that the culvert is circular. Here we have to determine, when we say designing the culvert, we have to determine the diameter of this pipe and what is the amount of flow water flow through this. We need to estimate these two things.

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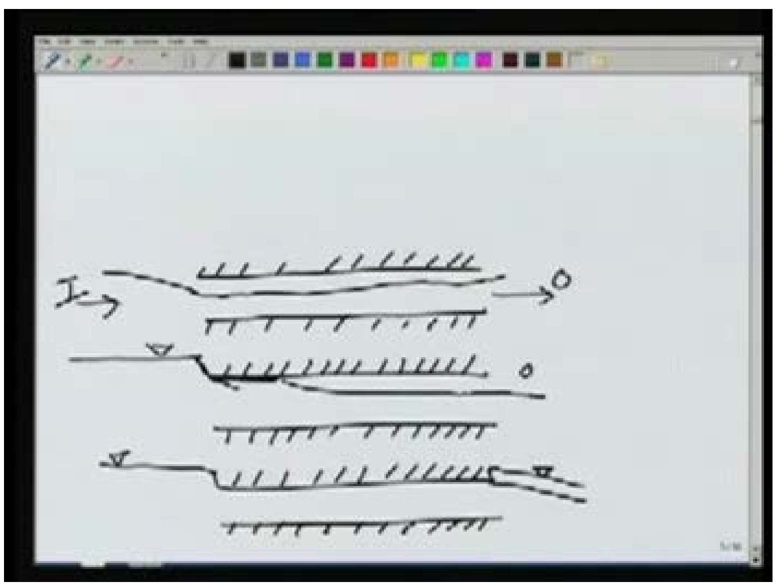

Before I proceed further, let me tell you that you may think bridge has a similar structure and we generally construct a bridge over a river. If I compare a culvert with a bridge then it is this span which makes the difference. Bridge is with a longer span and culvert is with a smaller span and generally eight meter is the limit. It means if this length is less than 8 meters we call it a culvert. Coming back to the different hydraulic conditions of a culvert, we can think of 4 different situations. Let us say this is the culvert and let us say this is the inlet and this is the outlet. At both the inlet and outlet, water may be below the top surface. This is the boundary of the culvert of the pipe line, this is the pipe line and it may be open channel flow throughout the pipe. Although the flow is inside a pipe, here it is taking place as open channel flow. Let me tell you the difference between open channel flow and pipe flow.

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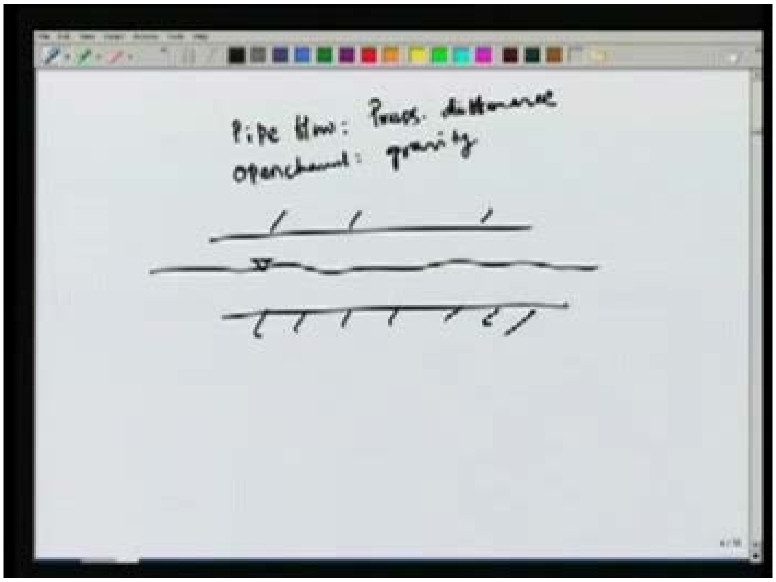

In pipe flow, the main motivating force is the pressure difference, whereas in open channel flow it is the gravity, so flow takes place due to the action of gravity. In case of channel flow (these are open channel flows); the flow is with a free surface. On the free surface, the pressure will be atmospheric. But in case of pipe flow, the pipe runs full and the flow is not due to gravity, it is due to pressure difference. The flow takes place from a higher pressure end to a lower pressure end. However inside a pipe there may be open channel flow. Let us say this is the pipe and this is the level of the fluid. Here it is not pipe flow because although the flow is taking place within a pipe, it is open channel flow. We may be depending on the flow condition. We may have 4 different types of culvert flows. Accordingly the design will be decided. Here in the first condition both at the inlet and at the outlet, the flow is below the top of the culvert, it means this can be considered as open channel flow.

In the second condition, we may think that at the inlet, the flow will be submerged, so here it will be above the top level of the culvert. This is water level and to some distance it runs full and then again it may come as free surface flow. So at the outlet it is not submerged but at the inlet, it is submerged. In both the cases, it is not submerged but in case two at the inlet, the flow is submerged, that means above the top level of the culvert. Here it is below the top level of the culvert. Third case will be, this is the culvert. We can say pipe, it is submerged here. So both at the inlet and at the outlet the flow is sub submerged that means if I talk from hydraulic point of view in here, I should consider the flow to be an open channel flow whereas in case two, it should be different. It is a partially filled pipe flow to some distance. It is pipe flow, after that it is an open channel flow whereas here it is completely pipe flow. There can be a fourth instance in which here it is just touching the top of the culvert. In this case also, it will be like pipe flow. Let us consider one by one, how to design these culvert flow conditions. In case of case one that is at inlet, it is not submerged and at the outlet also it is not submerged and we said that we should consider open channel flow for the analysis of the flow. When we say open channel flow, the simplest type of open channel flow is the uniform flow for the normal flow condition. We consider that the flow inside the culvert has normal flow.

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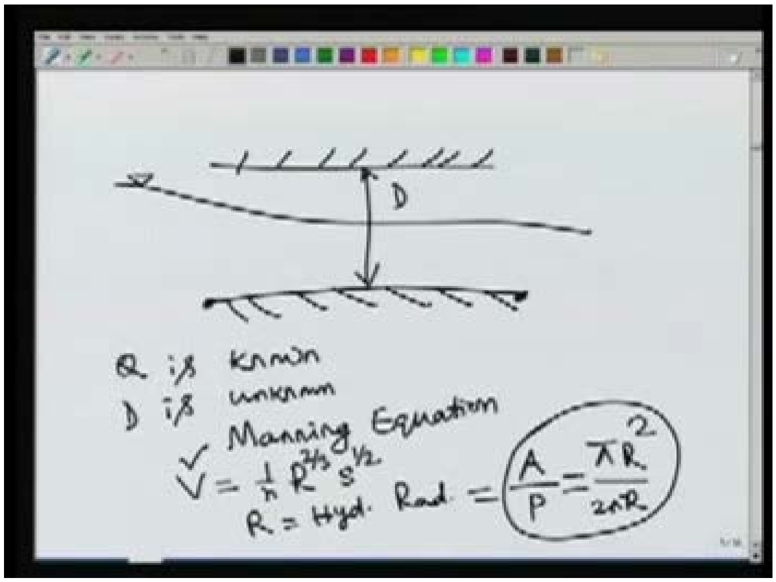

If we have to design this then what should we do? Let us assume that Q is known. Sometime later, I will let you know how Q is determined, but at the movement, let us assume that Q is known. The discharge to be passed through this culvert is known to the engineer and he has to design the size of this culvert pipe. What should be the diameter? What should be the opening that the flow can be safely passed through? Q is known and D is unknown. What is D? D is this diameter. Here I have assumed that the culvert is circular in shape. Now the common equation which we use in open channel flow is called the Manning equation which is V = 1/n R to the power 2 over 3 S to the power 1/2. V is the uniform velocity through this pipe and R is hydraulic radius which is the area over the weighted perimeter. In this case since this is the pipe, area can be considered as pi R square and perimeter will be two pi R.

Try to mark the difference. Here the pipe is not running full but we are still using this pi R square as if it is running full and this is the perimeter. So we get some value of R, hydraulic radius. In fact what one should do is take the actual. So basically we have to determine what is R. We do not know R, we have to determine R. We know the velocity. We know n, we know this flow, and S is the slope of this pipe line. This slope will be calculated based on the elevation at this place. We take the difference between the elevation at these two places and you divide by the distance. So you get the slope. In this Manning's roughness coefficient and depending on the material we use for the culvert, n will be decided and standard values will be available in text books or in charts. We use those standard values for determining Manning roughness coefficient and then we know velocity. We know that Q is known. This is a kind of trial and error procedure because we are trying to find out the design parameter. So it is an iterative process and Q is known.

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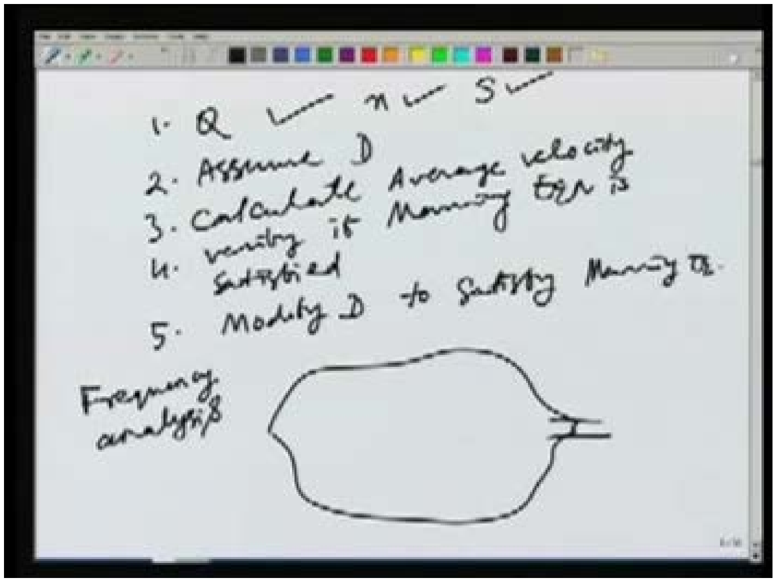

Assume D, once you assume D and n is known, Manning roughness coefficient. R can be found out by assuming D and slope is known. When Q is known and you assume the D, calculate with this assumed value of D you calculate the area average velocity and you verify if Manning's equation is satisfied. I try to verify the Manning's equation (what we wrote few minutes back). If is satisfied, then our assumption of D is alright. Otherwise modify D because Q is fixed, n is fixed, S is fixed. So modify D, so that your Manning's equation is satisfied. We know that if Q is known, D can be determined and S can be determined from the topography and n can be determined by seeing standard text books or charts and the material to be used for the culvert. Q is the design discharge and it is meant to pass safely through the culvert opening. So we need to do some ways of finding out the design flood and generally for a culvert, we use the frequency analysis and in the frequency analysis we take some return period. What is return period? Return period is the indicator of the probability of accidents. If I have the record, let us say this is the catchment which drains water through this culvert. This is the culvert to which water comes from this boundary. For this catchment what I need to do is to collect the rainfall data and I should convert it into the corresponding discharge or if I have directly the run off data for this catchment then use frequency analysis.

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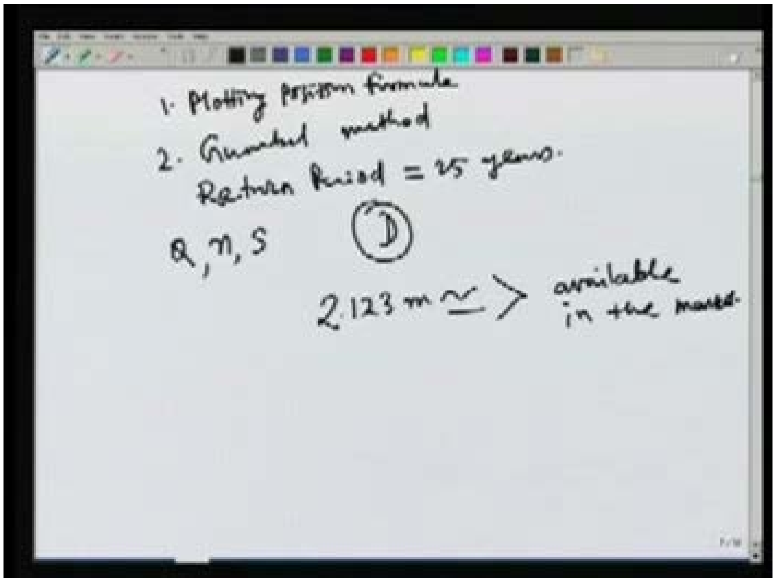

When we say frequency analysis, you can use plotting point. Plotting position formula like (Refer Slide Time: 17:27) method or you can go for Gumbel method. Gumbel method is suitable for extreme conditions. It means incase of flood, being an extreme condition; we can use Gumbel method and please remember that the culvert should withstand the maximum flood passing through it. Therefore we should consider a return period and in India we generally use a return period of 25 years. If you think the culvert is to be installed by a private agency that is rich, then maybe you can go for 50 years return period. Firstly you find out you estimate, what is the discharge corresponding to a certain return period and as per Indian codes, it should be 25 years. You find out the design flood, design discharge for 25 years return period therefore Q is known. Once Q is known you first think of some materials like gi or concrete or brick or any material stone. You decide the material and depending on the material, you determine n and depending on the topography, you determine slope. Then you apply Manning's equation to find out D and when D is determined, remember that your calculation may give you some number like, 2.123 meter but in the market you will get certain values of diameter. You will not get 2.123 meter. You should look for the nearest number which is rounded. Remember you should not make it less. It should be made more. You go for the nearest higher value which is available in the market. I think it is clear now. Let us discuss the second case.

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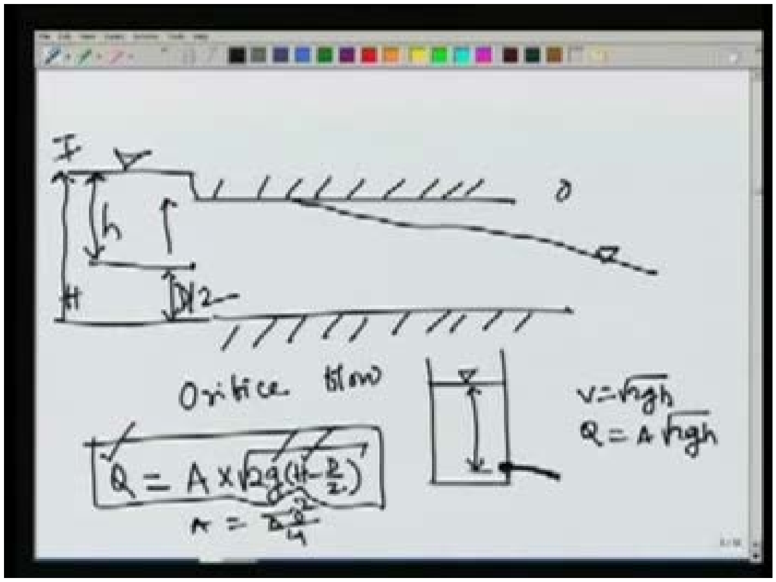

The second case is the culvert where the upstream condition or the inlet condition is submerged and here to some distance, it is running full and then it is running as open channel flow. Here you can say it is not submerged. This is outlet, this is inlet, and this is the water surface. Here this is the water surface here. Water surface here is above the top level of the culvert. Here the water surface is below or within the pipe is not submerged. We can consider this as an orifice flow. You know what an orifice is. Suppose I have a drum here, there is some opening here then through this opening water comes in like a jet. If water level is here, the velocity here will be square root 2gh. This is h, so discharge will be A or the orifice opening times the velocity. This is orifice discharge here also I should use the discharge relationship using orifice discharge equation. Here what will be the discharge? Please remember the control section will be here. It means this will decide what will be the discharge.

Analogically, you can think of this picture wherein this velocity and discharge will depend on this height. Here similarly, I should consider the center line of the culvert. This should be my h and I should use this h to find out the discharge. Discharge will be this area times the velocity. This will be square root 2 gh and what is h generally is this h will not be given. You will be given with this let us say this is capital H, and if this is diameter of the pipe, you can say this is D /2 because this is the diameter. H – D /2. If you look at this equation, we have D here, because the area of the pipe, this area of cross section will be pi D square /4. So if I look at this equation, here I know Q, g is known which is 9.81 meter per Second Square, capital H is known, (you know the condition here) and D is to be found out. Find out D by solving this equation. When you solve this equation, once again remember Q is given, g is given and D is to be found out.

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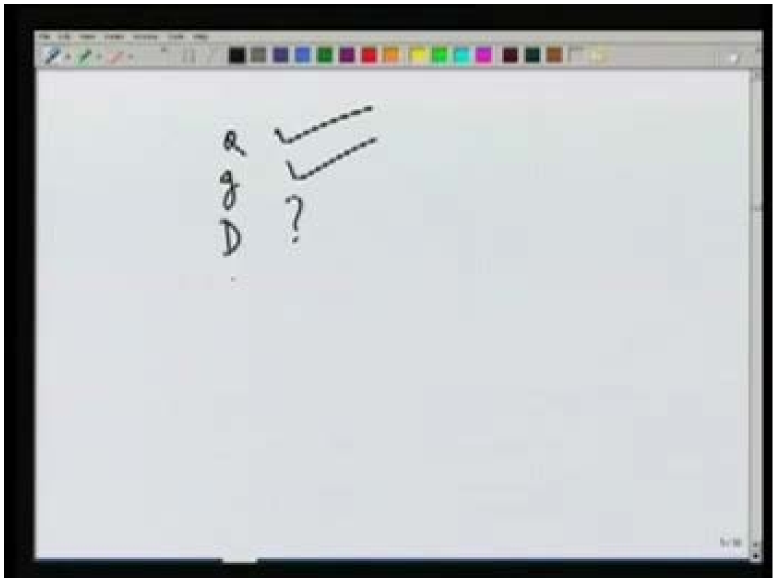

Once you determine D again same principle goes for the next higher value which is available in the market. Please remember here, the material does not come into picture, meaning the nature of the material of the culvert like whether it is concrete or a galvanized iron or stone or brick, the roughness is not coming into picture because we are assuming that the flow will be like a flow through the orifice and when the flow is from the orifice, it depends only at the inlet conditions. Let us come to the third case.

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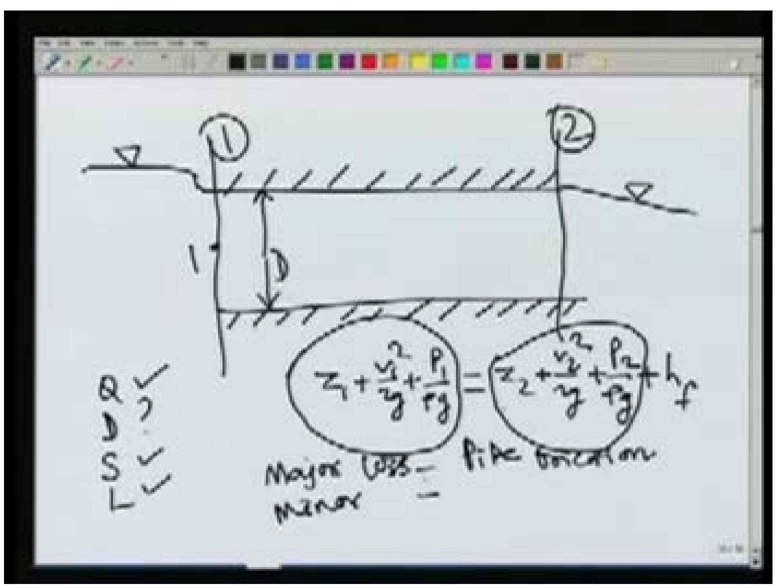

Here this is the culvert and the condition is here, also it is submerged here. We are considering a pipe flow. Let us say this is the diameter, so as usual Q is known D is to be determined and slope is also known. The elevation of this place and elevation of this place is known. You can say slope is known and of course this length is known. Here I am considering the flow to be like pipe flow. What should I use? I should use the basic energy equation. When I use the energy equation, the fundamental equation is Bernoulli’s equation and Bernoulli’s equation is Z_1 + V_1 square/ 2 g P_1/rho g = Z_2 V_2 square/2 g P_2 /rho g h_f which is head loss. This is basically the elevation head, this is the velocity head, this is the pressure head, so this is the total energy and here this is the total energy at point 2 in our case. One refers to inlet; this is 1, so this section is one. Similarly this section is 2. The reason for head loss is because as the flow passes through the pipe, the pipe wall will have resistance to the flow.

To overcome that resistance there will be some energy spent. Therefore there will be some energy loss and if I compare these two energies, this is the total energy at 2, this is the total energy at section 1 and if I compare these two energies then this will be less because some energy will be spent while the flow occurs through the pipe and what are the components of this head loss. One will be the major loss which is due to the pipe friction and what is the other one. This is minor and as you know in a pipe minor, head loss will be due to several factors like entrance loss, exit loss. If there is a bend, there will be loss. If the pipe is expanding or contracting, there will be a loss. If there is a junction, if a pipe is combined with another pipe there will be some loss. However in this case, since this length is not very much, we will have a straight pipeline and here the minor losses will be only due to entrance and exit.

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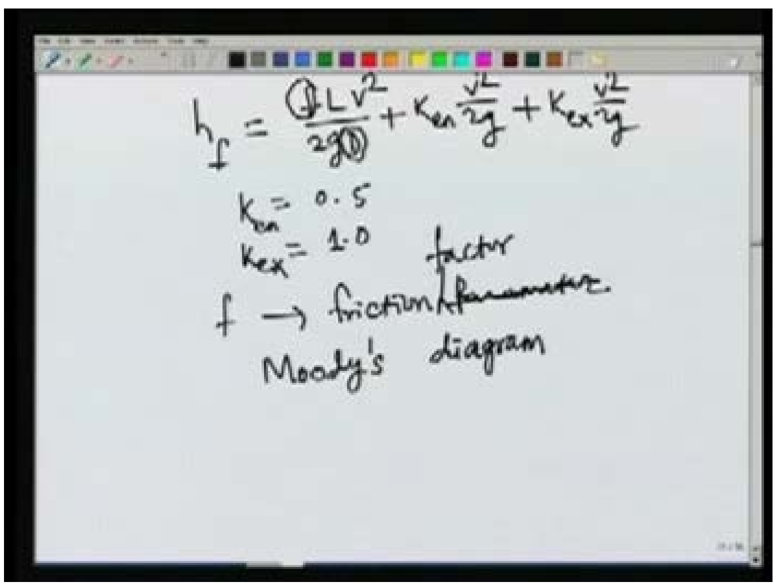

Head loss h_f will be, one will be friction which will be this (Refer Slide Time: 28:45) and minor loss will be due to entry. Let us say entry and it will be due to exit. We generally express the minor losses through some coefficient multiplied by the velocity head which is the average velocity inside the pipe. This value k at entry is generally considered to be 0.5 and k at exit is generally considered to be 1. Similarly to Manning’s roughness coefficient here, there is a parameter f which is friction parameter. You should use Moody's chart or Moody's diagram to determine the friction parameter. For a particular flow condition, it depends. It is a 3 parameter diagram, so you use 2 other parameters Reynolds's number and Roughness. Roughness basically depends on the material of the pipe, so depending on the wall, roughness, you determine the corresponding friction factor. Sometimes it is called friction factor, so you know the friction factor for a particular pipe. For a particular culvert material, length is known, V as usual is known. Here everything is known except this. If I go back here this is my energy equation. You consider one by one. We have 1, 2, 3, 4, 5, 6 and 7 terms. Let us consider one by one. Z_1 and Z_2, I told that the slope is known. This slope is known or in other words you can think that Z_1 and Z_2 both are known i.e., the elevation of the entrance and the elevation at the exit. We know these elevations for the slope. This is known. You can also consider this to be horizontal at same elevation. The difference of Z_1 and Z_2 might be taken at 0, similarly these two can be thought of as same. It means here, the velocity will be the same. We can assume that. The velocity head will cancel. Similarly P_1 so here what generally we think is that this is the pressure head and we assume that here the pressure will be hydrostatic. What is hydrostatic pressure?

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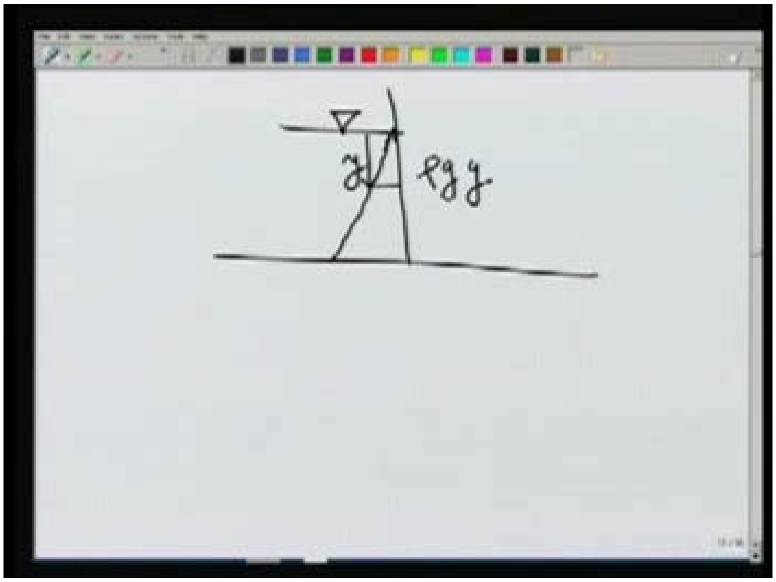

Suppose this is water level, then the pressure will vary linearly. It will be rho gy. This is at any point y, so here this pressure will be rho gy. As you go down, y will be more and pressure will be more. It varies linearly.

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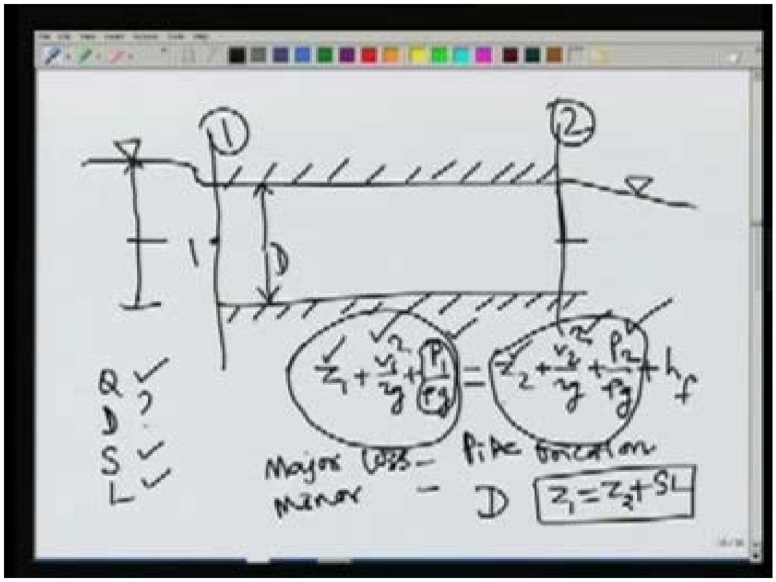

Here we assume that the pressure is hydrostatic. It means you can straight away use for this term, this height. Similarly here, the pressure will be this much. Whatever is the position of water, you can assume that here the pressure is hydrostatic. It means P 2y rho g will give me h for the water head available here. It means this is known and this is known. Out of these seven terms, we know this, this, this, this, this and this. About h_f is expressed through these 3 terms and out of these three terms, we know everything except this D. If I consider the previous equation, then in this equation, the only unknown is D therefore I can find out D if I know Q, S and L. Please remember this S and L will come into picture in z_1 and z_2. If the elevation at Z_2 is 0, then the elevation at Z_1, (I can express Z_1 to be = to Z_2 + slope times length) when I use this, then Z_1 – Z_2, can be used as SL. This becomes basically a single equation with one unknown. Solve this equation to find out D and as usual the discharge should be estimated priory. It means before trying to calculate the opening size, the diameter for the pipe, I should know the design discharge for the culvert and we should use frequency analysis. We should use the design period or the return period to be 25 years.

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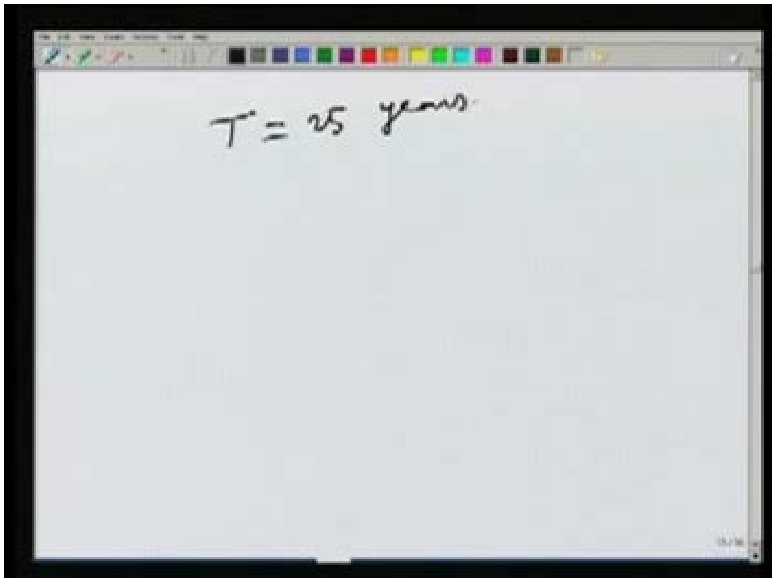

Please remember that this opening size D, it should be practically possible, which means you should look for a number which is available in the market and another precaution I want to tell you is in all the discussions, I told you that the size is assumed to be circular. It is not true in all the cases. The engineer can go for any shape, any size and similarly the material. Remember if the geometry is changed, shape is changed, if it is not circular then you use these equations. The basic philosophy is this. You use these equations, but you replace the D or the diameter by suitable parameter. Let us say if it is rectangular, you use suitable parameter. Similarly in Manning's equation, when you are calculating the hydraulic radius, you calculate suitably. If it is not circular, and has some other shape, parabolic or elliptic, or if it is rectangular or if it is of any other shape, you consider the shape factors and the parameters accordingly and design accordingly. Let me tell you that we consider 4 cases and the 4th case and 3rd case are all similar. It means we can consider both 3rd and 4th case as pipe flow and in case of pipe flow, we use we use Bernoulli's equation or energy equation to find out the design diameter.

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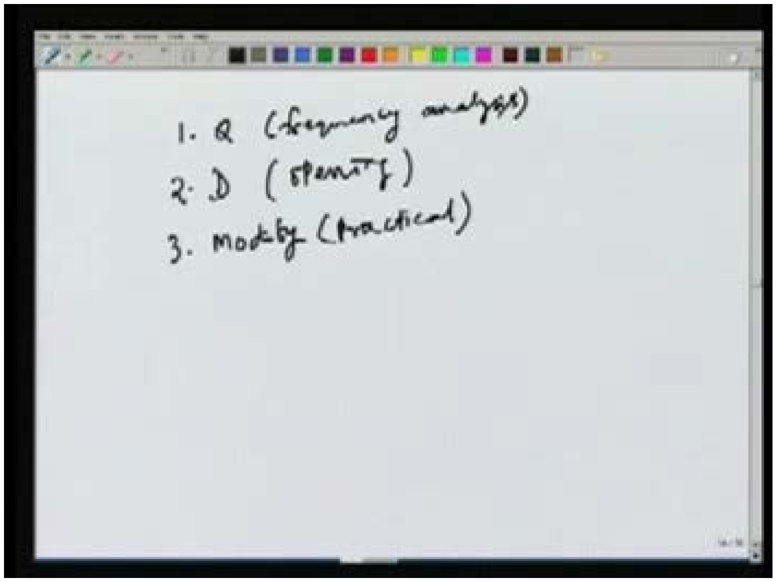

To summarize the thing, let me tell you once you estimate Q and how one should estimate Q by frequency analysis. Remember in class tests Q will be given and you will be asked to determine D. But think of a particular situation, suppose you are an engineer and you are deputed to do a job at some site so nothing will be available. Based on the discharge data, you do a frequency analysis and remember if the past records are not available, you should use alternative methods to find out the design discharge like rational method and I am sure you have been taught this while studying the run off calculation. First you find out based on frequency analysis, the design discharge then you should determine the opening here. I am writing it as opening, it could be a diameter. If the shape chosen is circular, it will be different. If the shape is different and then you should check or modify because the D you get here might be not be available in the market. So you should go for the practical one. With these, we conclude these and the next thing we will go is for the design of a detention basin.

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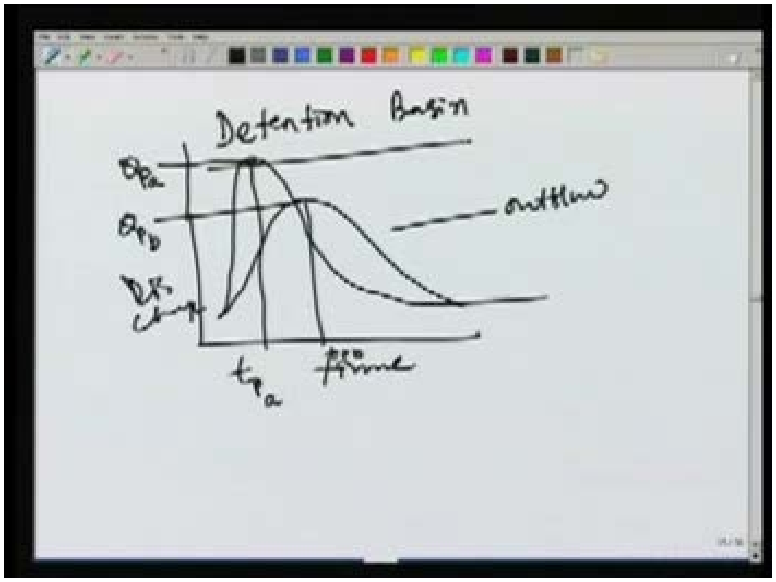

What is a detention basin? Suppose we develop a market complex or the place has become R_1, so what will happen is because of the effect of urbanization the buildings, it will be more. The roads will be more and we generally cut down the trees. Gradually the runoff will be more, so let us compare, and let us consider the effect of urbanization. Let us say this is the hydrograph outflow. Hydrograph means this is time, this is discharge and this is the area that was not developed into urban area. If we make the area urban then what will happen? This may be modified, the peak will be high and it may be something like this. Why this will happen is because now we have more buildings which mean the infiltration to the ground will be less. We have more roads and the trees are cut down. We are making towns. The infiltration will be less. Ultimately it will result in discharge. So the discharge will be higher and the time to peak discharge will be lower that means if I compare these two, let us say this is Q peak, after urbanization this is Q peak and before urbanization, Q_{pa} will be higher than Q_{pb}. Similarly if I compare the two times, this is time to peak after urbanization. This is time to peak before urbanization. We need to do something about this because now these higher amount of discharge needs to go somewhere. We should prepare in our town planning. We should prepare some detention basins and this detention basin has to be designed by the water resources engineer. To design these, we should apply the basic principle here.

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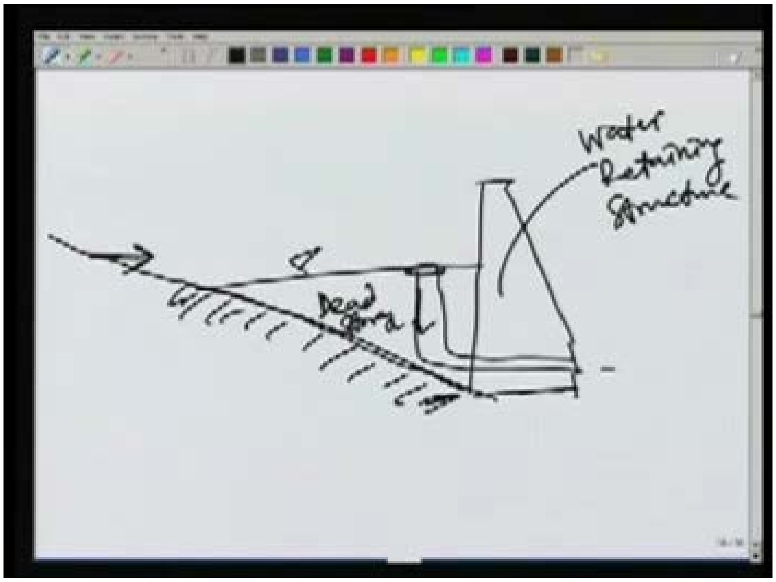

Let us say this is the basin with a slope. The water is coming in here; we have some detention structure here. It is not a dam, you can think of some water retaining structure and let us say this is the water level. This is the bed; this is a highly exaggerated vertical scale which is why it is seen like this. Here you may think this is the entry to this basin some flood is coming into this basin and here we should use some way to drain water. This is not very simple. This is a pipe like thing and this is meant to drain water from this and as you are seeing here, this is the dead storage and is not used. When water level goes beyond this level, water will flow through this pipe and come to downstream side. Here when we say design of the basin that means what should be the size of this basin? What should be the volume of this reservoir? How is this designed, so that water will be drained safely? Remember here, it is not very simple and we generally put a reaction here so that the whirling flow is not there, because while water will try to rush into this pipe, it will be a whirling flow. We need less of S, so there will be a mesh here and also sediments should not be allowed to come into these. It checks the flow of sediments and it also steals the flow because the turbulence should be less so that efficiently water can pass through this. We will discuss more about the design in the next class. We now think as to what could be the volume of this detention basin and what is the dimension of this pipe so that water is brought to this side safely and also one has to design the structural aspect of this water retaining structure.

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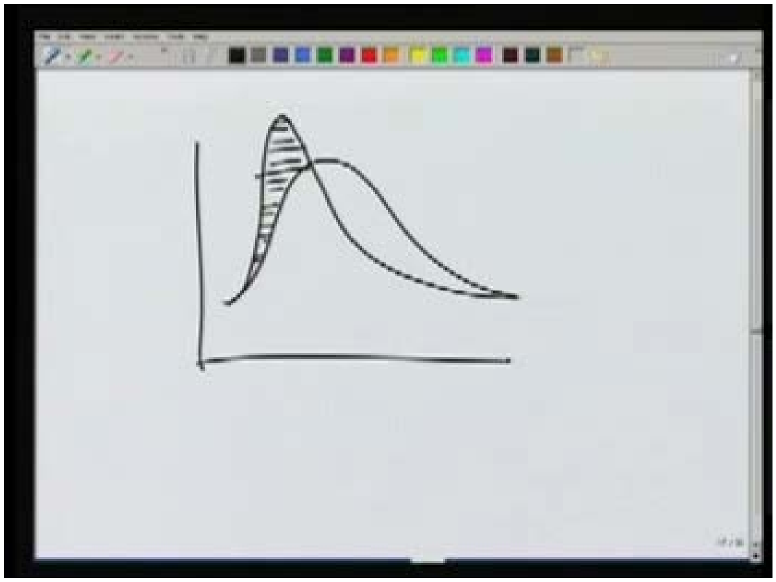

If you see the previous curve which I showed, for the effect of urbanization then this is the extra amount one should store. If I compare these two hydrographs then this is the extra amount required to be stored.

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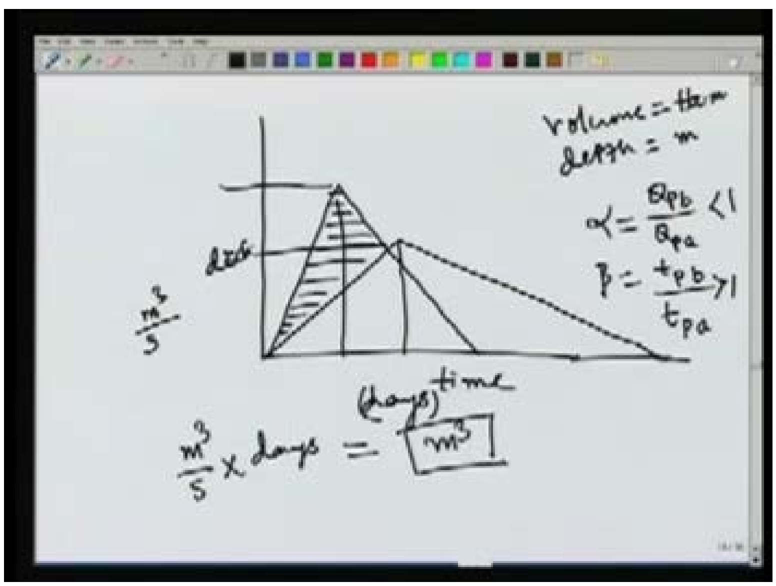

What we do is like this. We assume that these hydrographs are triangular. Why we assume these is because in practice, in actual conditions, it will be a curve like thing. But to simplify our calculations, we assume that this is a triangular thing and this is before urbanization, this is the discharge hydrograph before urbanization, this is time scale, this is discharge scale and after urbanization, it is again triangular something like this and what we need to store is these amounts. We have to find out the area of these and this is discharge, the unit of discharge is volume per unit time. This is meter cube per second. Let us say this is in hour per days, the unit is days. The area will give me this multiplied by this which is meter cube per second times days. I can compare the days into seconds. Finally I get meter cube or the volume. We generally express the volume in terms of hectare meter. The volume of the detention basin will be expressed in terms of hectare meter and many times we use just the depth. It means either we express in terms of volume, which is hectare meter or in terms of depth which is the meter. It means the volume divided by the area of the basin will give me the depth of water stored in the detention basin. Let me introduce 2 parameters, one is this ratio. The ratio of these two discharges will be called alpha Q peak before and Q peak after and similarly we have two time parameters, time to peak before and time to peak after. It is very clear that alpha will be always less than one. Why because, due to effect of urbanization Q peak will be higher. This is higher, that means this factor is less than one. While in case of beta, it is just the opposite. This Q peak happens early. So this is less compared to this. This will be more than one.

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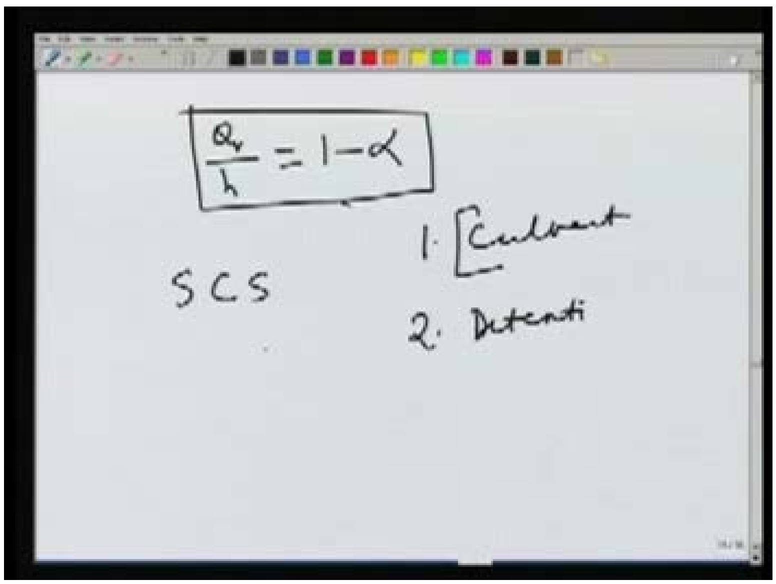

We can determine the volume. The height will be 1 – alpha. What is this? This is the volume to be stored or the design volume. The volume we require for the detention basin, will be determined by the depth of water multiplied by 1 – alpha. If I use this equation, this is of course based on many assumptions because I have simplified the hydrograph to triangles. Based on those simplified assumptions, I get this relationship. This is a very simple way of determining the volume of the detention basin. There are some other ways like SCS curve method. We will talk about these methods in some other class. To conclude this class, I will let you know the things we have discussed today. One is the design of the culvert and here we have discussed about 4 different conditions. But primarily three because third and fourth will be same and then we have just introduced what a detention basin is and how the volume will be calculated based on a simple assumption. We will discuss the design of detention basin by SCS curve method in the next class. I conclude here.