Soil and Water Conservation Engineering
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Lecture – 31
Hydraulic Design of Drop Spillway

Hello students. So, I am Dr. B. Sahu I am associate professor of School of Water Resources IIT, Kharagpur. So, in this lecture we will be talking about the Hydraulic Design of Drop Spillway, the hydraulic design of drop spillway. You know that the drop spillway is one erosion control structure which is specifically used for the stabilization of the gullies; it is a gully control structure. And it is mostly used for the elevation difference of or drop of around 3 meter; maximum we can use go for 3 meter of drop.

So, today we will discuss that; what are the components of this head wall this drop structure.

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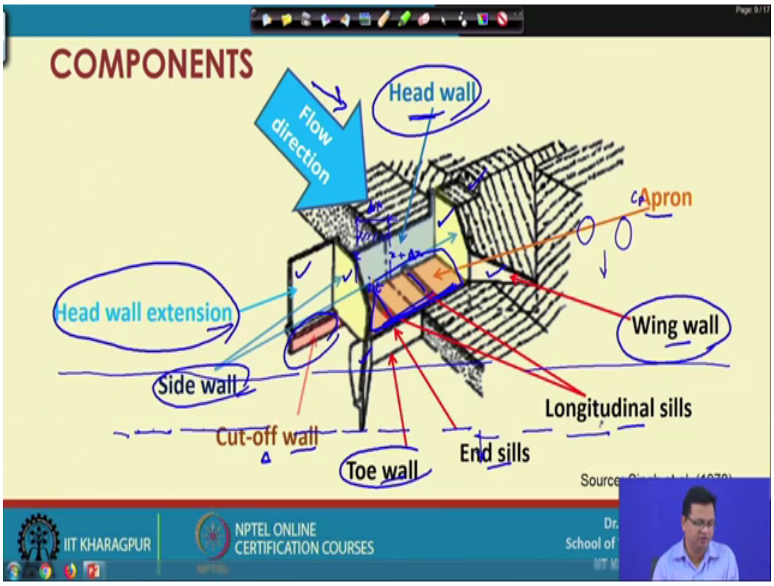

You can see this figure. So, the different components of this drop structure you can see there is head wall; this is head wall, apron, wing wall, longitudinal sills, end sills, toe walls, cut off wall, side wall, head wall, extension and the flow direction coming from this side ok.

So, the main function of this head wall is that the front wall against runoff flow in the drop spillway constructed occurs the gully or channel width. Second is your head wall extension so, this is your head wall extension. So, this is one head wall extension as well as this is another head wall extension. So, it is the extended portion of head wall into the gully sides that provides stability and a means against piping failure.

Then third is your wing wall you can see this is my wing wall. So, there are two wing walls this side and this side. So, these are the walls constructed at the rear end of the structure with usually at 45 degree from the vertical they provide stability to the soil field and protect the gully banks. Fourth one is the cutoff walls; you can see this is your cutoff wall. So, this side one cutoff wall on this side also there is cut off wall.

So, these walls provide structural strength against sliding of the drop structure prevent piping failure and reduce uplift pressure. Then toe walls you can see this is my toe wall. So, these toe walls they prevent under contain of apron due to erosion. Then we have sidewalls these are sidewalls. So, this is one side wall and this is another side wall.

So, these walls confine the water flow within the apron then there are end sills you can see this is the longitudinal end sill and these are the end sills this is longitudinal sill this is the end sill and these are the longitudinal sills. The end sills are the elevated sills of the Apron up to obstruct is usually mostly used to offer the water from directly moving into the channel below on raised the tail water level to create hydraulic jump for dissipation of energy of the flowing water.

The longitudinal sills are constructed lengthwise parallel to side walls to make the apron stable and this is the apron. It is constructed for dissipating the maximum kinetic energy of falling water by creating hiding job. So, that the velocity of tail water is significantly reduced.

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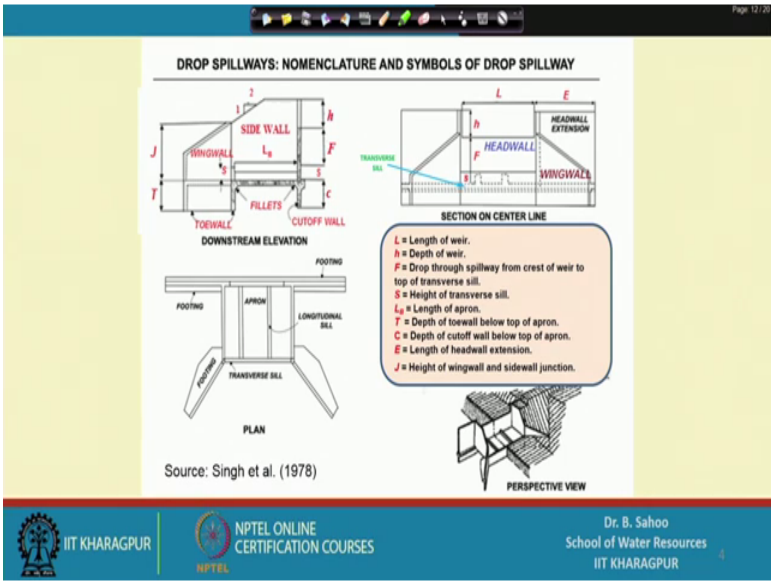

Showing the section of center line and in the left side there is downstream elevation or side view and also plumb. You can see the different comments head wall, wing wall, head wall, extension transversal sill, sidewall, wing wall, downstream elevation, footing. So, all these components will discuss in the next slides in detail.

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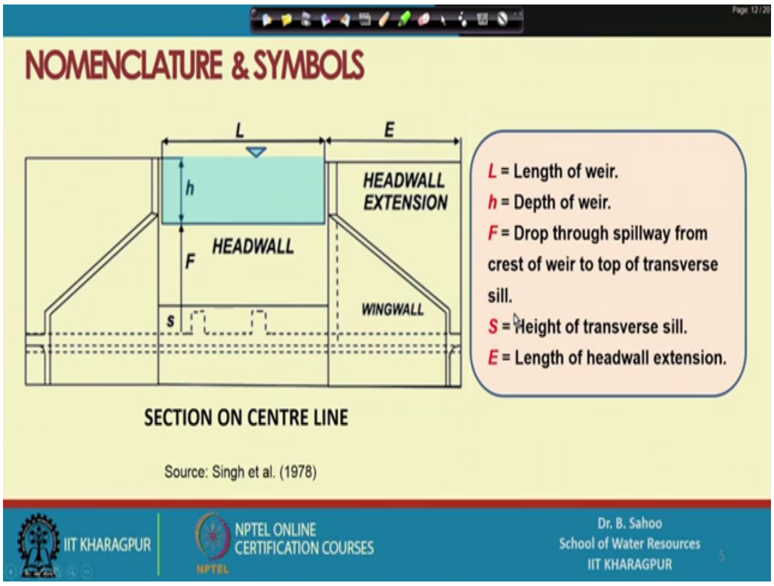

So, this is the section on central line specifically downstream front view. We can see here L is the length of the weir; specifically we use here rectangular type of weir. So, the length of L is generally selected based on the width of the approach channel in which that is the width of the gully. So, approximately we consider how much would be the length of the weir; small h is the depth of weir it is including the freeboard capital F is the drop through spillway from crest of weir to top of transverse sill S is the height of transverse sill and E is the length of head wall extension.

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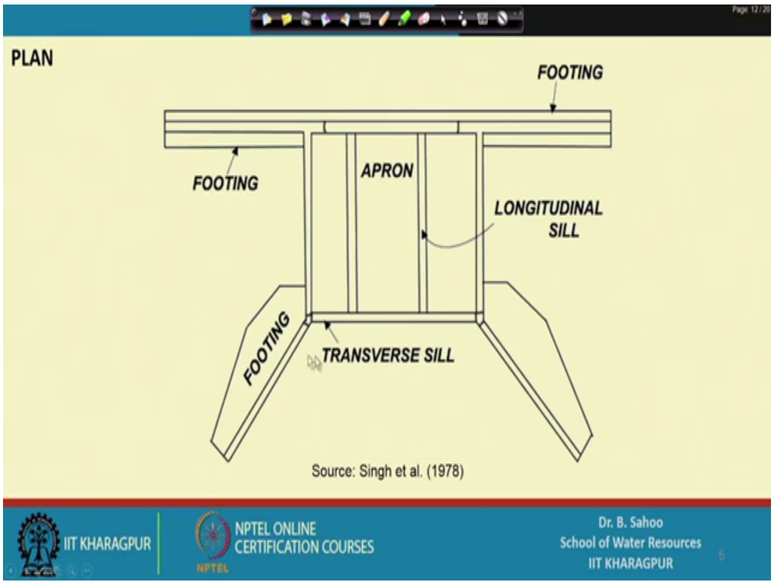

From the plan b we can see there are footings there is longitudinal sill and there is apron. So, on the apron there is longitudinally sill then there are transverse sill and along the transverse sill that is called as also end sill on these are footings and these are footings are mostly constructed at 45 degree angle to the vertical.

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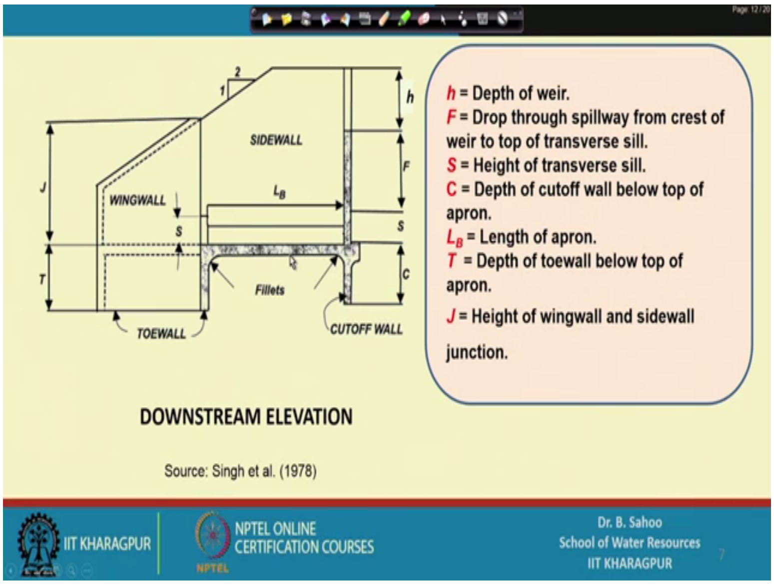

This is the downstream elevation or side view you can see this small h is the depth of weir, capital F is the drop through spillway from crest weir to top of transverse sill, S is the height of transverse sill, C is the depth of cut off wall below top of apron. L b is the length of apron, t is the depth of two wall below top of apron and j is the height of wing wall and sidewall junction.

And we provide also fillets to the cutoff wall.

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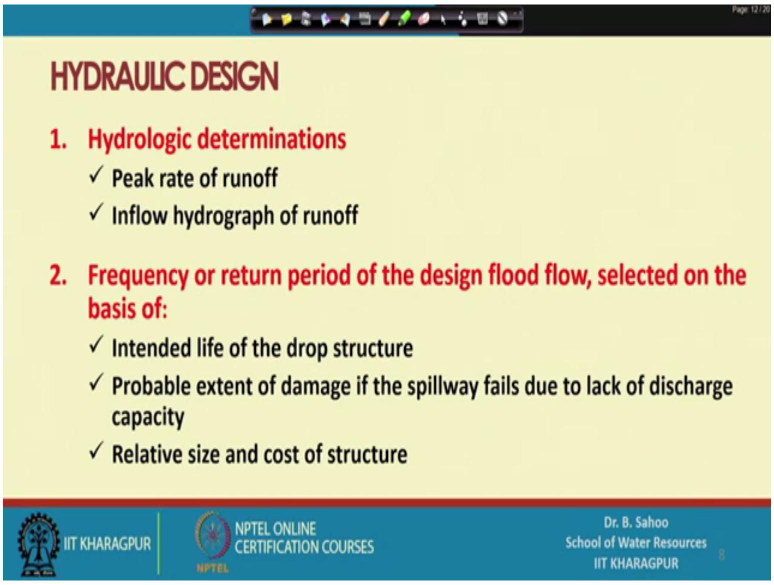

For the hydraulic design we generally consider two types of criteria one is your hydrologic determinations it is based on the peak of runoff in the gully or in the channel then inflow hydrograph of runoff. Second is the frequency or return period of the design flow selected on the basis of internal life of the drop structure probably extent of damage if the spillway fails due to lack of discharge capacity and relative size and cost of structure. The frequency or return period generally we can use for these the extreme value type of distribution functions are probably distribution functions to get the design flow at a specific return period.

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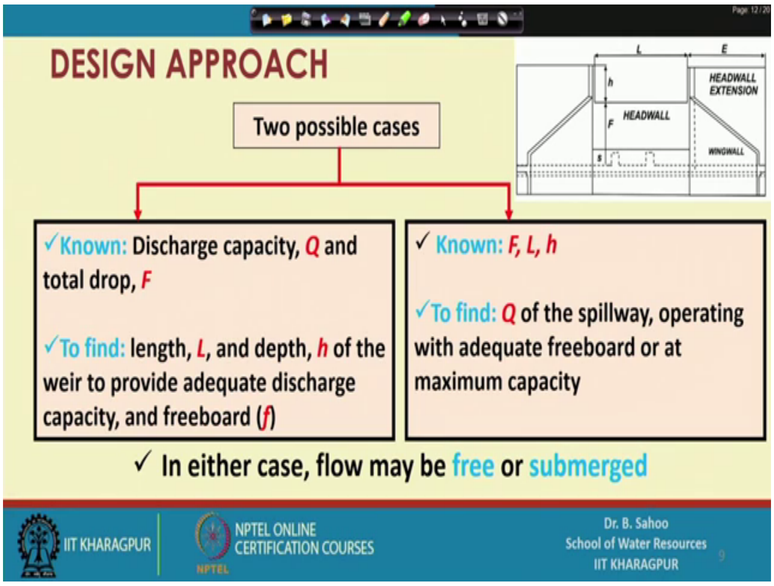

Then coming to the design approach; so, for the design approach there are two possible cases it can be either free flow condition or maybe submerge flow condition. For free flow condition generally the water should be freely flowing there is no disturbance are the tailwater on in case of submerged generally the tailwater height is above the crest level of the rectangular weir. So, this could be of two possible cases one is first is the known thing that the discharge capacity Q which is known before or estimated before and total drop is capital F.

So, these two things are known and we have to find; what is the length depth h of the weir to provide adequate discharge capacity and freeboard small h. In the second case it is the known values are capital F capital L or small h and we have to find the discharge capacity of the spillway operating with adequate free board or at maximum capacity.

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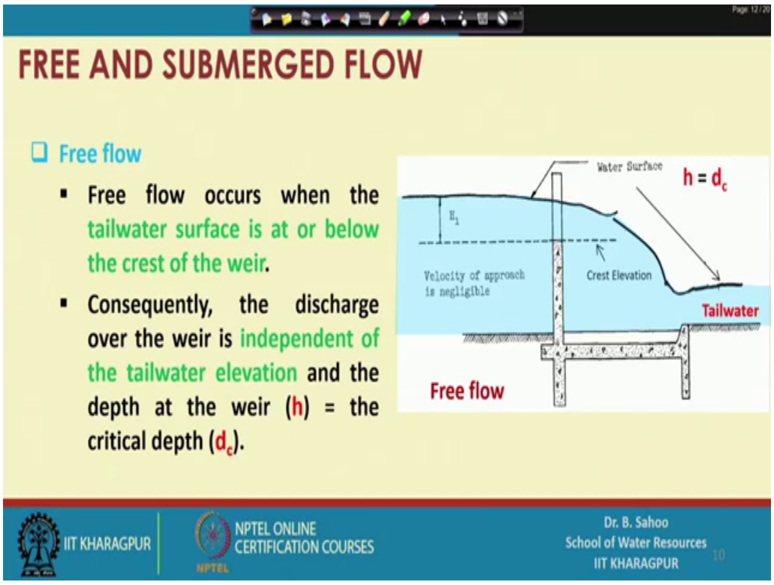

So, this is a picture showing the free and submerged flow you can see this picture. The tailwater is much below than that of the crest level. Here the velocity of approach of the flow above the crest level is capital H 1 and the tail water is not obstructing the flow of the water which is approaching to the crest. So that means there is no disturbance of tail water to the upstream flow.

So, free flow occurs when the tail water surface is at or below the crest of the weir consequently the discharge over the weir is independent of the tailwater elevation and the depth are the weir and in this case the depth of weir is generally considered as the calculated as the critical depth of flowing water. So, that is h equal to d c.

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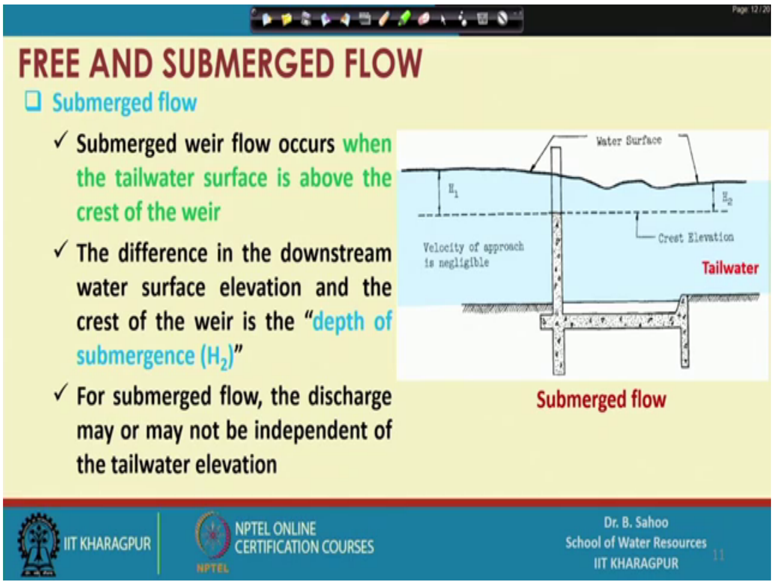

In case of submerged flow condition the submerged weir flow occurs when tailwater surface is above the crest of the weir the difference in the downstream water surface elevation on the crest of the weir is the depth of submergence that is capital H 2 we can see in this figure. So, it is capital H 2 it is the depth of submergence; for submerge flow the discharge may or may not be independent of the tailwater elevation.

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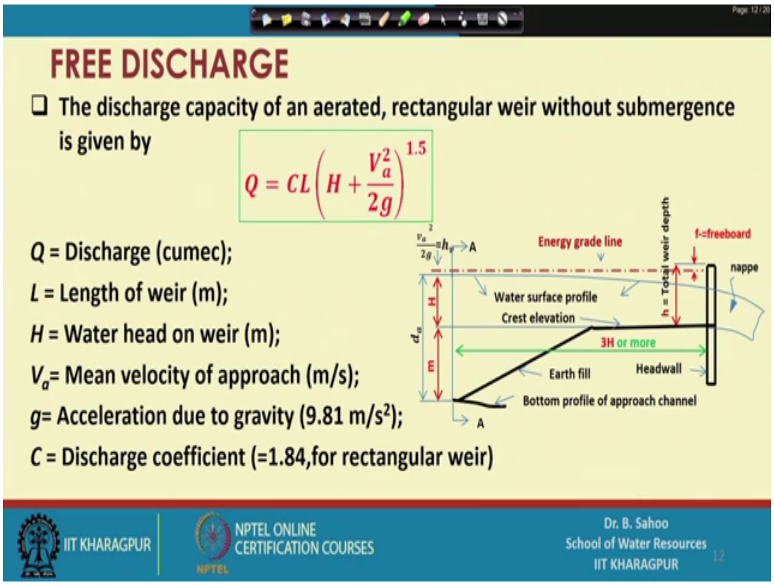

For free discharge the discharge capacity of an aerated rectangular weir without submergence can be given by this formula which is Q equal to C L H plus V a square divided 2 g whole to the power 3 by 2. The factor V a square by 2 g is the kinetic energy head which is nothing, but H v and capital H if you will see this figure capital H is the water height above the crest.

So, we can calculate Q equal to C L that is the weir formula general we use Q equal to C L H plus V a square divided 2 g whole to the power 3 by 2; your Q is the discharge in cumec, L is the length of weir, capital H is the water head on weir, V a is the mean velocity of approach, g is the acceleration due to gravity which is 9.81 meters per second square and C is the discharge coefficient which is usually 1.84 taken for rectangular weirs.

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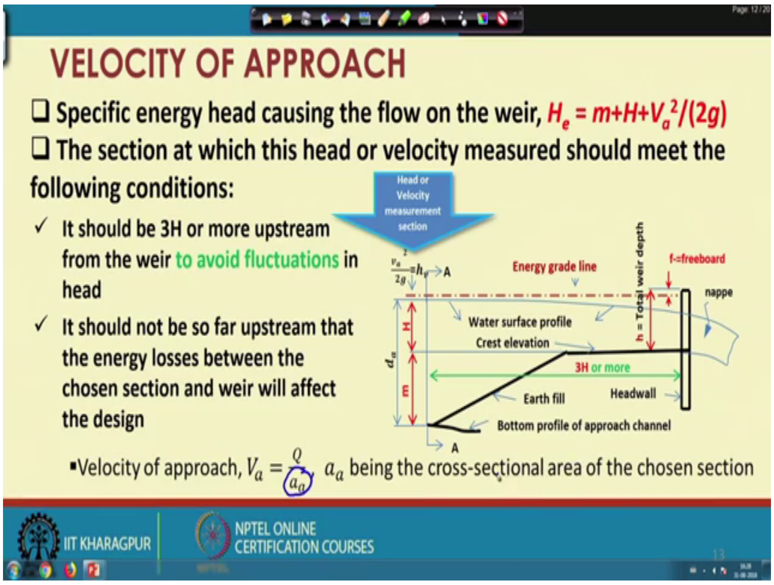

For estimating the velocity of approach the specific energy head causing the flow on the weir is given by you will see this figure H is equal to small m plus capital H plus H V that is V a square divided by 2 g. Here capital H is the depth of flow on the crest and small m is the elevation difference between the bottom profile of approach channel and that of the crest elevation. Usually m is remain remains at the level of the bottom profile of approach channel, but many times m also little bit is negative in that case the bottom profile of approach channel is just above the crest level, but it generally kept at the same level of the crest elevation.

So, in that case many times m is equal to 0 and all these heads like velocity and all these heads they are generally measured at distance 3 H 3 capital H you will see this figure the green line 3 H or more from this weir. This is two over the fluctuations in the heads; it should not be so, for upstream that the energy losses between the chosen section and weir will affect the design. And the velocity of approach can be computed as V a equal to discharge divided by the area of the approach channel. So, here A is the cross sectional area of the chosen sections chosen section means it is the cross section of the approach channel ok.

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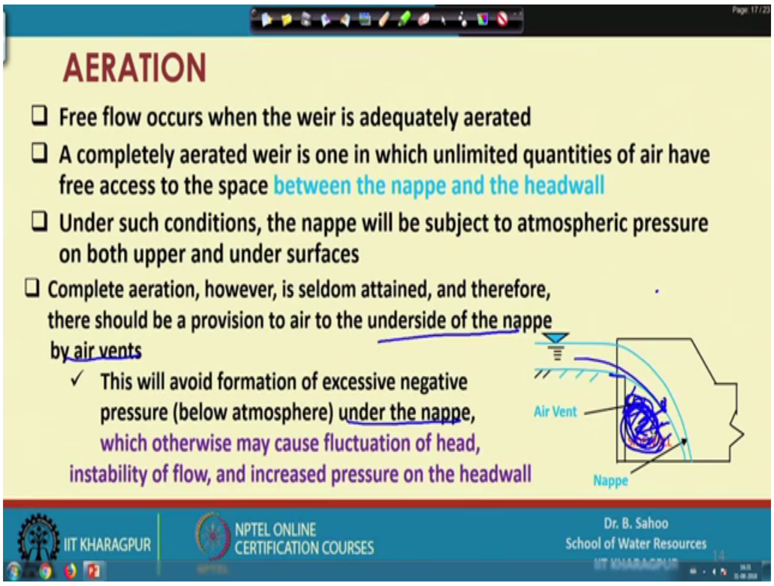

Now, we will talk about aeration. So, the free flow occurs when the weir is adequately aerated a completely aerated weir is one in which unlimited quantities of air have free access to the space between the nappe and the head wall. You can see this figure this is the nappe; we call it nappe. So, the discharge occurring from the crest and you will get this portion as some negative pressure is created in this portion.

So, if some negative pressure he created in this person what happens generally this nappe gets sawed towards this negative pressure so, to prevent that we generally provide some holes here or aerated holes. So, that this negative pressure is minimized and we get the atmospheric pressure in this region this will not obstruct the flowing of water.

So, for this the nappe will be subject to atmospheric pressure on both upper and under surfaces. For complete aeration however, is seldom attained and therefore, there should be a provision to air to the underside of the nappe by air vents. This will our formation of excessive negative pressure below atmosphere under the nappe; which otherwise may cause fluctuation of head instability of flow on increased pressure on the head wall. So, where to design provide designs. So, that are you have to choose appropriate holes for this which is generally provided at are the sidewalls. So, two holes are two side walls.

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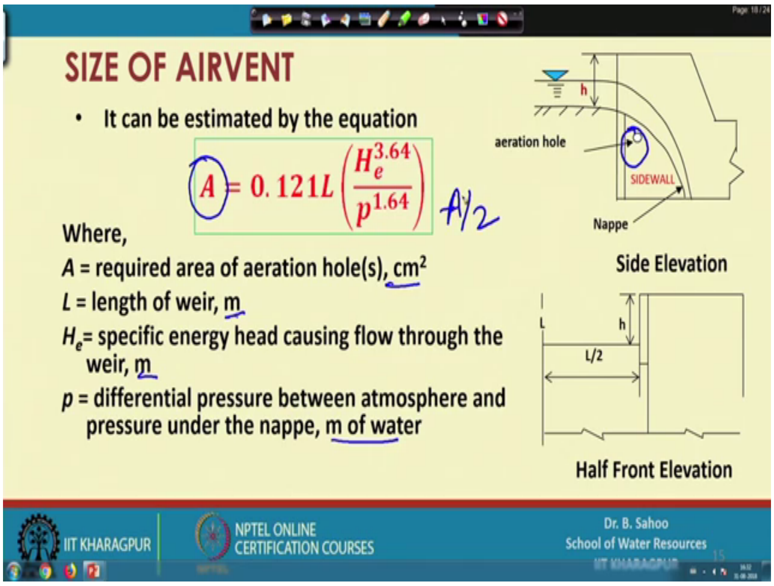

Now, how to design the size of air vent? So, this can be estimated by the equation a equal to 0.121 L into H e to the power 3.64 divided by p to the power 1.64 here a is the required area of aeration in centimeter square L is the length of weir meter H e the specific energy head causing flow through the weir in meter and small p the differential pressure between atmosphere and pressure under nappe in meter of water ok. So, if you will see this figure. So, this is the aeration hole and this has to be designed and this A whatever the area we are getting that is for the aeration hole of the air vents for two side walls. So that means, for each side wall you will get the value as a divided by two.

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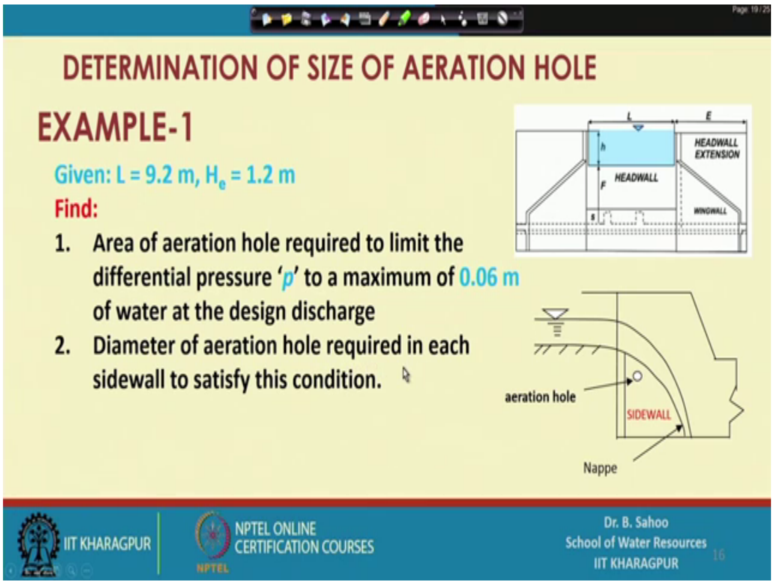

Now, coming to determination size of aeration hole; so, this is one problem example is given. So, in this case the value of L is given 9.2 H e equal to 1.2 meter. And you have to find the area of aeration of hole required to limit the differential pressure p we maximum of 0.6 meter so; that means, here small p equal to 0.6 meter then the diameter of aeration hole required in each side wall to satisfy the condition.

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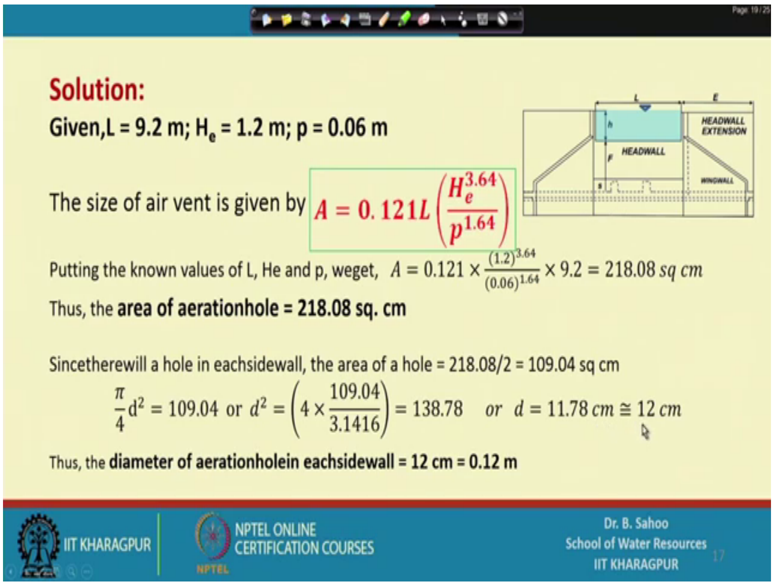

For this these are the given values L equal 9.2, H equal to 1.2, p equal to 0.06. So, the size of the vent air vent is given by A equal to 0.121 L into H e to the power 3.64 divided by p to the power 1.64.

Now, if will put the values of L 9.2 H e 1.2 and p 0.06 you will get A equal to 218.08 square centimeter. So, the area of the aeration hole or the air vents equal to 218.08 square centimeter. Since there are two holes in two side walls so, it will be divided by two as I was talking before. So, if you will divide by two then you will get 109.04 square centimeter and the that is equal to pi d square pi by 4 d square and this pi by 4 d square. Where d is the diameter of the hole and pi by 4 d square will be equal to 109.04. So, from this you will get d equal to 11.78 centimeter or approximately it is 12 or 0.12 meter.

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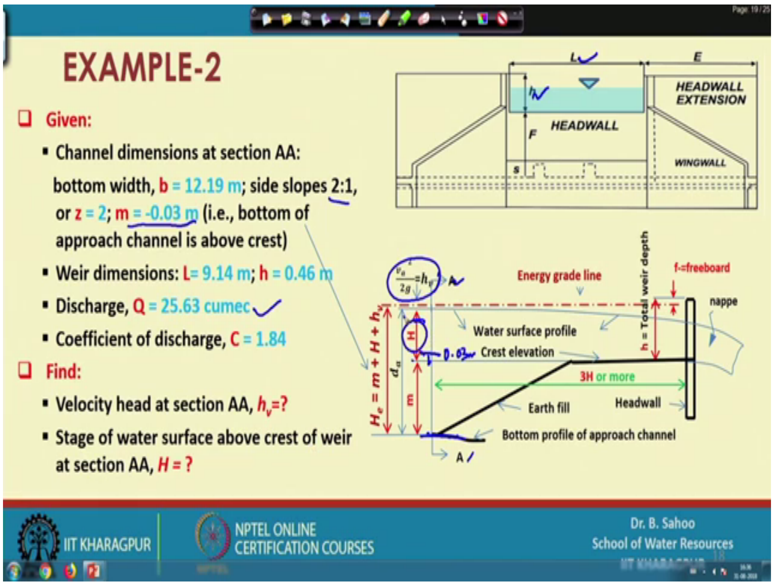

In the second example the given values are channel dimensions are section A bottom width b is given as 12.19 meter side slope that is 2 is to 1 that is your z is to 1. So, z equal to 2 and m equal to minus 0.3 meter that is the bottom it is the difference between the bottom of this profile and the crest level and you can see it is minus 0.3 means this level is actually elevated so that means, this distance the difference here is 0.03 meter and weir dimensions are like L the length of the weir. So, this 1equal to 9.14 meter small h this one that equal to 0.496 meter and the design discharge given 25.63 cumec and you know that for a return weir C equal to 1.8 you have to find the velocity head h v are this section A. So, what is the value of the velocity head and stage a water surface above crest of weir at section A that is capital H.

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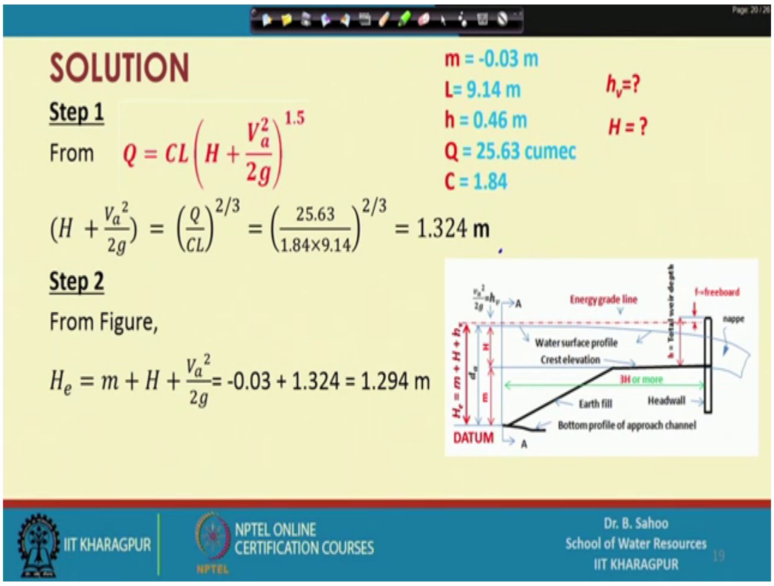

Now, for the solution you can use the weir formula that Q equal to CL H plus V a square divided by 2 g whole to the power 3 by 2 here the values are given m L H Q and C. So, by putting that you can get what is the value of capital H plus V a square divided by two g and that equal to Q divided by C L whole to the power 2 by 3. So, we will get 1.324. In step 2 from this figure you can get H e equal to m plus capital H plus V a square by 2 g and m is minus 0.03 on in the first step 1 you have already obtained capital H plus V a square by 2 g equal to 1.324. So, that will be equal to 1.294.

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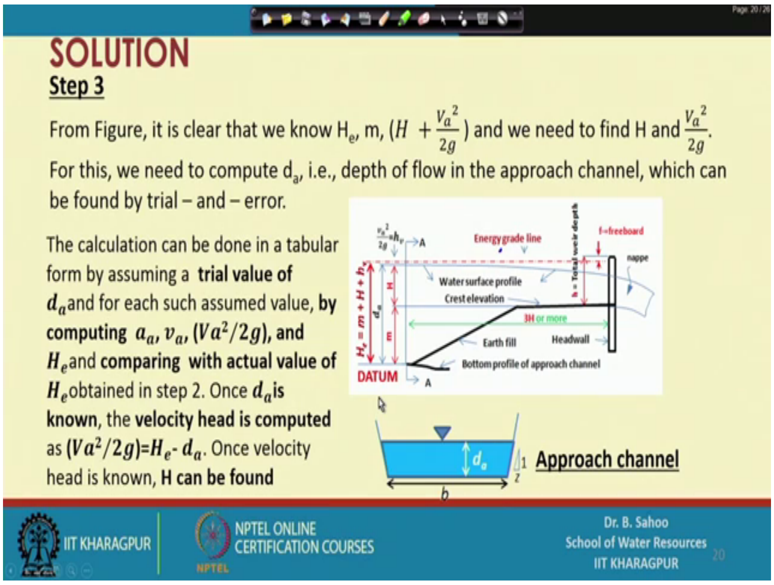

And in the step 3 from this figure we know that we know the value of h e in the previous slide we have already seen what is the value of h e m and capital H plus V a square 2 g and we need to find the value of capital H plus V a square by 2 g for this we need to compute the value of d a you can see this figure the value of d a equal to small m plus capital H. So, that is the depth of flow in the approach channel which can be found by trial and error method.

So, the calculation can be done in a tabular form by assuming a trial value of d a and for each such assumed value by computing the area of approach channel approach velocity V a V a square by 2 g and the specific energy head that is H e and comparing with actual value of H e obtained in step 2. Once d a is known the velocity head is computed as V a square by 2 g that equal to H e minus d a once velocity head is known so, H can be found out. You will see this figure the bottom figure the approach channel is a trapezoidal type of channel and the depth of water is here d a where d a equal to m plus capital H and small b is the bottom width and the side slope is z is to 1.

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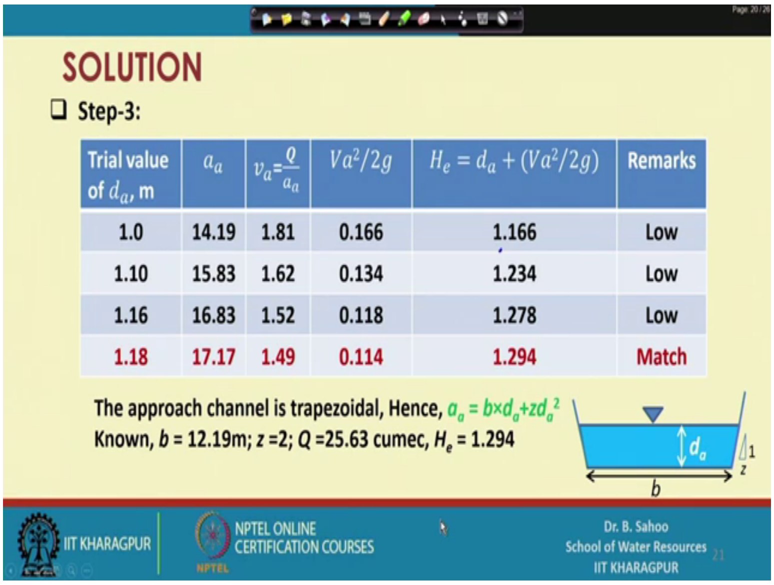

So, for the solution you can see this table for different trial values we have taken starting value d a equal to one then we are getting a a v a and finally, we will get what is the value of H e that is 1.166. So, by this many trials in this case we have obtained if you are putting d a equal to 1.18. So, we are getting the value of H e equal to 1.294 and that is matching with whatever the trial value have computed in the step 1. So, in this case d a equal to 1.18. So, you can get H equal to 1.294 here.

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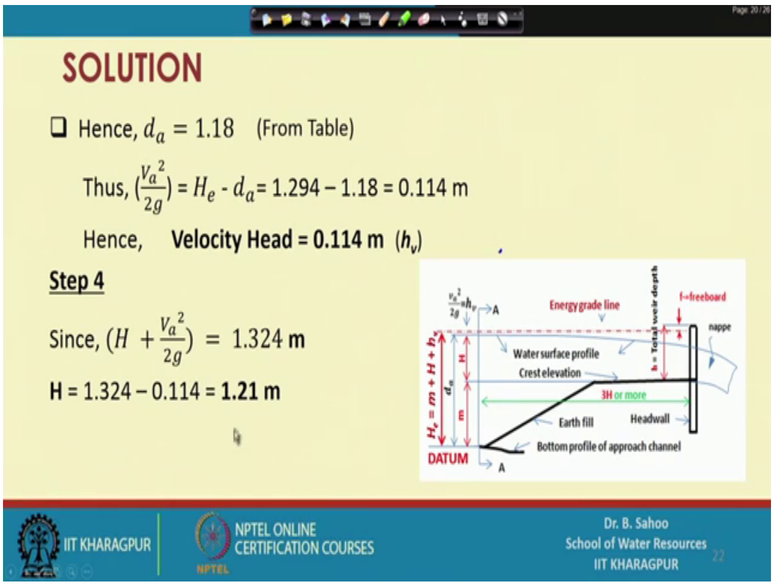

Hence d a equal 1.18 from this the table previous table and in this case you will get V a squared 2 is equal to H e minus d a. So, that equal to 1.294 minus 1.18 that equal to 0.114 meter. So, velocity head will be 0.114 meter and you can get the capital H value equal to 1.3 to 4 minus V a square by 2 g. So, that equal to 1.21 meter.

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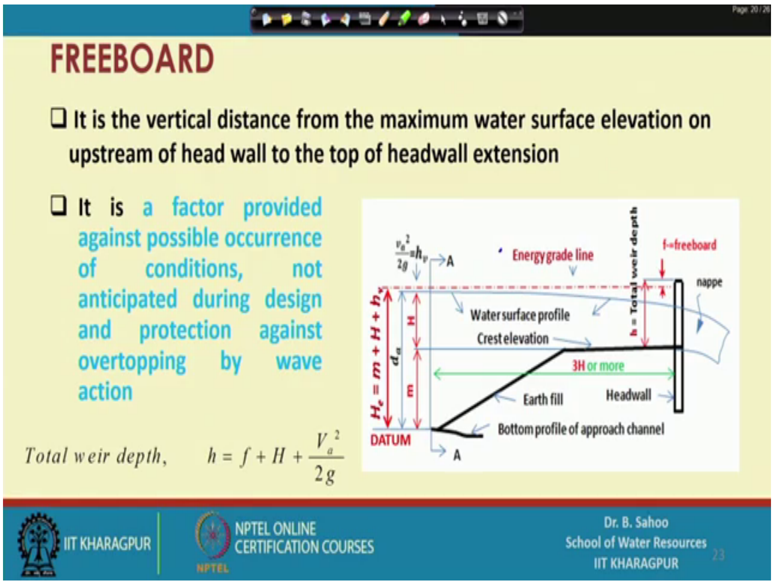

For free board it is the vertical distance from the maximum water surface elevation on upstream of head wall to the top of head wall extension it is a factor provided against possible occurrence of conditions not anticipated during design and protection against overtopping by wave action. The total weir depth is given by that equal to small h that equal to the free board plus capital H plus V a square by 2 g you can see this from the figure.

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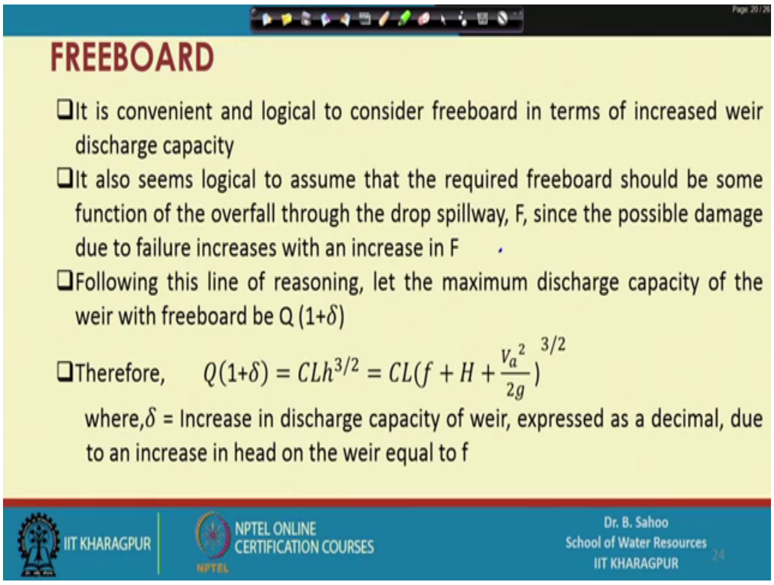

So, it is convenient and logical to consider free board in terms of increased weir discharge capacity it also seems logical to assume that the required free board should be some function of the overflow through the drop spillway that is the capital F it is in the possible damage due to failure increases with an increase in capital A value. Following this line of reasoning that the maximum district capacity of the weir with freeboard be Q into 1 plus delta

So, you will get Q into 1 plus delta that equal to C L to the 3 by 2. So, that equal to C L and you can replace the small h value as small f plus capital H plus V a square by 2 g and raise to the power 3 by 2. The delta is the increasing discharge capacity weir expressed as a decimal due to an increase in head on the weir equal to f.

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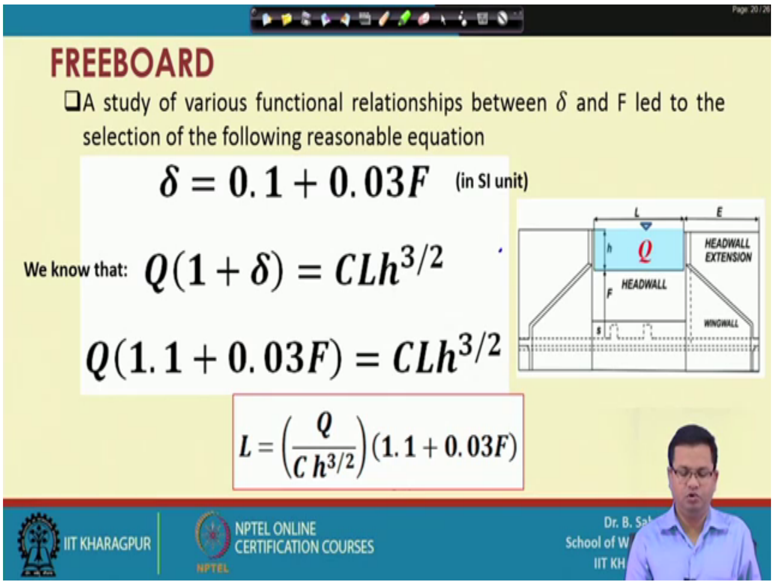

If you will for the freeboard calculation we use this relationship that equal to delta equal to 0.1 plus 0.03 capital F. Which is empirical relationship in SI unit and by solving you can get L equal to Q divided by C h to the power 3 by 2 into 1.1 plus 0.03 capital F.

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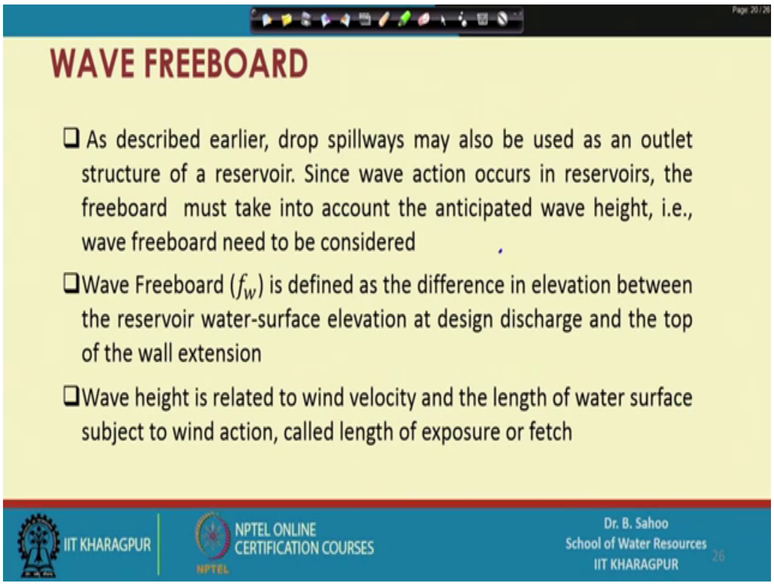

Next is the wave free board the wave free board is mostly provided in many cases. We use the drop spillway for reservoir also and in the reservoir will get the wave heights. So, for that our protection against these wave heights sometimes wave free boards are also provided.

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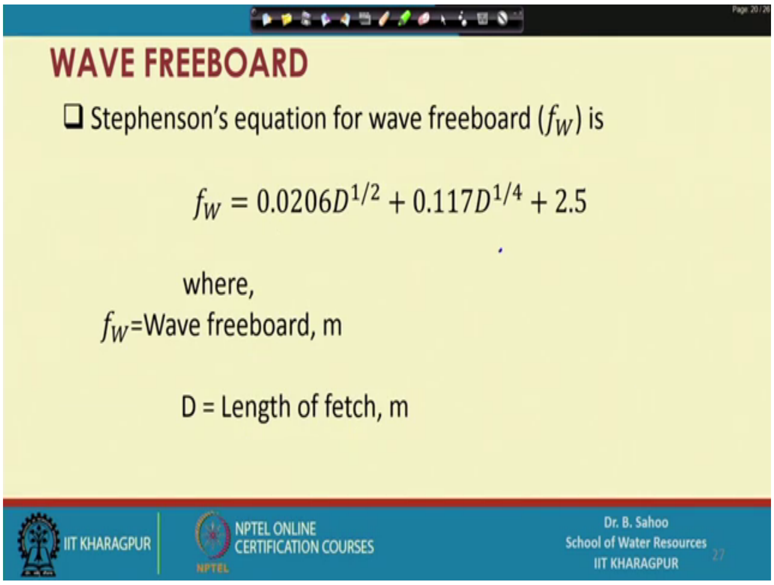

So, for this we generally use the Stephenson's equation which is given by f W equal to 0.0206 D to the power 1 D to the 0.05 plus 0.117 D to the power 0.25 plus 2.5 and here capital D is the length of fetch or the length of exposure from weir the wind is flowing and small f W is the wave freeboard in meter.

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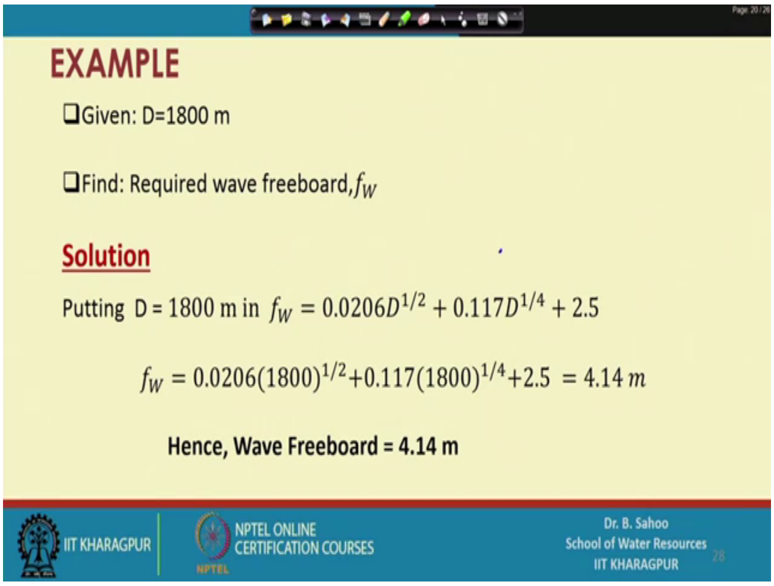

To solve one example so, D is given 1800 meter we have to find out what is the value of f W. So, by using the Stephenson formula we can put the value of directly D equal to 1800 and we will get the wave freeboard as 4.14 meter.

Thank you.