Soil and Water Conservation Engineering
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Lecture - 46
Ogee Spillway

Hello good morning, today we are going to start a new lecture on spillway design and design problems. Myself Doctor Poulomi Ganguli from agricultural and food engineering department at IIT Kharagpur is going to take this lecture.

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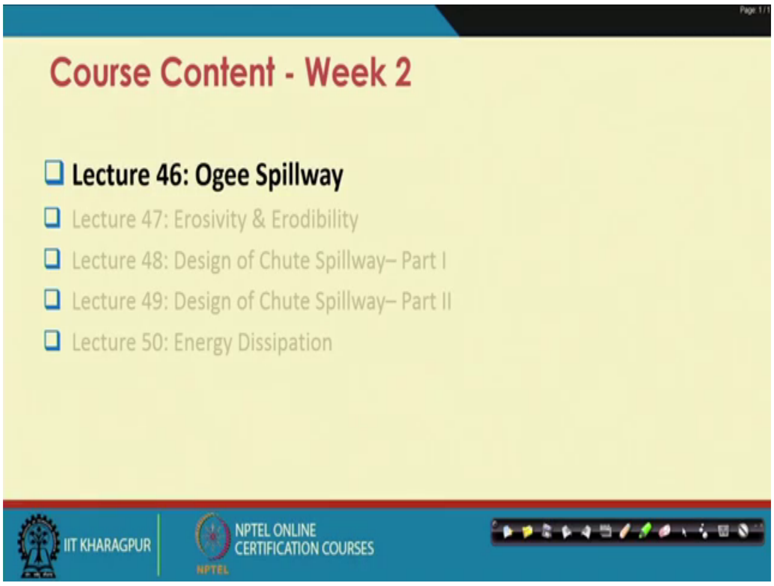

So, we have a couple of contents here Ogee spillway that is going to cover at lecture 46 it is design principle and a few problems.

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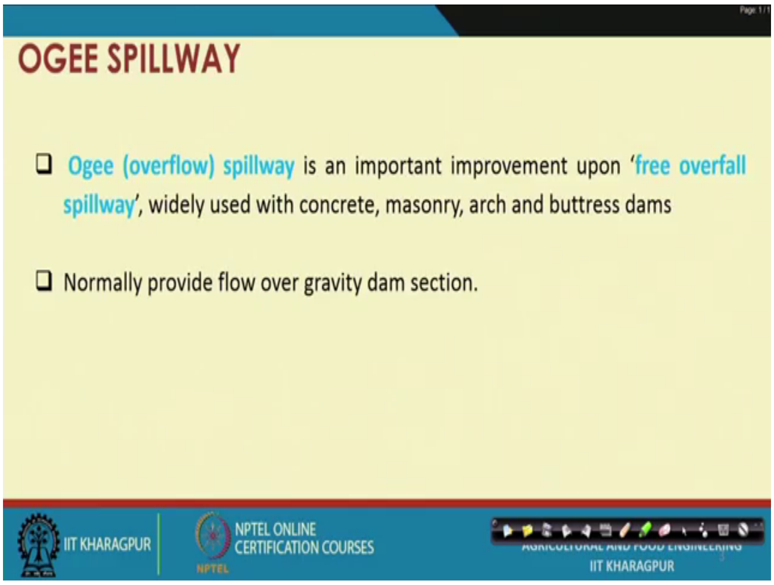

So, what is Ogee spillway? Ogee spillway is an important improvement upon free overfall spillway that is the free fall and widely used in concrete, masonry, arch and buttress dams. Normally, it provide flow over gravity dam section.

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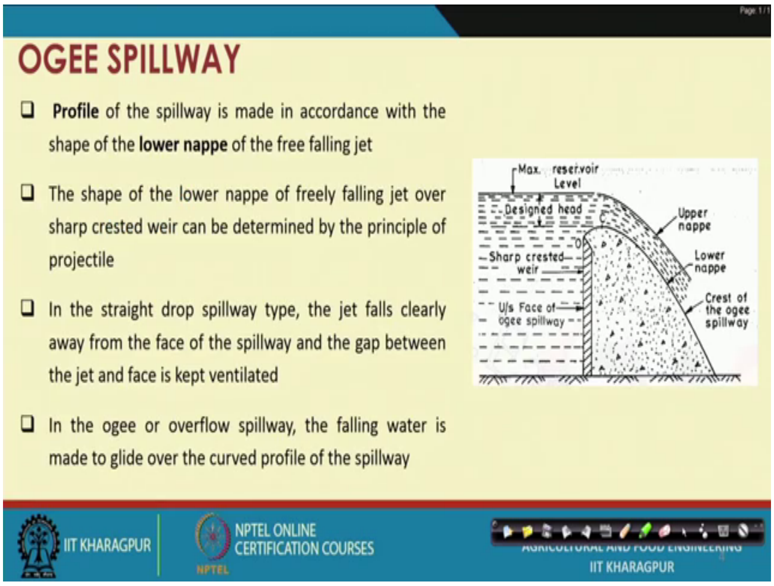

Now, coming to the next slide, now the profile of Ogee spillway is made in accordance with the shape of the lower nappe of free falling jet. So, this is the kind of structure in the Ogee spillway and here this is the upper nappe, the surface of the water profile and the lower nappe, which touches the spillway structure and this one is the crest of the spillway. The shape of the lower nappe of freely falling jet over the sharp crested weir can be determined by the principle of projectile.

In the straight drop spillway type, the jet falls clearly away from the face of the spillway and the gap between the jet and the face is kept ventilated. In the Ogee or overfall spill overflow spillway, the falling water is made to glide over this curved profile of the spillway. So, this is the kind of structures the Ogee spillway has and this part is the upstream face of the Ogee spillway. So, depending upon the structure this may be the vertical and it may have some angle. So, this is the kind of structure that we can play around.

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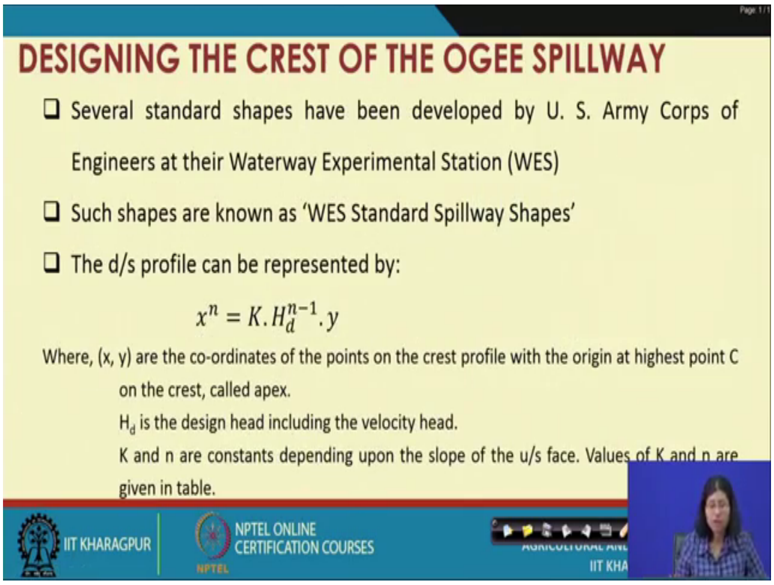

Now, designing the crest of the Ogee spillway. So, several standard shape have been developed by U. S. Army Corps of Engineer at a Waterway Experimental Station. So, this waterway experimental station this is abbreviated as WES taking the first word of each of this word. So, such shapes are known as WES standard spillway shape.

Now, the equation for downstream profile can be approximated by the simple empirical equation. So, x to the power n, where K is a constant, H d is the design head including the velocity head and y is the coordinate, x and y are the coordinates of the point on the crest profile with the origin at the highest point C. And K and n are constant depending upon the slope of the upstream face the values of K and n can be retrieved from a table.

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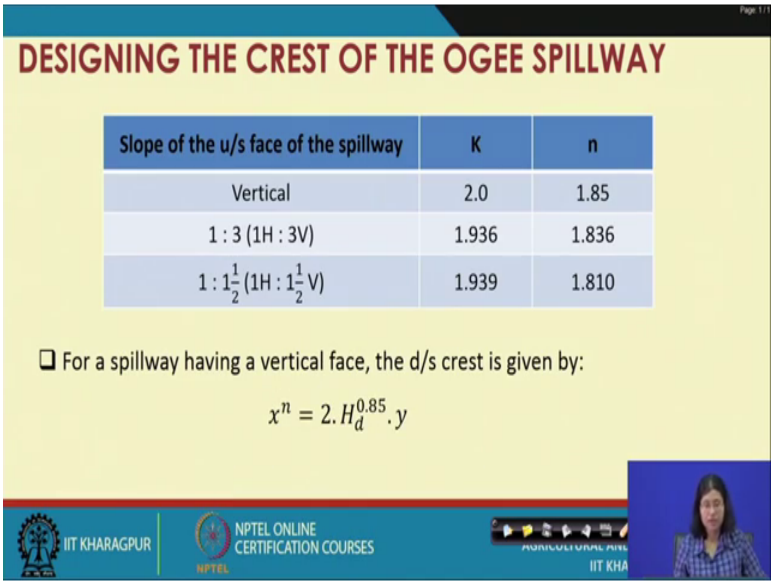

So, now as I was telling that a slope of the upstream face of the spillway can be varied and depending upon the shape and K and n values are also varied. So, for the vertical means it is 90 degree angle K is 2 and n is 1.85. For one is to 3 slope that is one horizontal and 3 vertical K value is 1.936 and n value is 1.836. For the slope 1 is to 1.5 that is one horizontal and one hand half vertical K value is 1.939 n is 1.810. So, depending upon the kind of problem generally these values are given beforehand.

For a spillway having vertical face the downstream crest is given by following empirical equation where x to the power n, n is the constant, 2 H d to the power 0.85 and multiplied by y, y is the total vertical height from the ground surface up to the spillway top.

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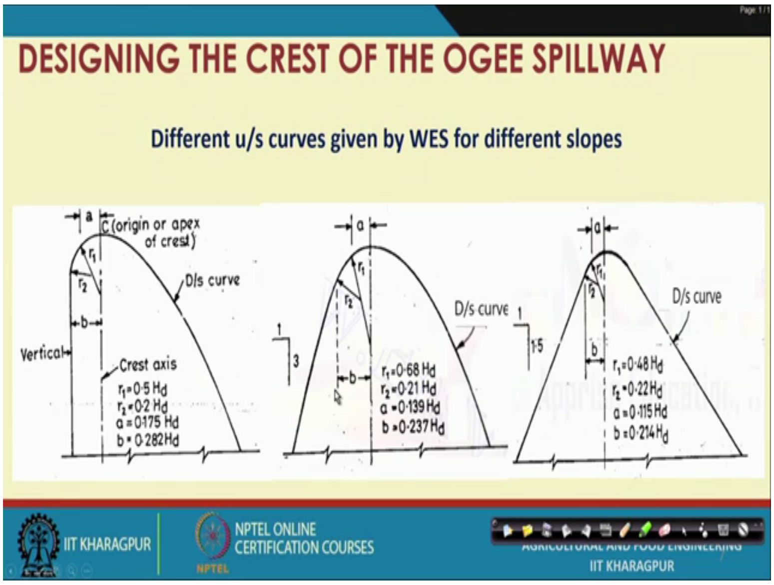

Now, as I was mentioning the different upstream shaped curve are given by WES for different slope. So, this is the example of vertical face where it is kept at a 90 degree angle and here r 1 the radius is 0.5 of H d, r 2 is 0.2 of H d, a is the this gap which is given by point 1.75 of H d and b the breadth is 0.282 of H d. So, these are the kind of dimension is given for the vertical face of the Ogee spillway.

Now, coming to 1 horizontal and 3 vertical so, the spillway shape looks like this and here again the dimensions are given as per the table. So, r 1 is 0.68 H d, r 2 is 0.21 H d, a is again this gap 0.139 H d and b 0.237 H d. And this is the downstream curve and this is the upstream curve in case of 1 is to 3 slope. And now coming to 1 is to 5, 1 is to 1.5 slope so, this is again a little bit steeper as compared to 1 is to 3 slope and here again the design values are given r 1 is 0.48 H d, r 2 0.22 H d, a is 0.115 H d, b is 0.214 H d. So, this is the different shape and corresponding dimension of the Ogee spillway crest profile.

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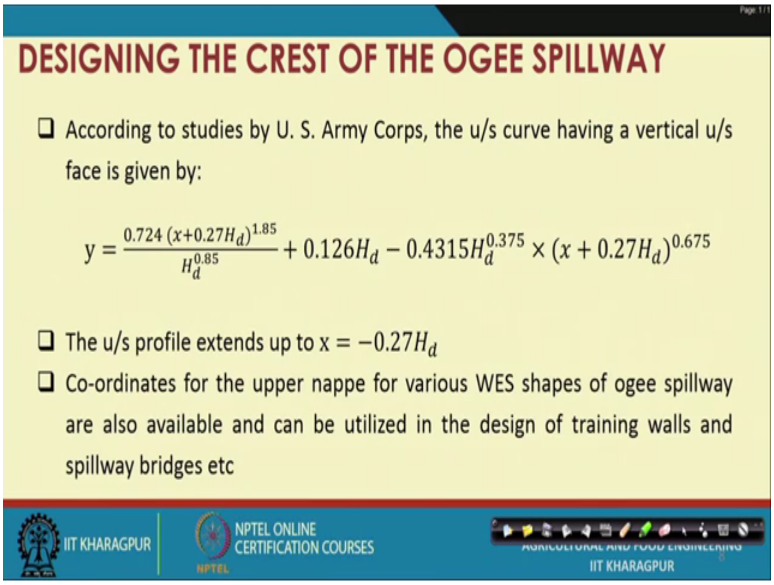

Now, coming to the next design step so, now, we will going to learn the vertical and horizontal coordinates and how to design the shape crest profile of the spillway. So, y is function of x, where it is and again an empirical formulation. So, y is 0.724 multiplied by x plus 0.27 H d, where H d is the design height over the spillway crest whole to the power 1.85 divided by H d. So, this is the kind of equation we are going to use for designing of y given we have x values.

So, the upstream shaped profile is extends up to the point where x equal to minus 0.27 H d, where the H d is the design height. So, co ordinates of the upper nappe for various WES shape of Ogee spillway are also available and can be utilized in design of training wall and spillway bridges etc. So, this table is given in the next slide so, that you can understand how this profile and co ordinates vary with respect to the space.

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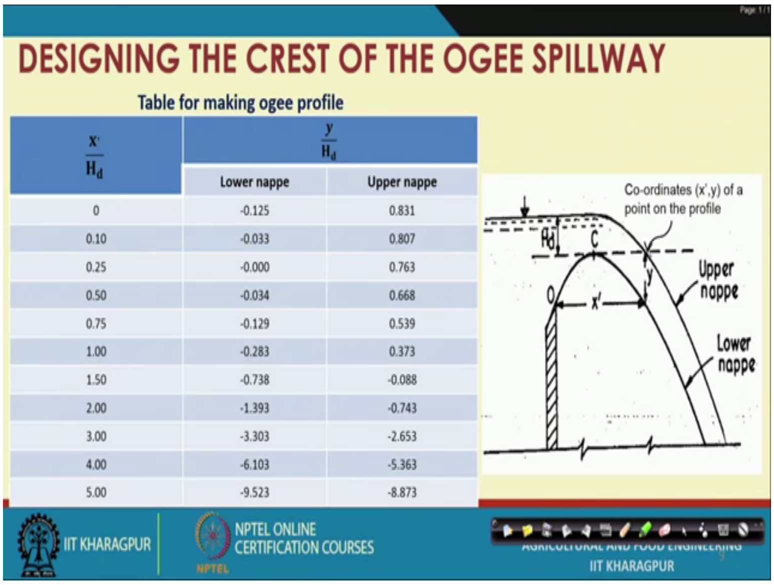

$\frac{x'}{H_d}$	$\frac{y}{H_d}$	
	Lower nappe	Upper nappe
0	-0.125	0.831
0.10	-0.033	0.807
0.25	-0.000	0.763
0.50	-0.034	0.668
0.75	-0.129	0.539
1.00	-0.283	0.373
1.50	-0.738	-0.088
2.00	-1.393	-0.743
3.00	-3.303	-2.653
4.00	-6.103	-5.363
5.00	-9.523	-8.873

So, this is the table for making Ogee profile so, as I mentioned. So, this is the H d, where H d is the design height just on the top of the spillway crest and to the surface of the upper surface of the profile and this is the point where the x y co ordinates are located. So, x is the horizontal, x bar is the horizontal distance and y bar is the vertical distance and this is the upper nappe and this is the lower nappe. So, based on this calculation we can design the free fall of the spillway crest and the corresponding upper and lower nappe.

So, this is the table for making Ogee profile. So, x bar by H d and we can get the corresponding values of y, the upper and the lower nappe co ordinate. So, if we put x equal to 0 the corresponding the lower nappe will be minus 0.125 and upper nappe is 0.832.

So, like this we again increase by after certain interval like the tabulated values are given for 0.10, then 0.25 and that continues up to 5 and we can get a corresponding values of the lower nappe as well as the upper nappe. So, this is the way we can get the profile of the spillway and corresponding lower and upper nappe.

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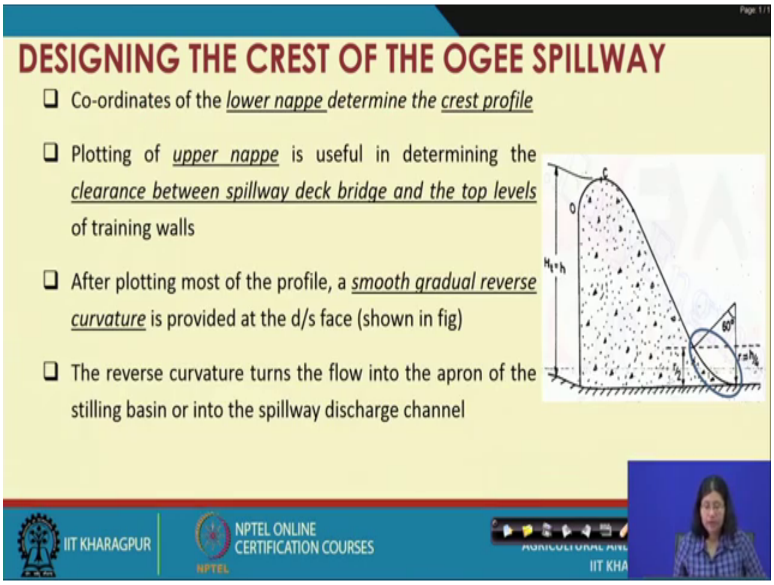

So, now coming to the designing of the crest of the Ogee spillway. So, co ordinates of the lower nappe is determined by the crest profile. So, here is the sample for the Ogee spillway where we can see the co ordinates of the upper and the lower nappe and plotting of upper nappe is useful in determining the clearance between spillway deck bridge and the top level of the training wall. And after plotting most of the profile a smooth gradual reverse curvature is provided at the downstream face. As you can see this part is highlighted in a circle.

The reverse curvature turns the flow into the apron of the stilling basin. So, here the apron is located or on to the spillway discharge channel. So, this is shown in the figure and height we mention keep it as R equal to h by 4 generally and there is some angle on which this design is calculated. So, here the angle theta is kept at 60 degree, but depending on the problem it again varies.

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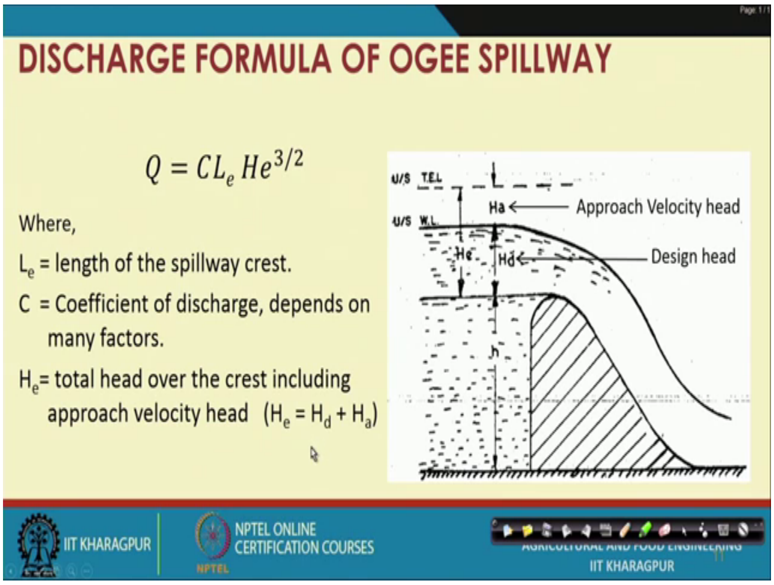

Now, the discharge formula so, this is the sample spillway where H as I explained earlier is the height between the ground and height of the upper profile of the spillway. H d is the design head, H a is the velocity of approach or it can be explained as approach velocity head and H e is the summation of H a and H d, that is sum of velocity of approach as well as the design head. Here it is the total the tail water and is the water level of the upstream surface of the spillway.

So, the design discharge is explained in C equal CL e He to the power 3 by 2 where 3 by 2 is the exponent here. So, L e is the length of the spillway crest C coefficient of discharge that again depends on many factors and we are going to explain the step by step how this coefficient of discharge varies. H e is the total head over the crest including the velocity of approach. So, H e as I explained earlier is a sum of H d and H a where H d is design head and H a is the approach velocity.

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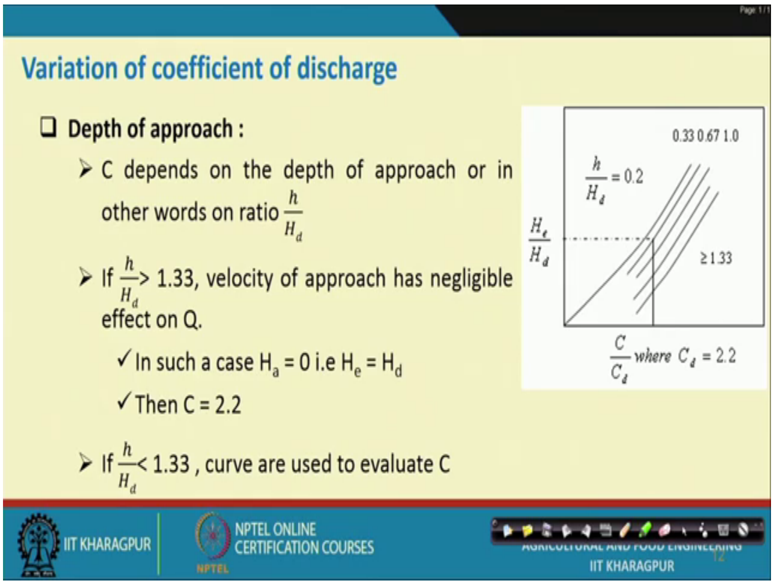

Now, the variation of coefficient of discharge so, the how the coefficient of discharge varies depending upon the problem in hand. So, C depends on the depth of approach or in other words the ratio between h by H d so, this is the h and H d. So, the C varies between the ratio of h by H d here. So, if h by H d is greater than 1.33 velocity of approach has negligible effect on the discharge in such a case H a is 0 and since H e is a summation of H d plus H a, if we put H a as 0. So, H e will become equal to H d and in that case C will become 2.2. So, as you can see this design chart where C is shown as 2.2 in case of h by H d ratio is 1 point greater than 1.33.

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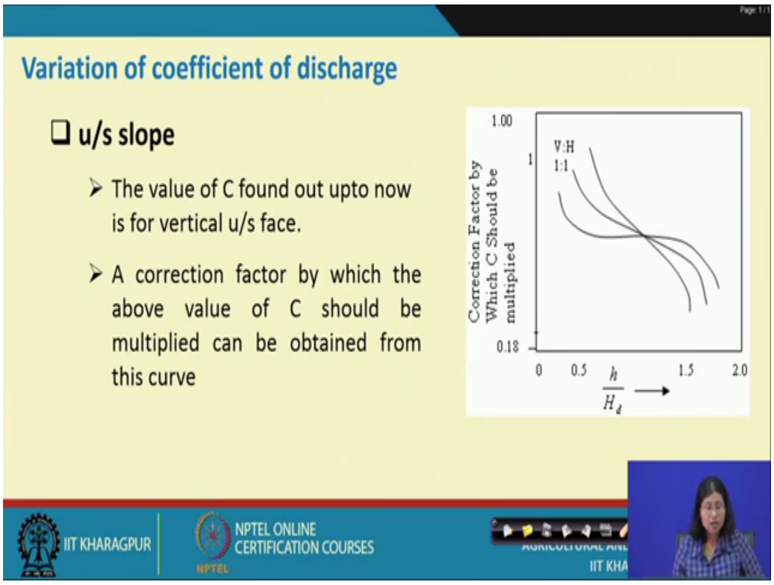

However, if h by H d ratio is less than 1.33 a curve like the shown in the figure is used to evaluate the value of C. Now, the upstream slope the value of C found out up to now is for only the vertical upstream face, but in case of the upstream V by h ratio is more somewhat different the correction factor by which above value of C should be multiplied if it is the V by h ratio is something different from 1 is to 1. So, a curve is drawn here so, in the centre this is V by h ratio is 1 is to 1 and here if the slope are different to that.

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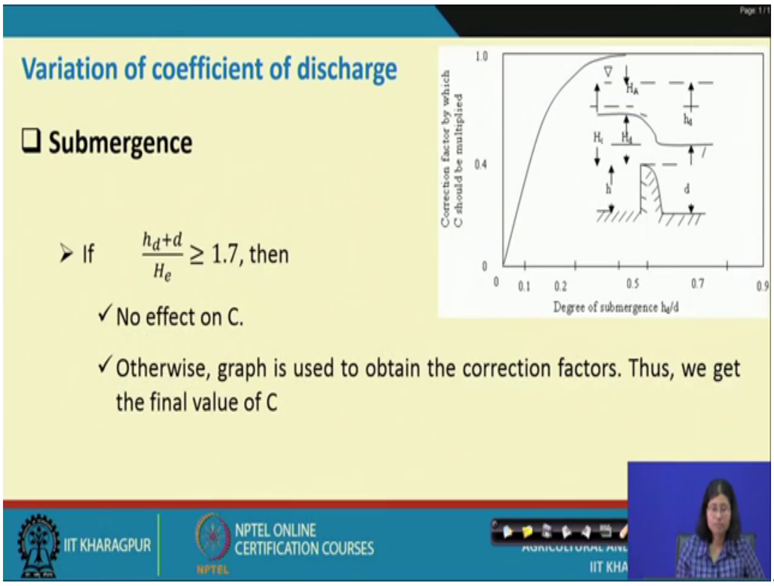

Now, coming to the submergence problem, if this is a case is showing where the submergence problem can arise. So, here h d where d is the depth of submergence and h d plus d again h d is the design head here and d is the depth of this profile and divided by H e is the total again the sum of H a and H d is greater than 1.7. Then what happens? There is no effect on C or the coefficient of discharge, otherwise a graph is used to obtain a correction factor thus we can get a final value of C.

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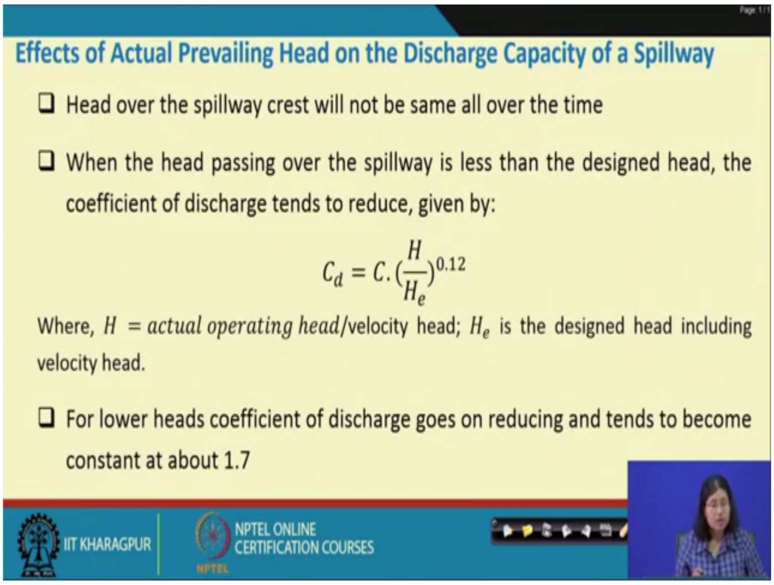

Effect of actual prevailing head on the discharge capacity of spillway. So, head over the spillway crest will not be same at all the time. So, when the head passing over the spillway is less than the neglect design head the coefficient of discharge tends to reduce and in that case it is given by C d equal to C the ratio between H by H e whole to the power 0.12. Where H is actual operating head or the velocity head and H e is the design head including the velocity head.

So, for lower head coefficient of discharge goes on reducing and it tends to become constant at about 1.7.

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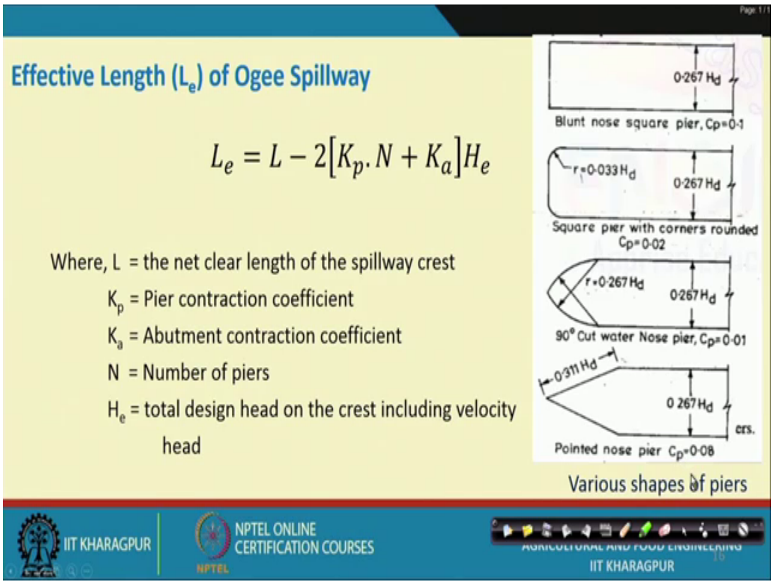

Now, coming to the design of the length of the Ogee spillway. So, here you can see the various shape of the piers are located. So, L e so, L e is the length of the spillway is a function of L that is that net clear length of the spillway crest and some empirical constant. So, L e is equal to L minus 2 K p n, where n is the number of piers used for the design and which is multiplied by H e that is total design head on the crest including the velocity head. As you remember the H e is again the sum of H a plus that is velocity of approach plus H d the design head.

So, the corresponding different shape of the pier is shown here. So, it can be in many form like pointed nose pier, again the 90 degree cut water nose pier, square pier with corners round and blunt nose square. So, these are some commonly used piers are used in practice and depending upon the design we use the coefficient of discharge as well as the C p constant varies.

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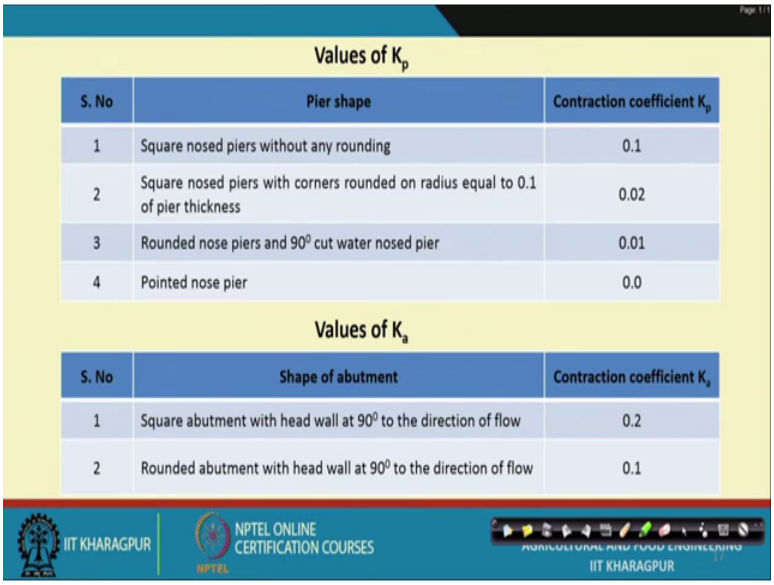

Values of K_p

S. No	Pier shape	Contraction coefficient K_p
1	Square nosed piers without any rounding	0.1
2	Square nosed piers with corners rounded on radius equal to 0.1 of pier thickness	0.02
3	Rounded nose piers and 90^0 cut water nosed pier	0.01
4	Pointed nose pier	0.0

Values of K_a

S. No	Shape of abutment	Contraction coefficient K_a
1	Square abutment with head wall at 90^0 to the direction of flow	0.2
2	Rounded abutment with head wall at 90^0 to the direction of flow	0.1

Now, coming to different values of K p so, for the square nose pier without any rounding as you can see here this is the square nose power pier, but the corners rounded, but here the square nose pier with without any rounding the coefficient of contraction is taken as 0.1. Again the square nose pier with corner rounded on radius equal to 0.1 of pier thickness it is 0.02.

So, like that for different values of different kind of shape the pier shape as well as the shape of abutment the coefficient of contraction the value K p as well as the coefficient of contraction coefficient K a varies and a table value is given depending upon the problem at hand.

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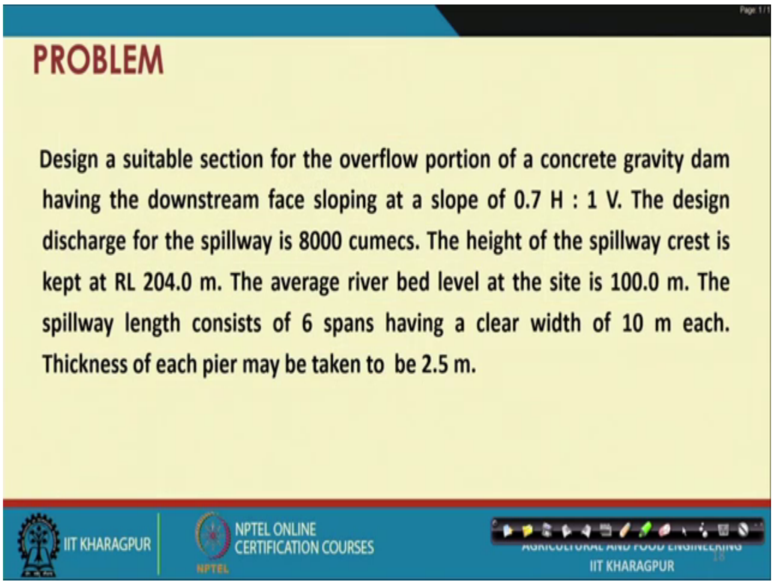

Now, these are some of the simple design principle which we explained earlier and now based on that once we have the problem it will be more clear how to design a Ogee spillway.

So, now, coming to the design problem design a suitable section of for the overflow portion of a concrete gravity dam having the downstream face sloping at a slope of 0.7 horizontal and one vertical. The design discharge for the spillway is kept around 8000 cumecs, the height of the spillway crest is kept as little relative level of 204 metre and average river bed level at the site is 100 metre. The spillway length consists of 6 spans having a clear width of 10 metre each.

So, this information will need it for designing the capacity and the thickness of the pier may be taken to be 2.5 metre. So, these are some of the basic information we are given.

So, how to design the spillway in this case?

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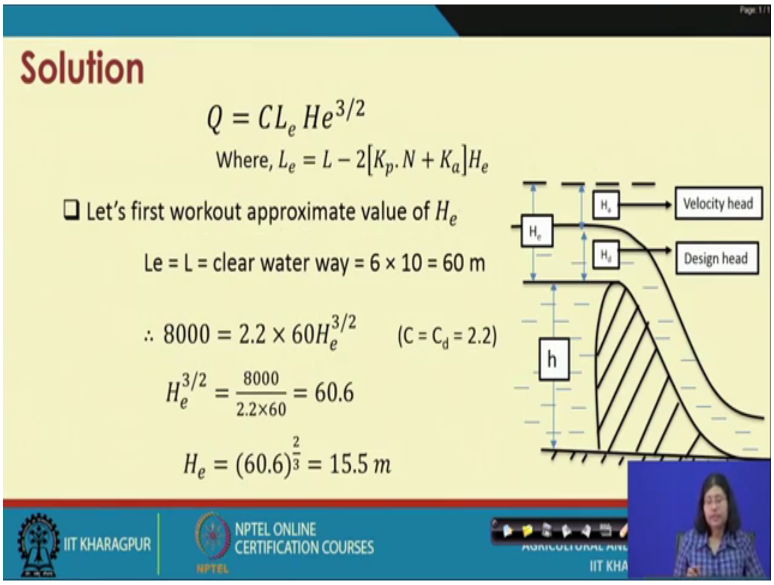

So, first we will study the discharge capacity of the spillway and the length and then one by one we are going to approach this problem. So, first as we mentioned earlier so, H is the height here and H e is the total height which is combination of velocity of approach as well as design head. So, these things we already have in mind. So, the discharge acquired to the constant of the times the L e the length e and H to the power 3 by 2.

So, let us first out and work out an approximate value of H e here. So, the L e is the length of the clear water way which was as I explained earlier which is a 6 pier. So, 6 multiplied by 10 which is the 10 metre was the width of this spans.

So, total length is around 60 metre. So, now, plug-in into this figures here. So, the discharge is 8000 and see first it is an approximation. So, first we take C as 2.2 and H e is the 60 metre, L is the 60 metre here and H e and thee to exponent 3 by 2.

So, like this we calculate the value of H e which is the total head is coming around sorry total head is coming around 15.5 metre. Now, coming to the next step.

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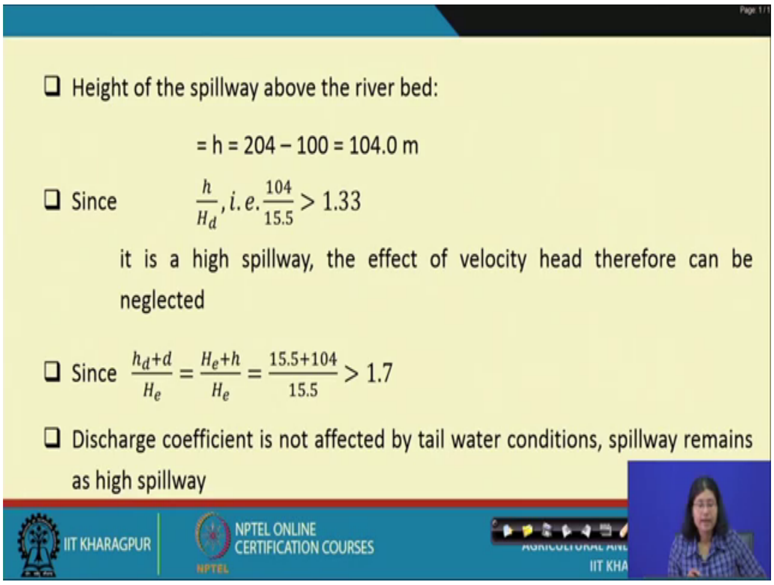

Height of the spillway above the river bed. So, here h is 204 which is this figure here. The height of the spillway crest is kept RL as 204 metre and average river bed level at the site is 100 metre. So, the total height of the spillway crest is h 204 subtracted by 100 is total now 104 metre.

Now, since h by H d that is the ratio between 104 and the design head is more than 1.33, we can directly assume that it is a high spillway and therefore, the effect of velocity head is negligible. Since, H d plus d upon H e is also we calculate and we found that it is again more than 1.7. So, here you can conclude that discharge coefficient is not affected by tail water condition and spillway remains act as a high spillway.

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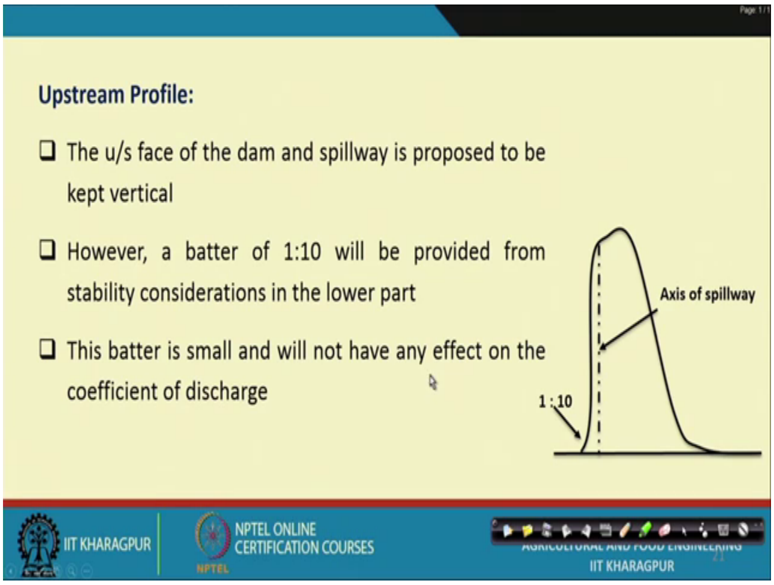

Now, we designed upstream profile, the upstream face of the dam and spillway is proposed to be kept vertical here; however, a batter of 1 is to 10 will be provided from stability point of view in the lower part which is shown here. So, this batter is small will not have any effect on the coefficient of discharge. So, this is the axis of this spillway which is supposed to kept vertical; however, a batter clearance of 1 is to 10 is provided for stability point of view which is shown here.

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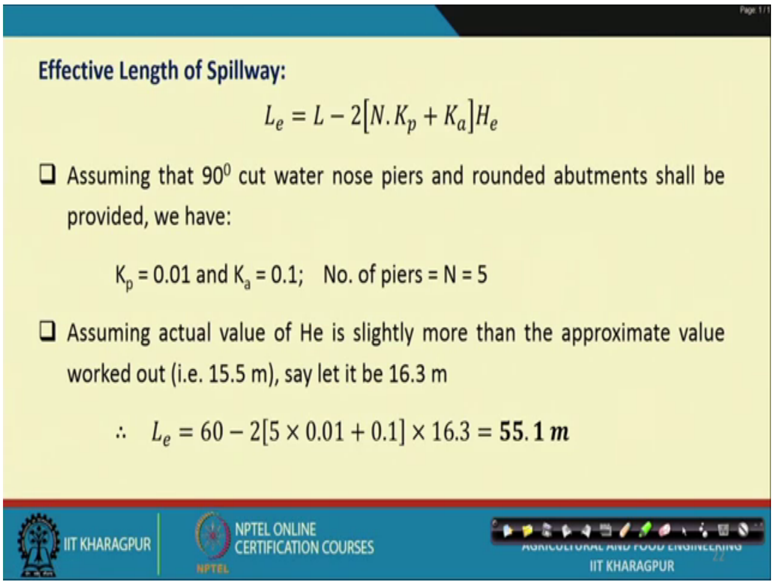

Now, coming to the design of effective length of the spillway where length is given by this formula assuming that 90 degree cut water a nose piers and rounded abutment shall be provided. So, in this case we have from the table the K p value is 0.01 and K a is 0.1. Hence, as the problem given the number of pier was 5. So, n equal to 5 here so, assuming the actual value of H e is slightly more than the approximate value which is worked out here let it say 16.3 metre.

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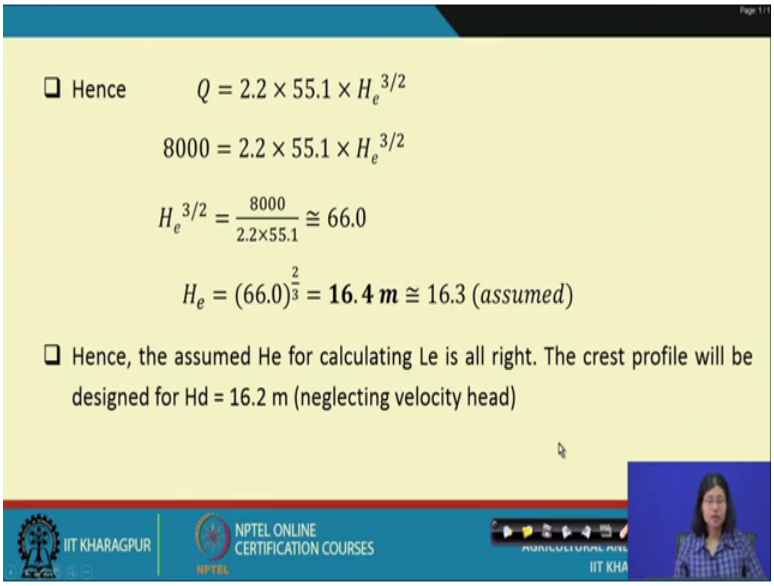

So, H e the coming to the L e after plugging all these values here which is the length is coming to be 55.1 metre. Now, plugging to the old equation the discharge coming here the H e is 16.4 metre where again the coefficient of discharge was taken as 2.2 and L we calculated the 55.1. So, if we plug these values here we get a H e value as 16.3 metre. Hence, the assumed H e for calculating L e is and the crest profile will be designed for H d that is height 16.2 metre and neglecting the velocity head.

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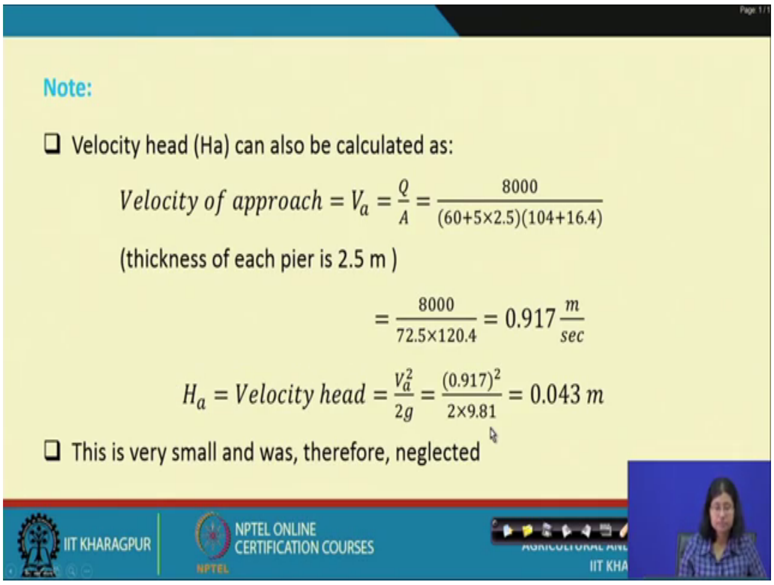

Now, coming to alternate way of calculating the velocity of approach. So, the velocity of approach can be calculated in any of this 2 formula other than the one we calculated. So, velocity of approach is can be the ratio of the discharge divided by the area. So, since this is the area calculation and the discharge we already given as the 8000 cumecs and thickness of each pier is 2.5 metre and we have the 5 piers and this is taken here. And the velocity of head is V square by 2g. So, this is this way also it can be calculated. So, this is very small therefore, it neglected.

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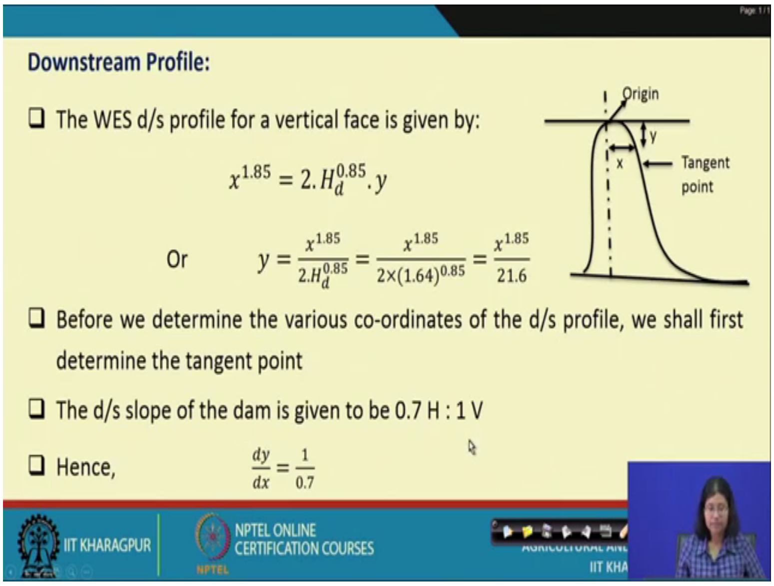

Now, coming to the downstream profile, the downstream profile is given by following formula. So, before we determine various coordinates of downstream profile we first determine the tangent point. The downstream slope of the curve is given as 0.7 horizontal and 1 vertical so, dy by dx is 1 upon 0.7.

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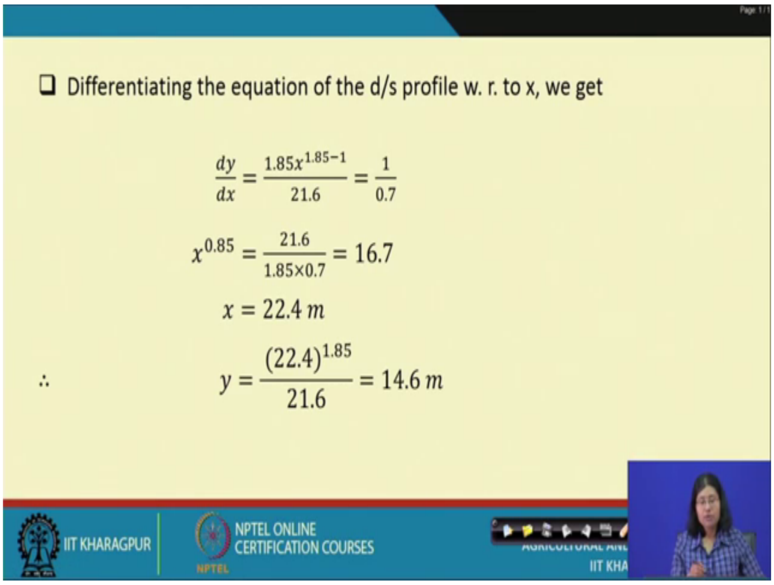

So, now, we need to differentiate and after differentiating this equation we can get the x value as 22.4 metre and y value as 14.6 metre.

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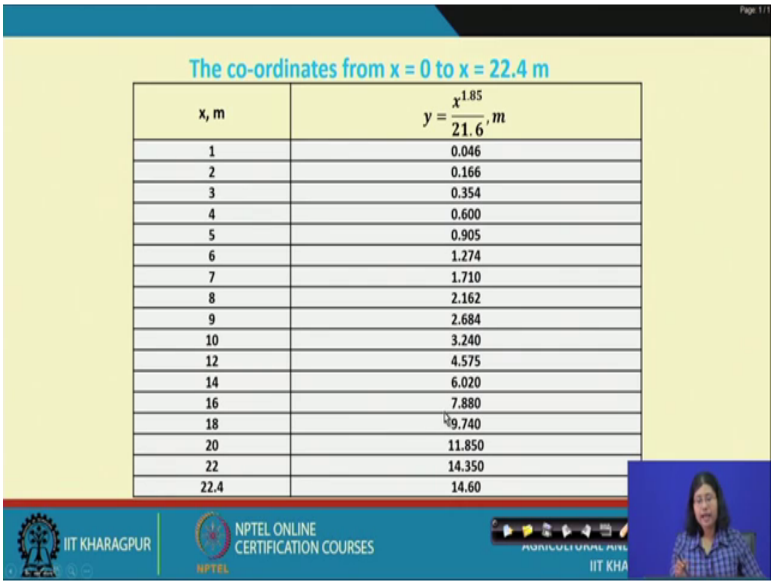

Now, we have this co ordinate and after plugging this value, we can get a profile shape or the curve.

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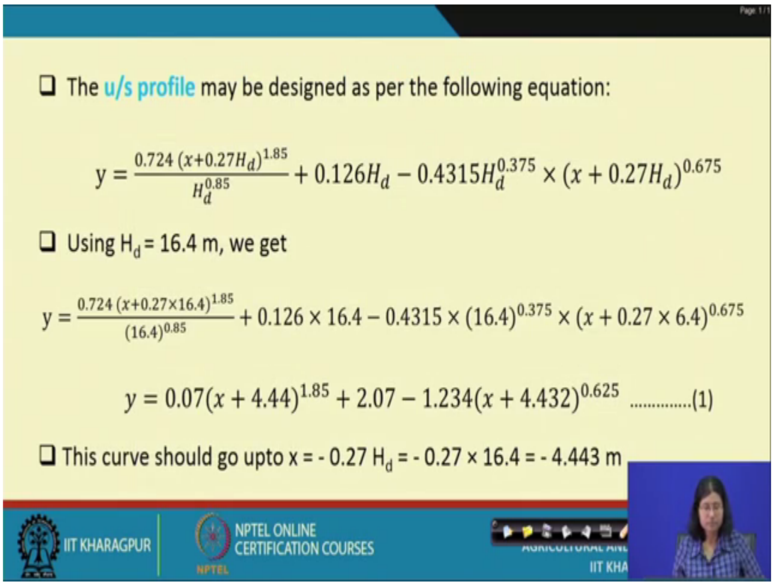

Now, the upstream profile maybe designed using this equation and using H d equal to 16.4 metre we can get a profile shape here and this curve should go up to x equal to minus 0.27 H d which is shown here.

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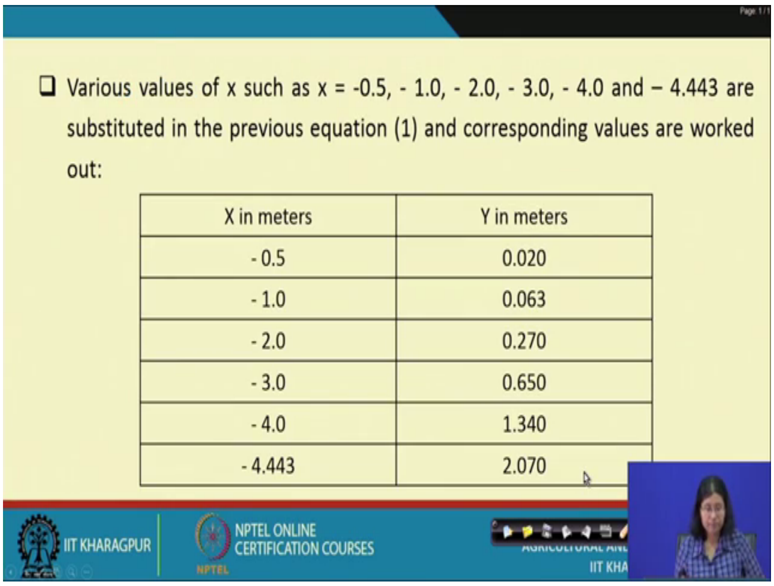

Now, after plugging this value 1 upon another we can get the clear x values and corresponding to y value of profile shape we can obtain.

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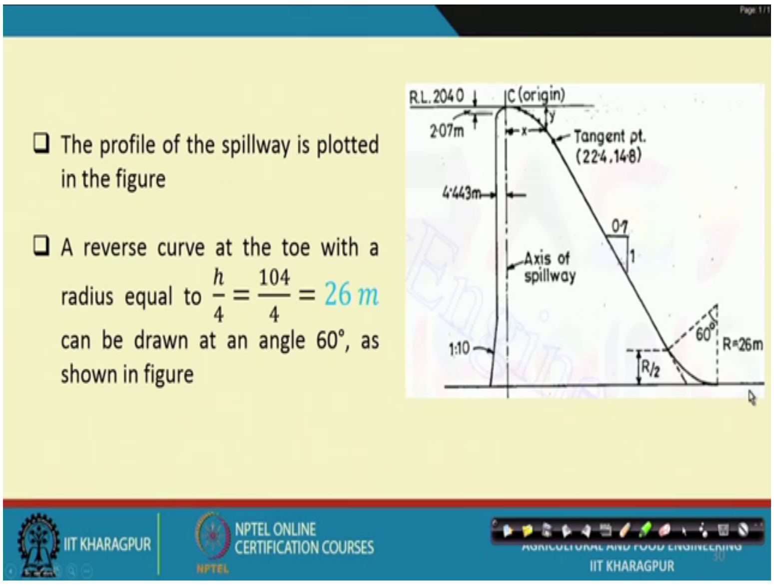

Now, this profile of the spillway is plotted in the figure and a reverse curve at the toe as a is mentioned here h by 4. So, 26 metre can be drawn at an angle of 60 degree as shown in the figure.

So, so in this way the profile shape is located, this is a tangent point axis of the spillway and this is the height that 1 is to 10 batter clearance is provided here at an angle and here R equal to 26 metre profile at the end. So, this way you design a Ogee spillway and it is lecture is ended here.

Thank you.