**Soil and Water Conservation Engineering**
**Dr. Bhabagrahi Sahoo**
**Department of Agricultural and Food Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 35**
**Structural Design of Drop Spillways – 2**

So, welcome students, so, this is our 5th class on the Design of Drop Spillway, we have already designed the drop spillway and we have in the last class we have already discussed about how to estimate the horizontal pressures.

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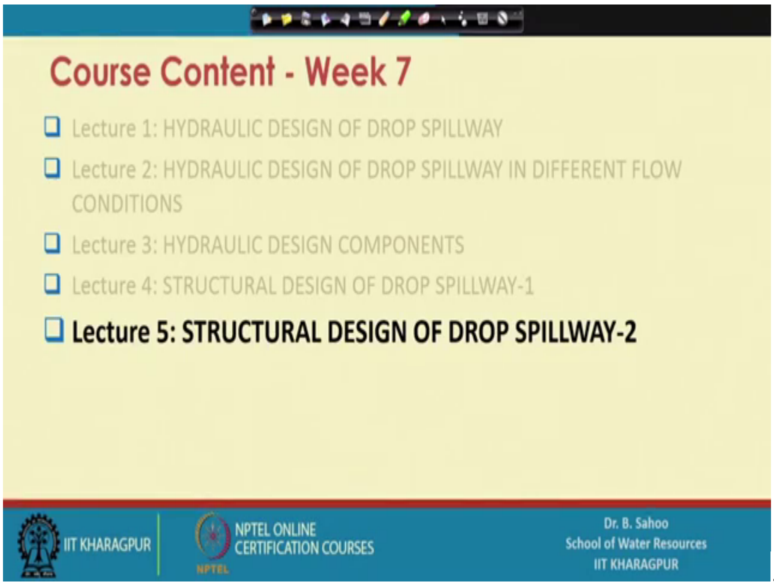


Here we will be discussing the structural design of drop spillway part - 2.

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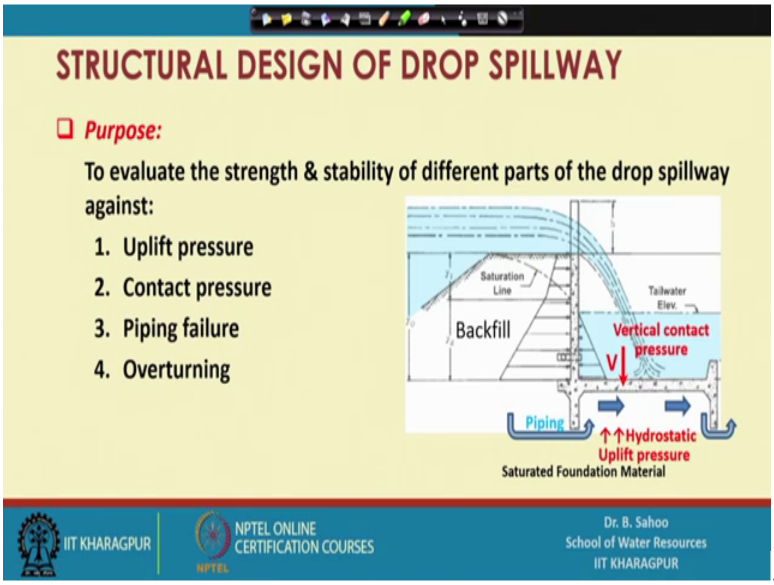


This lecture highlights the evolution of strength and stability of different parts of drop spillway against uplift pressure, contact pressure, piping failure, and overturning.

What is the uplift pressure? The uplift pressure happens because if the foundation metal gets saturated. So, pour water pressure develops and this hydrostatic pressure arcs upward. So, if this hydrostatic pressure arcs upward then it creates one negative pressure in the stability.

Second is contact pressure, the contact pressure is nothing, but it is the vertical pressure which is acting at the contact surface between the structure as well as the saturated foundation. So, you can see the contact pressure is given by the notation V, which is acting at the base of this foundation and depending on the location of this V that is vertical contact pressure the overturning of the structure will happen. If it acts at exactly or the centroid of this base section then there is more stability otherwise there will be overturning

Then the piping failure mostly occurs at the base of the foundation which is contacting between the structure and the saturated foundation material, you can see here the piping failure takes place along the contact surface between the structure and the saturated foundation material. So, all the details we will be discussing in this class.

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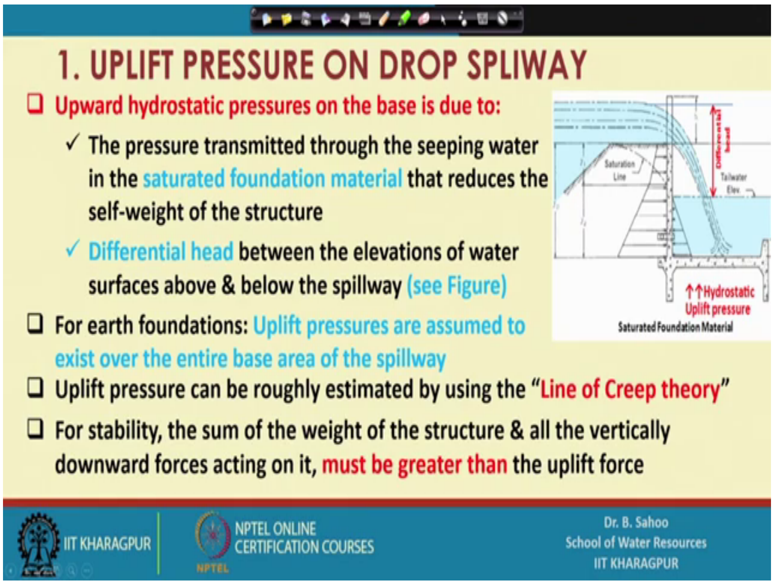


The upward hydrostatic pressure on the base is due to the pressure transmitted through the seeping water in the saturated foundation material that reduces the self weight of the structure. And this is mostly caused because of the differential head you can see this figure at the option site there is depth of water and at the downstream side rates tail water and the difference between these two water surface elevations is the differential head. And this differential head gives additional energy head and that is exerted on the saturated foundation material. So, because of that the pore water pressure the soil pore water pressure develops.

For earth foundations this uplift pressures are assumed to be existing over the entire base area of the spillway. Uplift pressure can be roughly estimated by using the line of Creep theory. The line of Creep theory talks about how the water moves are the contact surface between the structure and the foundation metal, you can see the line of creep goes like this as I am marking here on this figure.

So, along this line generally the water seeps and the piping phylogeny occurs. So, by using this line of Creep theory along this contact surface we estimate the uplift pressure. These uplift pressures are generally computed based on what are the water surface elevations at different contact surfaces along this line the creep line.

But stability the sum of the weight of the structure and all the vertically downward forces acting on it must be greater than the uplift pressure. If the uplift pressure is more naturally the structure will float. So, generally the uplift pressure is a negative pressure, which has to be deducted from the vertical pressure during all these force calculations.

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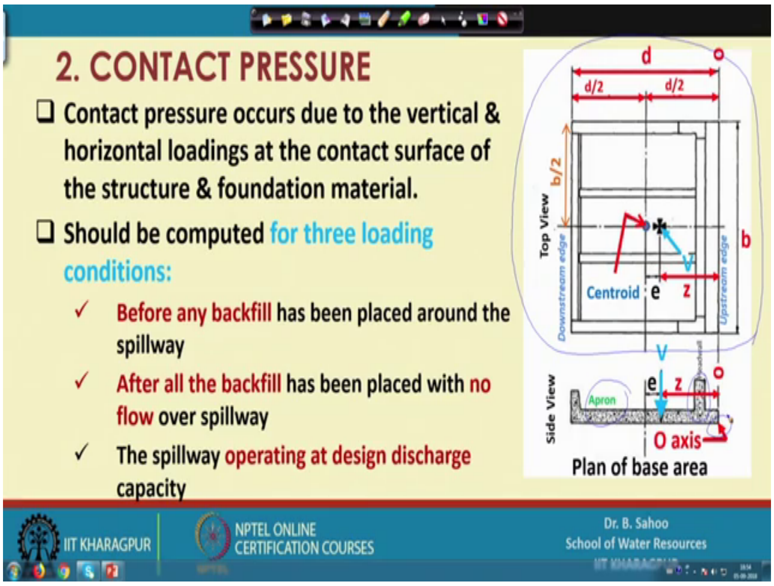


Now, coming to contact pressure, the contact pressure occurs due to the vertical and horizontal loadings or the contact surface of the structure and foundation material. You can see this figure; this is a very important figure to understand this figure shows the plan of base area. You can see this figure, this is the head wall and this is my upon section and the whole figure on the top shows the plan of the base area. And here I am choosing the axis the o axis just at the bottom corner of this upstream part of this.

So, this is my upstream edge and my axis is o o you can it is assumed that the whole structure is almost rectangular it has a width of d and length of b so; the centroid passes through d by 2 and b by 2. So, this is my centroid which is just exactly at the center of this rectangle and my vertical forces are acting at this location which is at a distance e from the centroid. So, this is my e distance and z is the distance between this upstream edge and the point of the line parallel line joining the point where V is acting.

So, at this section V is acting that is the contact force that the summation of all these vertical forces minus the uplift pressure force. So, is called as eccentricity here, if these are acting exactly at the centroid of this base they naturally the structurally more stable , but it is acting at a distance of e from the centroid which is called eccentricity naturally there will be momentum will be occurring. So, that it call as like your bending moment you have study might are studied so, that is lust like a bending moments and generally that will cause overturning of the structure. So, this e can be either this positive side to the centroid axis or it will be towards negative side that we in this side of this centroid.

So, before going to calculate the contact pressures you have to understand this figure and these contact pressures should be computed for 3 loading conditions. Before any backfill has been around the spillway, after all the backfill has been placed with no flow over spillway and the spillway operating at design discharge capacity. So, these are the 3 engineering condition generally we consider for calculating the contact phases.

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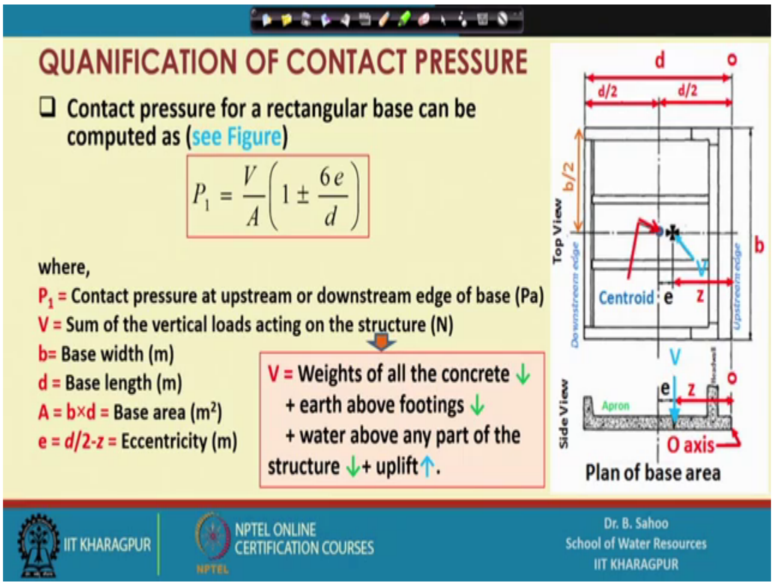


For calculating the contact pressure for a rectangular base we can use the equation P 1 equal to V by A into 1 plus minus 6 e divided by d. Here e is the eccentricity, d is the width of this base and V is the sum of all the vertical loads acting on the structure, which are equal to weights of all the concretes, earth above footings, water above any part of the structure and these are acting downward minus the uplift pressure.

So, here the uplift pressure is working acting upward so, it will be minus. Then you can calculate what is the resultant vertical load on this? And if it is acting at this central location then it be more stable if it is acting at a distance e from the centroid that is eccentricity naturally there will be turning our momentum will be there. Here A is equal to the base area that equal to computed as b into d, if e is equal to 0 in this equation naturally P 1 it will be equal to V by A that equal to force data area that is equal to your pressure.

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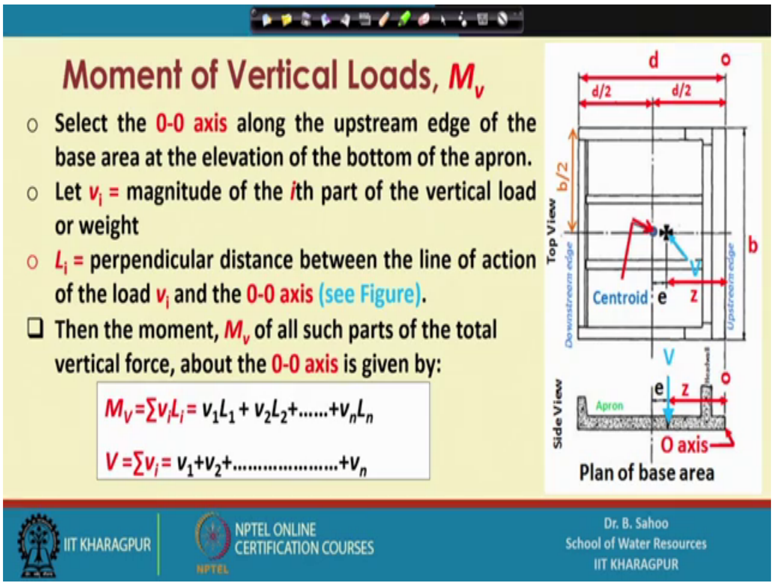


Now, we have to compute the moment of vertical loads M V, for this as to select the oO-O axis are seen this figure, from this O-O axis along the upstream edge of the base area the elevation of the bottom of the apron let this O. Let V i be the magnitude of the ith part of the vertical load or weight, because there are different vertical loads, these vertical loads can be because of the head wall it can be because of the apron it can be because of the backfill materials. So, these are different vertical load components, so, these are called as V i and they are acting at a location perpendicular distance between the line of action of the load V i and the axis o that is equal to L i.

Then the moment, M V of all such parts of the total vertical force about the O - O axis can be given by this equation you know that momentum equal to our moment equal to force into the length. So, M V equal to sigma V i L i that equal to V 1 L 1 plus V 2 L 2 plus V n L n, where V i are the different part loads, different part vertical loads and total resultant vertical load would be equal to summation of all these vertical forces acting on the base of the structure.

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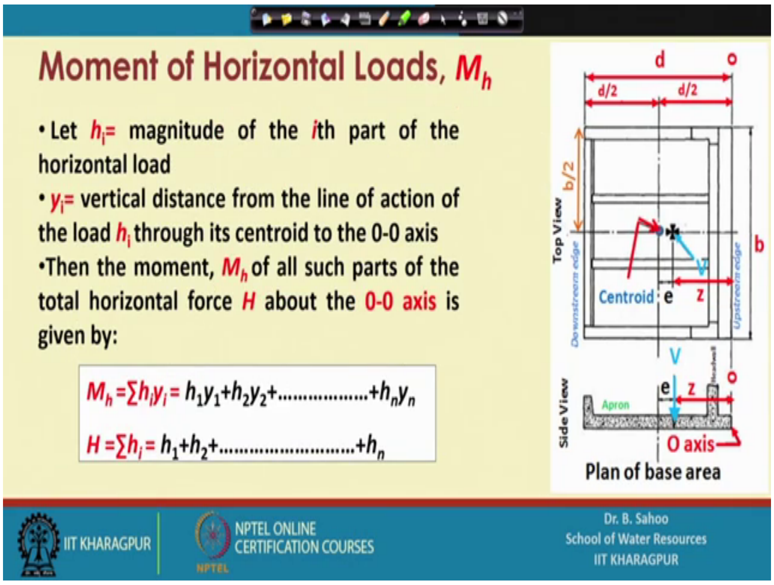


Then there could be the horizontal loads, the horizontal loads could be because of there is static water table or the upstream side and let these vertical loads be defined as different parts. Let h i equal to magnitude of the ith part of the horizontal load, y i is the vertical distance from the line of action of the load h i through it is centroid to the O axis, then the moment M h of all such parts of the total horizontal force is can be estimated similar as we have done for the vertical loads. So, your M h will be equal to sigma h i y ith and H will be equal to summation of h i that is the total horizontal loads.

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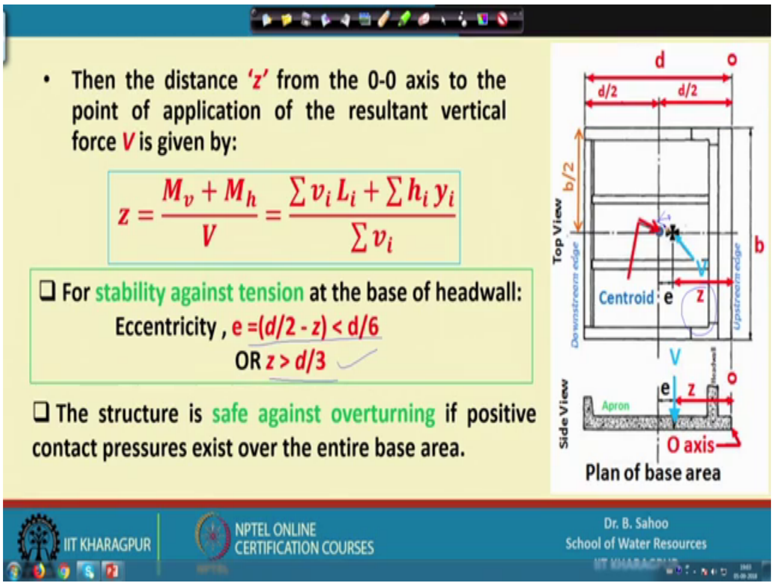

Then the total moment due to vertical loads and horizontal loads can be estimated by this equation which is M v plus M h that equal to total moment divided by V will be give you the value of z, because V is the resultant load , resultant vertical load. So, the total moment will be countered by V times z so, z is the distance from this O-O axis to the points to the line passing through this point where this V is acting.

So, you can estimate what is the distance z, by computing this z you can check for the stability again against tension. So, for stability against tension are the base of head wall we can estimate what is the eccentricity , from this figure you can see that d by 2 equal to e plus z. So, e will be equal to d by 2 minus z and for stability against strength so, near to design such that e should be less than d by 6 it will solve this equation then you will get z equal to d by 3 I will sorry z is greater than d by 3.

So; that means, for stability against tension z should be greater than d by 3, the structure is safe against overturning a positive contact pressure exists over the entire base area. So, depending on this position of eccentricity you can estimate whether the structure will overturn or not. So, to our the overturning you have to design such a that z is greater than d by 2.

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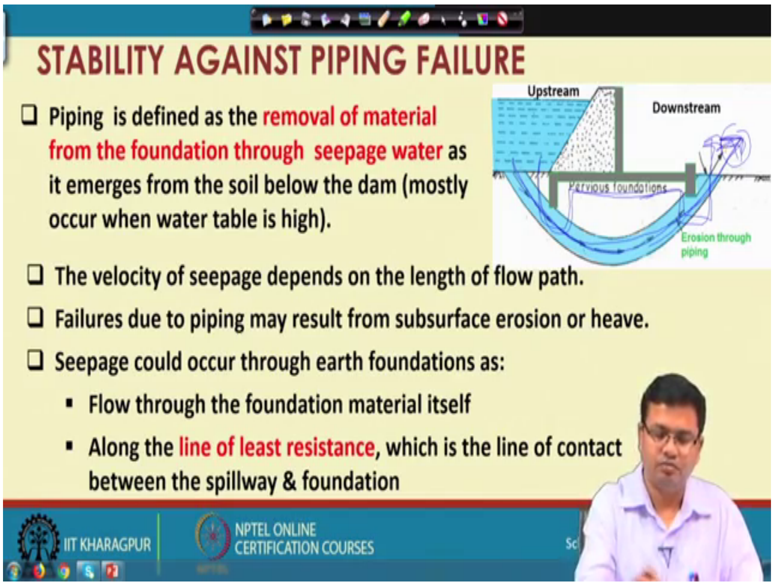


Now, next is stability against the piping failure, you can see from this figure that piping defined as the removal of material from the foundation through seepage water as it emerges from the soil below the dam, on this mostly occur when the water table is high, if the upstream water table is high it creates additional water facer.

And because of this generally the what we as foundation is gets saturated and when it gets saturated the upstream pressure the water pressure which is causing the flow of our which is causing generally the saturation of this foundation. So, it will create additional pressure so, that this water will move along with the soil particles and it will make a pipe like structure and if the there is more loss of the soil materials along this pipe line then the structure will fail.

The velocity of seepage depends on the length of flow path; failures due to piping may result from subsurface erosion or heave. So, because of these the subsurface erosion causes; that means, the soil particles along this line they emerges out at the downstream section and sometimes this creates quicksand condition you might have studied already that what is quicksand condition.

The seepage could have occur through earth foundation such as flow through the foundation material itself, it can directly flow through these foundation material as shown in this figure or along the line of least resistance which is the line of contact between the spill and foundation. That means, these seepage may occur also along this contact surface as I am showing in this diagram; that means, it will pass through this line and this is called as the line of creep as we have studied in the previous slides.

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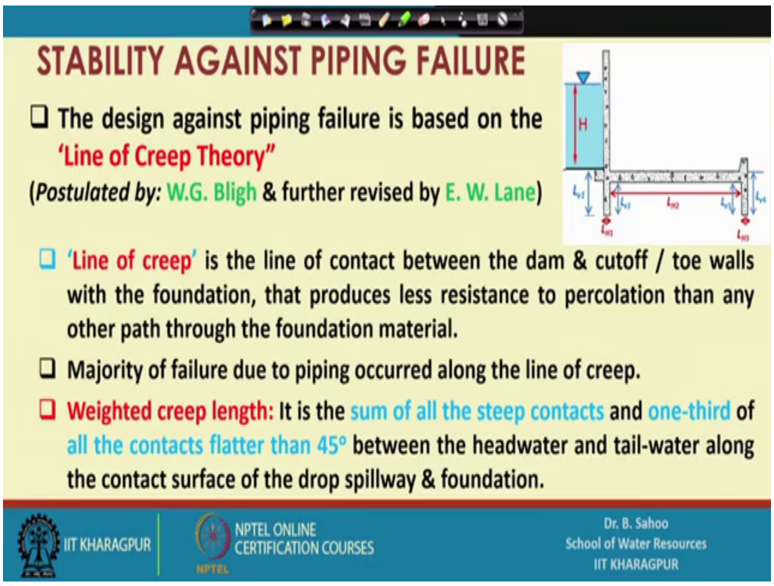

Now, for the stability against piping failure the design against piping failure is based on the line of Creep theory and it is postulated by W G Bligh and further revised by E W Lane so, less theory is the most advanced one so, that is why we will use the lens theory for all our designs.

The line of Creep is the line of contact between the dam and cut off or toe walls with the foundation, that produces less resistance to percolation than any other path through the foundation material.

If you will see this figure the values that is L v1, L v2, L v3 and L v4 these are all steep contacts the vertical contacts under distance L H1, L H2 and L H3 in this figure all are horizontal distances. And all these are called as horizontal plot distances if the slope is less than 45 degree.

So, we generally calculate the weighted creep length the effective seepage length, so, the effective or weighted creep length is estimated as one third of all these horizontal distances plus the sum of the vertical distances. So, it is the sum of all the steep contacts and one third of all the contacts flatter than 45 degree between the headwater on tail water along the contact surface of the drop spillway and foundation. And capital H is the static water table or the upstream side which is mostly causing the seepage below the foundation. So, that is why H is the driving head or driving energy head.

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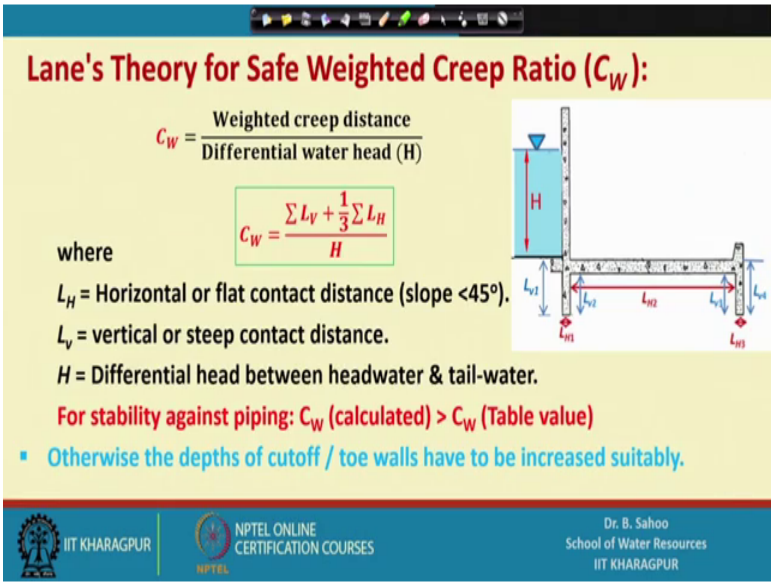

So, the length theory for a safe weighted creep ratio is given by C W. So, C W equal to weighted creep distance that we have already estimated our summation of L V. So, L V equal to L V 1 plus L V2 plus L V3 plus L V4 and 1 third of the horizontal distance. So, that equal to one third of L H1 plus L H2 plus L H3 as shown in this figure divided by capital H, capital H is the driving or static water head which is causing these seepage or the piping failure.

So, for stability against piping generally the calculated C W value should be greater than the tabular value and the C W of table value is estimated already computed depending on the different soil type of the foundation material. Otherwise, the depths of cut off or toe walls have to be increased if it is less than the table values, then you have to increase the depth that is L V 1 or L V 2 or L V 3 and L V 4. So, that the stability against piping failure is achieved.

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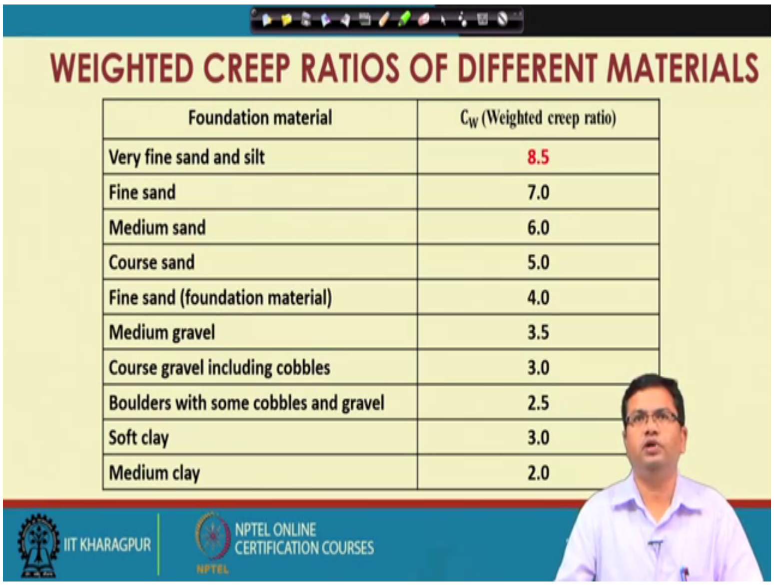
WEIGHTED CREEP RATIOS OF DIFFERENT MATERIALS

| Foundation material | $C_W$ (Weighted creep ratio) |
|---|---|
| Very fine sand and silt | 8.5 |
| Fine sand | 7.0 |
| Medium sand | 6.0 |
| Course sand | 5.0 |
| Fine sand (foundation material) | 4.0 |
| Medium gravel | 3.5 |
| Course gravel including cobbles | 3.0 |
| Boulders with some cobbles and gravel | 2.5 |
| Soft clay | 3.0 |
| Medium clay | 2.0 |



So, these are the different weighted creep ratios of different foundation materials you can see the, for very fine sand and silt which is having more porosity it has a greater C W value. So, greater C W value means it is less stable for fine sand is 7, medium sand 6, course sand 5, fine sand 4, medium gravel 3.5, course gravel including cobbles the decouples that is 3, boulders with some cobbles and gravel 2.5, soft clay 3, medium clay 2 then hard clay 1.8 and the least it is very hard clay or hard can that is 1.6 that in that means, it a more stable.

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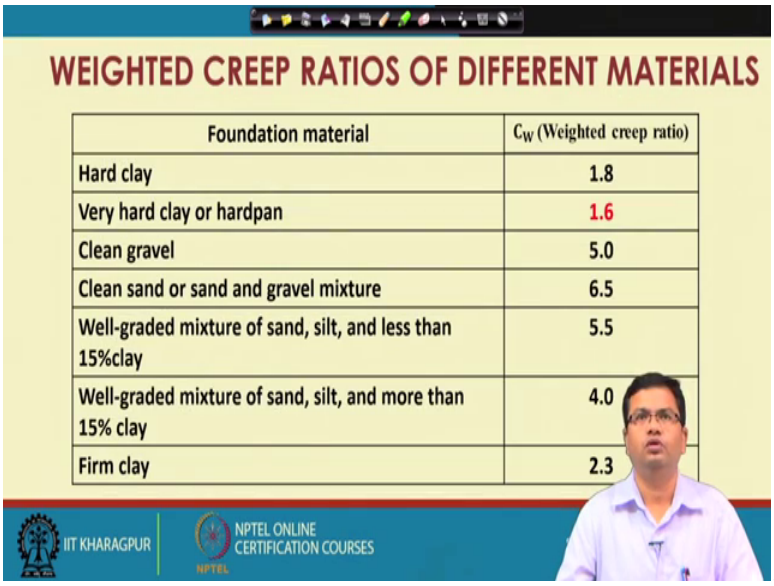


Clean gravel as 5, clean sand or sand and gravel mixture 6.5, well graded mixtures of sand silt and less than 15 percent clay that is your 5.5, it is more than 15 percent clay then it is 4 on 4, and form clay it is 2.3. So, these are the tabular values of C W so, our values should be greater than this tabular value.

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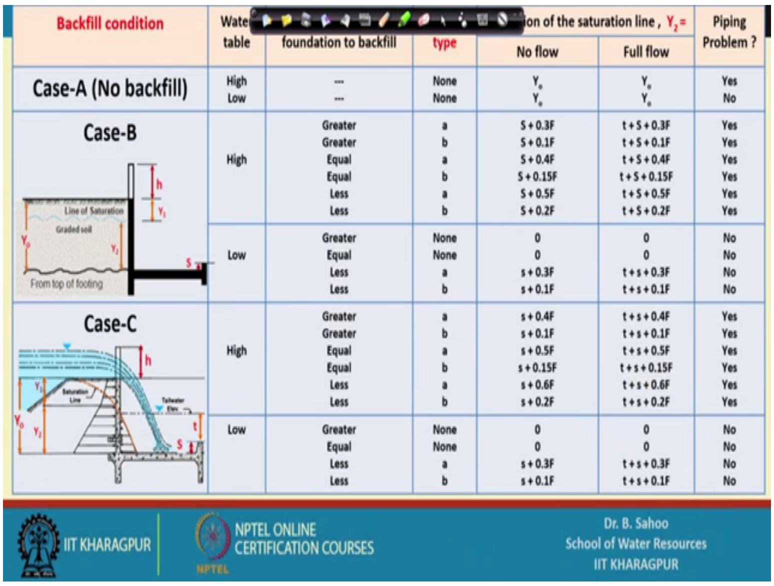

Then, as we have already studied in our previous lecture so, depending on the backfill condition and drainage condition you can design or you can estimate the elevation of the saturation life line Y 2 you can see from this figure case C suppose for example, for case C this Y 2 value you can estimate and that is depending on different water table conditions.

If your water table condition is suppose high and the relative permeability between the foundation to backfill material is equal suppose and drainage condition is a, then known for no flow condition I can get Y to equal to S plus 0.5 F. And this S plus 0.5 F is nothing, but the value of Y 2 and this Y 2 value we can estimate because, it is mostly responsible for estimating how much is my water table depth.

So, the saturation line shows the water table depth in the backfill material. So, that is why during the load computation so, this is Y 2 value is very much important. So, this table will be always referred for all these design calculations of the drop spillway.

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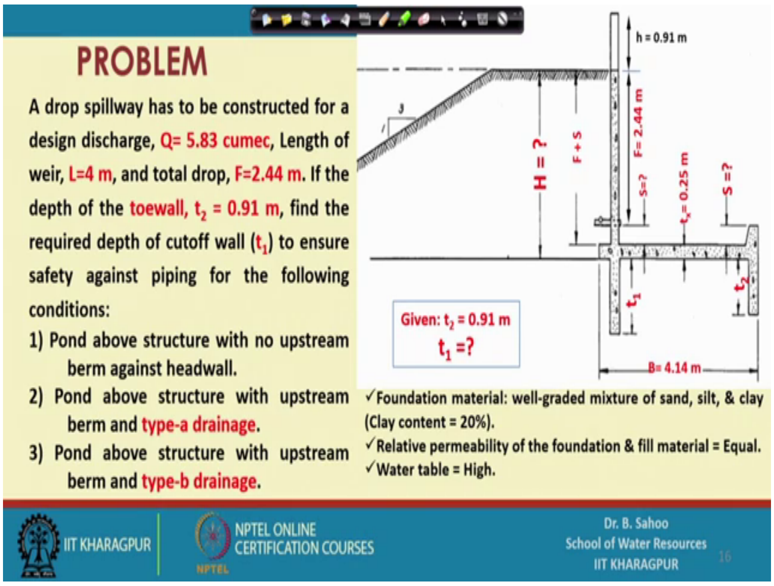


So, everything will be clear with if you follow a problem you will solve your problem you can see in this problem a drop spillway has to be constructed for a design discharge, Q equal to 5.83, cubic length of weir is 4 meter, total drop is 2.44 meter. If the depth of the toe wall t 2 as shown in this figure equal to 0.91 meter, find the required depth of cut of all t 1 to ensure safety against piping for the following conditions.

So, if there are three conditions given 1 is pond above structure with no upstream bomb against red wall, 2nd is pond ever structure with upstream berm type  a drainage and pond above structure with upstream berm type  b drainage and the conditions of foundation metal are given.

So, it is well grade a mixture of sand, silt, clay, having clay content 20 percent which is greater than 15 percent relative permeability of the foundation and fill metal equal is equal on water table is high. So, for the foundation metal that is will grade a mixture of sand silt and clay which having clay content greater than 20 percent, you can estimate what is your C W value from this table given table. But for designing this you have to estimate, what is the value of H are shown in this figure. To estimate the value of H naturally you have to estimate what is the value of S?S is nothing, but it is the depth of end silt.

So, as we have studied in the previous classes S can be estimated by using Q and L relationship like by computing the hut the critical depth d c and d c you know that not equal to Q square divided by L square g whole to the power 1 by 3. So, once this is estimated so, S will be equal to d c divided by 2. So, those calculations are can be down in the next slides.

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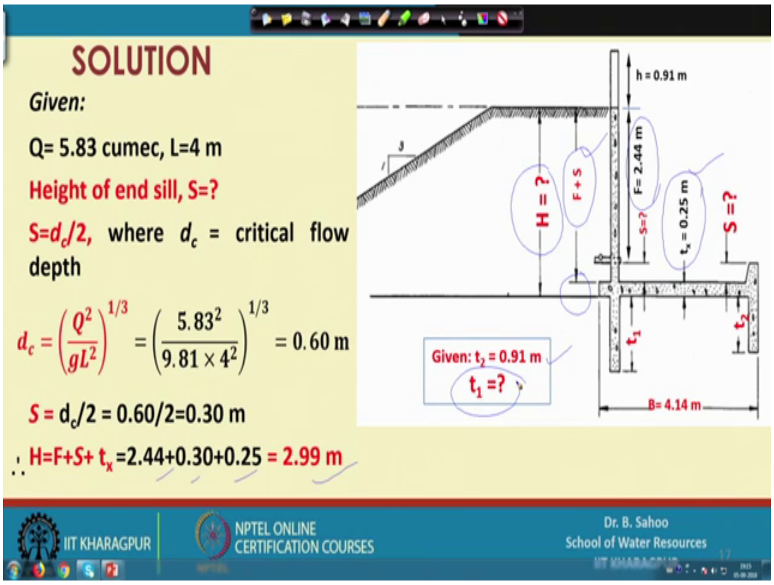

So, for estimating S you have to estimate, what is your d c value? So, here by putting the value of Q and L on z equal 9.81 you can get d c equal to 0.6 meter and S equal to d c by 2 that equal to 0.3 meter.

So, here H can be calculated as shown in this figure that equal to F plus S plus this distance or this height that equal to t x and t x is given as 0.25 meter. So, H will be equal to F plus S plus t x and that equal to 2.44 plus 0.3 plus 0.25 equal to 2.9 and meter, because F is already given that equal to 2.44 meter. So, once H is estimated and we have given t 2 equal to 0.91 meter already. So, to estimate what is my t 1 value by using the lines Creep theory, I can estimate what is mind t 1 value so, that the piping failure would not be happening.

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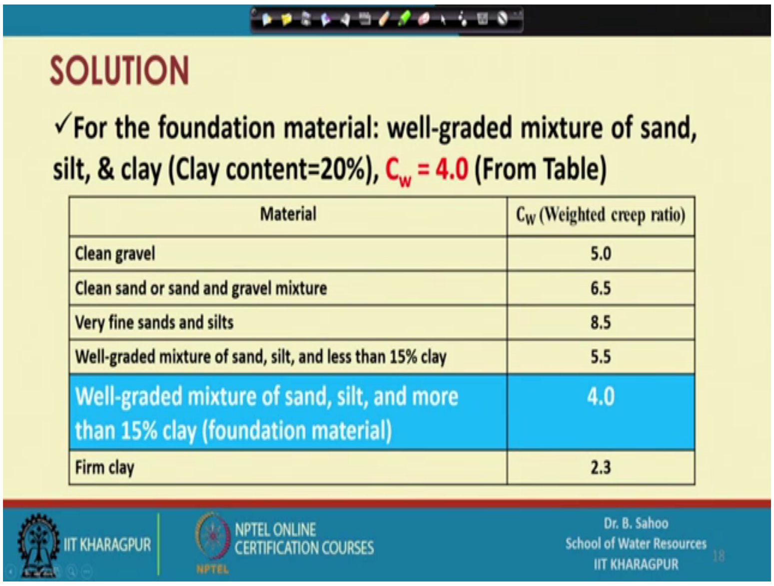


| Material | $C_W$ (Weighted creep ratio) |
|---|---|
| Clean gravel | 5.0 |
| Clean sand or sand and gravel mixture | 6.5 |
| Very fine sands and silts | 8.5 |
| Well-graded mixture of sand, silt, and less than 15% clay | 5.5 |
| Well-graded mixture of sand, silt, and more than 15% clay (foundation material) | 4.0 |
| Firm clay | 2.3 |

Now, for this you have to estimate what is the table value of C W and for the given condition well graded mixture of sand, silt and clay and having clay content 20 percent. So, you can calculate that C W equal to 4.

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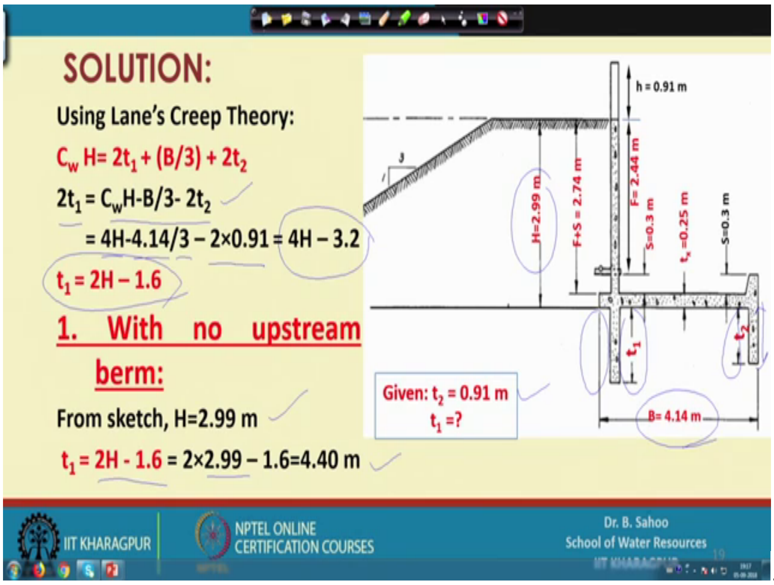


So, for all the estimates you can take C W equal to 4, now using lanes creep theory you know that C W H is equal to sigma L H the length of all these horizontal distances divided by 3 plus the summation of all the vertical distances or vertical depths.

So, in this case the length of vertical distances will be equal to 2t 1 plus 2t 2, if you will see this figure this is t 1 and this side also will be equal to t 1, this is t 2 on this side will be also equal to t 2. So, 2t 1 plus 2t 2 and this B is the horizontal distance, so, it will be divided by 3. So, by solving this you will get 2t 1 equal to C W H minus B or B or a 3 minus t 2 and H I have kept here without putting this value so, that we can do later on. So, B equal to 4.14 divided by 3 minus 2 into 0.91 because, t 2 is given as 0.91, So, we will get 4 H minus 3.2 now t 1 will equal to 2 H minus 1.6.

So, whatever the condition is are given so, depending on that the H value will change. So, for this condition first condition that is with no upstream berm here H is equal to 2.99 meter and directly you can get t 1 equal to 2 H minus 1.6. So, H is 2.99 so, we will get it is 4.4 meter, so, this is for the first condition.

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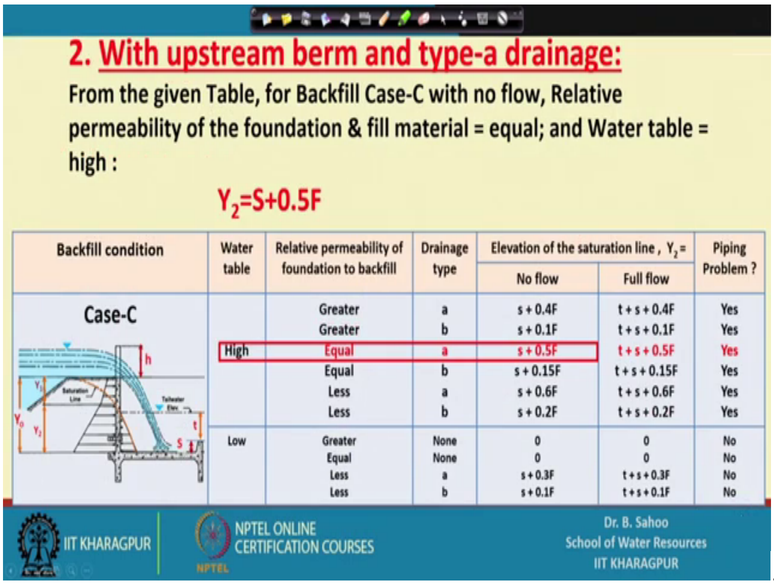


| Backfill condition | Water table | Relative permeability of foundation to backfill | Drainage type | Elevation of the saturation line, $Y_2$ = | | Piping Problem ? |
|---|---|---|---|---|---|---|
| | | | | No flow | Full flow | |
| Case-C | | Greater | a | s + 0.4F | t + s + 0.4F | Yes |
| | | Greater | b | s + 0.1F | t + s + 0.1F | Yes |
| | High | Equal | a | s + 0.5F | t + s + 0.5F | Yes |
| | | Equal | b | s + 0.15F | t + s + 0.15F | Yes |
| | | Less | a | s + 0.6F | t + s + 0.6F | Yes |
| | | Less | b | s + 0.2F | t + s + 0.2F | Yes |
| | Low | Greater | None | 0 | 0 | No |
| | | Equal | None | 0 | 0 | No |
| | | Less | a | s + 0.3F | t + s + 0.3F | No |
| | | Less | b | s + 0.1F | t + s + 0.1F | No |

Now, coming to the second condition that is with upstream berm and type a drainage: For type a drainage for the given condition you can find out what is the value of Y 2, as shown in this figure. So, you can estimate what is the value of Y 2 so, this is my Y 2. So, here I am getting Y 2 equal to S plus 0.5 F that you can estimate from here for no flow condition.

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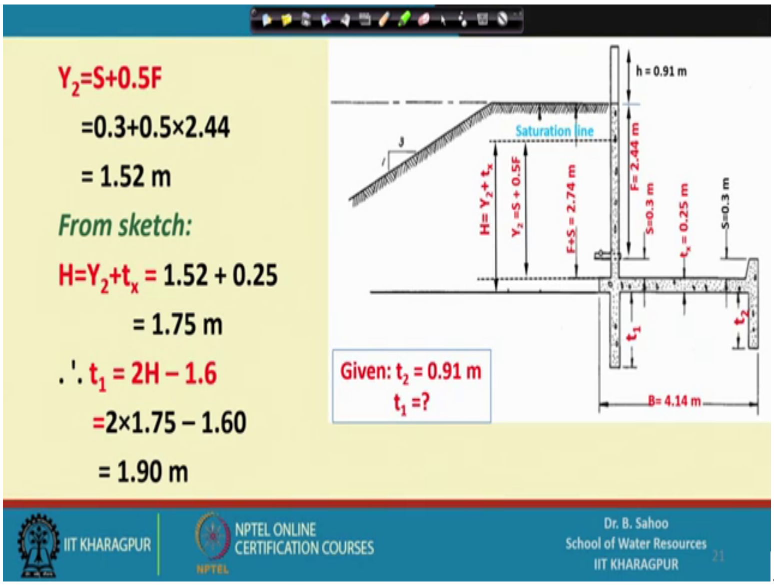


So, once this value is known Y 2 equal to S plus 0.5 F that you can use for your subsequent calculations. So, as shown in this figure here H equal to Y 2 equal to S plus

0.5 F, we have already seen that one that Y 2 equal to S plus 0.55 F. So, we can estimate what is the Y 2 value, so, here Y 2 equal to 1.52 meter and this Y 2 is corresponding to that is the depth between the saturation line and the line from this bottom of this say top of this apron so, this is my Y 2 value.

So, that is you can estimate as 1.52 meter and from this case you can get this H equal to Y 2 plus t x, because these t x has to be added here then you will get this 1.52 that equal to Y 2 plus 0.25 that equal to 1.75 meter. So, t 1 will be getting that is 2 H minus 1.6 and H equal to 1.75 meter. So, we will get 1.9 meter. So, my t 1 value is 1.9 meter.

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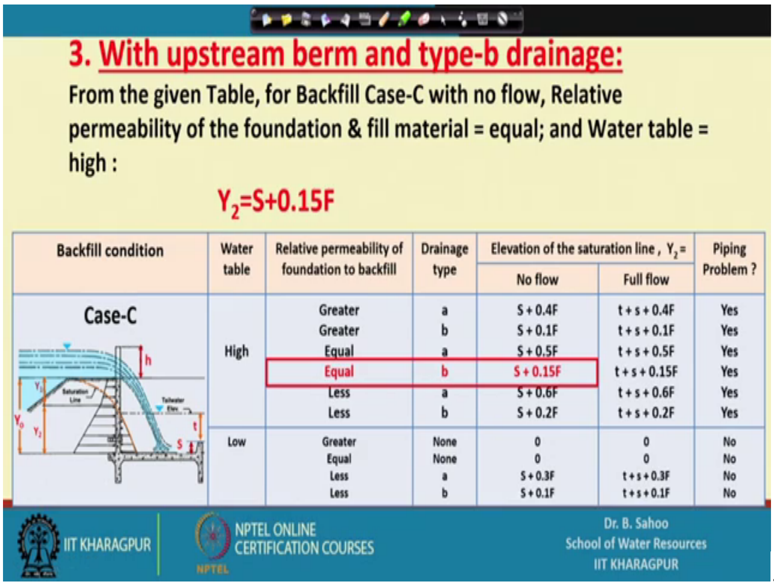


Similarly, you can do for the 3rd case, so, for the 3rd case it is type b drainage, for type b drainage similarly can selects what is my Y 2 value. In this case you can see the Y 2 value is equal to S plus 0.15 F that you can see from this table. So, this is the distance from this bottom surface to the saturation line. So, once Y 2 is known so, by using this you can estimate what is my H value.

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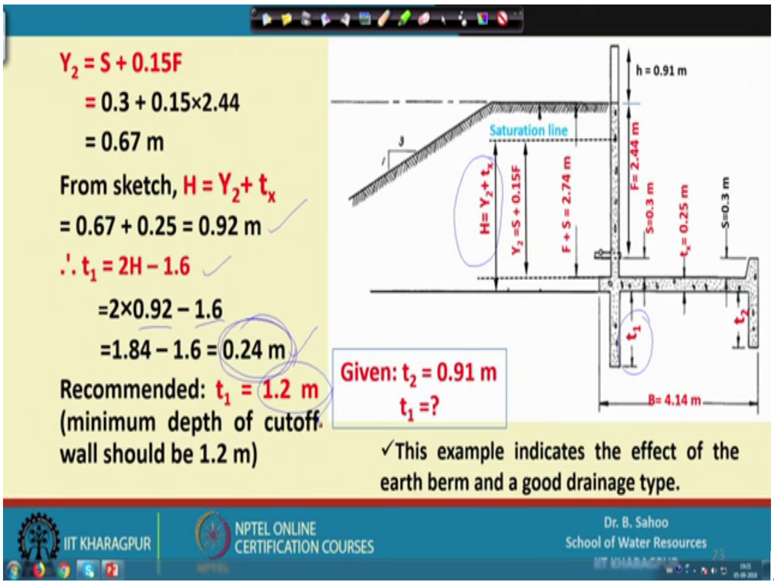


So, for this first I have to estimate what is my Y 2 that equal to S plus 0.15 F that I can compute here. So, S equal to 0.3 and F equal to 2.44. So, I can get Y 2 equal to 0.67 meter, on from the sketch you can get H equal to Y 2 plus t x and Y 2 equal to 0.67 plus t x equal to 0.25., so, we are getting 0.92 meter.

So, once H is known this H is known, you can estimate what is t 1 that equal 2 H minus 1.6. So, by putting the values of h and that is 1.6 here, so, we will get t 1 equal to 0.24 meter. You know that the minimum depth of this cutoff wall should be 1.2 meter, but this value is 0.24 meter which is much below than that of 1.2 meter. So, for this case you can recommend the minimum value that equal to 1.2 meter so, your minimum t 1 value equal to 1.2 meter.

So, if you are providing a cut off wall of depth 1.2 meter, then it is c code from the piping failure. So, this example shows that, what are the effect of different earth wall and the drainage condition? It can be drainage condition a, it can be drainage condition b and it can be no flow and because of that how the cutoff wall depth is changing or it can be optimized so, that there would not be any piping failure.

So, from this lecture we summarized that what are the contact pressures, what is piping failure, what are the main causes of piping failure, and to withstand against the piping failure, how will design our depth of cutoff wall and what is the optimized depth of cut off wall and we discussed about the overturning depending on the uplift pressure and the vertical pressure loads at what is my z? That is the or the eccentricity according to that whether it will be overturning or not ok.

So, this completes our lectures here and then in the next class we will be discussing about how the contacts pressures will be estimated by using the line of creep theory. So, we will end our lecture here.

Thank you very much.