Soil and Water Conservation Engineering
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Lecture - 37
Structural Design of Drop Spillway – 4

Welcome students to our next lecture on the Structural Stability of Drop Spillway against sliding. So, in this case, we will in this class we will talk about what is sliding and what are the different forces acting for sliding, and what are the different resistance forces which are responsible for sliding.

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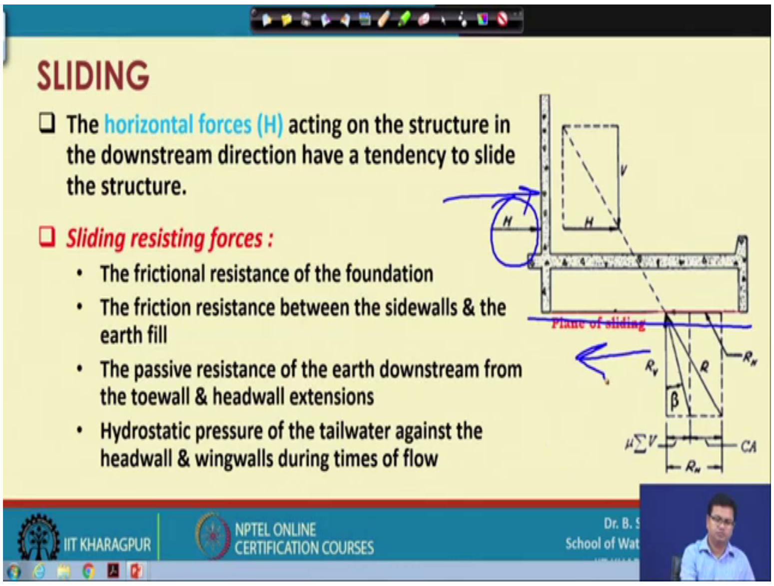

So, we can say that the different horizontal forces, which are acting off stream of this drop structure against headwall. They are mostly causing the sliding along the plane of sliding as you can see in this figure. So, the horizontal forces acting on the structure in the downstream direction having a tendency to slide the structure. And this H is the horizontal force, which is responsible for sliding along the plane of sliding. And there are different sliding resisting forces this could be friction resistance of the foundation. Friction resistance between the sidewall and the earth fill passive resistance of the earth downstream from the toewall and headwall extension. And hydrostatic pressure of the tail water against the headwall and wingwalls during the time of flow.

So, you can see this figure, the H is the horizontal forces, which are acting or which is pushing the structure to slide along this plane of sliding. But, there are different resistive forces of this foundation material, which is acting in opposite direction to that of H and which is the main cause of stability of this structure against sliding. Now, we will discuss what are the different forces acting on this, and how to compute all these forces. We have already discussed in our last lectures that how to estimate the horizontal forces, what are the vertical forces. We can see this diagram the sigma V is the summation of all these vertical forces, which is because of the pressure of this standing water. The vertical pressure or the vertical width because, of the earth fill or the backfill materials. And the vertical forces because of the concrete structure that is the concrete structure or the drop.

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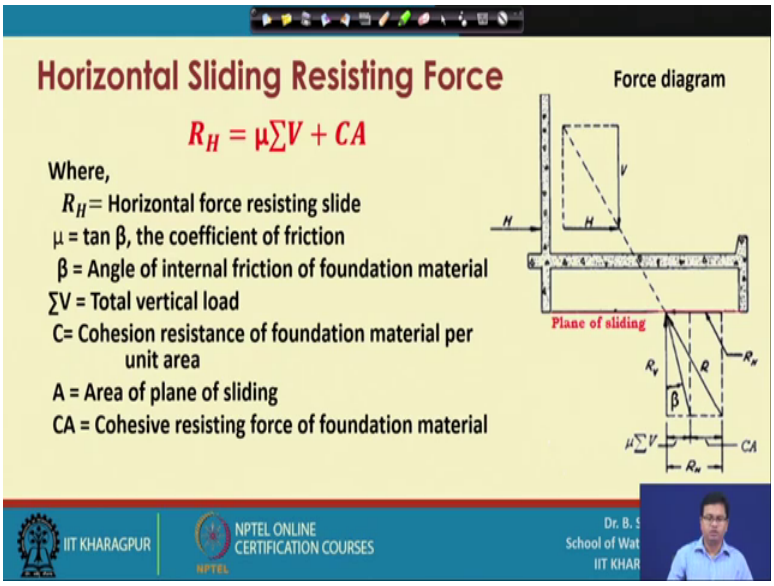

So, these are the different horizontal forces, which is given by R H that equal to mu into sigma V plus C A, where mu is the coefficient of friction, and that estimated as tan beta, where beta is angle of internal friction of the foundation material, because the friction force, which is existing at the foundation metal is the main force, which opposing the sliding of the structure, which is causing because of the force H or the horizontal forces.

Then plus C into A, C the cohesion resistance of foundation material per unit area and A is the area of plane of sliding. So, you will multiply C into A, so that is the cohesive resisting force of the foundation material, so that is also opposing the horizontal forces. In ideal condition if H equal to R H the all those horizontal forces, it will be equal to the horizontal sliding resisting force. So, there would not be any slide, so that is the most ideal condition, but that seldom occurs.

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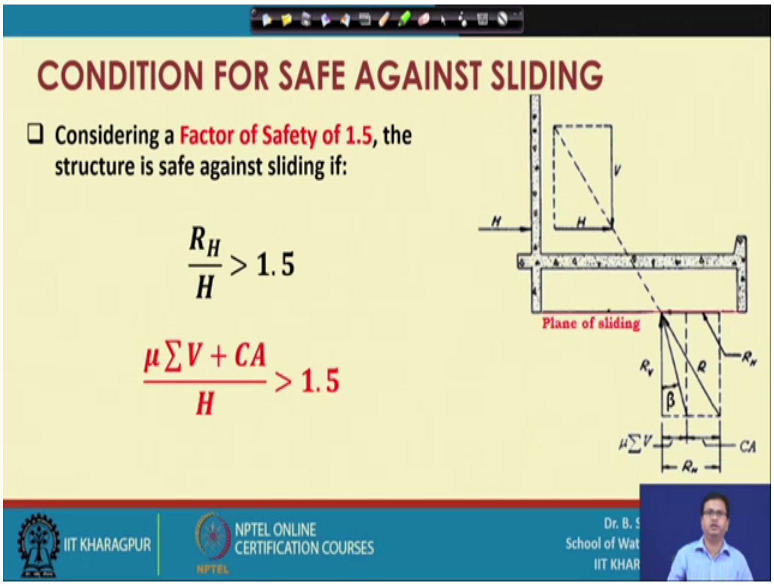

So, in this case we have to take some factor of safety. So, the factor of safety is taken as 1.5, so that R H divided by H is greater than 1.5. In other words, mu into sigma V plus CA that is equal to R H divided by H that should be greater than 1.5. So, everything will be clear, we will solve a practical example. So, will solve this problem, you can get a clear picture how to estimate the values of vertical forces, then horizontal forces, then take the ratio of that R H divided by H. Then if it is greater than 1.5, then the structure is stable against sliding. Otherwise, we have to increase the weight of the structure and that is possible by increasing the depth of the cutoff wall or toewall.

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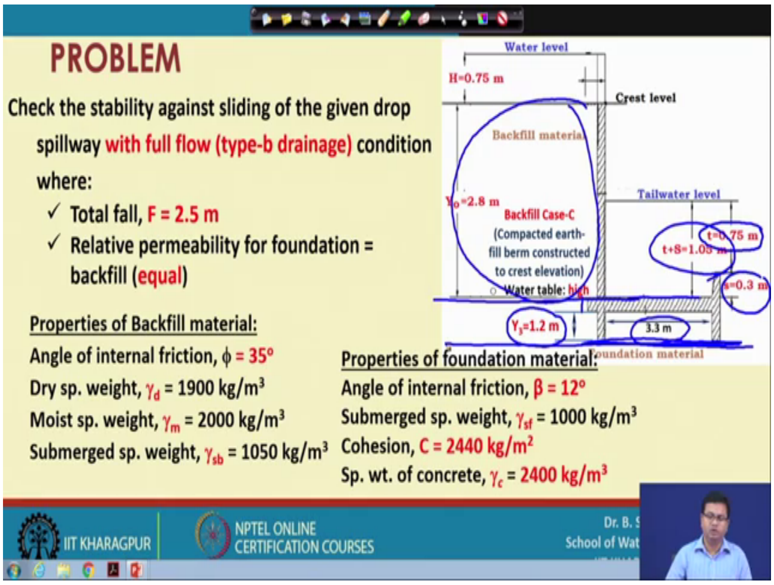

This is a problem the for solving this problem, we have to clearly understand what is given here. So, the problem is that check the stability against sliding of the given drop spillway with full flow condition. We have already talked what is full flow condition that means, the water is flowing over the crest, and the type-b drainage, total fall is 2.5 metre relative permeability for foundation equal to backfill. So, here the ratio is equal that we have already also solved similar type of problems.

And the property of backfill material are angle of internal friction phi is given as 35 degree dry specific weight of the backfill material, so that equal 1900 kg per metre cube. Moist specific weight of the backfill material that equal to 2000 kg per metre cube, and submerged specific weight is given as 1050 kg per metre cube.

Then the properties of foundation material, which is resisting the sliding they are given by the angle of internal friction, beta that equal to 12 degrees that is that we can use for completing the mu value, mu equal to tan beta. Then submerged specific weight of this foundation material is 1000 kg per metre cube. Cohesion C that equal to 2440 kg per metre square and specific weight of concrete, because the whole structure is constructed by using concrete, so that equal to 2400 kg per metre cube, so that will be the useful for calculating the vertical weights of different parts of this drop structure.

And using the figure you can see, the crest level water is 0.75 metre, then the height of the head wall is given by Y naught that equal to 2.8 metre from the plane of that is above the top of this apron, and this is filled with the backfill material. And the backfill is case-C, case-C means it is compacted earth and filled with berm constructed to crest elevation and water table is high. This is for the drainage condition type-b drainage condition, and here water table is high condition.

And there is tailwater, you can see the tailwater depth above the endsill is given us t that equal to 0.75 metre, height of endsill equal to 0.3 metre. So, the tailwater depth above the apron is t plus S that equal to 1.05 metre. And the depth of cut off wall equal to 1.2 metre and the thickness of this apron is equal 0.3 metre, and this distance is 3.3 metre. And the plane of sliding is this one that is at the bottom of this toe wall or cut off wall, so that means, we have to estimate all these vertical forces and horizontal flow forces in reference to this plane of sliding. So, this is the main basic thing, you have to understand before solving the problem.

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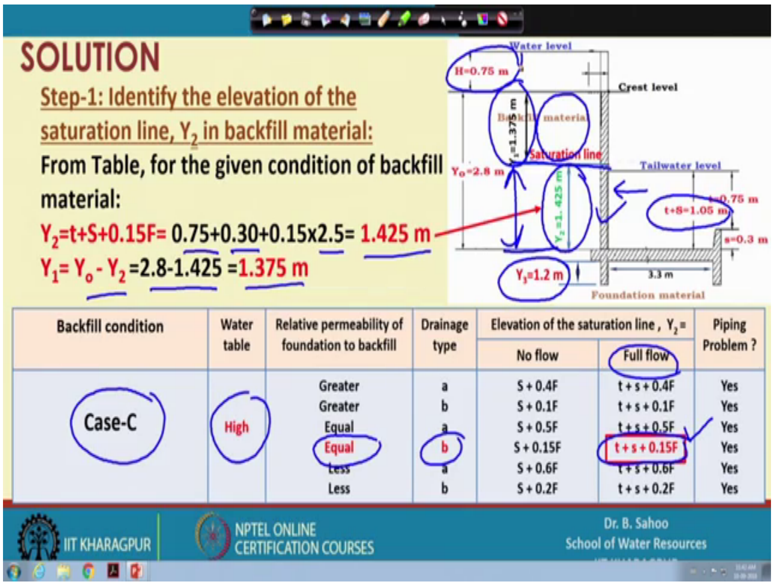

Now, we have to go for solving the problem. As a first step, we have to identify the elevation of the situation line Y 2, because there is full flow condition and type-b drainage. So, in this case the value of Y 2 will be computed by using the tabular value that we have already solved in the previous classes. So, from the table we can see for case-C backfill condition, high water table, the relative permeability of foundation to backfill equal, drainage type-b, and full flow condition the value of Y 2 equal t plus s plus 0.15F.

So, by using this value we can calculate, what is the value of Y 2. So, know the values of t that is 0.75, S 0.3 and F 2.5, so you can get 1.425 metre, so that means this depth is 1.425 metre. So, this shows that the saturation line lies above the apron at a distance of 1.425 metre that mean this backfill material is now saturated or submerged. And this backfill material is moist, because it is no more saturated. And this depth is computed as Y naught minus Y 2 that equal to 2.8 minus 1.425, so that is 1.375. So, this depth is now 1.375, which is the moist backfill.

Now, the pressure difference will be there. So, for this depth Y 1, you will be getting the weight because of moist backfill and for the depth Y 2, you will be getting the vertical pressure or horizontal pressure because of the saturated or submerged backfill. And for depth Y 3 equal to 1.2 metre, we will have water pressure as well as submerged foundation. And there will be tailwater pressure for a depth of t plus s equal to 1.5 metre, which is acting in opposite direction to that of H. And there will be water pressure because of this crest water level of H equal to 0.75 metre. Once this is clear, then we have to go for our next step.

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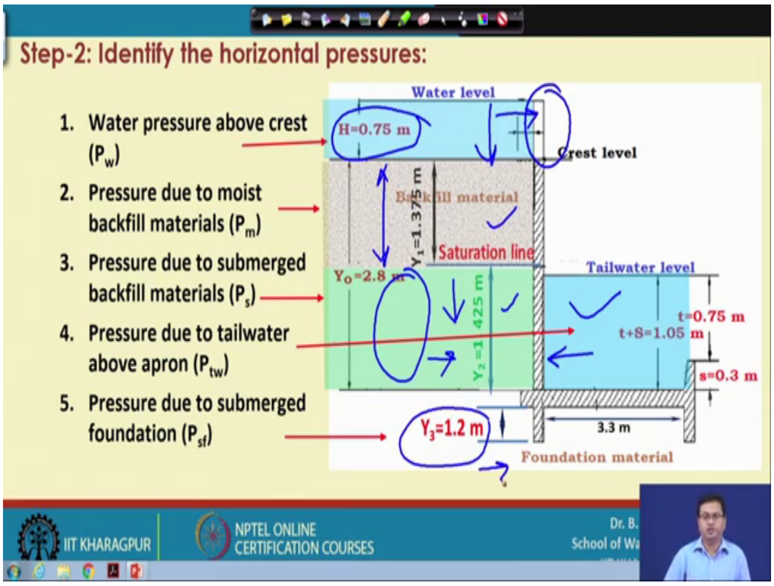

So, here you have to identify the, what are the different horizontal pressures or the what are the different vertical pressures without that we cannot solve the problem. So, for that as discussed I was discussing that water pressure have crest, it will exert horizontal pressure as well as vertical pressure, so because of this water depth of 0.75 metre. The horizontal water pressure, what will be created that will cause the flow of the water to the downstream side. So, there is no headwall here, so because of that the horizontal pressure is 0. But, because this water column, it will be exerting down or water pressure. And that will be transmitted to the backfill material for a depth of Y 1 as well as for a depth of Y 2.

Then second is the pressure due to the moist backfill metal up to this depth, which is both vertical as well as horizontal. The vertical weight will be transmitted to the downstream saturated or submerged soil layer, which is of depth Y 2 equal to 1.425 metre. Then for this depth, you will be getting submerged weight, and that is also causing horizontal pressure as well as vertical pressure.

Then the pressure due to tailwater above the apron so, this one it will be causing the pressure in the opposite direction. Pressure due to submerged foundation here that is for a depth of Y 3 equal to 1.2 metre, you will be getting the submerged weight as well as water pressure of at this location, which is causing horizontal pressure forces. So, by using this concept now will be solving our problem.

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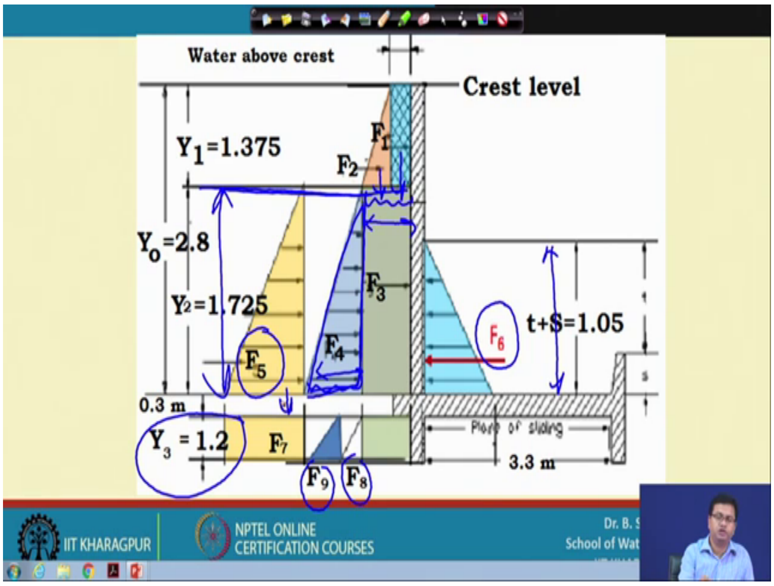

So, this is the whole pressure diagram. We can see F 1 if the pressure that is water pressure, which is flowing above the cross above the crest. And this water pressure is giving a vertical load to the top soil layer, so because of that we will be getting a rectangular pressure diagram. Now, the force F 2 is the pressure at the horizontal pressure, which is because of the moist soil or the moist backfill material.

Similarly, the value F 3 if will see, so this F 3 the magnitude of F 3 will be equal to because this pressure, because of water and this pressure from the moist backfill, they will they will get transmitted to the lower soil layer, and will be getting F 3 as a horizontal will be getting a rectangular pressure diagram. And the backfill material in this zone Y 2 equal to 1.725 metre depth will have also, it is own horizontal pressure, so that is given by your F 4.

And you know that in all these pressure triangles, when solved the base of these pressure triangle gives the value of pressure force that equal to gamma into H, the specific weight in times the depth of this soil column or water column. If want to complete what is your total force that is F, then we have to multiply or we have find out what is the area under this pressure triangle. So, that will go half, into pressure, into the height, so you will be getting the total area. And total area gives you the force value. And this F 5 is the water pressure, because this water is this the depth is now saturated, because this is a saturation line because of type-b drainage.

F 6, we have already talked about. This is your tailwater pressure, because as tailwater here, so that is causing horizontal pressure forces also. Then we have F 8 and F 9; F 8 is the horizontal pressure force, which is because of the foundation material, which is submerged and F 9 is the water pressure in this submerged foundation, which is having a depth of Y 3 that equal to 1.2 metre. And F 7 will be the transmitted vertical pressure from F 5. Once this is clear, so the we can see that total 9 forces along with the 9 forces, these are the 9 horizontal forces, then there other vertical forces as well as the uplift pressure forces. Which is also the main cause of sliding, because it reduces the vertical force component, which is opposite which is working in a opposite direction.

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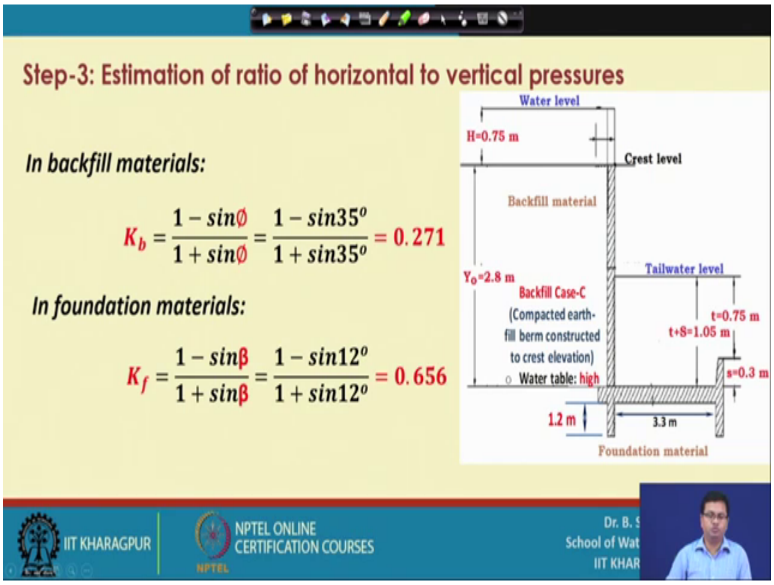

Now, in the third step, we have to we have to estimate the ratio of horizontal to vertical pressures for the backfill material, because here phi equal to 35 degree already given in the problem. So, you will be getting K b equal to 1 minus sin phi divided by 1 plus sin phi, so that equal to 0.271 that means, if you have some vertical pressure to convert that vertical pressure into horizontal pressure, we have to multiply with 0.271 for the backfill material. And for foundation material, this value is equal to 0.656, which is equal to 1 minus sin 12 degree divided by 1 plus sin 12 degree. So, in the foundation material to convert the vertical forces into a horizontal forces, you have to multiply the vertical force with 0.656, then you can get the value of horizontal forces.

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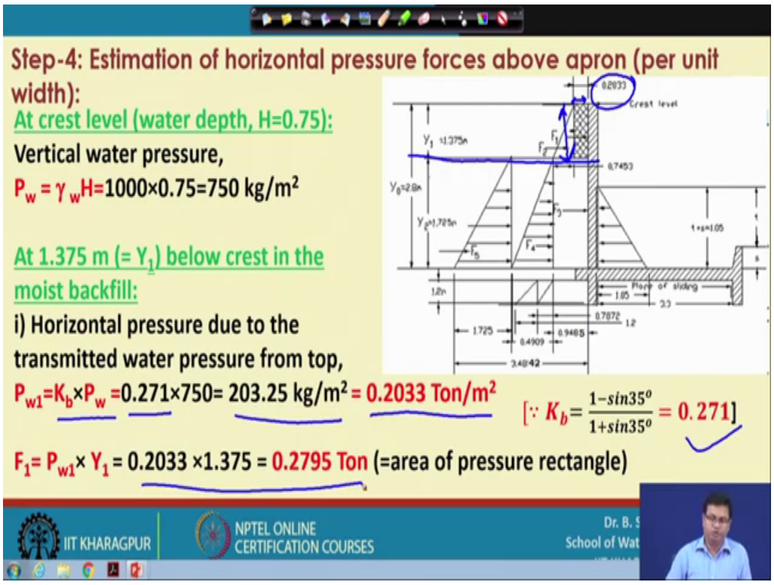

Now, in step-4, you have to estimate the horizontal pressure forces above apron. So, all the forces are computed for unit width that means I am taking one meter width, which is normal to the plane of paper. So, at crest level, the water depth is 0.75 metre. So, you will get vertical pressure that equal to P w, so will get gamma w into H. So, gamma w the specific weight of water you know that it is 1000 kg per metre cube into 0.75 metre the water depth, so will get 750 kg per metre square.

So, this water pressure, because there is no head wall at the above the crest level. So, is not exerting any horizontal water pressure, but it is exerting the vertical water pressure, which getting transmitted to the bottom soil layer that is to a depth of Y 1 that equal to 1.375 metre. So, for that you will be getting the F 1 pressure diagram as rectangular pressure diagram. So, at 1.375 metre below crest in the moist backfill that means, at this reference line the horizontal pressure due to the transmitter water pressure on top will be equal to K b times P w, K b we have estimated as 0.271 in the previous slide.

And that you have to multiply with the P w that is the vertical pressure, which is coming from the top because of standing water level, so that vertical pressure is converted into horizontal pressure force by multiplying with K b, so that equal to 203.25 kg per metre square, so that is it will convert into ton per metre square it is coming 0.2033 ton per metre square. So, you can see this value as 0.2033 ton per metre square, so that means this length of this pressure diagram is 0.2033. So, total force will be equal to this result

0.2033 times Y 1, so this is the height of this force. So, you will be getting total area as Y 1 into P w 1, so you will be getting 0.2795 ton, so that is the area of the pressure rectangle.

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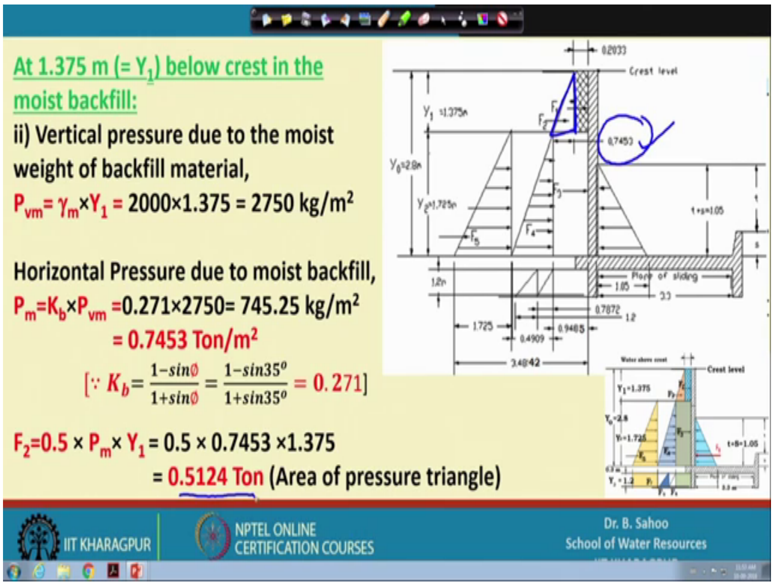

Now, we have to estimate what is the value of F 2. So, for F 2 the vertical pressure due to the moist weight of backfill material is given by gamma m into Y 1. Gamma m is the specific weight of the backfill material, so that equal to 2000 into 1.375, so that equal to 2750 kg per metre square. So, this is within the moist soil, which is above the saturation line. So, this vertical pressure has to be converted into equivalent horizontal pressure, so that is given by P m that equal to K b times P v m, so that means we have to multiply with 0.271. So, by multiplying with 0.271 will be getting P m equal to 0.7453 ton per metre square, so that you can see also here, in this figure that is 0.7453 ton per metre square.

So, the total area will be calculated as the area of this pressure triangle. So, the area of the pressure triangle will be base that equal to 0.75 7453 into the height that is 1.375 divided by 2, so that the area of triangle you know this. So, F 2 will be equal to 0.5124 ton so, this the area of the pressure triangle. So, we have compute already F 1 and F 2 once this F 1 and F 2 are computed, so the whole value the vertical value will be transmitting to the next soil layer that is Y 2.

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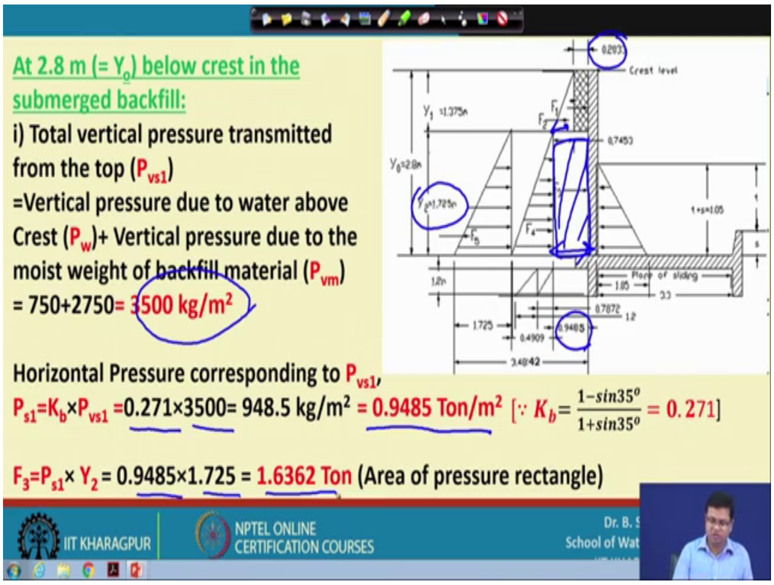

So, our next step is to compute, what is my vertical forces at 2.8 metre below crest in the submerged backfill, because this Y 2 depth is totally submerged. So, total vertical pressure transmitted from the top, so that is denoted by P v s 1, so that will be equal to vertical pressure due to water above crest, this value plus vertical pressure due to the moist weight of backfill material that equal to P v m. So, this value so total will be transmitted, so total will be equal to 750 plus 2750, so that equal to 3500 kg per metre square, so that means this value is now 3500 kg per metre square.

Now, this value has to be converted into equivalent horizontal forces, so that we can do by using multiplying this value with the value of K b, we have already done before. So, K b value equal to 0.271 for the backfill material. So, now you multiply 0.271 with 3500, so you will be getting 0.9485 ton per metre square. So, this is the of value of P s 1, so that means, this value is now 9485, so that is the you can see width of this pressure rectangle is 0.9485.

And what is the depth you calculated the area, so depth is Y 2 this value, so this the depth. So, we will get the area of this pressure rectangle now, so that equal to F 3. So, F 3 will get 0.9485 into 1.725, so that equal to 1.6362. Now, similarly we will go for calculation of pressure F 4. So, the pressure F 4 is caused because of the own weight of this submerged backfill of two depth 1.725 metre.

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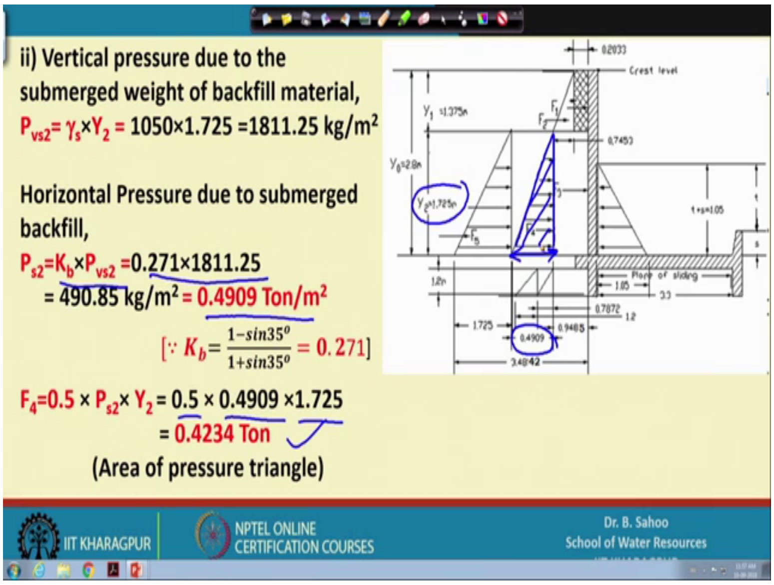

So, the vertical pressure due to the submerged due backfill material will be given by gamma s into Y 2. So, gamma s is the specific weight of the submerged backfill that is 1050 into 1.725, so will get 1811.25 kg per meter square. So, this is the vertical pressure. Now, this has to be converted into the horizontal pressure force. So, by multiplying with K b, so we will get P s 2 that equal to K b into P v s 2, so that will get 0.271 into 1811.25 that equal to 0.4909 ton per metre square. So, we can see this value is 0.4909 ton per meter square.

So, this basis base of this pressure triangle F 4 is now 0.4909. So, we have to calculate the area of this pressure triangle, area of this whole triangle so that is equal to base into the height equal to that equal to Y 2, so that is 1.725. So, multiply 1.725 with 0.4909 divided by 2, so will be getting 0.4234 ton so that means, this F 4 value is equal to 0.4234 ton.

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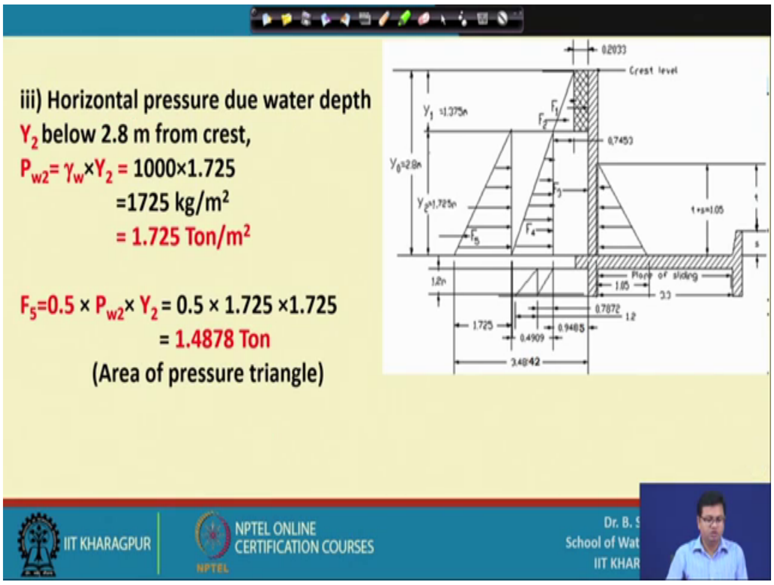

Now, we have to estimate the value of F 5. So, F 5 is caused because of the water pressure in the submerged backfill, so that you can compute as P w 2 equal to gamma w Y 2, so that equal to 1000 into 1.725, so that equal to 1.725 ton per metre square. Now, we have to estimate what is the value of this pressure area related to 5 corresponding to F 5. So, F 5 will be equal to half into base, base is equal to 1.725 into the height Y 2 is equal to 1.725. So, will get 1.4878 ton, so now you have calculated what is the pressure F 5.

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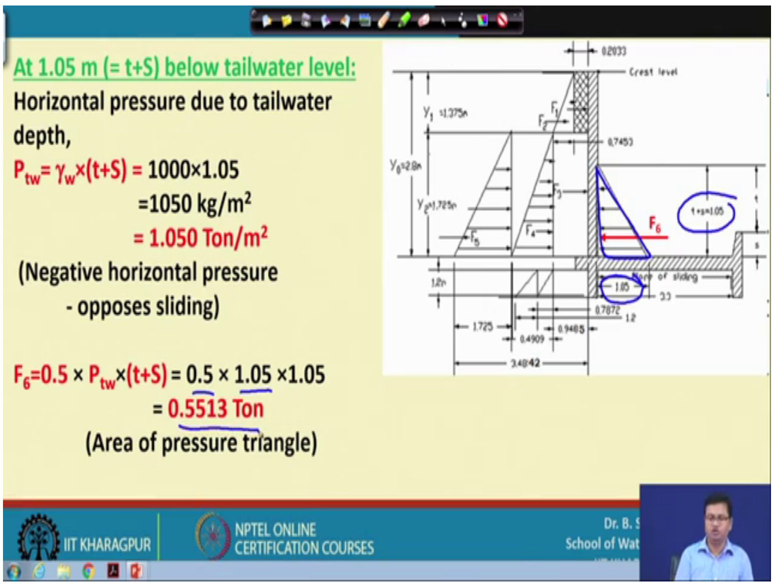

Similarly, we have to calculate what is pressure F 6. F 6 is the water pressure because of the tailwater. So, simple way you can estimate that equal to gamma w into height of this tail water, so that equal to t plus S, so that equal to 1.050 ton per metre square. So, here we can see this is 1.05 ton per metre square. Then we have to estimate what is the area of this pressure triangle to calculate the value of F 6. So, for this we have to estimate, you have to multiply 1.05 with the height of the tail water that equal to 1.05, then into half of that so, will be getting 0.5513 ton.

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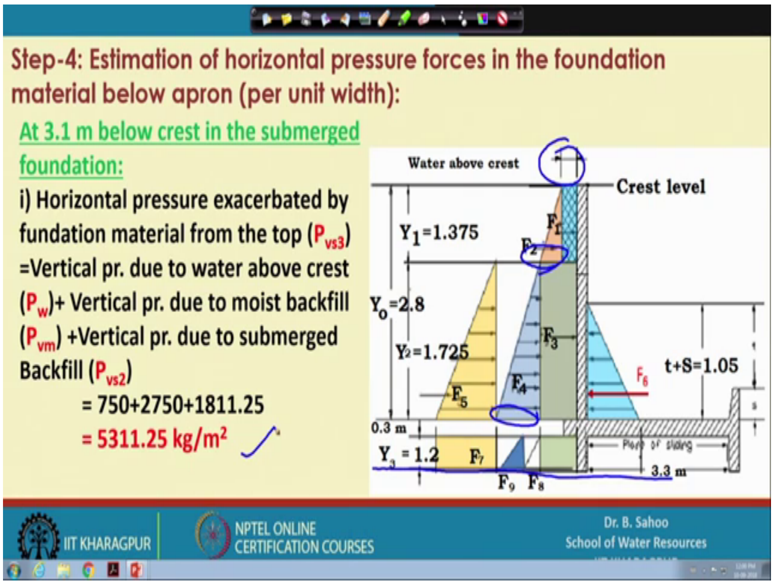

Now, we have to estimate what is the values of F 7, F 8, and F 9. So, for that you have to calculate at 3.1 below crest in the submerged foundation that is along the plane of sliding. So, along this plane of sliding, we have to estimate what is the total horizontal pressure. So, the horizontal pressure exacerbated by the foundation material from the top equal to vertical pressure due to water above crest, this water pressure plus vertical pressure due to moist backfill, this pressure plus vertical pressure due to submerged backfill, so this pressure. So, total will be equal to as we have estimated before 5311.25 kg per metre square. So, this is the horizontal pressure, which is because of the submerged foundation.

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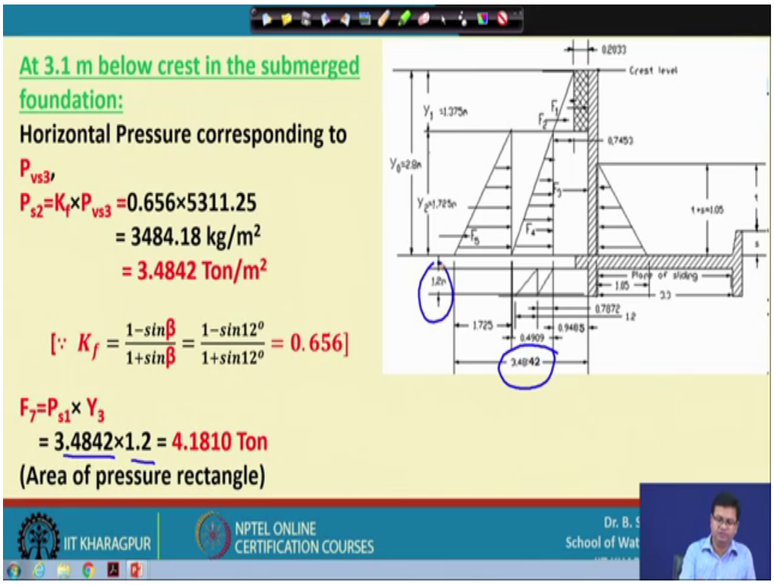

So, the horizontal pressure corresponding to P v s 3 will be equal to K f into P v s 3. So, those pressures were vertical pressures, whatever we have calculated those are vertical pressures not horizontal pressures, so that is the correction, we can change to vertical pressure. So, we have to multiply with the value of K f, so K f equal to 1 minus sin beta divided by 1 plus sine beta, we have computed before that equal to 0.656. So, 0.656 times 5311.25 that is the vertical pressure, which is exerted to the foundation material. So, will be getting 3.4842 ton, so that you can see also from the figure that is 3.4842 ton per metre square.

So, then we have to get what is the area of the pressure triangle. So, the area of the pressure triangle will be 3.4842 into half sorry 1.2, so this value is 1.2. So, we will get the area of the pressure triangle, so that equal to 4.1810 ton. So, the value of F 7 is equal to 4.1810 ton.

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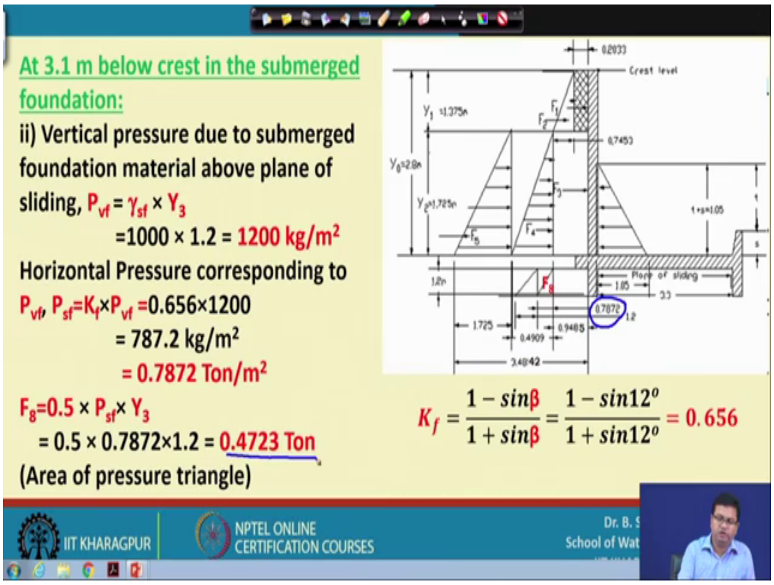

Now, we have to estimate what are the values of F 8 and F 9. The vertical pressure due to submerged foundation material above plane of sliding, so that is equal to we have already computed, so gamma s f into Y 3. So, gamma s f is given as 1000 into 1.2, so, will get 1200 kg per metre square. So, we have to convert this vertical weight into equivalent horizontal pressure forces. So, we have to multiply this with K f. So, K f we have estimated as 0.656 times 1200 will give you 0.7872 ton per metre square, so that you can see from this figure this value is 0.78 72 ton per metre square.

Then we have to calculate what is the area of this pressure triangle. So, area of this pressure triangle will be half into the base that is equal 0.7872 into the depth is Y 3 that equal to 1.2, so will get 0.4723 ton. And the next pressure will be our water pressure, which is in the foundation metal because of depth of 1.2 metre.

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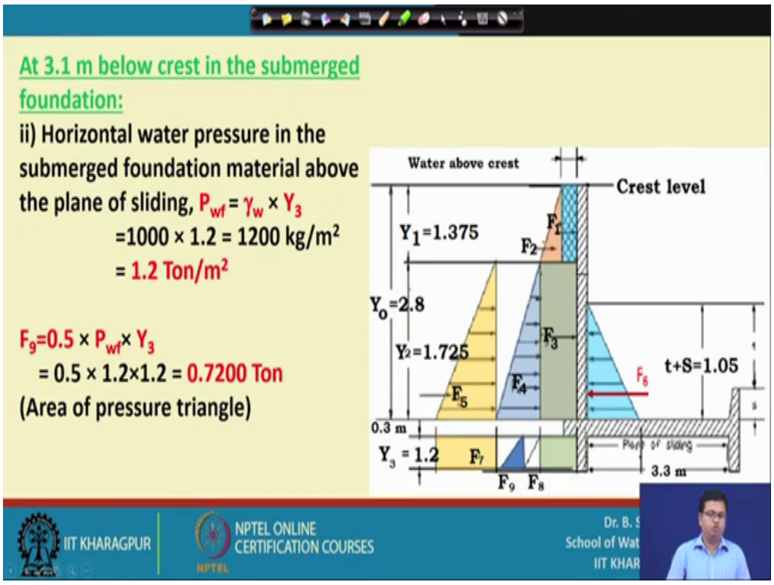

So, the water pressure will be given by gamma w into Y 3, so that will be equal to 1000 into 1.2 that equal to 1200 kg per metre square. And you have to convert into pressure triangle area of the pressure triangle, so that will be equal to half into 1.2 into 1.2 is this the value Y 3, so will get 0.72 ton. So, you have already computed all these horizontal pressure forces.

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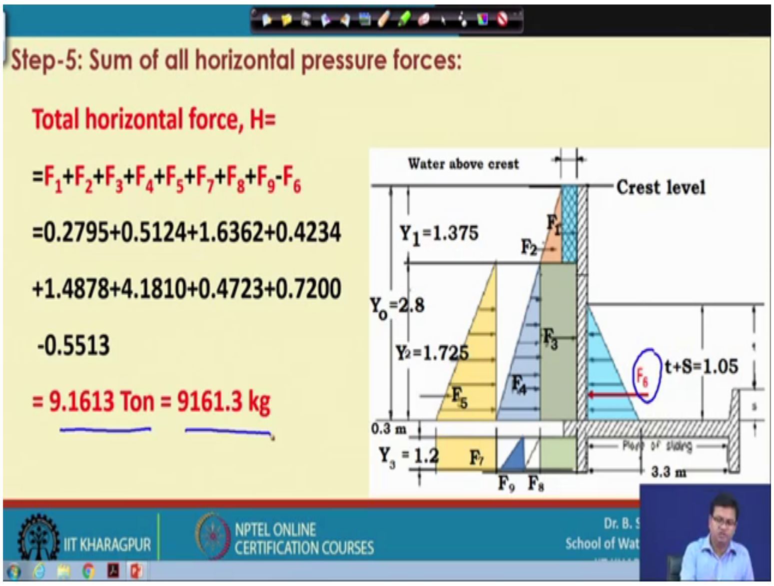

So, our some of these horizontal forces will be equal to F 1 plus F 2 plus F 3 plus F 4 up to F 9 minus F 6. This F 6 is negative, because it is exerting the pressure in opposite direction, which is against the sliding force. So, total we will get 9.1613 ton that equal to 9161.3 kg. So, once this pressure forces has been computed now, will go for computation of our vertical forces.

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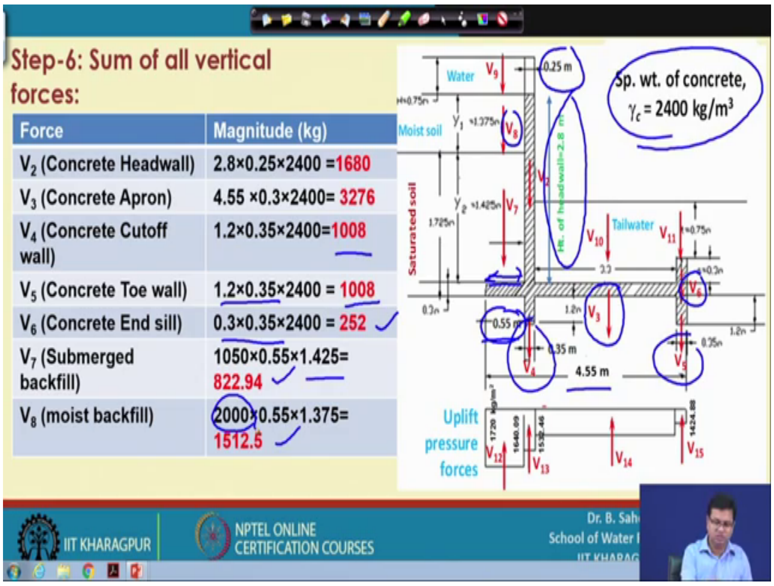

We have already computed in our previous class that how to estimate the total vertical forces. These are the different vertical forces as shown in the diagram. The force V 2 is because the concrete head wall, because it a concrete structure, so because the concrete headwall, which is having a depth of 2.8 metre, and the thickness is 0.25 metre. So, the area of this cross sectional area of this headwall will be equal to 2.8 into 0.25 into 1 metre. We have taken 1 metre or as width which is normal to our plane of paper. So, will be getting 1680, it will multiply with 2400 kg per metre cube, which is the specific weight of concrete.

Similarly, the force V 3 is the due to the concrete apron. So, we have total length is 4.55 metre into 0.3 the thickness of this apron into 2400, you will get 3276 kg. Similarly, V 4 is the concrete cutoff wall this force, so that will be equal to similarly we can compute that equal to 1008. V 5 is the concrete toe wall, similar way we can compute the area is 0.3 into 0.35 into 2400 sorry 1.25 into 0.35 into 2400 you will get 1008.

Similarly, for end sill that is your V 6 that we computed 252. For submerged backfill it is the specific weight is 1050 into 0.55 for is depth into 1.425 for a depth of Y 2, so that is coming as 822.94. For the moist backfill that is V 8, so the width is 0.55 metre, because of the all the pressure will be acted on the structure. The structure is elongated up to a depth, length of 0.55 metre. So, all the pressures will be acting on this only on this structure. So, for the moist backfill we will be getting it is 1512.5, because 2000 is the specific weight of this moist backfill.

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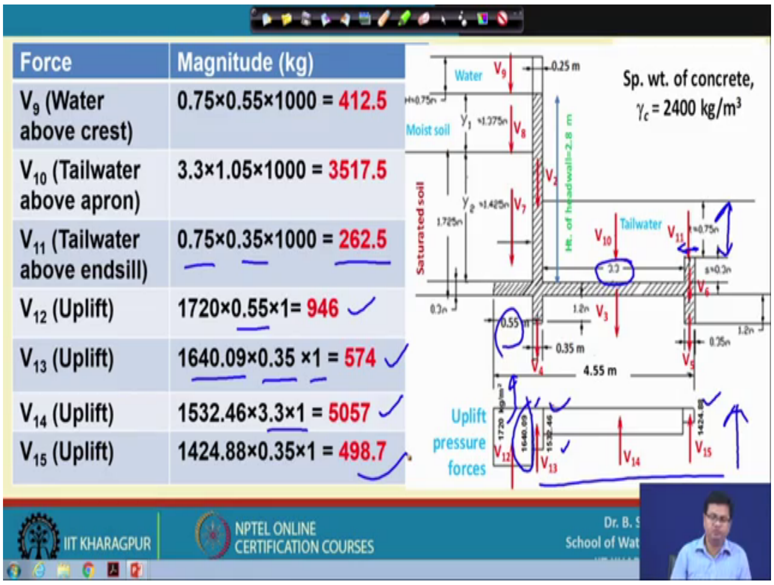

Then V 9 is the water above crest, which is also causing the vertical force, so that equal to 412.5. V 10 is the tail water above apron, so that equal to 3517.5, because 3.3 metre is the length of this apron. V 11 is the tail water above end sill. So, the tail water above end sill will get this value. This is the tail water above end sill, so you will get 262.5 in the similar way if you compute, because t is 0.75 into 0.35 is the this thickness. So, you will get 262.5.

And the other forces like V 12, V 13, V 14 and V 15 all are the vertical forces, which are acting upward direction. So, all will be in a negative forces. And here the pressure diagram is given, the pressures are given here 1720, 1640.99 13 1532.46 and 1424.88. So, this pressure forces will be multiplied with the area. So, for V 12 the area is 0.55 into 1 which is acting on this. So, you will get 5 sorry 946.

Similarly, for V 3 the uplift force will be equal to 0.35 into 1 that is the area into 1640.09 this value so, will be getting 574. For V 14, similarly it is 3.3 metre is the length of this apron, so on this structure it will be acting. So, for this we have to multiply 1532 this value with 3.3 into 1, so that is 5057. Similarly, we can compute for V 15, so that equal to 498.7 kg and all these forces are the uplift forces are negative.

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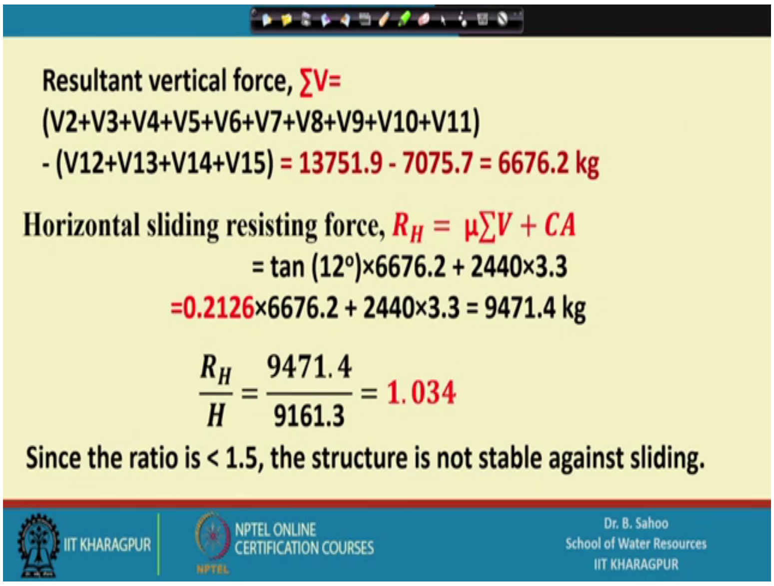

So, now you can compute what is the total resultant vertical forces which is acting on this structure. So, the total resultant forces will be equal to the sum of all this process from V 2 to V 11 minus V 12 to V 15, so that you will get as 6676 kg. Now, the horizontal sliding resisting force can be computed as we know this formula that is R H equal to mu into sigma V plus C A, so that will be equal to if you put mu equal to tan 12 degree, so will get the value as 9471.4 kg. And the ratio you can get as 9471.4 w equal to R H divided by 9161.3, so we will get 1.034 value, but this value is much less than 1.5, so because of that the structure is not stable against sliding.

So, this is very if R H equal to R that is ideal case, so in this case the ideal case is not generally prescribed. So, for that this structure you can say that is not stable against sliding. So, this ends our lecture here so, in this lecture we discussed that how to calculate the sliding condition. The stability analysis, we have carried out against sliding. So, for that you have to estimate what are the total horizontal pressure forces, total vertical forces including the uplift pressure, then take the ratio between R H and V. So, if it is greater than 1.5, then the structure is stable against sliding. Otherwise, this is not you have to redesign the structure again, so that this will be a slight stable against sliding.

Thank you very much.