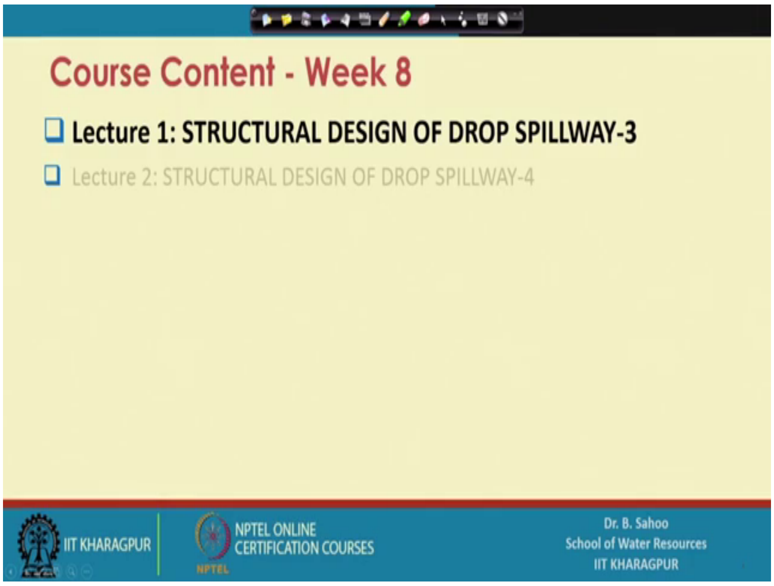
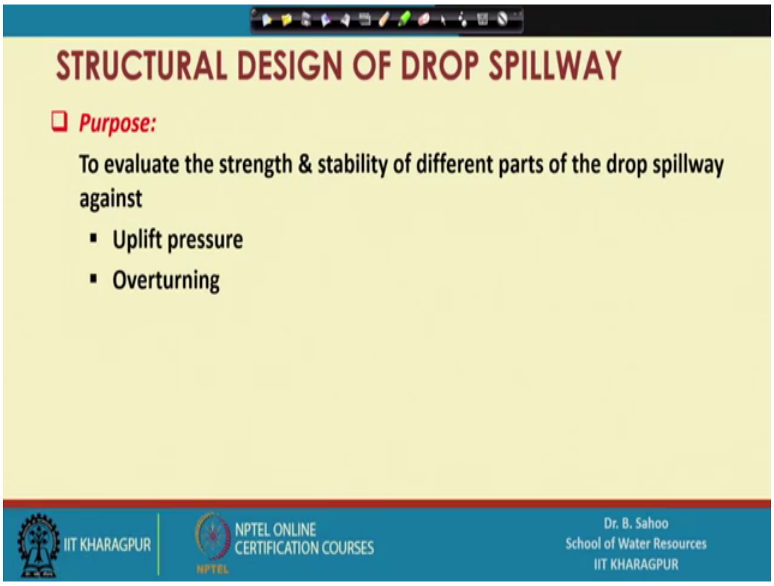
Soil and Water Conservation Engineering
Prof. Rajendra Singh
Department of Agricultural and Food Engineering
Indian Institute Of Technology, Kharagpur

Lecture-36
Structural Design of Drop Spillway – 3

(Refer Slide Time: 00:26)

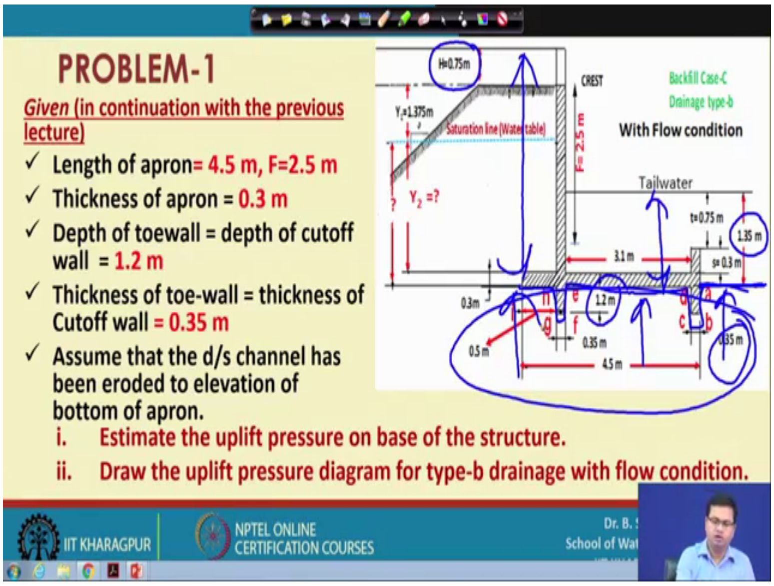


(Refer Slide Time: 00:28)



Welcome students. So, this is our next lecture on Design of Drop Spillway. So, in this lecture, we will be talking about the evolution of uplift pressure, and what is the condition of overturning, and all the things will be solving by using a example problem. So, all these problems are connected with our past lectures.

(Refer Slide Time: 00:52)



So, while solving these problems, you should remember or you should go through all the previous lectures, what I have already told to you. Suppose, we will be solving this problem, it is in continuation with the previous lecture of week 7 and lecture number 5. So, here the given length of apron is 4.5 meter, the drop is 2.5 meter, thickness of apron is 0.3 meter, depth of toewall and depth of cutoff wall there of 1.2 metre, as you can see in this figure.

The thickness of toewall and cutoff wall both are of 0.35 metre, you can see in this figure. Assume that the downstream channel has been eroded to elevation of bottom of apron that means, this channel has eroded up to the bottom of apron up to this line, so that mean this shows that the tail water is up to this depth, that is equal to 3.5 metre in this slide.

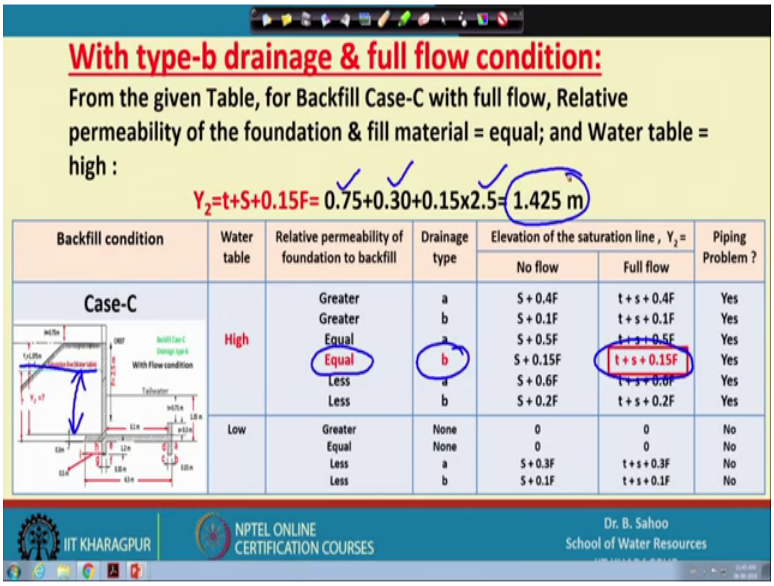
So, our question is that estimate the uplift pressure on base of the structure, and draw the uplift pressure diagram for type-b drainage with flow condition. So, before solving this type problem, first we have to clearly visualise what is given in the problem. You can see this diagram, try to understand this diagram, it is full flow condition. So, full flow condition implies that there is water above the crest. So, here the water level is given as

H is equal to 0.75 metre, and there is tail water, so that means, are the dumps inside, you have tail water, so that it is full flow condition.

So, we know that the uplift pressure is due to the soil pore pressure that means, there is standing water and because of this standing water are submerged with the pore pressure generally develops, and that is exerting pressure of what at the foundation material. So, for this, we have to use the as we have already discussed before that for solving the uplift pressure, we have to use the Lane's Creep theory, the Weighted Creep length has to be estimated, so that means, the uplift face are developed in this diagram you can see along the line a, b, c, d, e, f, g, h, and i. So, this is the contact surface between the structure and the furvius foundation material.

So, because of the standing water on the sub stream side as a large in the downstream side the pore water pressure develops in this foundation material that is why the pore pressure or the operate pressure is created are these contact surfaces of the structure and the foundation material. So, once this is clear, then we can go for calculation of the uplift pressure.

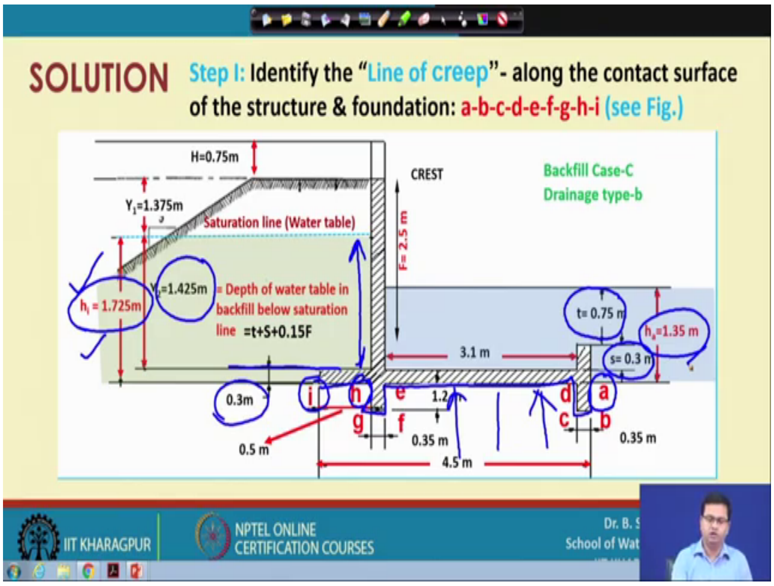
(Refer Slide Time: 04:36)



So, this is a type-b type of drainage with full flow condition. And for that you have to estimate the Y 2 the value of Y 2. You can see in this figure, the value of Y 2 what is this value of Y 2, this Y 2 is nothing but it is the depth below the saturation water table. So, this Y 2 depth is the depth or the submerged weight of this backfill material, which is computed just above the upfront and the saturation line. So, this you can estimate from the table, we have already solve this type of problem in our previous classes.

So, in this condition from this table, you can see for high water table and relative permeability of foundation backfill material equal, and type b drainage. For full flow condition, we can estimate Y 2 equal to t plus s 0.15F. So, here t is given 0.75 that is the depth of tail water, S is 0.3, and F is 2.5 meter, so we will get 1.425 meter, so that means, the height of this submerged backfill material from the top of this apron is 4 point 1.425 meter. So, by knowing this one, now we will go to our next step.

(Refer Slide Time: 06:14)



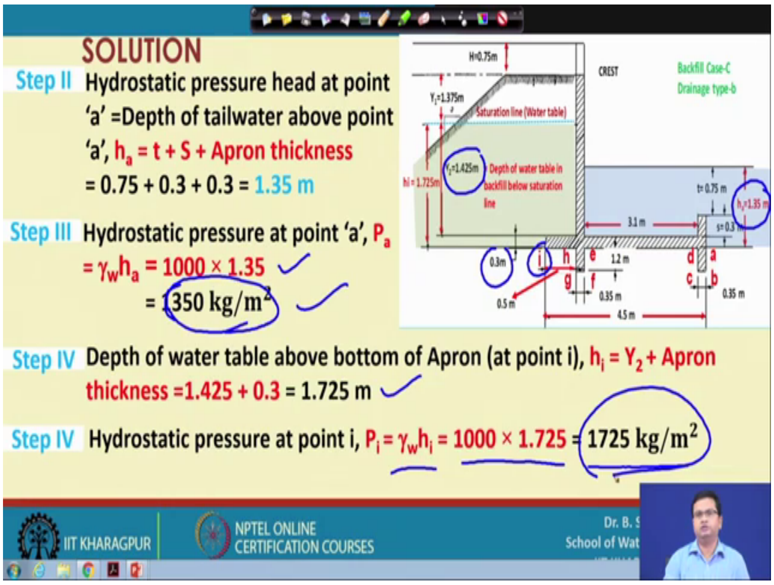
So, in this step, we have to identify the line of creep along the contact surface of the structure and foundation, which is along the line a, b, c, d, e, f, g, h, and i. So, for solving, you should understand the whole picture here. So, if can understand this whole picture here, it may differ to estimate the uplift pressure. So, as shown in this figure, we have already estimated the what is the value Y 2 that is 1.425 meter, so that is the depth of water table in backfill below saturation. And this is nothing but your submerged weight, so that means pore water pressure is created in this field material, which is up to a depth of Y 2, which is above the apron this is above the apron.

So, to get the value of h i, because we have taken our line of creep as a, b, c, d, e, f, g, h, and i, and here our contact pressure or the uplift pressure generally develops here. Here in our uplift pressure develops, which is vertically upward. So, along this line, we have to estimate what is our pressure. So, at this point i, what is my water height, so that is given by the depth h i. So, here h i you can say h i equal to 1.425 that is Y 2 plus the apron thickness of 0.3 meter, so I will get h i equal to 1.725 minute. And you know that this is our water height, so gamma w into h i that is the specific weight of water into the water height that is h i, you will get how much is your pore water pressure or the uplift pressure at point i.

Similarly, we have to estimate how much is the water pressure above the point h, g, f, e, d, c, b, and a. So, what will be the water height above point a, here it will be equal to the tail water that is 0.75 plus s that is 0.3 plus my apron thickness that equal to 0.3, so I will get h a equal to 1.35 meter. So, here the water pressure above point a will be h a that equal to 1.35 metre into gamma w that equal to 1000 kg per meter cube that is the specific weight of water.

And once these pressures are calculated at i and a, and from i to a along the line a, b, c, d, e, f, g, h, i, so this is my contact surface, and there are horizontal lines or horizontal surfaces. The horizontal surfaces are i, h, g, f, then e, d, and c, b. So, this horizontal lines will be taken as one-third of that length, so that will be the weighted length for the horizontal lines you know this Lane's Creep theory, so that is taken as one-third of the horizontal length. And the vertical or strip lengths are a, b, c, d, e, f, and g, h, and they will be taken as full. So, by using this concept, we can now go for our next calculation.

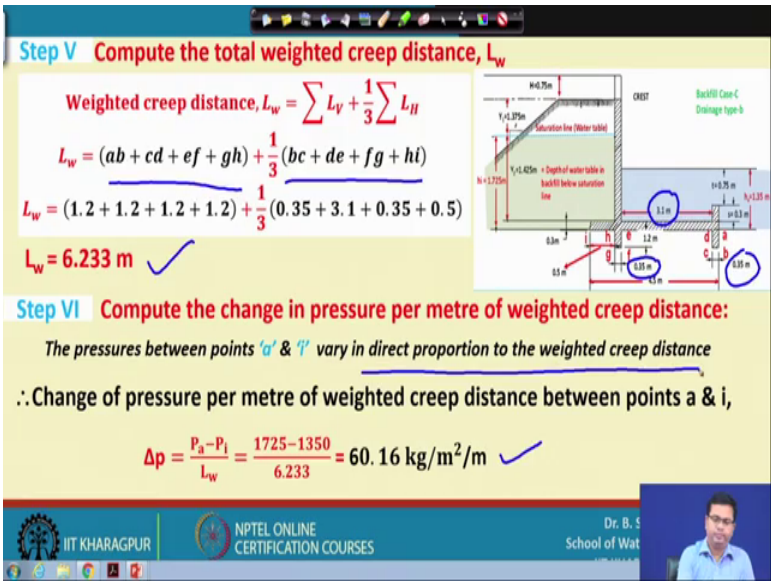
(Refer Slide Time: 10:17)



The 2nd step is that we have to estimate the hydrostatic pressure head at point a that I have already told you, so that that equal to depth of the tail water above point a, so that equal to t plus S plus apron thickness, so that equal to 1.35 meter, so this is equal to 1.35 meter. And the hydrostatic pressure at point a that is equal to P a, we can calculate as 1000 1.35 that equal to 1350 kg per meter square. Now next step is that the depth of water table above point i that will be equal to Y 2, this is my Y 2 plus the apron thickness of 0.3, so we will get 1.725 meter. And the hydrostatic pressure at point i will be equal to gamma w h i, so that equal to 1000 into 1.725, so you will get 1725 kg per metre square.

So, we can see along this contact surface a, b, c, d, e, f, g, h, i at point a, we have the pressure of 1350 kg per metre square. And at point i, we have the pressure of 1725 kg per meter square. So, once this pressure difference is there, so it is mostly the pressure is distributed proportionately at the weighted creep distance. So, we can estimate what is our weighted creep distance along the line a, b, c, d, e, f, g, h, and i. So, by getting the weighted creep distance, I can estimate what is the pressure variation or incremental pressure per unit creep distance.

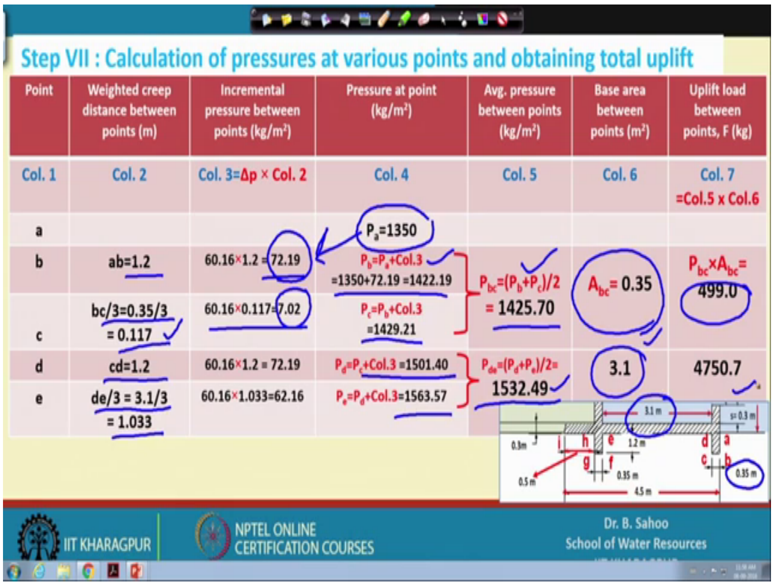
(Refer Slide Time: 12:22)



So, my first calculation will be to estimate the weighted creep distance that equal to L W, so that is equal to sigma L V plus one-third of L H, so we can get L V those are the strip lines or vertical distances. So, these are ab plus c d plus e f plus g h, and these values are 1.2, because all these depths are cut of wall toewall both are of 1.2 meter, so 1.2 into 4 you will get, so that (Refer Time: 12:49) 4.8 meter and one-third of the all the horizontal lines. The original lines are b, c, d, e, f, g, and h, i, and these values are given as 0.35, 3.1, 0.35, and 0.5 as shown in this figure. So, we will get L W equal to 6.233 meter, so that is my weighted creep distance. So, one important thing here is that the vertical distance are taken as whole and the 1 by 3 weight has been taken for the horizontal distances.

Then compute the change in pressure per meter of weighted creep distance. So, for that we have to get delta p, delta p equal to P a minus P i divided by L W, so we will be getting 60.1916 kg per metre square per metre 60.16 kg per metre square per metre length of weighted creep distance. So, this is based on the assumption that the pressure between the points a and i vary in direct proportion to the weighted creep distance. So, if you want to estimate the pressure level or the pressure for a specific creep distance, then we have to multiply delta p with that weighted creep distance, then we will get the pressure at in between points that is b, c, d, e, f, g, and h. Now, we will go for our next calculation.

(Refer Slide Time: 14:36)



So, this shows that how the pressure varies in between the points b to h, and then to get the total uplift pressure. So, first try to understand this table. The 1st column shows the points a, b, c, d, e, f, g, h, and i. 2nd column shows the weighted creep distance between points, so these are the lengths ab equal to 1.2 meter; bc that is the horizontal distance.

So, in this case bc equal to 0.35, so it will be weighted value will be divided by 3, so we will get 0.177 meter; cd is the vertical distance, so that is equal to 1.2 metre; and de is horizontal distance, so that is taken as the weighted divided by 3, so we will get 1.033 meter.

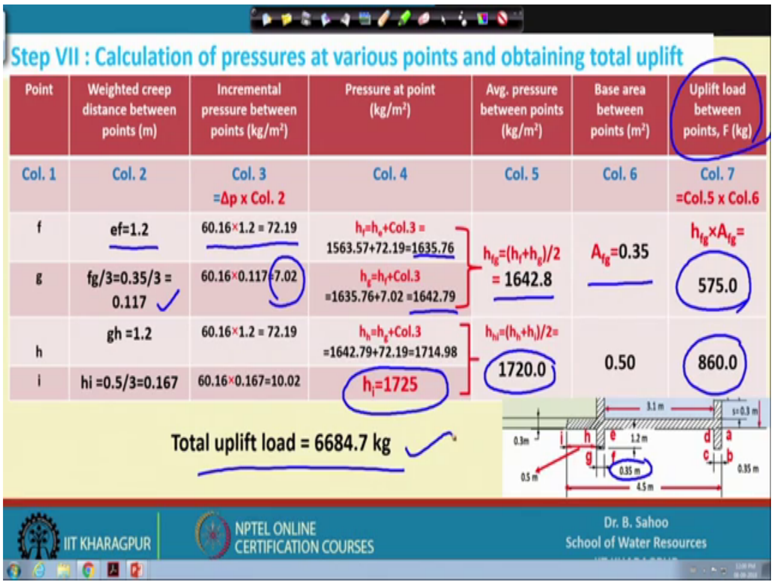
Now, our 3rd column shows that it is incremental pressure between points. So, we have the pressure at location a or at point a 1350, we have already estimated this one. So, my incremental is here delta p into column 2, so that is 60.16 our delta p value that we estimated in the previous slide into one point is our distance, so I will get 72.19 kg per metre square that means, this 72.19 kg per meter square is the incremental value on the value of P a. So, for getting P b that is pressure at point b, we will get P a value plus the value that is the incremental value estimated at column 3, so we will get 1350 plus 72.19 that equal to 1422.19 kg per metre square.

Similarly, at point c, we have the weighted creep distance that equal to 0.177 meter. So, the incremental value will be 7.02 kg per metre square. And my pressure at point c will be P b value plus this incremental value of 7.02, so we will be getting 1429.21. Similarly, can calculate for point d so, we have point d is fifteen 1501.40. And for point e, it is 1563.57 kg per meter square.

Then the average pressure between the points will be estimated as average of P b and P c, it is in between the average pressure between b and c, so that will equal to P b plus P c divided by 2, so we will be get 1425.70, because the bc is a horizontal distance. So, if the pressure, the point pressure changes at b and c, but still then the average because it is the horizontal distance, the pressure will act uniformly along this horizontal line, so that is why we can take average pressure, so that equal to 1425.70. Similarly, P de, so that equal to 1532.49.

Now, the base area for bc per unit width of the structure, so that equal to 0.35 A bc. So, you can see the length of bc equal to 0.35, so 1 meter is perpendicular to the plane of this paper, so that is equal to 0.35 into 1, so we will be get 0.35 metre square. So, pressure into the area, you will get the total force, so here you will be getting 499 kg that is your uplift load for bc along the line bc. Similarly, you can calculate for line de. So, here the base area is 3.1, you can see here 3.1, and uplift load will be this P de 32.49 into 3.1, so we will be get 4750.7. So, similarly we can go for calculation of other points.

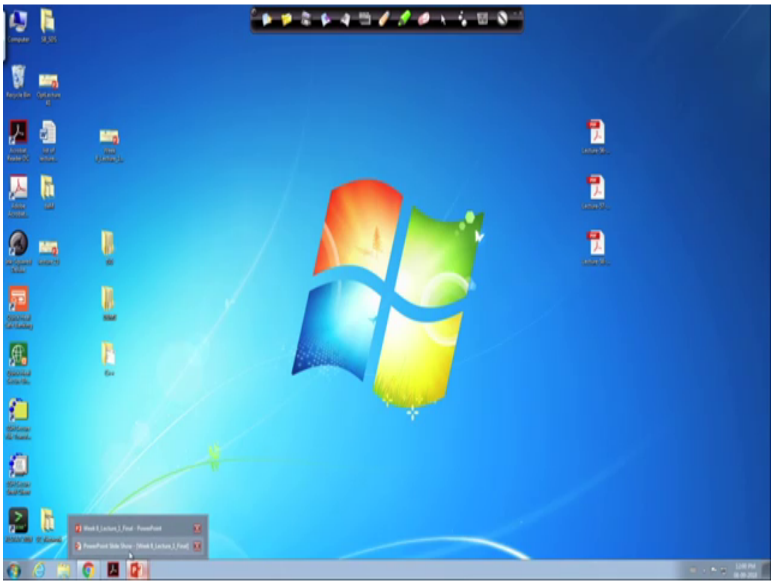
(Refer Slide Time: 19:24)



The next slide shows our calculation for the points f, g, h, and i. So, here you can see ef is a vertical line, so it is 1.2 meter. Similarly, you can estimate our incremental pressure that equal to 72.19 kg per meter square. And h f is estimated 1635.76 that equal to h e plus column 3. And the average pressure is estimated as 1642.8 kg per meter square. A fg equal to 0.35, you can see here it is 0.35. And multiplication of this column 5 with 6, we will get 575 kg that is our uplift load. Similarly, for fg the weighted creep distance is 0.177, and here we will get incremental load as; our incremental pressure as 7.02 kg per meter square. So, pressure at point g, you will be getting 1642.79.

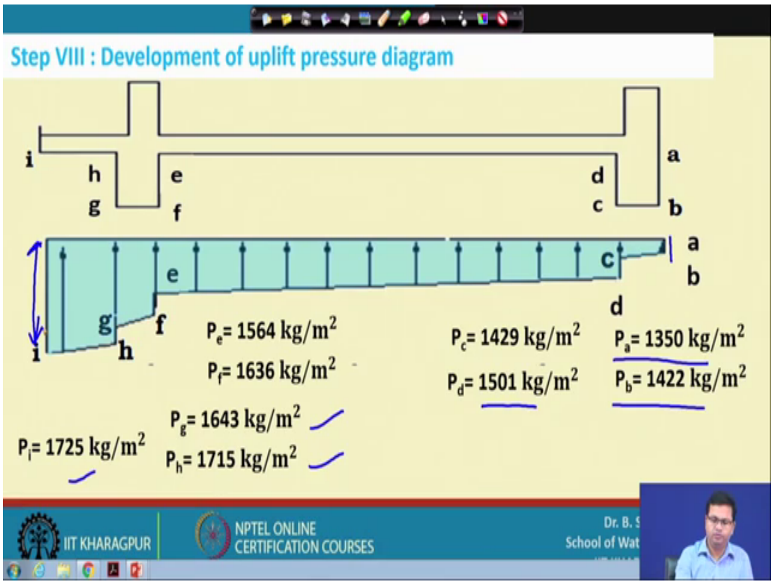
Similarly, for gh, we are getting uplift load as 860. And my average pressure as 1720, and finally, you can say h i that the pressure at point i is 1725 kg per metre square that we have already estimated before. So, total uplift load will be summation of all these f values, so that is coming as 6684.7 kg. So, by knowing the pressure at different points, we can develop our pressure diagram, because that is our second question second bit of the question, so we can develop our pressure diagram.

(Refer Slide Time: 21:18)



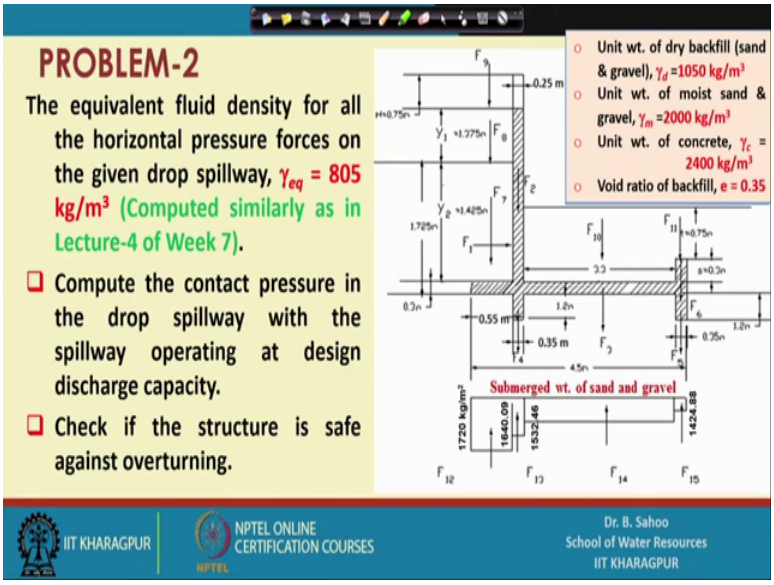
Sorry.

(Refer Slide Time: 21:32)



So, this shows our uplift pressure diagram. You can say all these values have been computed P a, we have estimated 1350, P b 1422. So, here P a the length is 1350, then P b is 1422, P c 1429, P d 1501, P e 1564, P f 1636, P g just 1643, P h 1715, and P i 17.25 kg per metre square, so that means, this length is or this value is 1725 kg per metre square. So, by knowing these pressure values, we have developed our uplift pressure diagram.

(Refer Slide Time: 22:35)



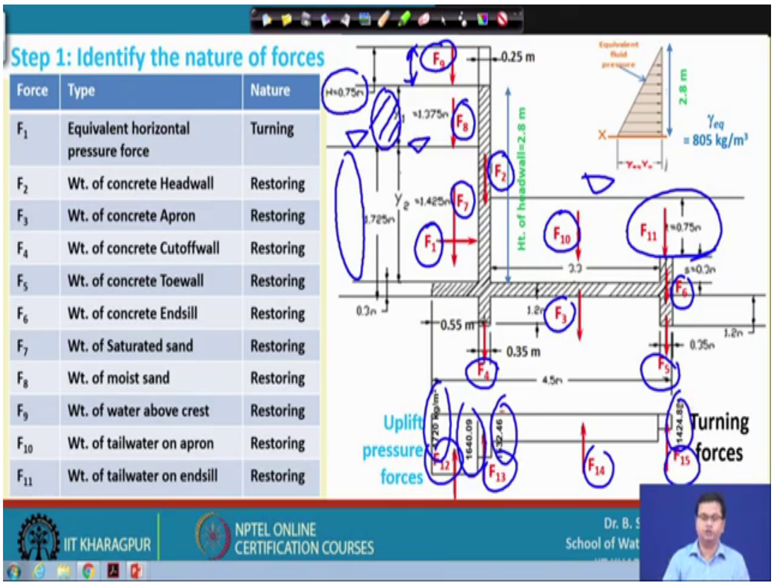
Now our next problem will be to calculate whether the structure is safe against overturning or not. So, all these competitions have been taken forward from the previous lectures. So, this is a problem, which we have already solved in lecture 4 of week 7 in similar way you can solve it. And those pressure calculations or force calculations can be followed those type of pressure calculations, the same procedure we can follow also in this lectures, because we cannot repeat those things to save our time.

So, now try to understand the problem the equivalent fluid density for all the horizontal pressure process on the given drop spillway equal to 805 kg per meter cube. You will remember in our lecture 4 of week 7 that we have estimated what is our horizontal pressure load, then the whole pressure horizontal pressure is converted into equivalent fluid pressures, which is having a weight density specified density of 805 kg per metre cube. So, you have to correlate this problem with those that class.

Now, second is compute the contact pressure in the drop spillway with the spillway operating at design discharge capacity, design discharge capacity means it is flowing full the flow condition is full flow condition. Check if the structure is safe against overturning. You know that why the overturning occurs, the overturning occurs because of our horizontal pressure process, and the uplift pressure process, which is acting upward and that is counted by our vertical forces. And the vertical forces are because of the weights of water on the structure as well as the backfill material.

So, by using this, we have to estimate the bending moment, the moment along some reference axis that I will talk about here. Then you have to say whether the structure is safe against overturning or not. Here the given values of unit weight of dry back filler gamma d that equal to 1050 kg per metre cube, unit weight of moist sand and gravel are 2000 kg per metre cube, and that of concrete is 2400 kg per meter cube, void ratio of backfill that equal to 0.35.

(Refer Slide Time: 25:19)

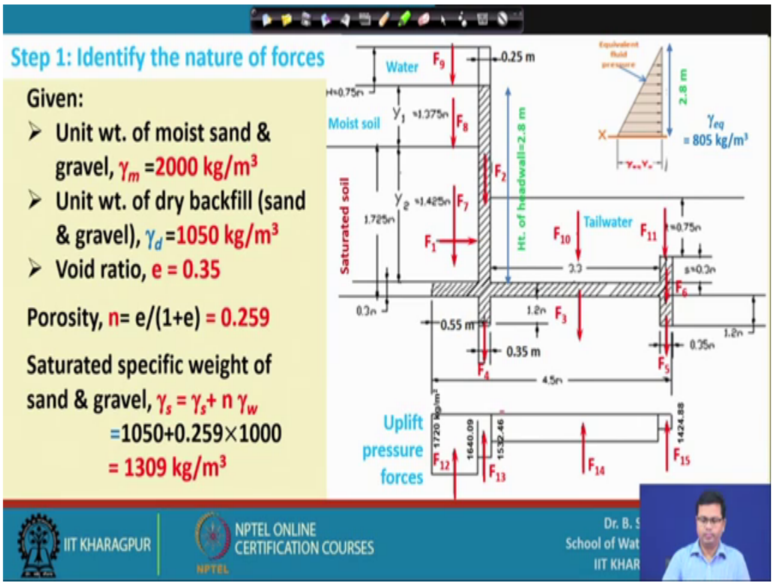


The first step is that identify the nature of forces. So, these are all the force diagram, we have already done in our previous classes, how to estimate the different forces by using our phaser triangles. So, here you can see in this figure, there are total 15 forces acting. Among this 15 forces F 1 is the equivalent horizontal pressure force. So, F one is the equivalent horizontal pressure force, which has to be estimated as you have done before in the previous lecture that is lecture 4 of week 7. Then F 2 so, this F 1 force it is horizontal, so it is a turning force, it is the moment is turning in nature. F 2 that is your weight of concrete headwall, you can say F 2 is our weight of concrete headwall. You know the concrete density, and the area you can calculate for unit depth or unit width, so that you can get volume, so you can estimate what is the force.

Then F 3 is weight of concrete apron. F 4 is the weight of concrete cutoffwall; these are cutoffwall. F 5 is for toewall. F 6 is for concrete endsill. F 7 is weight of saturated sand, because in this condition by you will consider the drainage type-b, you know that this is my water table, so this soil will be saturated one. So, for this you have to estimate what is the value of Y 2, hear it is 1.425 meter, so that is my F 7. What is F 8? F 8 is the weight of moist sand. You can see this is weight of moist sand, because our water is here, so water table is here, so naturally this soil or backfill metal will be moist sand.

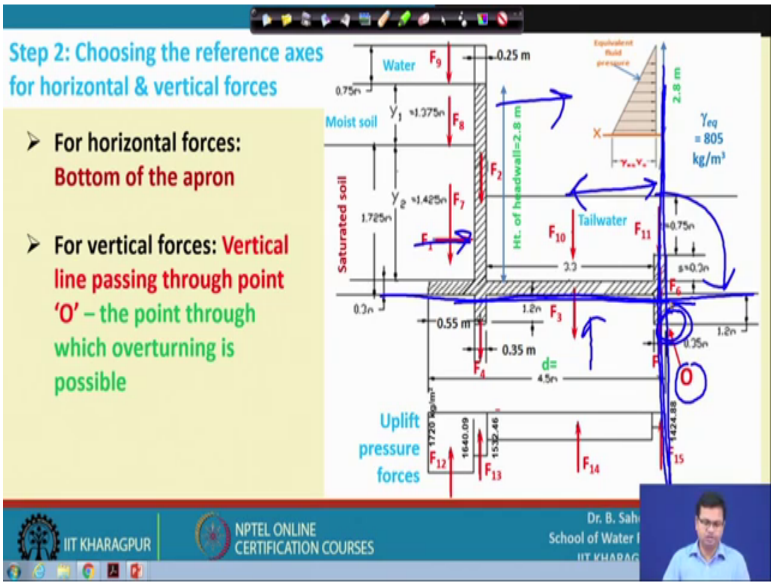
F 9 is weight of water above crest. So, this is the weight of water above crest, because the water is flowing full, which is having a height of 0.75 meter. Then F 10 is weight of tailwater on apron. This is F 10, because this is our tailwater, and this is our water pressure. Then F 11 is weight of tailwater on endsill, because some weight is also above the endsill, so that is my F 11. And F 12, F 13, F 14, and F 15, these are all operate face of the just we have completed in our previous problem. And the pressure values are given already here all these values are mentioned here, so we can estimate what is the pressure process.

(Refer Slide Time: 28:30)



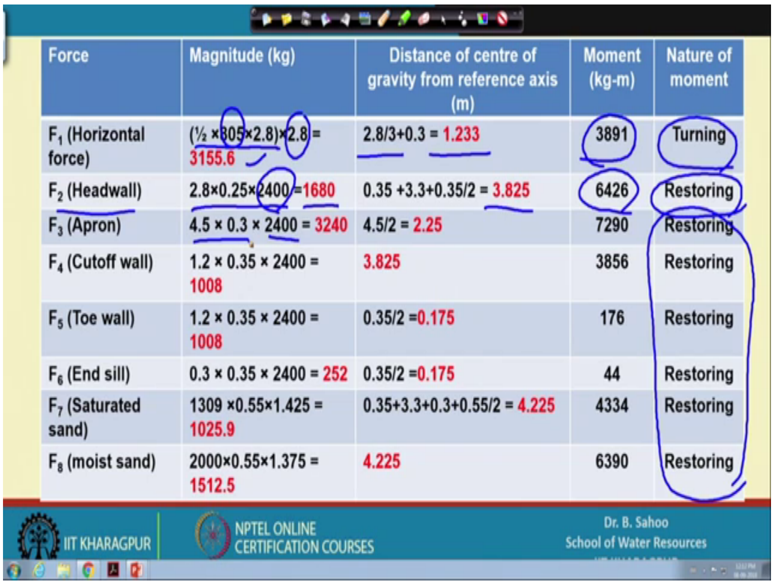
Now, next step is that we have to calculate what is the porosity, because the void ratio is given, so porosity equal to e divided by 1 plus e, void ratio equal to 0.35, so we will get point 0.259. And the saturated width specific weight of sand and gravel will be equal to gamma s plus n gamma w, because up to level Y 2 we can see in this figure up to level Y 2, our soil is saturated. And in the saturated soil how much water is there, so the water is filled in the void spaces or the pore spaces. And porosity is 0.259 that is equal to 25.9 percent, so that means, 25.9 percent of the soil force are having filled with water. So, we will be multiplying 0.259 1000, that is the specific weight of water 1000 plus gamma s is the that is the dry weight, so that is 1050, so we will get 1309 kg per metre cube.

(Refer Slide Time: 29:51)



Now, you have to choose the references axes for horizontal and vertical forces. So, in this figure, we have to choose the reference axes. So, here I am putting taking this downstream location, this is the O, this is my reference point, because of this horizontal forces and this upward forces, the turning will occur along this point, so that is why I have taken this o point as my you can say reference point. And I will be taking a reference line along this downstream edge that is for your horizontal forces, because I have to compute the momentum, so that is for my all these vertical forces. For all the vertical forces, this is my axes reference axes, and for all the horizontal forces like F 1 my reference axis is the base of this apron, so that the base of this apron, so this point as taken as my reference point. So, next then I will calculate all the distances along this line.

(Refer Slide Time: 31:10)



Force	Magnitude (kg)	Distance of centre of gravity from reference axis (m)	Moment (kg-m)	Nature of moment
F_1 (Horizontal force)	(½ ×805×2.8)×2.8 = 3155.6	2.8/3+0.3 = 1.233	3891	Turning
F_2 (Headwall)	2.8×0.25×2400 =1680	0.35 +3.3+0.35/2 = 3.825	6426	Restoring
F_3 (Apron)	4.5 × 0.3 × 2400 = 3240	4.5/2 = 2.25	7290	Restoring
F_4 (Cutoff wall)	1.2 × 0.35 × 2400 = 1008	3.825	3856	Restoring
F_5 (Toe wall)	1.2 × 0.35 × 2400 = 1008	0.35/2 =0.175	176	Restoring
F_6 (End sill)	0.3 × 0.35 × 2400 = 252	0.35/2 =0.175	44	Restoring
F_7 (Saturated sand)	1309 ×0.55×1.425 = 1025.9	0.35+3.3+0.3+0.55/2 = 4.225	4334	Restoring
F_8 (moist sand)	2000×0.55×1.375 = 1512.5	4.225	6390	Restoring

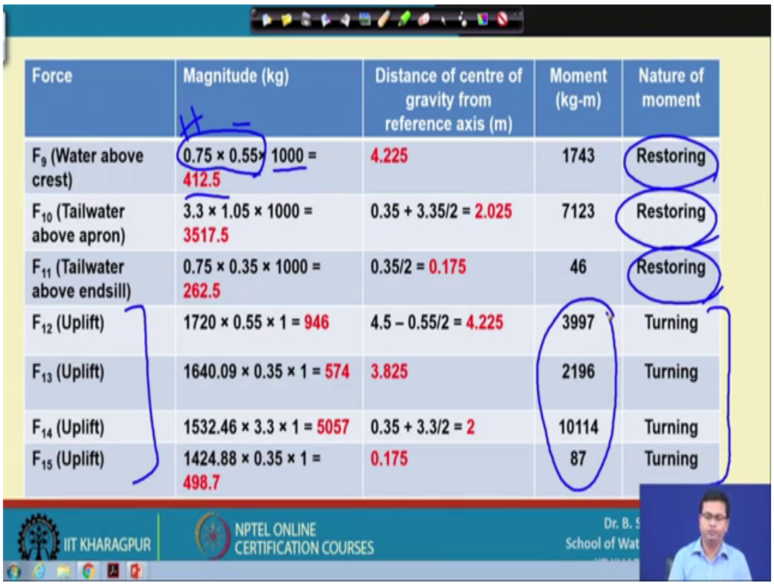
Now, I have to fill up the table right now here. I have to estimate what is my force F 1, F 2, F 3, F 4, F 5 all these, and what is the magnitude. You know that the force is equal to the pressure into the area that pressure triangle, so that is estimated as for F 1, because this is equivalent fluid pressure, so it is half into 805 my gamma equivalent into 2.8 is the height of the that equivalent pressure. So, you can see from the previous figure, so into the height again 2.8, so that I am getting 1355.6.

And the distance centre of gravity from reference axes is 1.233 meter, so that is equal to 0.3, so that is the base of the apron, the thickness of the apron plus 2.8 is the height divided by 3, because the centre of gravity will acts at a distance one-third of the height from the base. So, the moment will be the magnitude into the distance, so I am getting here 3891 that is my turning moment, because there is a horizontal force, and it is causing turning moment.

F 2 is for headwall. And here the magnitude will be equal to area into the weight density of the concrete that is 2400, so I am getting 1680. And the distance of centre of gravity from reference axis is 3825 that you can estimate by looking at that figure. And the moment is 6426, which is restoring in nature, because this is the vertical force.

Similarly, F 3, F 4, F 5, F 6, F 7, and F 8 all are vertical forces and these are having the nature that is your restoring in nature, because these are vertical forces. And these forces can be estimate similarly, which is gamma w or gamma that is the specific weight of concrete into the area of the pressure triangle. And this is the distance of the centre of gravity, so that you can follow the figure and you can compute all these distances, and you can do the calculations subsequently.

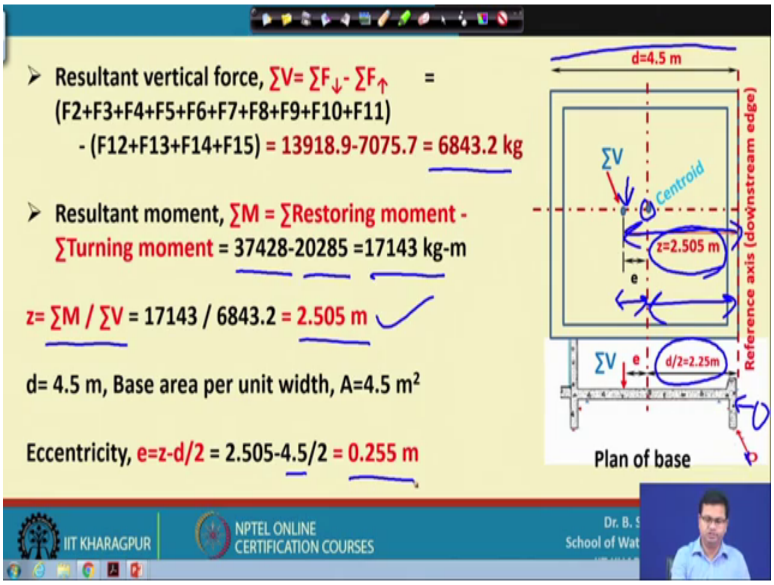
(Refer Slide Time: 33:51)



Force	Magnitude (kg)	Distance of centre of gravity from reference axis (m)	Moment (kg-m)	Nature of moment
F_9 (Water above crest)	0.75 × 0.55 × 1000 = 412.5	4.225	1743	Restoring
F_{10} (Tailwater above apron)	3.3 × 1.05 × 1000 = 3517.5	0.35 + 3.35/2 = 2.025	7123	Restoring
F_{11} (Tailwater above endsill)	0.75 × 0.35 × 1000 = 262.5	0.35/2 = 0.175	46	Restoring
F_{12} (Uplift)	1720 × 0.55 × 1 = 946	4.5 – 0.55/2 = 4.225	3997	Turning
F_{13} (Uplift)	1640.09 × 0.35 × 1 = 574	3.825	2196	Turning
F_{14} (Uplift)	1532.46 × 3.3 × 1 = 5057	0.35 + 3.3/2 = 2	10114	Turning
F_{15} (Uplift)	1424.88 × 0.35 × 1 = 498.7	0.175	87	Turning

Now, coming to the uplift pressure similarly, you can do for water above crest for water above crest that is F 9. So, the density is gamma w that equal to 1000 kg per metre cube, and this is my area 0.75 is the height of water into 0.55 is the distance or the that is the length of the apron on which this pressure is acting, so that is we will get a rectangular type of pressure diagram. So, in this case, you will get F 9 as 412.5. And similarly, this is restoring. F 10 is also restoring, F 11 that is tailwater above endsill that is also restoring in nature. And all these uplift pressure that is F 12 to F 15 all are turning in nature, so that we have already estimated in our previous problem. And the moment values are given here calculated like this, so you can try on your own.

(Refer Slide Time: 35:05)

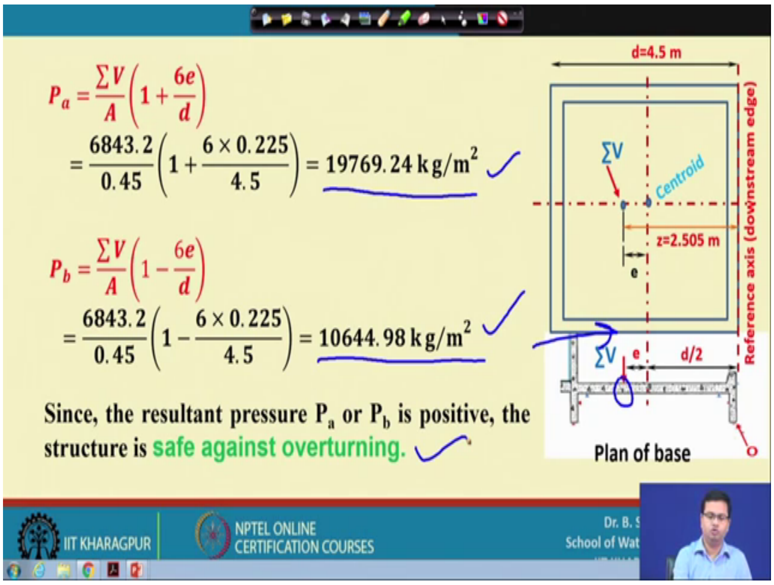


Now, the resultant vertical force will be sigma V, so that is equal to sigma the vertical forces, which is causing downward minus the summation of vertical forces, which are upward, so we will get as 6843.2 kg. And the resultant moments sigma M will be equal to restoring moment minus sigma turning moment, so that is equal to 37428 minus 20285, so that equal to 17143 kg metre that we have taken from the previous table.

So, z value will be getting sigma M divided by sigma V, so that equal to 2.505 metre. So, what is this z value, if you remember in the previous lecture, we have already discussed. So, this figure if you look at this figure is the plan of base, and we have taken O as here not here, but here it is O, and my reference axis is downstream edge, and the this is the my centroid point, this is d by 2 that is equal to 4.5 metre. And here z is equal to 2.505, which is just exceeding the centre point or the centroid axis from this reference axis. So, this is my 2.505 metre. But, d by 2 equal to 2.25 metre, and this is my eccentricity.

And all these vertical resultant vertical forces are acting at this location. So, this eccentricity is estimated as here in this figure, it is this whole distance is z, this is d by 2, so e will be equal to z minus d by 2, so that equal to z we have estimated as 2.505, and d is equal to 4.5, so we are getting 255 metre, so that is my eccentricity.

(Refer Slide Time: 37:21)



Now, we know the formula that is the pressure sigma V divided by A whole into 1 plus minus 6 e divided by d. So, if we will take plus symbol and put the values, you can get P a equal to 19769.24 kg per metre square. And for 1 minus 6 e divided by d, you are getting 10644.98 kg per metre square. So, all these values are positive values. Since, these values are positive, here pressure P a or P b both are positive, so the structure is safe against overturning. And all these vertical forces are acting here. So, if the overturning forces are acting here, then they are not able to overturn this structure. So, this is the condition for overturning, so that our structure is safe against overturning.

So, in this lecture, we have estimated how to compute a uplift pressure, and what is the condition of overturning. For the overturning, what are the horizontal moments or the restoring the turning moments, and the restoring moments by equating those, we can estimate our eccentricity. And based on that we can estimate what is the, whether our pressures are positive or negative. If it is the pressures are positive, then you can tell that the structure is safe against overturning.

So, for all these when we are going for solving all these problems, first we have to know that how to; first we have to understand the problem that means, the pressure diagram is very much important, the force diagram is very much important. Because, based on the force diagram, you can estimate what is my pressure, what is the area of this pressure triangles then the force will be equal to area into the pressure. Then at what location the centre what is the location of centre of gravity, so that you can estimate the moments of the special forces, then we can equate the moments. So, we are ending here, in our next lecture will be on specifically how to prevent from sliding, we have to design for sliding.

Thank you.