Soil and Water Conservation Engineering
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Lecture – 34
Structural Design of Drop Spillway – 1

Hello students, welcome to the 4th lecture on the Design of Drop Spillway.

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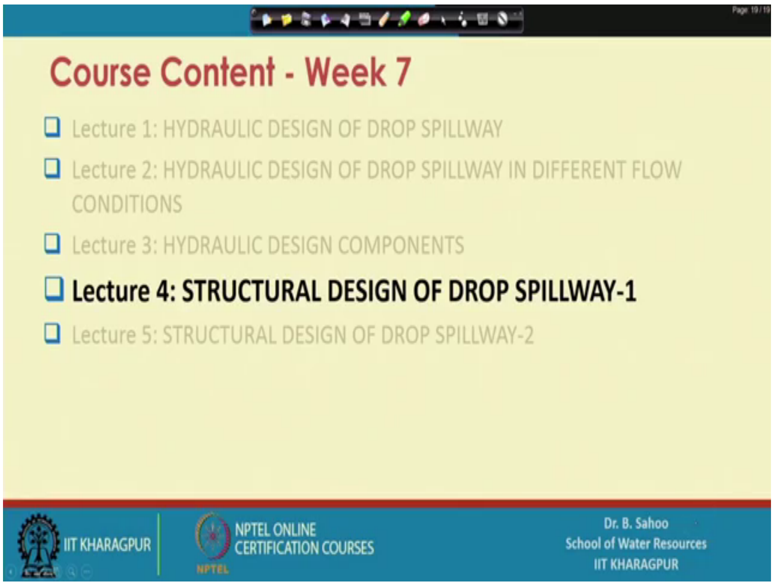

In this series, this is our fourth lecture and I will be discussing of part 1 of this design.

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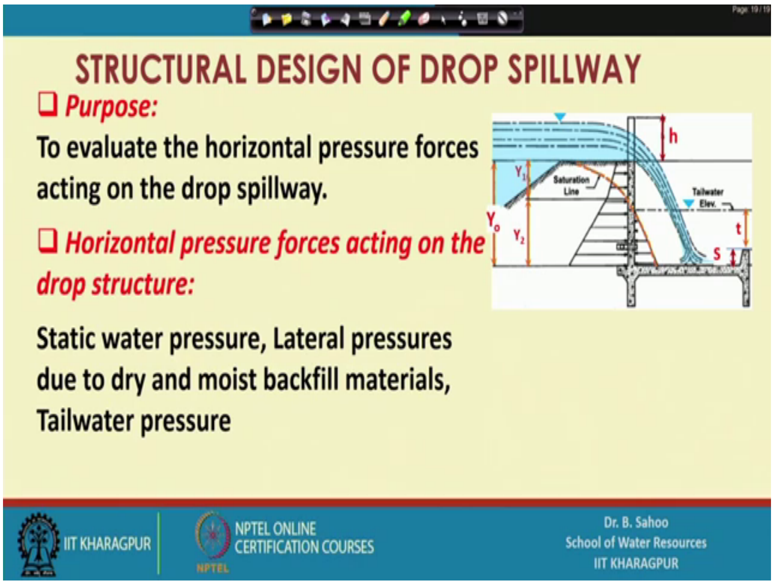

So, the main purpose of this lecture is to evaluate the horizontal pressure forces acting on the drop spillway. You know that for evaluating the stability of any structure, we need to estimate what are the different pressure forces acting on this drop structure?

So, here we will be a estimating the different horizontal pressure forces which may be because of the static water pressure, the lateral pressures due to dry and moist backfill materials and the tail water pressure you can see this figure the tail water pressure. If there is tail water, then some negative pressure is created which is opposite in direction as compared to that of the static water pressure at the upstream side and lateral faces due to dry and moist backfill materials.

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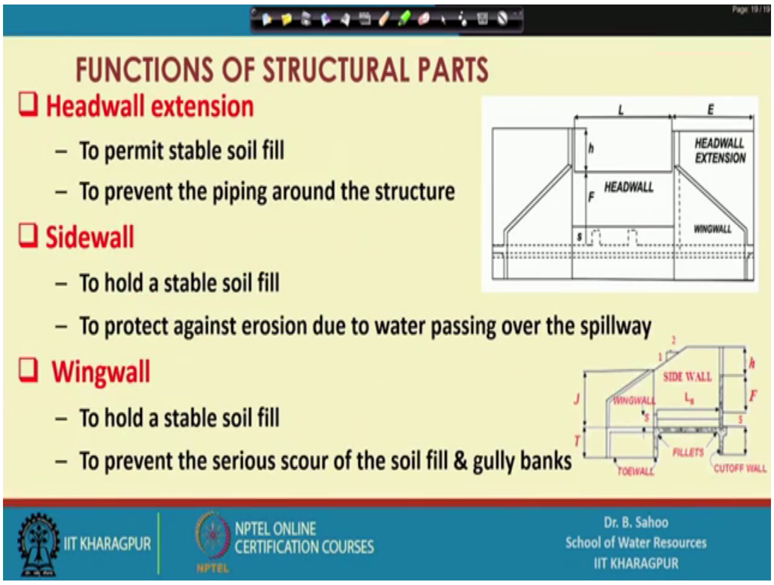

So, before that, you should know what are the different functions of different structural parts of this drop structural? So, we have headwall extension it mostly permits stable soil fill, it prevents the piping around the structure. So, the piping failure is avoided by this, the sidewalk holds a stable soil fill protects against erosion due to water passing over the spillway, the wing wall holds a stable soil fill and also prevents the serious scour of the soil fill and gully banks.

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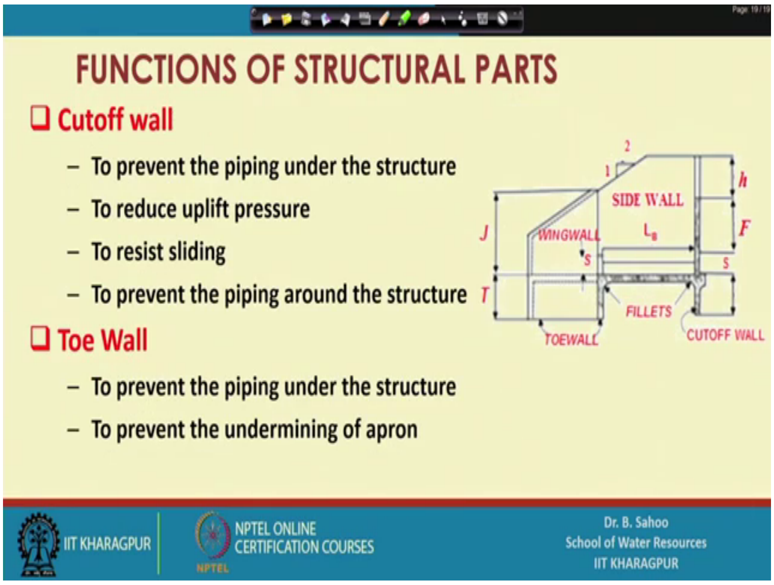

Similar, the cutoff wall prevents the piping under the structure, generally, the piping occurs because of water pressure in the upstream side here. It exerts water pressure and because of that the water is emitted through this contact surface of this cut off wall and toe wall to arise at the downstream section like this. So, cut off if the cutoff wall depth is more than generally, the piping failure is avoided**.** Then, to reduces the uplift pressure, it resist sliding prevents the piping around the structure and the toe wall also prevents piping around the structure and prevent undermining of apron.

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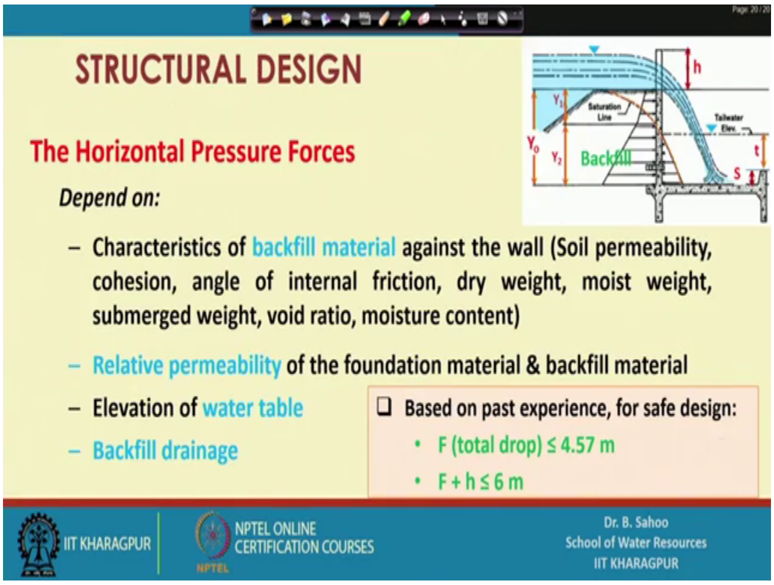

The horizontal pressure forces generally depend on the characteristic of backfill material against the wall, soil, permeability, cohesion, angle of internal friction, dry weight, moist weight, submerged weight, void ratio and moisture content. Then, relative permissibility of the foundation material and backfill material elevation of water table and the backfill drainage based on past experience for safe design, generally the total drop is considered as less than equal to 4.57 meter, but in general cases we allow maximum 3 meter and F plus h should be less than equal to 6 meter.

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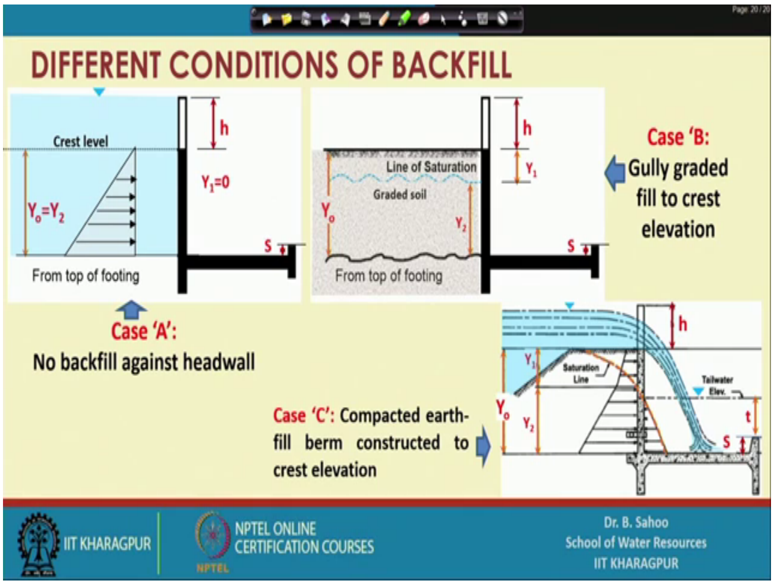

So, before estimating the different horizontal pressure forces, we should know what are the different conditions of backfill. So, generally we consider three cases of backfill as shown in this figure the case A so, that the no backfill against headwall. So that means, there is no backfill and the depth Y 0 a shown in this figure is equal to the water depth which is below the crest level. And the middle figure shows the case B which is for gully graded fill to crest elevation so that means, the gully is graded up to the crest elevation.

So, in this case you have to estimate a way to know first what is the line of saturation? You can see this the line of saturation is at a depth of Y 1 from the crest and after knowing this Y 1, you can estimate what is the value of Y 2 that equal to here Y naught minus Y 1 so, that equal to Y 2. So, this is the case B condition and case C condition is for compacted earth fill constructed to crest elevation. You can see here there is in this case there is tail water, the tail water depth is given as t plus S and the saturation line is shown here this is saturation line and where it is touching the head wall so, that is my depth Y 1. And below the saturation line, the depth below to the bottom of this foundation is Y 2 such that Y 1 plus Y 2 equal to Y naught and h is my depth of weir.

So, for designing, for estimating the horizontal pressure process, you have to know this value that is Y 1, Y 2, Y naught t and S. So, once this values are known, we can estimate what are water my pressure forces. So, we should do remember this three cases case what is case A, what is case B and what is case C?

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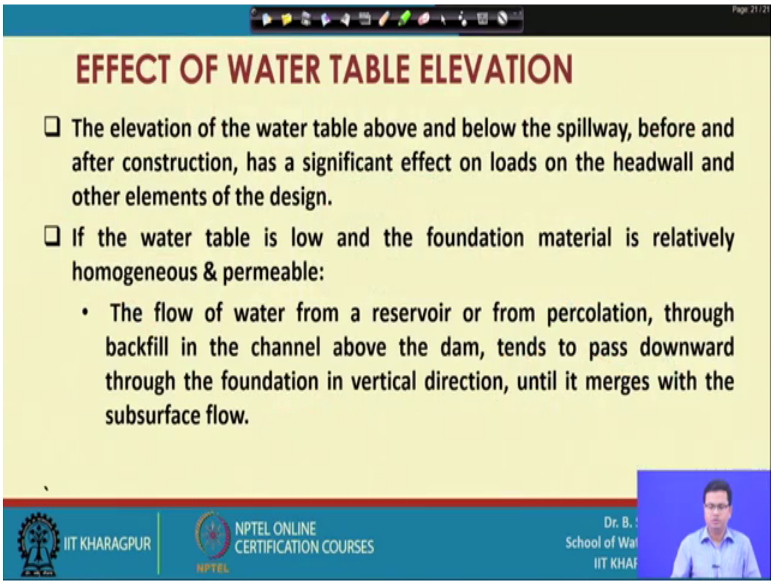

Now, coming to the effect of water table elevation, the elevation of the water table above and below the spillway before and after construction has a significant effect on loads on the head wall and other elements of the design. If the water table is low and the foundation material is relatively homogeneous and permeable, the flow of water from a reservoir or from percolation, through backfill in the channel above the dam, tends to pass towards through the foundation in vertical direction, until it merges with the subsurface flow.

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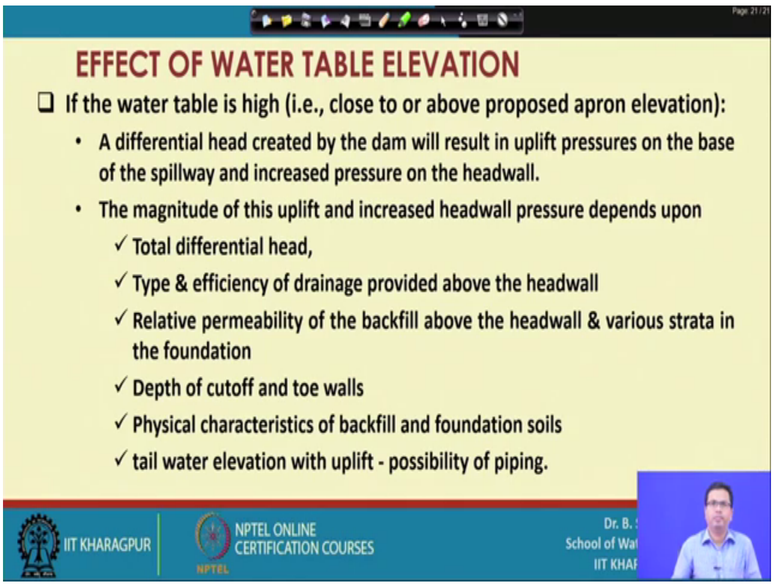

And if the water table is high which is close to or above proposed approach apron elevation, so in this case, a differential head created by the dam of water will result in uplift pressure on the base of the spillway and increased pressure on the head wall.

Then, the magnitude of this uplift and increased headwall pressure depends upon various conditions like the total differential head, type and efficiency of drainage provided above the head wall, relative permeability of the backfill above the head wall and various strata in the foundation, depth of cut off and toe walls, physical characteristics of backfill and foundation soils and tail water elevation with uplift and in this case the possibility of piping.

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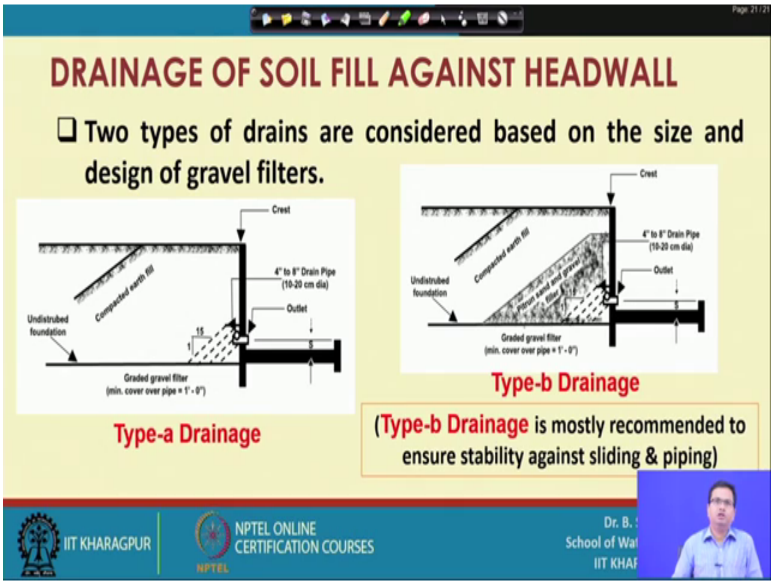

So, for that we have to provide different drainages. You can see from this figure there are different drainages are provided on basically reserve of two types; one is type small a and type small b and types small b is mostly recommended to ensure stability against sliding and piping failure.

So, here you can see in case of type a, this is a graded gravel filter and the outlet is given here and this is your backfill material which is compacted earth fill here and in case of type b the outlet is given here and there is pitrun sand and gravel filter are shown in this case. So, in most of the cases, type b is recommended.

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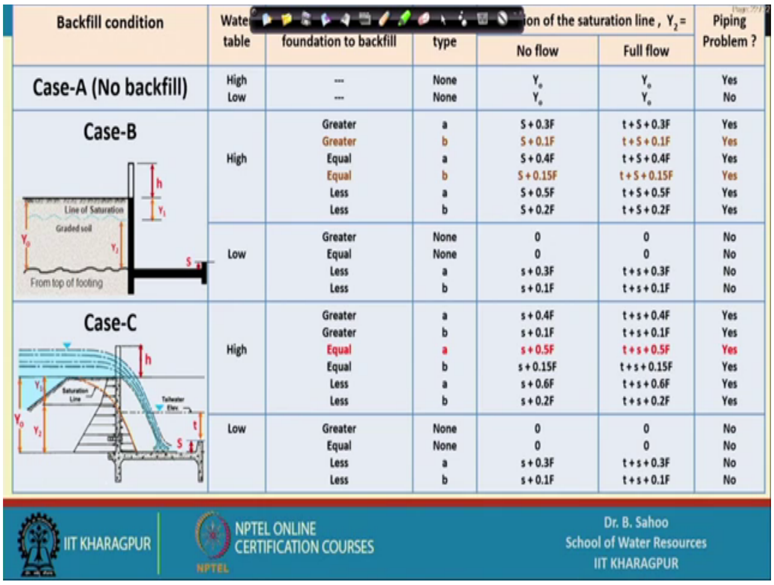

Backfill condition	Wate table	foundation to backfill	type	ion of the saturation line, Y_2 = No flow	Full flow	Piping Problem ?
Case-A (No backfill)	High	---	None	Y_o	Y_o	Yes
	Low	---	None	Y_o	Y_o	No
Case-B	High	Greater	a	S + 0.3F	t + S + 0.3F	Yes
		Greater	b	S + 0.1F	t + S + 0.1F	Yes
		Equal	a	S + 0.4F	t + S + 0.4F	Yes
		Equal	b	S + 0.15F	t + S + 0.15F	Yes
		Less	a	S + 0.5F	t + S + 0.5F	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
Case-C	High	Greater	a	s + 0.4F	t + s + 0.4F	Yes
		Greater	b	s + 0.1F	t + s + 0.1F	Yes
		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

So, for designing, you have to know this table, so, there are three cases as we have discussed for back fill condition case A, back fill condition case B and backfill condition case C and the water table condition can be high or low as we have discussed, then 3rd column shows the relative permeability of the foundation material to backfill. Then next column shows the drainage type, so, type small a or type small b, generally we have already discuss that is type small b is most recommended and the elevation of the saturation line that is Y 2.

You can see from this figure Y 2 is the elevation below the saturation line and that can be estimated under no flow and under full flow condition. Under no flow condition, Y 2 equal to Y naught for case a and for full flow condition also Y 2 equal to Y naught. And for high water table and depending on different type of foundation relative [per/permeability] permeability of foundation to backfill, you can estimate what is the value of Y 2 from this figure and here S is the depth of end sill and F is the total fall and this t S and a values are given and accordingly you can see whether there is piping problem or not. If it is yes, then there is piping flow piping problem and if there is no, there is no piping problem.

So, depending on that condition, you can select what is the value of Y 2? Your design value of Y 2, so while selecting Y 2 suppose I have highlighted here the red one for equal permeability condition and type your drainage no flow condition. So, Y 2 will be S plus

0.5 F and for full flow condition Y 2 will be equal to t plus S plus 0.5 F and in this case, there is a piping problem in case of full flow in case of C condition of backfill so, you may get tail water. So, here the t process is the depth of tail water; fine by knowing all these things from the table, so you can estimate what is your horizontal pressure forces? So that means, you have to know this table, without this table, you cannot design or you cannot estimate the horizontal pressure forces.

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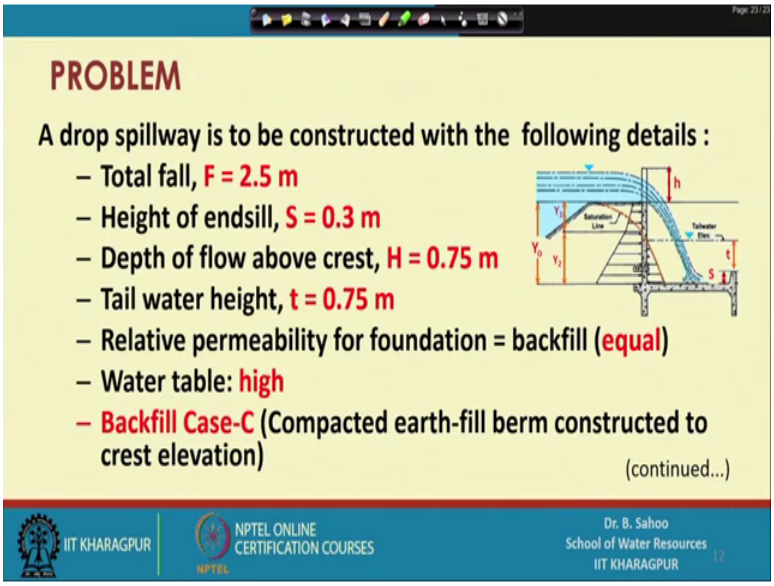

Now, everything will be clear if will solved a problem. This typical problem, a drop spillway is to be constructed with the following details. Total fall is given as 2.5 meter, height of endsill, S equal to 0.3 meter, depth of flow above crest that equal to capital H is given as 0.75 meter, tail water height small t that equal to 0.75 meter, relative permeability for foundation equal to backfill.

So that means, you have to use the equal condition as you have seen in the previous table water table is high and backfill case is C that is compacted earth fill berm constructed to crest elevation. So, all these values has to be used in the previous table as I have shown to find out what is the value of Y 2 and by considering the Y 2 value as shown in this figure, you can go for estimating the value of Y 1, Y naught and t plus a that is your total tail water height above the apron, then I can estimate what is my pressure forces.

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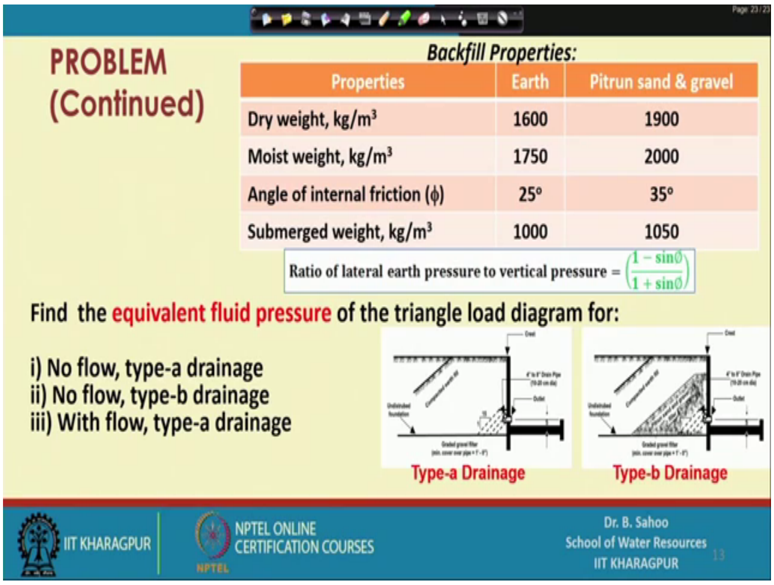

And what else you need, so, for this, the given values of backfill properties are for dry weight for earth is 1600 k g per meter cube, pitrun sand and gravel 1900 that is mostly used for drainage type b, moist weight is 1750 for earth, for pitrun sand and gravel it is 2000, angle of internal friction 25 degree for earth pitrun sand and gravel it is 35 degree submerged weight for earth is 1000, And for pitrun sand and gravel it is 1050 and one you should know that this is the formula that is ratio of lateral earth pressure to vertical pressure equal to 1 minus sin phi divided by one plus sin phi where phi the angle of internal friction.

So, here vertical pressure is nothing but that is the total weight of the earth. So, weight can be computed by using the density of dry weight or moist weight then phi is known. So, by using that you can estimate what is the value of the lateral earth pressure? So, the question that find the equivalent fluid pressure of the triangle load diagram for no flow type a drainage, no flow type b drainage and with flow type a drainage? So, in this figure you can see this is type first one is a type a drainage and second one is a type b drainage in which case you have used pitrun sand and gravel filter.

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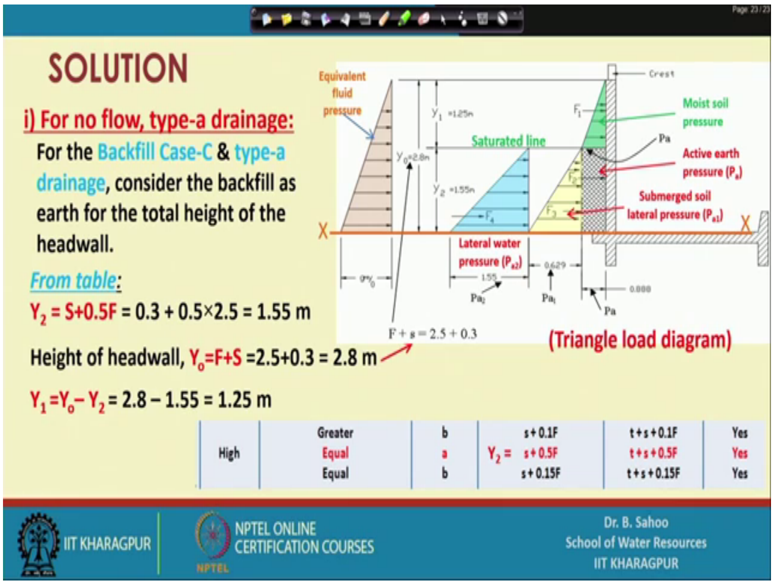

So, once these are clear, so now, you can go for designing. So, this figure shows a triangle load diagram the pressure forces are generally estimated as, pressure that equal to gamma pressure is extended gamma into h you know this h is your height of any soil fill or water gamma is the specific weight. Then you have to estimate what is the pressure diagram in this the pressure triangle what is the area of this pressure triangle, then you can estimate what is the total force from this?

So, here you can see that the different forces acting on this, F 1, F 2, F 3, F 4 and the question was that you have to estimate the total lateral pressure forces in terms of equivalent fluid pressure. So, this the main criteria, you have to understand this problem may be attentively. So, come no flow and type a drainage, for the backfill case C and type a drainage considered the backfill as earth for the total height of headwall.

So, in this case you have to follow the table, whatever table I have shown, so, this table are given I have cut a portion of that. So, here you have to design for equal permeability condition, drainage type small a and in this case for no flow condition, I am getting Y 2 equal to S plus point 5 F and this is for full flow condition. So, have to use the value of Y 2 that equal to S plus 0.5 F. So, here S equal to Y 2 equal to S plus 0.5 F is computed F is known as 2.5 S equal to 0.3, so, I can estimate it has 1.55 meter.

So, height of headwall from this figure you can see, the height of head wall is given as Y naught that equal to F plus S. So, that equal to 2.5 plus 0.3 that equal to 2.8 meter. So, once Y 2 is known, Y naught is known, so I can estimate what is the value of Y 1, so, that is 1.25 meter. And this F 1 diagram shows the moist soil pressure and the diagram F 2 shows the active earth pressure that is P a, the submerged soil lateral pressure is given by P a 1 which is given by this triangle which is in yellow colour.

Then this blue colour F 4 is given as lateral water pressure that is P a 2 which is acting below this saturation line and this triangle which is a brown colour. So, this show the equivalent flied pressure and this XX is my reference line. So, you have to take the moment of all these forces along this X X line to estimate what is my equivalent fluid pressure corresponding to different pressure forces of F 1, F 2, F 3 and F 4. So, this is my basic concepts. If you can understand this basic concept, then you can go for estimating the lateral pressure forces.

Now, you have to estimate what are the pressure acting below this pressure triangles. For F 1, you can see the pressure is acting as P a, this value is P a. So, this is moist soil pressure, so, moist soil pressure will be gamma into this heights, the weight of moist soil into h. So, h is your equal to Y 1 that equal to 1.25, so gamma into Y 1, so that will be equal to moist soil pressure.

So, that can be equal to P a, similarly, we can estimate for active earth pressure by using the previous equation W into 1 minus sin phi divided by 1 plus sin phi, then you can estimate the pressure at the bottom of this different pressure triangles. Then you can multiply with area to estimate the total pressure area of this triangle, then you can take the moment about X X line. So, those these tail soil discuss in the next slides.

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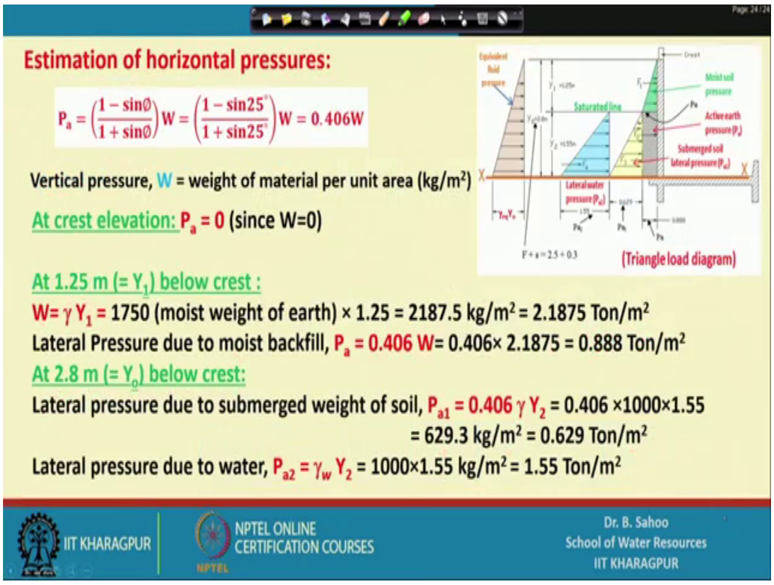

So, P a is estimate that is 1 minus sin phi divided by 1 plus sin phi into W, W is your vertical pressure that is nothing but you weight. So, here phi is 25 degree so, you can get P a equal to 0.4 naught 6 W. The W is the weight of material per unit area in k g per meter square at crest elevation, there is no pressure at crest elevation. So, P a will be equal to 0, at 1.25 meter below crest.

So, at along the saturation line you can see, along this saturation line you have to estimate the value of W. So, W equal to that is the weight of the or the pressure due to the moist weight of earth. So, gamma into Y 1, here, gamma is given as 1750 in the question is given and Y 1 equal to 1.25 meter. So, you can get 2187.5 k g per meter square and that equal to 2.1875 ton per meter square.

The lateral pressure due to moist backfill can be estimated as because, this is your vertical pressure or vertical weight that is W here. Now, I can use that equation to estimate what is the value of P a that equal to 0.406 W. So, you can get 0.888 tone per meter square.

Now, at 2.8 meter below crest, so, 2.8 meter below crest means it is along the X X line or the bottom. The lateral pressure due to submerged weight of soil is given by 0.406 gamma into Y 2. So, that equal to 0.406 into 1000 that is your submerged weight which given the question and Y 2 equal to 1.55 meter. So, you will get 0.629 ton per meter square. So, this is my that is equal to P a 1 as shown here.

Then letter pressure due to water that equal to P a 2, so, that is different by the force F o. So, P a 2 will be equal to gamma W into the height of water that equal to Y 2. So, gamma W equal to 1000 into 1.55, so, you are getting 1.55 ton per meter square.

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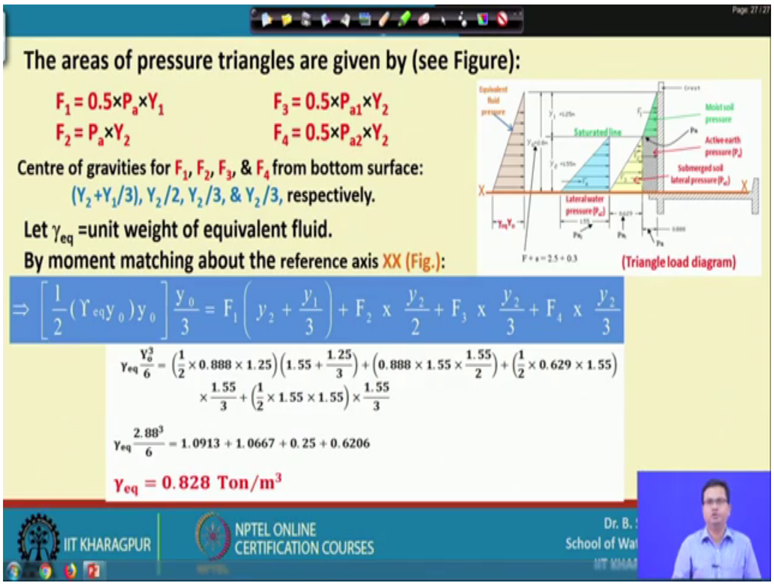

So, once this is known, now you have to calculate the areas of different pressure triangles. The area of F 1, you can estimate that is best as P a as seen in the figure and height is here Y 1. So, this area will be equal to half into P a into Y 1.

Similar for F 2, it is a rectangle, so, we will get P a into Y 2. So, this height is Y 2 so, P a into Y 2. Similarly, for F 3 the base is P a 1 that equal to 0.629 and height is Y 2 so, this height is Y 2 so, it will half into P a 1 into Y 2. Similarly, for F 4 the base is P a 2 so, that is 1.55 ton per meter square, you have estimated and the height is also Y 2.

So, once this is area are know, so, you can estimate what are the pressure forces. Now, you have to estimate what are the centre of gravity for all these pressure forces that is F 1, F 2, F 3 and F 4. So, the center gravity for F 1, F 2, F 3 and F 4 from the bottom surface are given by this value. So, for F 1, it is Y 2 plus Y 1 divided by 3, it is acting here, then for F 2 it is Y 2 divided by 2 for F 3 Y 2 by 3 and for F 4 it is Y 2 divided by 3. So, now, you have to take the moment I was the reference axis X X. So the moment for this equivalent fluid pressure and here base is gamma equivalent into Y 0 into height is equal to Y naught that equal to Y 1 plus Y 2. So, this area also you can estimate so, this is your equivalent force which is at acting at a distance x by 3 from this base at the centre of gravity.

Now, you can take the momentum of this triangle on that is should be equated to the sum of the moments of all these pressure forces of triangles. So, that you can estimated, that you can estimate by using this equation. So, the first one shows the moment of the equivalent fluid pressure, the second one is the moment of the force F 1.

This term shows the moment of force F 2, this one shows the moment of force F 3 and this shows the moment of force F 4 from the X X line. So, once this is known, you can put all these values of these values are already calculated. So, you can get by solving this we can get the value of q gamma equivalent equal to 0.828 ton per meter cube.

So, this solve solves the first part of the problem. So, once this is solved, now I will go little speedily for other conditions. So, once this understood, the same procedure must be followed for solving the next bit of the problem.

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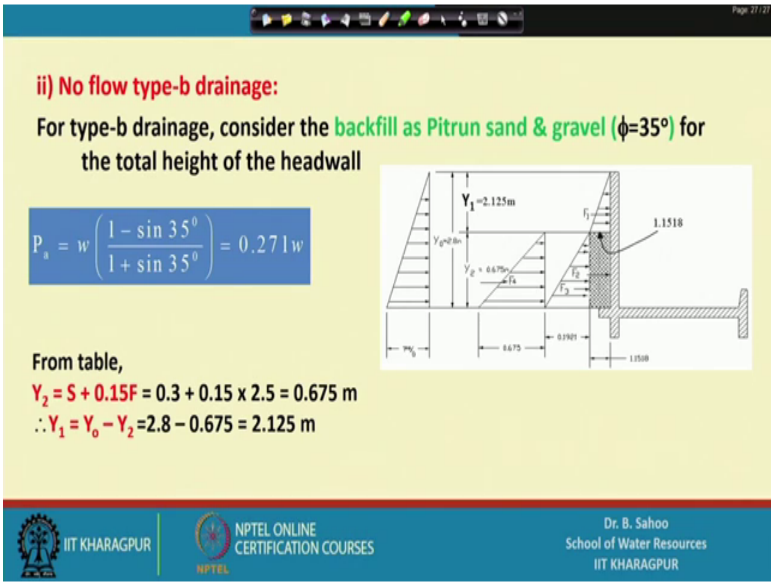

For no flow type b drainage so, let us assume that the backfill is pitrun sand and gravel for this phi equal to 35 degree and you have to and this is fill up to the height of the head wall. So, in this case P a can be estimate are W into 1 minus sin 35 degree divided by divided by 1 plus sin 35 degree that equal to 0.271 W and from the table, you can get Y 2 equal to S plus 0.15 F from the drainage table that I have already shown.

So, here Y 2 equal to 0.675 meter and Y 1 will be equal to Y naught minus Y 2. So, that equal to 2.125 meter and here you can see there are similar forces are acting because you know flow type F 1, F 2, F 3, F 4 and the equivalent pressure are shown in the diagram. So, you can follow the same procedure as done in the first bit of this problem.

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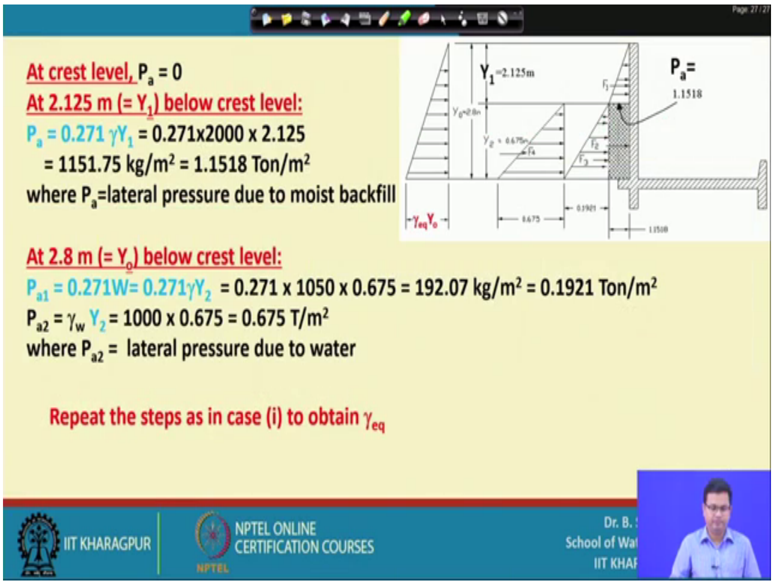

So, at crest level P a equal to 0, at 2.125 meter, you can estimate P a that equal to 0.271 gamma Y 1. So, that will give you 1.1518 ton per meter square, then at the crest level P a equal to 0 or not 2.25 meter, we can calculate P a equal to 1.1518 ton. So, this value and a 2.8 below crest level, you will get P a 1 equal to 1.921, this value and P a 2 will be equal to gamma W Y 2. So, that equal to 0.67 ton per meter square, so, this value and after getting these values, we have to repeat the steps as we have done in the previous bit.

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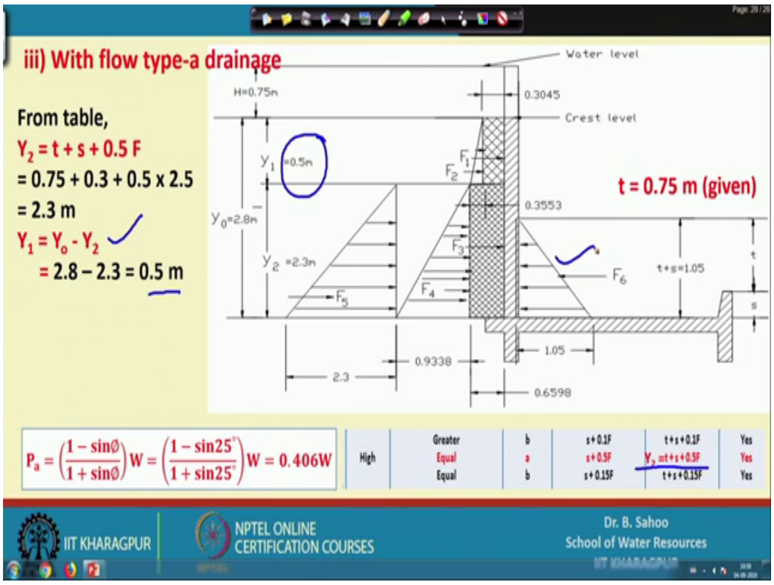

Now, for the third problem we have to use the type a drainage for type a drainage, here Y 2 is computed as t plus S plus 0.5 F from this table. You can see from this table this value you have taken for flow condition and Y 1 equal to Y 0 minus Y 2 that equal to 0.5 meter. So, we can estimate Y 1 equal to 0.5 meter. Here, additional force will be the F 6, F 6 is nothing but this is the negative pressure which acting backwardly because of this tail water.

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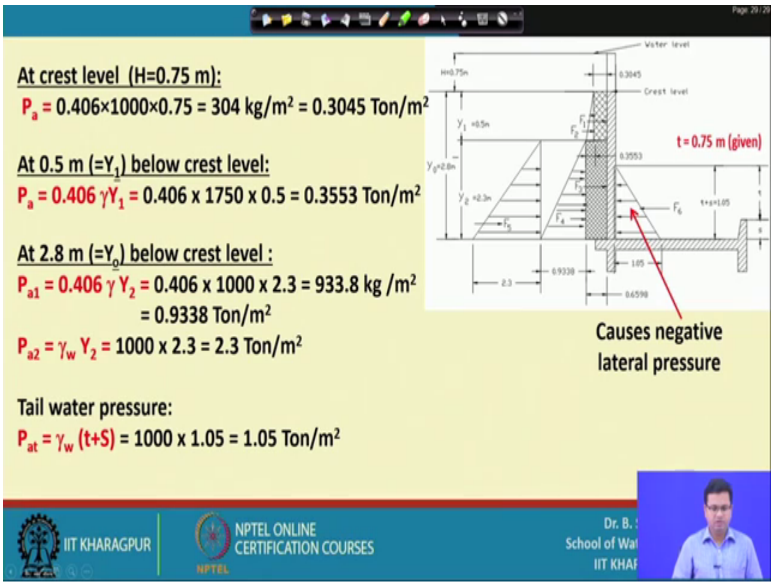

Now, at the crest level, so there is standing water, so, H equal to 0.75 meter. So, will be getting some water pressure here and P a will be equal to 0.406 into 1000 2.75. So, that equal to 0.3045 ton per meter square at 0.5 meter that is below crest level, you will be getting p equal to 0.406 gamma Y 1. So, that equal to 0.3553, so, this is equal to 30.3045 at 2.8 meter below crest level, you will be getting P a 1 equal to 0.406 gamma Y 2.

So, that equal to 0.9338 ton per meter square and P a 2 will be gamma W into Y 2. So, that will be equal to 2.3 ton per metre square this value and tail water pressure will be equal to gamma W into t plus S because t plus S is the depth of tail water. Here, t plus S equal to 1.5 which is nothing but the F 6 for F 6, so, will get 1.05 ton per meter square. So, this is my 1.05 ton per meter square.

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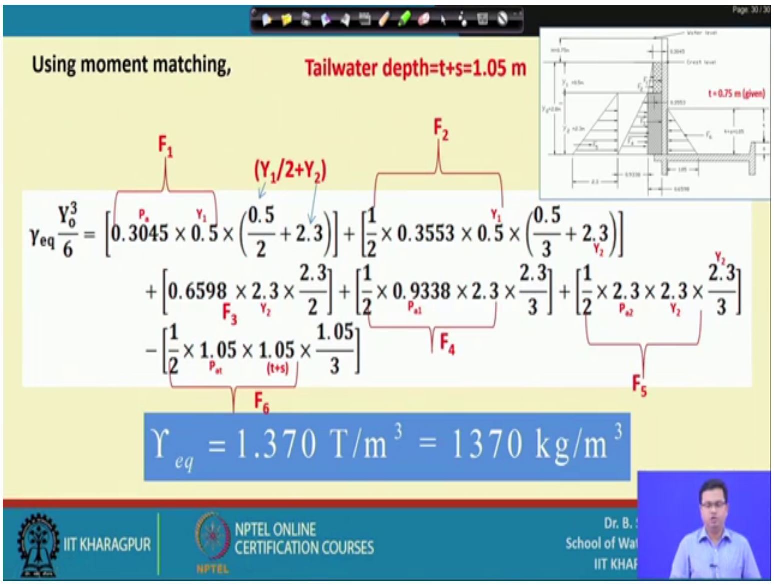

Now, by similar way, now you can use the moment matching technique about the line X X. So, the total moment due to the equivalent fluid pressure that is given by gamma eq into Y naught q divided by 6. So, at the sum in the total moments you can see here, the negative pressure because of tail water is given by F 6. So, that is half into 1.05 into 1.05 into 1.05 divided by 3 and this value is the distance of the centre of gravity from the bottom of the foundation of that X X axis. So, we can get this value is F 1, this is F 2, this is the distance of centre of gravity from the X X axis and similarly, this is the distance of the centre of gravity from the X X axis, this is F 3, this is F 4, this is F 5 and this is F 6 which is negative. So, by equating that one, you will get gamma equivalent equal to 13.7470 k g per meter square.

So, the same procedure is followed as I have told you in the previous bits in the first bit, you can do this exercise then more clarity will be there. Unless you want to solve this one will be difficult to understand this because, slightly difficult is there here in calculating the area of the pressure forces, then you have to calculate total force equal to pressure into the area of the pressure triangle. Then you have to estimate what is the centre of gravity the distance of the centre of gravity from this bottom surface that is your X X line, then force into the distance that is a moment and you have to equate the moments for equivalent fluid pressure and the other pressure forces.

Then, you will get what is the equivalent pressure corresponding to different lateral pressure forces. So, this ends the lecture here, so, you have to little practice the problems, then only you can understand all the details other it very difficult to cover each and every bit of this pressure calculations. So, you have to in detail have already told in first bit and you use those first bit solution to solve the second bit and third bit of this problem. So, this ends our lecture here.

Thank you.