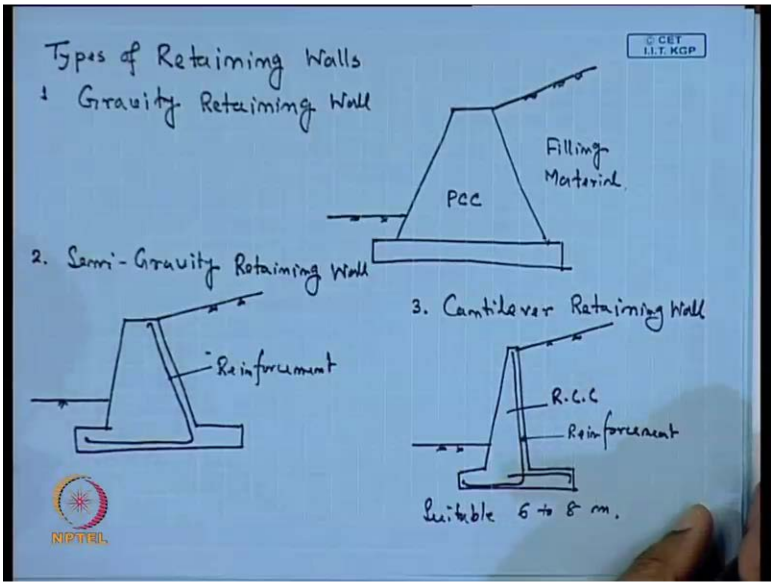
Advanced Foundation Engineering
Prof. Kousik Deb
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

Lecture - 23
Design of Retaining Wall

Retaining wall, because retaining wall is very important structure in geotechnical engineering. So, to retain the soil, so we have to build the structure for this type of retaining wall. So, there are different types of retaining wall. We will discuss about various type of retaining wall, how to choose the dimension, and what are the different factor of safety that we have to consider, during the design of retaining wall, then those things will be discuss in this class. So, first I will discuss about the different types of retaining wall. So, first the types of retaining wall.

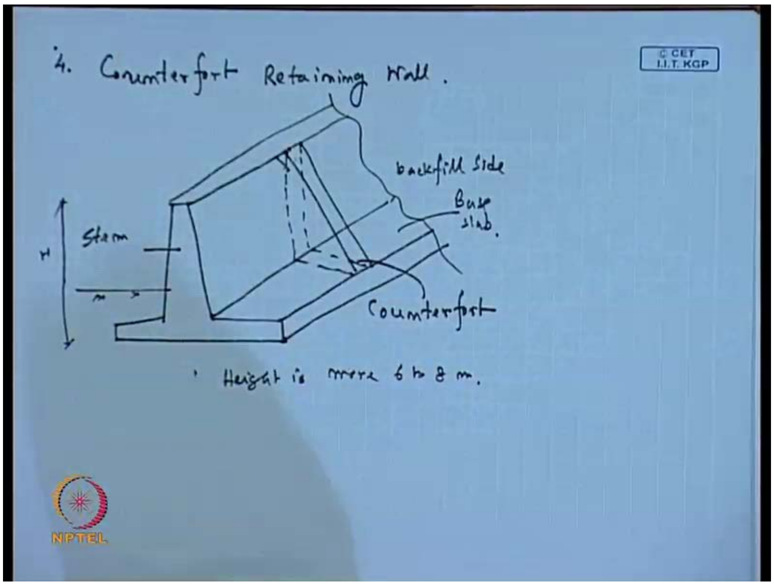
(Refer Slide Time: 00:58)



So, first one is our gravity retaining wall, where we can go for this type of arrangement. This is ground surface, and this is, so this type is filling material. Now depending upon it is weight, we will get the stability for this type of gravity retaining wall. And this is constructed for PCC, plain cement concrete; we will not use any reinforcement for this type of retaining wall. And this is not economical for large height, if the retaining wall height is very large, then this type of retaining wall is not very economical. But and then the next one is, a semi gravity retaining wall, and this type of retaining wall. Again this is ground surface; this is the retaining wall, where the size of retaining wall is slightly reduced, compared to the gravity retaining wall, by providing small amount of reinforcement in the back phase side.

So, you can say that this is gravity retaining wall, the most of the stability is given by the weight of this retaining wall, and here reinforcement is not use. So, that is why, we have to use a very huge a size of retaining wall, but in semi gravity retaining wall, the size of this retaining wall as compared to the gravity retaining wall, is slightly reduced, is reduced by providing a small amount of reinforcement, in the face of this retaining wall. So, this is reinforcement that is used, and this is the filling material this side. Now third type of retaining wall, is cantilever retaining wall. For this type of retaining wall, which is made up of PCC; plain cement concrete, so this is the ground surface. Now, this type of retaining wall, which is made by RCC reinforce cement concrete, and where these are the reinforcements, and which is suitable for a height of 6 to 8 meter, suitable for a height of 6 to 8 meter.

(Refer Slide Time: 05:26)

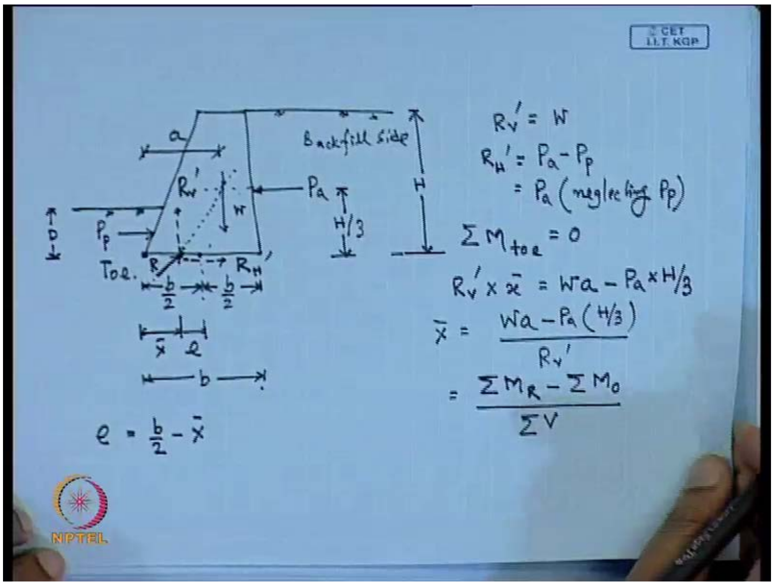


And the next one, another type of retaining wall is, that is counter fort retaining wall, where this is the retaining structure, and this is the longitudinal side, where with some interval this counter forts are used. So, these are called counter forts, this is. Now this type of reinforce, this type retaining wall, they providing. The use of this counter fort is to reduce the shear force, and the bending moment in the vertical steam of the slab. So, this portion is call as steam of the retaining wall. So, this counter forts are used, to reduce the shear force and bending moment, moment which is inducing the vertical steam of the retaining wall, and the base slab also. This is the base slab.

So, to reduce the shear force and bending moment of this base slab, and the steam, these retaining and counter forts are used. This counterforts are use which certain intervals. Now economical for, if the retaining wall height, if this is the height of the retaining wall. Now, if height is more than 6 to 8 meter, then this type of retaining wall is very suitable, and this counterforts are used on the backfill side, because this is our backfill side. So, this counter forts are used in the backfill side. So, these are the four different types of retaining wall. So, first one is gravity retaining wall, where this most of the stability is get in from the weight of the retaining wall, and where these where use using the plain cement concrete; PCC. Then the next one is semi gravity retaining wall, where the size of the gravity retaining wall is reduced, by providing the small amount of the reinforcement.

And the third one is cantilever retaining wall, where the RCC reinforce cement concrete is used, for that type of retaining wall. Now, if get cantilever retaining wall is suitable for the 6 to 8 meter height, now if height of the retaining wall is more, more than 6 to 8 meter, then you have to go for this counter fort retaining wall, to provide the counter fort which is used to reduce the bending moment and shear force, which is induced in the vertical stream and the base of the slab. And this counterforts are provided at the backfill side. Now we have to we have to design, we have to these different types of retaining wall. So, first I will go for this gravity retaining wall, and then we for you go for the gravity retaining wall, you should know what are the different types of factor of safety we have to determine, what are the checks we have to do for this design of retaining wall.

(Refer Slide Time: 09:41)



First, suppose if this is a typical section of retaining wall; say, where this one is the backfill side, this is ground surface, and this is foundation. So, this is our backfill side. So, this portion is filled with soil, and this portion is avoided, and here this is foundations soil. So, this retaining wall, as to retain the soil pressure, so that means, the soil will give the lateral pressure on this retaining wall. So now, if I go through the fill body diagram of this, different retaining wall structure. So, these are the, if this is the center of this retaining wall, or if this is b by 2, this one also b by 2, so total it is b. And if this is the height of the retaining wall H, then first this active earth pressure, that will act at, this is P a; active earth pressure, that will act at H by 3 distance from the base of this retaining wall, because this. And then similarly when we know that this retaining wall, if it is move in this direction, then this space will be active earth pressure. Similarly these soil, these portion, below the foundation soil, this soil will also provide a lateral pressure, in opposite to the P a.

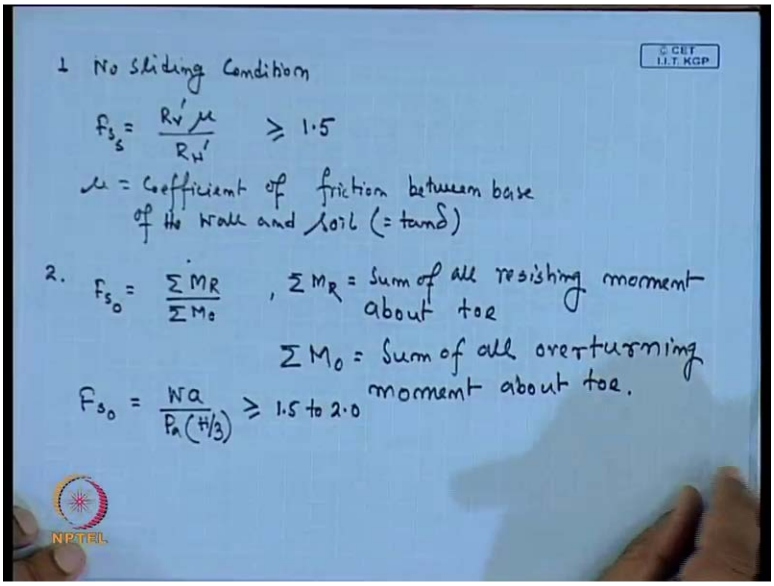
So, that is the opposite to the moment of this retaining wall. So; that means, here act one passive earth pressure; that will act. So, this is our passive earth pressure P P. So, this one is the 2 of the retaining wall. So, this passive earth pressure also acts. Suppose this is the depth of the, or the portion of, base of the retaining wall is at a depth of D, from the foundation soil. Then, where this soil will provide applied a passive earth pressure, and this soil will applied as active earth pressure. And now, if we go for the reaction force, for this base of the retaining wall, because this weight of the retaining wall; so that will act in this direction, this is the weight self-weight of the retaining wall; that will act. Now of this is this reaction will act in this direction, if we take the two components of this direction R. So, about this is, this reaction is R, and if we take the two components; this is R H dash, and this one R v dash.

So, now the, this distance from the two of this reaction force, is say x bar, and from the center this one say e. So, now, what are the forces that we will consider, so that means, we consider the active bar pressure, we will consider the passive bar pressure, we will consider the self-weight of this retaining wall, for the gravity retaining wall delta 1 will, when we go for the cantilever retaining wall, then for different theories, we have to consider the weight of the soil also. So, this weight will act in the downward direction, this active earth pressure will act from this direction, and the passive earth pressure act in the opposite direction. So, there is a friction that will act, in between the base of the foundation, or retaining wall, and the soil.

So that means, then, for this vertical and horizontal force. So, there is two basically vertical and horizontal force, then there is a reaction that will developed, at the base of the foundation. So, if I take the two components of this reaction; one is R H dash, one is R v dash. Now say this R is acting as a distance of x bar, from the two of the retaining wall, and so that point of this reaction force, is also at a distance of P from the center of the or the of the retaining wall. So now, if I go for this equilibrium condition, so say R v dash is equal to W, so that means, this R v dash, that is equal to the W. This vertical components equal to this term. Another one, this R H dash; that is equal to this R H dash, is equal to P a minus P p. The if I neglect this P p, because this portion of force, if I neglect, because as this P p is very small compact to this P a, and this P p will also provide additional safety for this retaining wall. So, if I neglect this P p, and consider only P a by neglecting P p, then R H dash will be equal to P a. Now another condition we have to take moment, from the with the respective toe, and that moment should be 0. For equilibrium condition, if I take moment from the toe, and this will be 0.

So, we can write, that R v dash into x bar; that is equal to W, and if W is acting at a distance of a, or is acting at x distance of a, from the toe of the retaining walls, and this is W into a, then minus P a into H by 3, as we are neglecting the P p. So, we can write, that x bar is equal to W a minus P a, into H by 3 divided by R v dash. So, we can write this all, if we can write in the general form, then W a; that is the summation of all moment, which is giving the resistance, because this o at, this actually giving the resistance. And this P a, is trying to overturn this retaining wall. So, it is pushing from this side, and trying to overturn this retaining wall, and this weight of the retaining wall, basically providing the resistance. So, that moment is resistive moment, minus summation of the over turning moment or M, and divided by all force of the vertical force. So, these are the vertical force. So; that means, we can calculate the x bar in the summation of resistive moment, minus summation of overturning moment, divided by summation of vertical force. So now, we can right that our e, eccentricity is equal to b by 2 minus x bar. So, once we get, we determine was we this x bar using this expression. So, we can determine the e value also by b by 2 minus x bar.

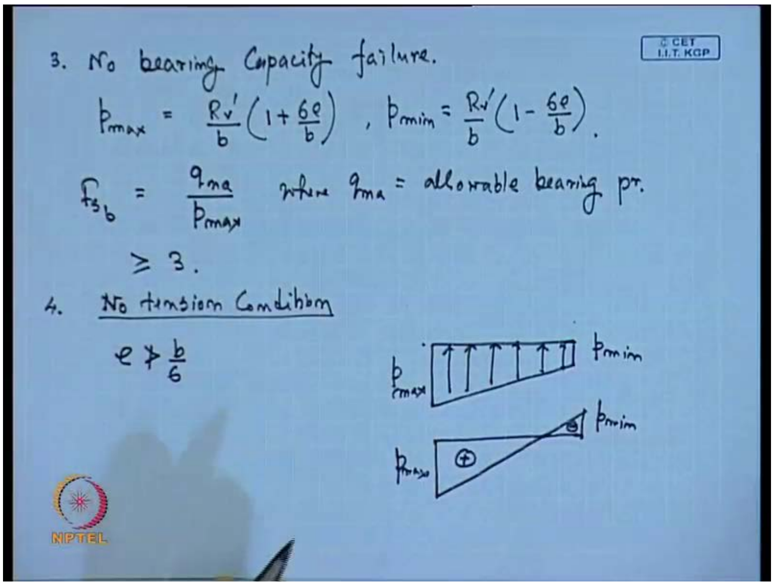
(Refer Slide Time: 18:03)



Now, based on that, what are the different stability check that will consider. The first one is that there is a sliding between, if I take this a photographs here. So, there is a sliding between the soil, and the retaining wall base. So; that means, it may fail, because of the sliding. If the sliding is, if the friction force is not enough in this base, and of the retaining wall and the soil, then there is a possibility of sliding. So, that sliding we have to prevent. Now sliding force; that means, for no sliding condition, we have to check the factor of safety. So, factor of safety f, is for the no sliding condition. The sliding force is a resisted by this vertical force into the coefficient of friction. So, this R v dash, and mu, and the sliding force is this, there is this is a possibility of slide, because of these R H force. So, that is R H dash. So, where we can write; that mu is the coefficient of friction, between base of the wall and soil, we can write that is equal to tan delta.

Now in this case, this factor of safety should be equal to 1.5, so that will give the no sliding condition. So, next one is, overturning, no overturning condition; that means, because of this force, because of this P a force it will overturn this retaining wall, and this weight will assist this overturning force. So, we have to no overturning condition; that means, if we consider the first factor of safety for no overturning condition; that is the summation of M R, divided by summation of M O; overturning. So, where summation of M R is sum of all resisting moment about toe, and summation of M O is sum of all overturning moment about toe. So, for this previous case, if I get the factor of safety for overturning case F a o, or factor of safety for sliding F a s, then if o that will give us for the this previous case, W a divided by P a into H by 3, and that should be also greater than 1.5 to 2. So, next check that we have to toe, that for the bearing capacity check.

(Refer Slide Time: 22:06)

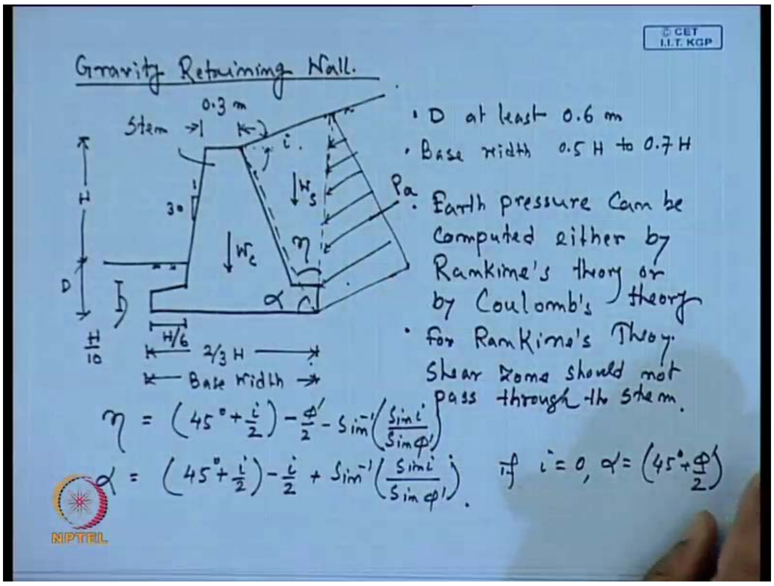


So; that means, next check is no bearing capacity failure. So, no bearing capacity failure means, if the base soil or foundation soil is very poor, then we have to check, then there is a possibility that soil will fail, because of as the vertical load is coming on that soil. So, we have to check for the bearing capacity failure also, whether this soil is capable to take the load of these retaining wall, including that soil pressure, that is coming on the that foundation soil. Now for that purpose, we have to calculate the stress p max of the soil; that will give us the R v dash, all the summation of vertical force divided by, with of the retaining wall, into 1 plus 6 e divided by b, and or the P min, minimum 1 is R v dash divided by b 1 minus 6 e divided by b. But here as we are considering the maximum state, so we work as a, taking this P max. And now for the factor of safety, for bearing capacity failure; that will be q m a divided by P max, where q m a is equal to the allowable bearing pressure, or this, can this F s this should be greater than equal to 3. So, that means, this soil pressure, that it can take it can able to take and divided by P max, so that we will give this factor of safety. Then first check, forth check, that no tension failure, no tension condition, and that totally depends on.

Suppose if I get, this is our base of the retaining wall, so this stress distribution, as we will go for this P max and P min. So, we may get this type of distribution for the stress the stress distribution, at the base of the retaining wall, we may get this type of stress distribution; this is P min, and this is P max. Now there is a possibility, that we may get this type of distribution also, where this will, if this is positive if this will give us this P min, this is P max, so this will give us the tension condition. So, this will give you the negative stress, and that will give us the tension condition. So, we have to avoid this no tension condition, if this type of situation arises, then we have to avoid this no tension condition. And for the no tension condition, it is occur when if a is greater than equal to b by 6. So, if e is less than b by 6, then we have to read re design the dimension of the retaining wall, to avoid the no tension, to avoid the tension developed in the base of the retaining wall.

So, for the no tension condition, this e should be equal to greater than b by 6. So, these are the four checks, we have to do during the design of retaining wall first. first We have to design the rough step, if I go for the design of this retaining structure, first we have to roughly design the dimension of the retaining wall, by based on the provided guidelines. Then we have to first see, whether this retaining wall is safe, we can sliding and bearing or not. If it is safe, then we have to go for, whether the no tension condition is occurred or not, then finally, we have to go for the bearing pressure calculation. So, all this four conditions if satisfy, then we can decide, so this dimension will proved for the retaining structure. Now, next one that, for the other these checks, addition to this checks, what are the different other design criteria is all guidelines.

(Refer Slide Time: 27:07)



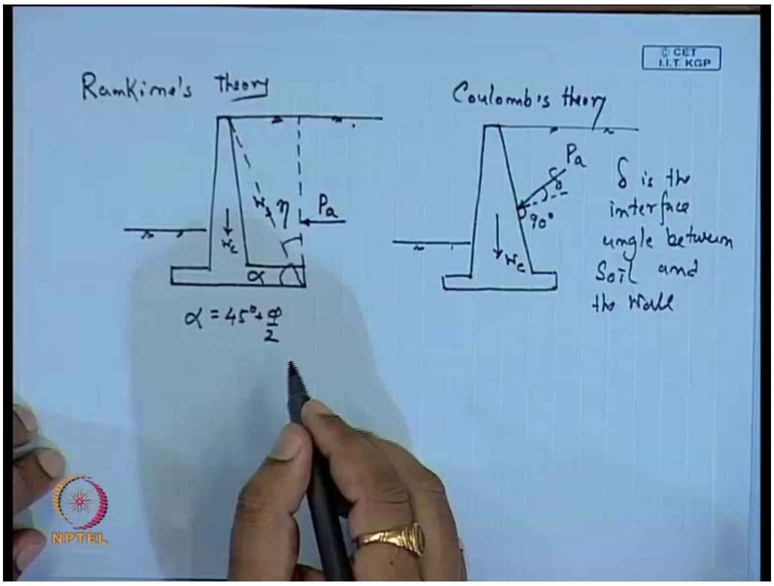
So, first we will go for the gravity retaining wall. Suppose, this is the retaining wall, this is gravity retaining wall, and this is the ground surface, which is inclined at angel i with the horizontals surface, this is our vertical string. Now provided guideline, suppose this is the existing soil, and this is the backfill. Now this say, is the depth of the retaining wall t. And then for this, if I consider the vertical line along the, this face, then will give the, this height of the retaining wall is H say. So, this is say, height of the retaining wall H. Now for the guideline, which is provided that this top portion, it take around 0.3 meter, or 300 millimeter. Now the slop is one is 230. Now this height of this base; that is taken as H by 10. Now with this guideline, this is weight an consider two third of H, and this portion, this extended portion is taken H by 6. Now, if I joint this line with this extend point, and if this angle is alpha, and this angle is eta, then and what are the forces that will act? So, this is the weight of the concrete W c, and this is weight of the soil, you can consider.

So, if I go that D value, this D is at least 0.6 meter, we have to provide this D value at least 0.6 meter. Whereas, base width, this base width of the retaining wall, so base width we can consider 0.5 H to 0.7 H, in between 0.5 H 2.7. Now, this earth pressure that will act; so now this earth pressure diagram, if I consider this earth pressure; so this earth pressure act, this will act P a for the soil, and here we also act the passive earth pressure, this is active earth pressure, which if we consider, neglect this passive earth pressure. So, this earth pressure can be calculated, either Rankine's formula or Coulomb's theory.

Now for this Rankine's theory if I consider, this earth pressure can be computed either by Rankine's theory or by Coulomb's theory. Now for Rankine's theory, the shear zone should not pass through the stem; that means, that this line is the extreme line of this condition. If this line is passing through this stem, then that is not acceptable, if I consider the Rankine theory.

So, to satisfy that condition, and this angle we can calculate this is 45 degree, plus i by 2 minus phi dash by 2, phi is the friction angle, minus sin inverse, sin i divided by sin phi dash. Similarly alpha is equal to 45 degree plus i by 2, minus i by 2, plus sin inverse sin i divided by sin phi dash. So, now, if i is equal to 0, then alpha is equal to 45 degree, plus phi dash by 2. So, first we have to check whether this line is, if I consider the Rankine theory, we have to consider, check whether this line is passing through this stem or not. So, this for the shear zone, this line should not be pass through this stem. So, this is the extreme point. Now, there is a few things, that we have to clarify, that if I consider, suppose this is the retaining wall and we can use the Rankine's theory. Now if I use the Rankine's theory, suppose this is the two, if I consider the same Retaining's wall.

(Refer Slide Time: 34:35)

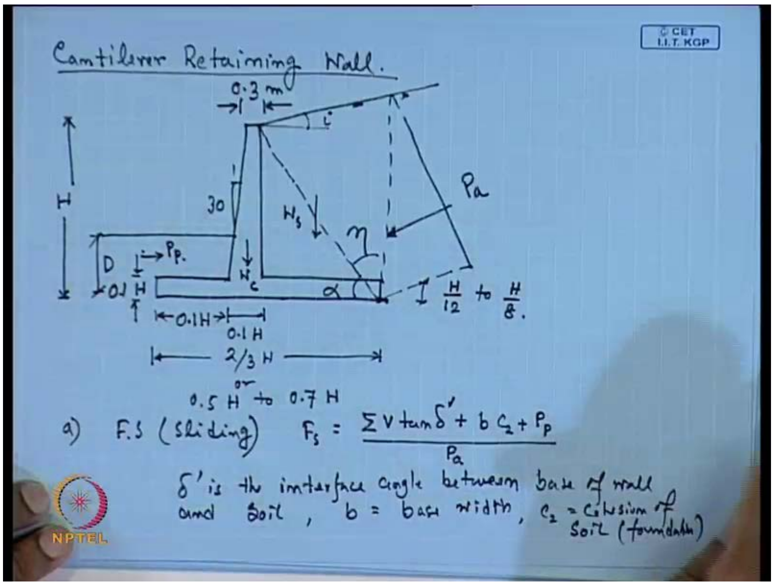


So, if I this is our foundation, this is the ground surface, this is backfill side. So, then we first, we if we use the first case, we will use the Rankine theory; and next one, if I use the coulomb's theory; so the same retaining wall if I consider for the coulomb's theory, for the different forces that you have to consider, that again if I join this point, so this is alpha. So, here alpha as i is equal to 0, alpha will 45 degree plus phi by 2, and then this angle. So, now this P a will act here, now this is our base. Now for the coulomb’s theory as you know this, if I draw a vertical line a perpendicular line, so this is 90 degree perpendicular line, if the face of this size side of the retaining wall, then P a we will act with an angle delta of the vertical line. So, this perpendicular line P a will act with an angle delta. Now, whereas in case of Rankine’s theory, it will act if the parallel to this backfill side size; if it is angle i then it will act with an angle of i, where as it will act, it parallel to this. So, here also, this is the surface, ground surface in parallel to ground surface.

Now what are the forces that will consider this, here the weight of concrete that we will consider. Again, this is also the ground surface, here the weight of this concrete we will consider. In additional to that, we will consider the weight of the soil also, it mean this area. So, that mean here we are not considering the weight of the soil. Here we are considering the weight of the soil, and weight of this concrete also. But here this will act parallel to this ground surface, here it will act perpendicular line with making angle delta, where delta is the friction angle between the soil and wall. So, delta is the interface angle between soil and the wall. So, these two things we have to remember, when if you use the two different theory, so as this analysis point. The next one for the semi gravity retaining wall, for the gravity retaining wall, we have discussed about different types of loading condition. Now semi gravity retaining wall, where this base width is slightly smaller, as compare to the gravity one, rest of the design process are same.

So, next when we will go for the cantilever retaining wall design; so for the cantilever retaining wall, so for the cantilever retaining wall, suppose this is the particular cantilever retaining wall. So, this is the ground surface in the backfill size, which is making an angle i again, and now this is the D, depth of the retaining wall, and this one is the H, height of the retaining wall. Now, again if I consider the ranking expression, then if you joint this line, this will give the H, and if I join the vertical line. Now, this is the earth pressure distribution. So, this P a will act, which parallel to the ground line.

(Refer Slide Time: 38:34)

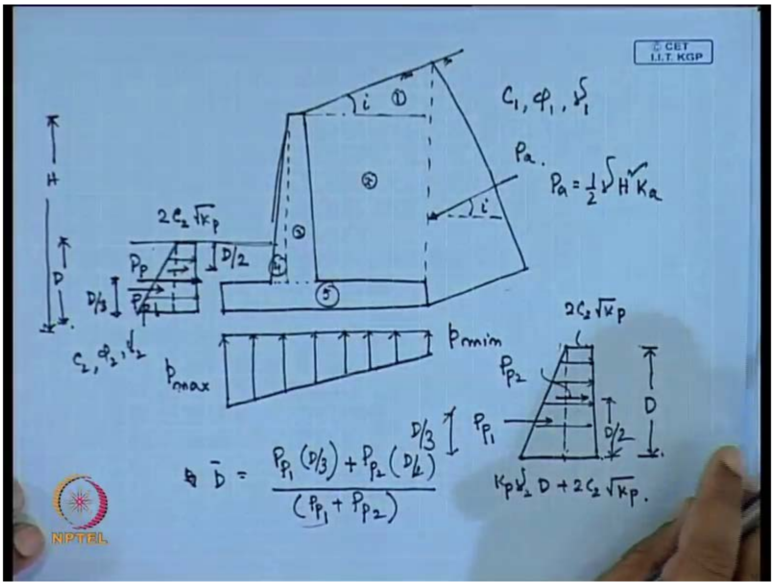


And now the recommendation this, as this top portion is 0.3 meter, now this angle is again 1 by 30. Now this H, this height or the base width, the thickness of this base is 0.1 H, this is 0.1 H. Now this distance is also 0.1 H, this one this, at this t junction, this thickness is also recommended 0.1 H, and this one is two third of H roughly, or its base width is two third of H or 0.5 H to 0.7 H. Now, similarly thickness of this side is also, is taken at it is either 0.1 H, or H by 12 2 H by 8. So, that means, it is in between; that is H by 10 this is consider here. So, this is average value of this two, this 0.1 H, but the, this range is H by. So, these are the guidelines, to starting the, to choose the initial dimension of the, this retaining wall. So, now this one is, this distance we can first choose, then we will consider the weight.

So, these are different weights; first we will consider, we will consider weight of concrete, we will consider weight of soil, if I check the ranking expressions. Now for this condition, what are the factor of safety, we will choose for this type of retaining wall; that first one, that we will consider the factor of safety, factor of safety against, this is sliding. So, in this factor of safety that will give us the, total vertical force for the sliding, into 10 delta or delta 1; so where this delta or delta dash, where delta dash is the interface angle between the base of wall and soil. So, this is the interface friction angle, between the base of wall and the soil. So, this is the summation of v into tan delta, plus this if this total width is b, suppose this base width is b, b into C 2; C 2 is the cohesion of the base soil, plus this P p, if I consider the passive force P p; that is also acting here.

So, if I consider P p is the passive force, so that will give you the base friction angle, divided by P H or the P a; that is horizontal force so; that means, this force, this P p will act here, this is the passive resistance that will act. So, P P b, where b is the base width, and C 2 is the cohesion of soil, or foundation soil. So, there is two type of soil; one is foundation soil, whether retaining wall is resting, another is backfill soil. So, C 2 is the cohesion of the foundation soil, so that means the summation of all the forces into the friction angle, divided by b into C 2, divided by P p, this passive resistance, plus this is plus b C 2 plus P p and divided by P a. So, this is for the sliding force that we can consider for this type of analysis. Now if I consider the total few body diagram, or the total forces of these type of retaining wall, then this is the vertical portion.

(Refer Slide Time: 44:59)



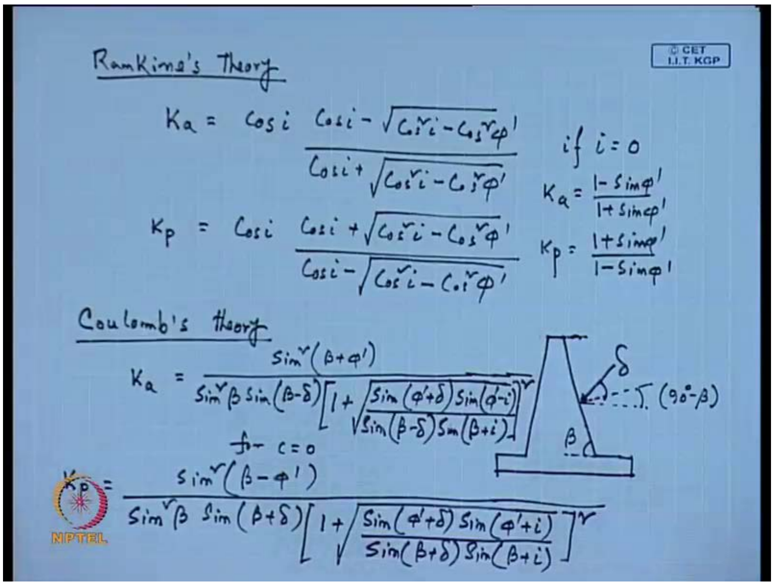
So, this is retaining wall on this angle, which is making an angle i, this is ground surface, so therefore this edge. So, this is our active pressure that will act, so with an angle i. So, P active with an angle i, this is for the backfill soil. The next for this type of soil, where this backfill soil, generally this is a phi type of soil that mean cohesion is not consider, this phi type of soil, then if it is a base soil, if it is a C phi type of soil, then we will get this type of distribution of the soil pressure. So, this is our C type of soil. Now, here we will consider this passive pore pressure, and this the reaction force that will act in the base, in this point, and this is P min, and this is P max. So, this reaction will act in this form, so that will give us, this is P min P max. Now to calculate the weight, suppose for this top portion, this I will give us C 2 C root K p, and for this bottom portion, and this P p 1; that will act at distance of D by 3. This is P P, if this distance is D. So, for this P P we can divide this part into two different portions; one this is P P, so one is P p 1, and another one, for this one is P p 2. So, this is P p 2, that will act at a distance of D by 2. So, now, final if I consider this stress again if I draw here. So, this is the passive force distribution for this portion.

So, this is the D; depth of the this foundation soil, and then this stress value is 2 C 2 root K p, and this value is K p gamma 2 D plus 2 C 2 root K p. Where K p is the coefficient of passive earth pressure, and gamma 2 is the unit weight of the base soil. So here, this base soil, so there is, we can say the dimension, this is the C 1 cohesion of the, and phi 1 and this is gamma 1. Similarly, here also C 2 phi 2 gamma 2, most of the cases this C 1 is 0 for the backfill case. So, this is the, if I consider this forces. So, these are the pressure that will act. So, if I take the two parts; one is this is P p 1 which is acting, this is triangle at distance of D by 3, from the base. Another is, acting as P p 2, this is P p 2, which is acting as a distance of D by 2 from the base. So finally, so we can, first we have to determine the stress of this triangle portion, which is acting as a distance of D by 2, and then this stress of this rectangular portion, which is acting as distance of D by 2 from the base.

Then certainly if we act these two stress, then we will get the total passive force; that is acting P p for this portion, and then we can acting, we can determine the point of application. So, suppose if the H bar or D bar is the point of application of this passive force, that we can determine that P p 1 into D by 3 plus P p 2 into D by 2, divided by P p 1 plus P p 2, so total force. So, in this way, first we have to calculate the P p 1 from this triangular force, this triangle that, because we know the stresses at this edge and this edge, and then P p 2 for this rectangular portion. Then we can determine D b bar, and this stress P P max and P min we can determine by using the previous expression, then P a will also calculate for the passive of the active force, that is active.

So, now for the width calculation, we can divide this retaining wall into different section. Suppose, so first we can consider, this is the first section, this is section 2, this is section 3, this is section 4, this is section 5. So, this 1, 2, 3, 4, 5, so all these section we can divide, we can take, and then separately we can determine the weight of every section. And then finally, we can determine the factor of safety, against the sliding, overturning, then bearing capacity and all those things. Now when we calculate this P a, then we can calculate this P a value, then P a, this force will give us the half into gamma into H square into K a, where gamma is unit weight of the soil, H is the height of the retaining wall, suppose this is the height of the retaining wall, and K is the active coefficient of active earth pressure. Now, this coefficient of active earth pressure for the Rankine's and the Coulomb's, there are different expressions have given.

(Refer Slide Time: 52:25)



So, for the Rankine's theory, if I use the Rankine's theory, then this K a is equal to cos i into cos i minus root over cos square i minus cos square phi dash, then divided by cos i plus root over cos square i minus cos square phi dash. And for the passive, this passive earth pressure for the Rankine's case cos i; that is cos i plus root over cos square i minus cos square phi dash divided by cos i minus root over cos square i minus cos square phi dash. Thus if i is equal to 0, then K a for the ranking case is 1 minus sin phi, dash 1 plus sin phi dash, and K p is just reversed 1 plus sin phi dash, 1 minus sin phi dash. Now, if I use the coulomb's theory, then we will get that K a is equal to, for the case of coulomb's theory K a is equal to. So, now suppose if this is our. So, retaining wall, and here this force is acting here, we draw a perpendicular line, is acting angle delta, so and this is our horizontal line. And if this angle is beta, so this angle is beta, this is acting a delta is horizontal line, and this angle will give us that 90 degree minus beta.

Now, here this is the value, now for this type of K a will get, by this expression; that sin square beta plus phi dash. Now this is sin square beta, sin beta minus delta, then 1 plus root over sin phi dash plus delta, into sin phi dash minus i divided by sin beta minus delta, into sin beta plus i and total this is square, for c 0 condition. Now, similarly for the K p, that will calculate by sin square beta minus phi dash, divided by sin square beta, sin beta plus delta 1 plus root over sin phi dash plus delta, sin phi dash plus i sin beta plus delta, sin beta plus i, then total square. So, by this where we can determine the passive and active coefficient of earth pressure for Rankine's theory, and for Coulomb's theory if we use different condition. So, in the next class I will discuss about the different, and solve a few problems to show that how to design; design means to determine the dimension of the retaining wall, by considering the different factor of safety for sliding, overturning, bearing and no tension condition, and to choose a proper dimension of the retaining wall.

Thank you.