

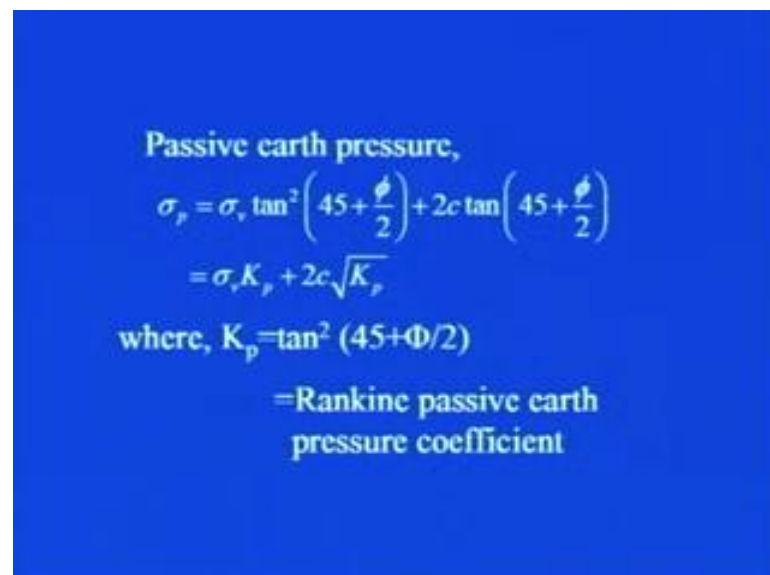
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Module - 02
Lecture - 03
Lateral Earth Pressure Theories and Retaining Walls - 3

Good afternoon, we were discussing about Lateral Earth Pressure Theories and Retaining Wall. In that we already have seen that how you can calculate or estimate active earth pressure using Rankine as well as Coulomb's theory and then we started with estimation of passive earth pressure, likewise as it was there in case of active force.

In passive force also there are mainly two theories are used one is Rankine's passive earth pressure theory and other one is Coulomb's passive earth pressure theory. In last class, we saw some of the aspects of Rankine's passive earth pressure theory. Now, let us try to see that, how we can analyze the situation as per Rankine's passive earth pressure theory. We have already seen that how the Mohr Coulomb diagram can be plot in case of passive earth pressure.

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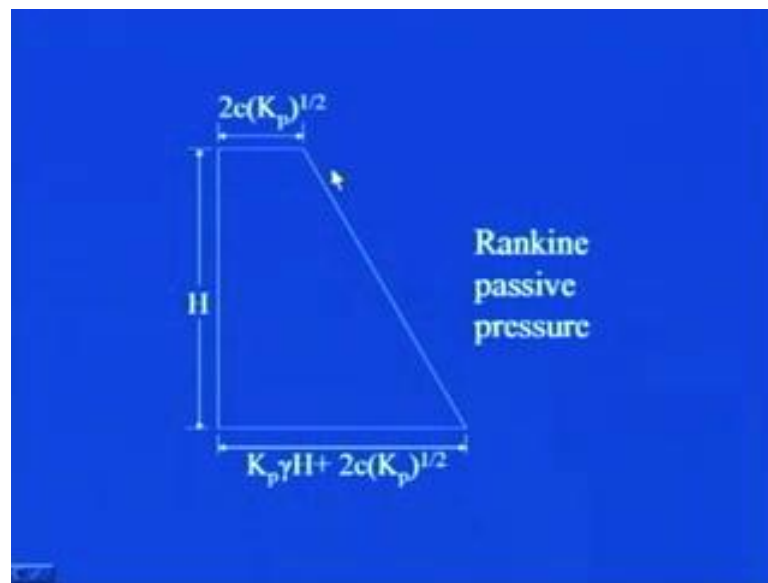
Passive earth pressure,
$$\sigma_p = \sigma_v \tan^2 \left(45 + \frac{\phi}{2} \right) + 2c \tan \left(45 + \frac{\phi}{2} \right)$$
$$= \sigma_v K_p + 2c \sqrt{K_p}$$
where, $K_p = \tan^2 (45 + \phi/2)$
= Rankine passive earth pressure coefficient

And then, in that one, we saw that the major principle stress was σ_p while the minor principle stress was σ_v . So, as we did in the case of active earth pressure in case of passive earth pressure, exactly you have to follow the similar lines and then you will be

getting this expression for the evaluation of passive earth pressure, which is equal to $\sigma_v \tan^2 45 + \phi$ by 2 plus $2c \tan 45 + \phi$ by 2.

And in the simpler form, you can write this expression as σ_p equal to σ_v into K_p plus $2c$ square root of K_p where what is K_p , K_p is Rankine passive earth pressure coefficient which is defined as $\tan^2 45 + \phi$ by 2. Where your ϕ is angle of internal friction of the backfill soil which is to be retained by the retaining wall at any retaining structure.

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Now, let us try to see that how you can plot this in pictorial form, in this case you have this it is equation that $\sigma_v K_p$ plus $2c$ square root of K_p . So, at depth z is equal to H in the absence of water table your σ_v value will be equal to γ times H . And then, you have two terms as it was there in active case, in this case also you have two terms, one term is $\sigma_v K_p$ which is equal to γH into K_p . And another term which deals with the cohesion at the soil that resulted into this quantity that is $2c$ square root of K_p .

So, here two terms are there one is here, another one is here at Z is equal to 0, this term will not be there in the picture, because, σ_v is 0 there, so simply you will be having this $2c$ square root of K_p at z is equal to 0. However as the depth increases that is from this level as you go towards the bottom of the wall, what happen is, your z increases.

And then, simultaneously this second term which is σ_v into K_p that is γ into z into K_p that goes on increasing and it attains the maximum value at z is equal to H , that is this coordinate. So, the magnitude of this coordinate will be $K_p \gamma H$ plus $2c$ square root of K_p , so this is how you can draw Rankine passive pressure diagram.

Now, as you know as you did for the active case, once you have plotted this pressure diagram, you simply have to take the area of that particular diagram and then you will be getting resulting total force per unit length of the wall. So, exactly the similar analysis you have to carry out to determine to estimate the passive force.

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- at $z = 0$, $\sigma_v = 0$ & $\sigma_p = 2c \sqrt{K_p}$
- at $z = H$, $\sigma_v = \gamma H$ &
 $\sigma_p = \gamma H K_p + 2c \sqrt{K_p}$
- Passive force per unit length of wall
 = area of pressure diagram

$$P_p = \frac{1}{2} \gamma H^2 K_p + 2cH \sqrt{K_p}$$

So, as I explained you, if I want to put it in words, then we can see here that at z is equal to 0, your vertical stress is going to be 0 that is σ_v is equal to 0. And then, subsequently your passive pressure will result into $2c$ square root of K_p K_p is nothing but your passive earth pressure coefficient. Then, at depth z is equal to H σ_v will be equal to γH and subsequently σ_p 's expression will result into this expression as $\gamma H K_p$ plus $2c$ square root of K_p

So, now we know the coordinate of or ordinate of the earth pressure diagram, once we know this it is simply a trapezoidal shape, so we can find out its area and get the resultant passive force per unit length of the wall. So, here we result into this kind of expression which is equal to that is passive force it is not the stress, because we are considering the

area now. So, your passive force will be equal to half gamma H square K p plus 2 c H square root of K p.

So, you can compare this expression with the expression in case of active pressure, if you compare, then you will see that there it was K_a and with the minus sign over here. So, that you must always take care of that in case of active earth pressure or in case of estimation of active earth force, you have to use active earth pressure coefficient and in case of passive, you have to use passive lateral earth pressure coefficient.

Then you see, as it was there in the case of active condition to achieve or to arrive a passive condition the wall displacement should be sufficient enough. So, depending on our experience of various research workers and their engineering judgment some of the guidelines have been given. See these guidelines are not very hard and fast they are simply gives you a little idea about the occurrence of passive condition.

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Approximate wall movements for failure under passive conditions

| Soil type | Wall movement for passive condition, Δx |
|------------|---|
| Dense sand | 0.005H |
| Loose sand | 0.01H |
| Stiff clay | 0.01H |
| Soft clay | 0.05H |

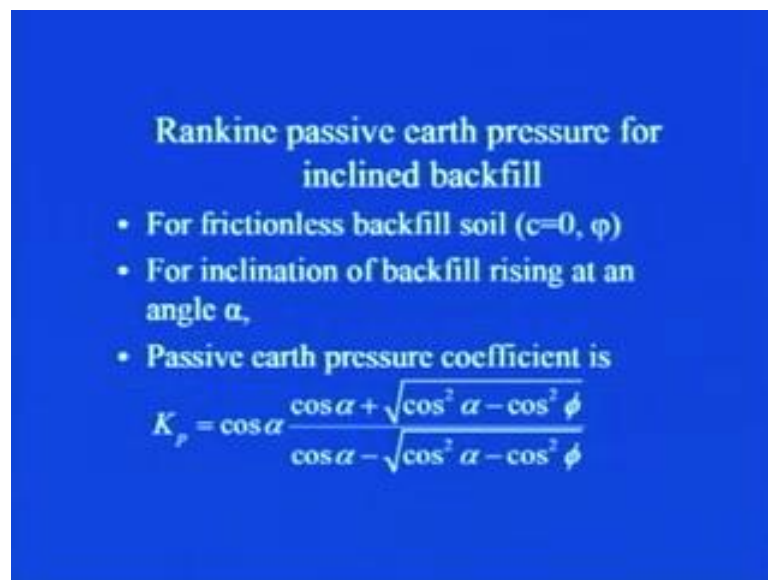
So, approximate wall movements for failure under passive conditions, you have different type of soils. Now, what is this soil, this is nothing but your backfill soil. So, depending on the type of backfill soil, you can have different wall movement with respect to the vertical height of the wall. So, if you have a look on this particular table, you will get little idea that how much should the wall be displaced in order to arrive at passive condition.

In case of dense sand, this wall movement should be of the order of 0.005 times the height of the wall, the vertical height of the wall. It is most likely that when the wall movement attains this value, then the passive condition is right, but again I will repeat that it is not hard and fast.

In some cases, you may get passive condition at say 0.004 H, so that you have to decide upon, but it gives you a general and rough guideline to deciding upon whether the passive condition is being achieved or not. In case of loose sand this value of wall movement is 0.01 H, in case of a stiff clay, now clay is you cohesion material. So, here it was frictional friction less material and here it is cohesive material. So, in case of stiff clay it is 0.01 times H.

In case of soft clay it is 0.05 times H, so when you go for analyzing the wall or when you go for estimating the passive force. Then you know the, what will be vertical height of the wall, you can roughly estimate that what should be the wall movement. To attain the passive condition and accordingly you can carry out further analysis.

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Rankine passive earth pressure for inclined backfill

- For frictionless backfill soil ($c=0$, ϕ)
- For inclination of backfill rising at an angle α ,
- Passive earth pressure coefficient is

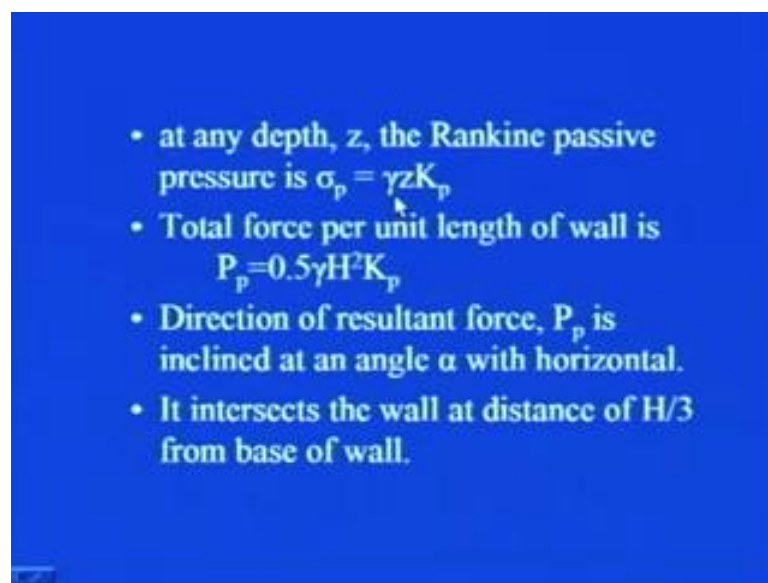
$$K_p = \cos \alpha \frac{\cos \alpha + \sqrt{\cos^2 \alpha - \cos^2 \phi}}{\cos \alpha - \sqrt{\cos^2 \alpha - \cos^2 \phi}}$$

Then, we discussed about the Rankine passive pressure theory with horizontal backfill. In nature usually, you do not come across horizontal black backfill, usually that backfill has some inclination with the horizontal how will you take into account this inclination in your analysis. So, if I take this frictionless backfill soil in that case, your c will become 0 and angle of internal friction will be there that is phi will be present. And, the

inclination of backfill rising at an angle α , so inclination of backfill is α with respect to horizontal.

In that case, your passive earth pressure coefficient will be given by this expression which is equal to $\frac{\cos \alpha + \sqrt{\cos^2 \alpha - \cos^2 \phi}}{\cos \alpha - \sqrt{\cos^2 \alpha - \cos^2 \phi}}$, where α as I told you is the inclination of the backfill of the wall and your ϕ is angle of internal friction on backfill soil.

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So, in that case, at any depth, z , the Rankine passive pressure will be your simply σ_v into K_p and at any depth is z your σ_v will result into γz . So, subsequently σ_p will become γz into K_p .

Once you know the lateral pressure diagram, simply you have to take the area to get the total force per unit length of the wall which is given by this expression as $0.5 \gamma H^2 K_p$. Now, this is what is the magnitude of the passive force, we have to see that where exactly it will be acting for proper designing of the wall. So, you see, direction of resultant force passive force that is P_p is inclined at an angle α with the horizontal and it intersects the wall at a distance of $H/3$ from its base.

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Values of passive earth pressure coefficient, K_p

| α (deg) | Φ (deg) \longrightarrow | | |
|-------------------|--------------------------------|-------|-------|
| | 28 | 30 | 32 |
| 0 | 2.770 | 3.000 | 3.255 |
| 5 | 2.715 | 2.943 | 3.196 |
| 10 | 2.551 | 2.775 | 3.022 |
| 15 | 2.284 | 2.502 | 2.740 |
| 20 | 1.918 | 2.132 | 2.362 |
| 25 | 1.434 | 1.664 | 1.894 |

As we did, for the case of active pressure, it becomes very difficult to remember sometime those tedious, and long expression, so to make it easy to make the determination of this passive earth pressure coefficient easy. Standard tables are available in a standard text book, I am showing you some of the typical values from those tables.

So, here for different value of angle of inclination of backfill that is 0 5 10 15 20 25 and for different angle of internal friction. In this table I am showing it for 28 degree 30 degree and 32 degree, you can have a look that how this K_p values are varying. So let us, say if you get any numerical problem or any practical problem and any key problem you know, what is the inclination of the backfill? You know the property of the soil you simply select from this table and pick the corresponding value.

Now, what you will do, let us say you can say that the phi degree is between 29 phi degree is 29 degree. So, how will you pick, in that case you pick any value of alpha which is corresponding to your actual condition and simply you assume a linear variation in between the two extreme values and you can interpolate or you can simply use the formula which I have already discussed with you.

Similarly, for phi is equal to 34, 36, 38, 40 degree for different values of alpha you have the coefficient passive earth pressure coefficient K_p value. So, you just decide upon what is the problem, you fix the value of alpha, you know the value of phi, you pick the

corresponding value of K_p and then subsequently you can find out the total force per unit length of the wall.

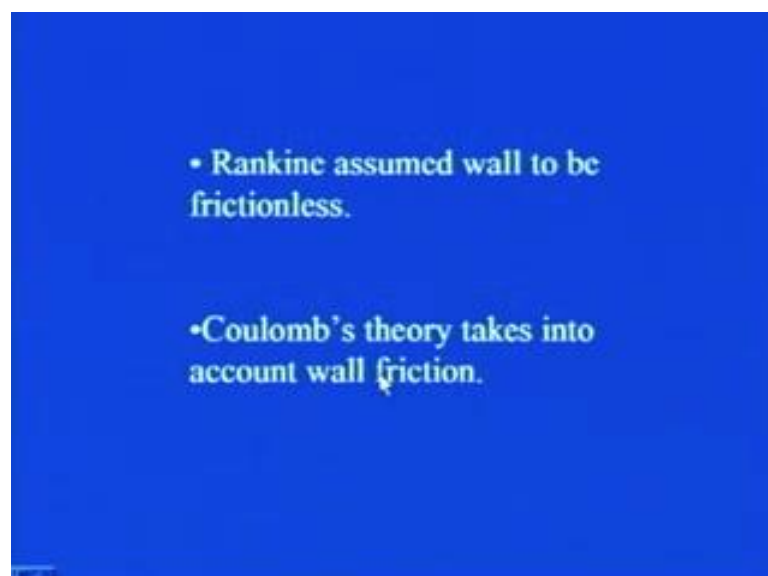
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Now, this was all about Rankine passive earth pressure theory, similarly as it was there in the case of active earth pressure, you have Coulomb's passive earth pressure theory.

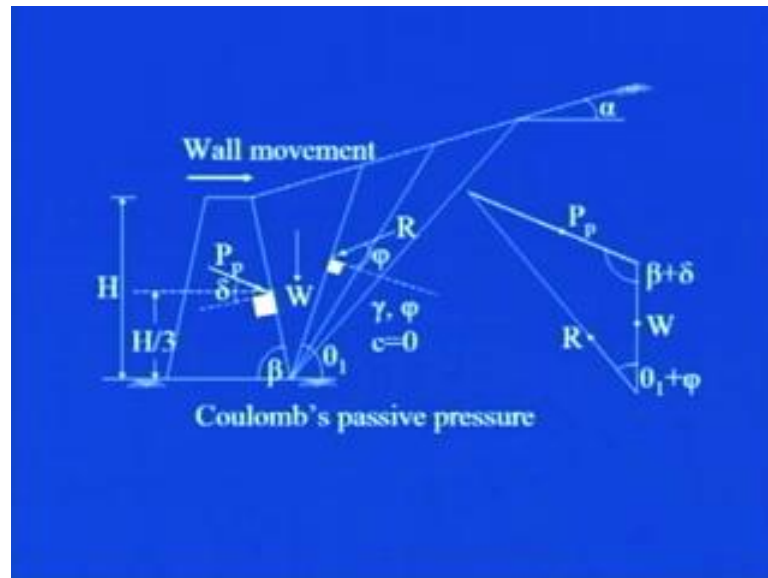
Let us, try to have a look on the analysis procedure and how you can estimate the passive earth pressure using this Coulomb's earth pressure theory, how it is superior or inferior to Rankine earth pressure theory. Let us try to have a look on all these aspects

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As, it was there in case of active earth pressure, in this case also the Coulomb theory takes into account the wall friction; however, it was not there in case of Rankine's earth pressure theory. As, I have already told you in previous lectures that no wall is perfectly smooth some or other friction will be present, so they that makes Coulombs theory more advantageous over Rankine's earth pressure theory.

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Now, since it is passive earth pressure that we are talking of this wall movement is towards this one, that is towards the backfill that is how the passive condition is getting generated in this particular soil.

So we really do not know, how the failure is going to take place, the failure can take place along may be this wedge, it can take place along this wedge, it can take place along this wedge. So, to analyze let us try to have a look on a particular trial wedge and let us try to see that what all are the forces which are acting on this particular wedge and then we can generalize the procedure, so for the time being if I considered this trial wedge.

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- β = inclination of back face of wall with horizontal
- α = slope of backfill
- δ = angle of wall friction
- Assuming a failure wedge, one has to obtain the forces acting on it and subsequently passive force.

So, you can see that your beta is the inclination of back face of wall with horizontal, alpha is the slope of the backfill delta is angle of wall friction.

Now, we assume that a failure wedge that is any trial wedge we assume and then we have to obtain that what are all the forces which will be acting on this particular wedge. Again let us try to have a look on this figure (Refer Slide Time: 14:40) This is the trial wedge that I have taken, its weight will be acting in vertical direction.

Let us call that as W , then at this particular face, what will be happen, the failure is taking place along this wedge. So, the soil will have tendency to move relatively, so what will happen, you will be getting a normal component and a shear component of forces whose resultant is shown here in this figure as R which will be acting at an angle of ϕ from the normal to this tan trial wedge. So, this is a trial wedge this is the normal from this an angle ϕ you have the resultant of normal as well as the shear force, so that is what is R .

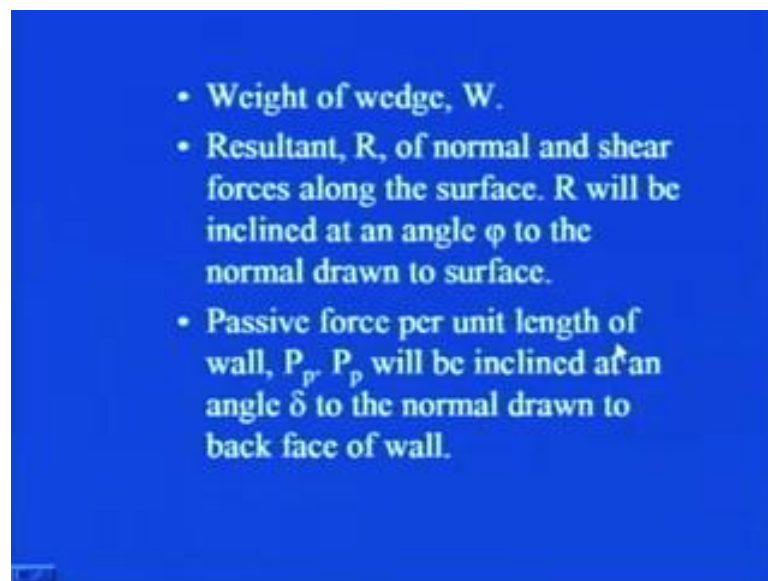
Then, you have another force which will be acting on this trial wedge is your passive force that will be acting at a distance of $H/3$ from the bottom of the wall and will be making an angle δ from the normal of the back face of the wall. So, this is the back face of the wall, this is the normal from here you make an angle δ and that will be the line of action of your passive force, where this H is the vertical height of the wall, since

it is I have assumed that it is frictionless backfill c is equal to 0, only ϕ will present and unit weight is γ .

Now this trial wedge, I am assuming that it is extending an angle θ_1 to the horizontal as shown here in this figure. Now, as we did exactly in the case of active earth pressure diagram when we were dealing with the Coulombs theory in that particular case, we have to follow the similar steps to get or to estimate the total passive force per unit length of the wall.

See again, as it was there in case of passive sorry active pressure, in this case also we do not have the magnitude of this resultant. We can just estimate this value of the magnitude of this weight W , but we know that, what is the angle subtended between W and P_p , that is $\beta + \delta$ see simply by trigonometrical things you can find out that, what is the angle between W and P_p , and what is the angle between W and R .

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So, different forces as I explained you weight of the wedge W , resultant R of normal and shear forces along the surface and this R will be inclined at an angle ϕ of the normal drawn to the failure surface. Then, passive force per unit length of the wall P_p which will be inclined at an angle δ to the normal drawn to the back face of wall.

Now, how can we find out this magnitude of this passive force? I can assume at a particular scale I know the magnitude of this weight W , accordingly I can draw a vertical

line that is R parallel line to this line and I can know that this much is the weight of the W.

Now, what I do is, I draw the line parallel to this P_p and a line parallel to this R, wherever they intersect and you can simply measure this length and you can get directly from this force diagram the magnitude of the passive force. This a whole procedure you have conducted for one trial wedge; however, we are not showed whether the failure is taking place along this trial wedge or may be along some other trial wedge. So for that, you need to conduct many trials in this case,

So, you have to assume another trial wedge get the weight of that and then draw the force diagram follow all the steps as explained to you and then you can find out the passive force for that particular trial wedge. Similarly, you can go for different different trial wedges, what will happen, when you will start with the earlier, what will happen is earlier, this passive force will go on reducing and after certain stage it will start increasing. So, the minimum value of the passive force that you will obtain in this procedure will be the Coulomb's passive force.

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- From force diagram, P_p can be obtained for particular trial failure wedge. Process is repeated for various trial wedges and minimum value is Coulomb's passive force. It is expressed as

$$P_p = 0.5 K_p \gamma H^2$$

From force diagram, your passive force can be obtained for particular trial failure wedge. This process is repeated for various trial wedges and minimum value is Coulomb's passive force which is expressed as 0.5 times $K_p \gamma H^2$, K_p you know the expression you have standard tables using you pick the corresponding value of K_p .

You know the property of soil, you that is how you know unit weight of the soil, you know the height vertical height of the wall and simply use by using this expression you can find out the magnitude of this total passive pressure force per unit length of the wall.

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Coulomb's passive earth pressure coefficient

$$K_p = \frac{\sin^2(\beta - \phi)}{\sin^2 \beta \sin(\beta + \delta) \left[1 - \frac{\sin(\phi + \delta) \sin(\phi + \alpha)}{\sin(\beta + \delta) \sin(\beta + \alpha)} \right]^2}$$

- In actual design of retaining walls, angle of wall friction, δ is assumed to be between $\phi/2$ and $2\phi/3$.

Where this is for inclined backfill, you have this long expression for your Coulomb's passive earth pressure coefficient. Then again, I will show you some of the values which are available in standard text book, you do not have to remember all the time this long and lengthy expression you can simply use those standard tables and go ahead with the calculations.

As it was there in the case of active, earth pressure in this case also, when you carry out the actual design of retaining wall you really cannot estimate exactly that, what will be the value of wall friction angle. So, from the experience of many previous research workers, it has been seen that, you can pick the value between $\phi/2$ and $2\phi/3$ of this angle of wall friction.

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Values of K_p for $\beta = 90^\circ$, $\alpha = 0^\circ$

| Φ (deg) ↓ | δ (deg) → | | |
|-------------------|------------------|-------|-------|
| | 0 | 5 | 10 |
| 15 | 1.698 | 1.900 | 2.130 |
| 20 | 2.040 | 2.313 | 2.636 |
| 25 | 2.464 | 2.830 | 3.286 |
| 30 | 3.000 | 3.506 | 4.143 |
| 35 | 3.690 | 4.390 | 5.310 |
| 40 | 4.600 | 5.590 | 6.946 |

So, for beta is equal to 90 and alpha is equal to 0 degree, that is the back face of the wall is vertical and for horizontal backfill if you take any typical value of delta and value of phi you can pick corresponding value of K_p for delta is equal to 0 5 10 and phi varying here. Now, it may happen that you do not arrive at any value of the phi which is mentioned over here.

Let us say, that you come across any phi value that is let us say 32 degree and if delta is 5 degree, then how will you pick the value, you simply either use the expression or if you want to use this table approximately, what you can do, you can assume linear variation between this value at 30 degree and the value at 35 degree and you can simply interpolate and get the value corresponding to phi is equal to 32 degree and delta is equal to 5 degree.

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Values of K_p for $\beta = 90^\circ$, $\alpha = 0^\circ$

| Φ (deg) ↓ | δ (deg) → | |
|-------------------|------------------|--------|
| | 15 | 20 |
| 15 | 2.405 | 2.735 |
| 20 | 3.030 | 3.525 |
| 25 | 3.855 | 4.597 |
| 30 | 4.977 | 6.105 |
| 35 | 6.854 | 8.324 |
| 40 | 8.870 | 11.772 |

These are few more values corresponding to delta is equal to 15 and 20 for different values of phi, you simply have to choose the corresponding parameters which is suitable or appropriate for your problem. And then, pick corresponding value of K_p and then go ahead confidently to estimate the total passive force per unit length of the wall.

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RETAINING WALLS

- Retaining walls are structures used to retain soil.
- Various lateral earth pressure theories discussed earlier are used to design various types of retaining walls.

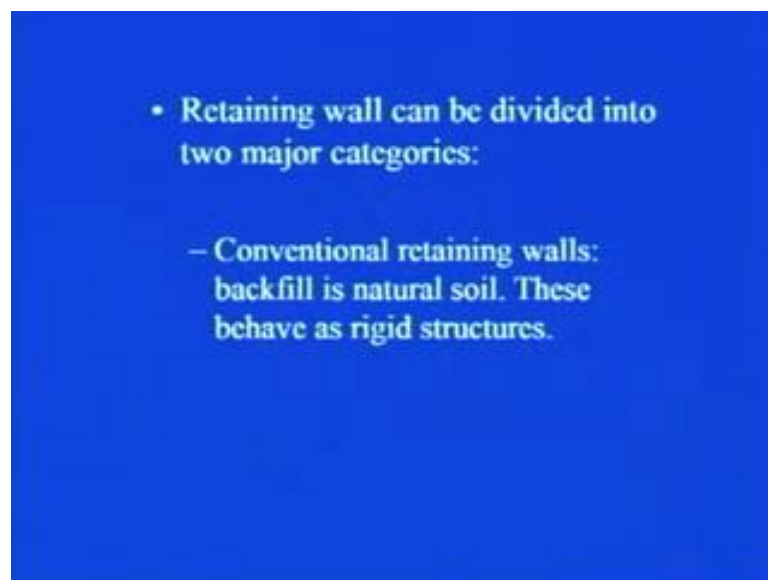
Now, this was what all about, your theories which are available to you for the estimation of passive as well as active forces per unit length of the wall.

Now, as you remember that in first lecture, we discussed about that why this estimation is so, necessary. Now, once we have estimated, now what to do, the estimation of this forces was necessary for the proper design of retaining wall. Right and then, so once now I have estimated these forces I can go ahead for the design of retaining wall. Before going for the design of retaining wall first I would like you to tell you about that, what are the various types of retaining wall, that are used, what are their shapes, how they are different from each other, what exactly are the purpose that they serve.

So, let us start with the another part of this particular chapter, that is retaining walls, what do you mean by retaining wall, retaining wall are structures which are used to retain the soil. As you have seen that, you once the soil is having the tendency to slide to stop that sliding of the soil you have to provide some structure over there which will retain that soil and that is why those structures are called as retaining walls or retaining structures.

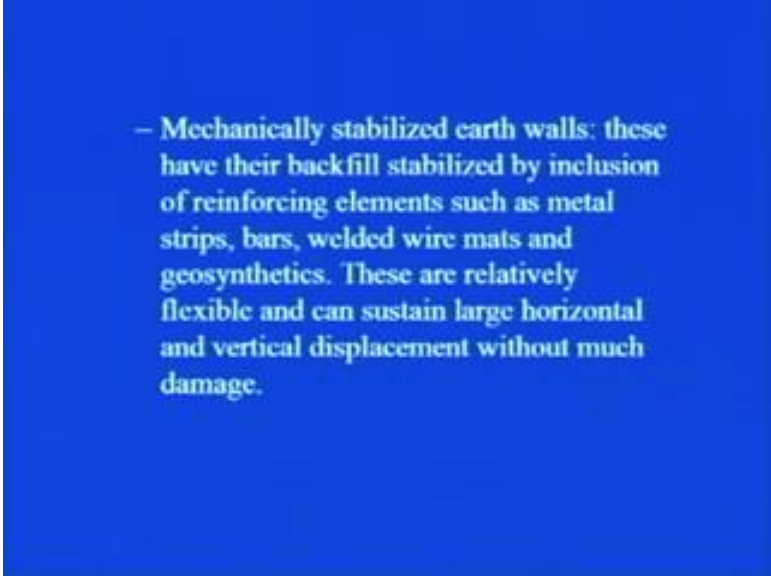
Various lateral earth pressure theories which we discussed earlier are used to design various types of retaining walls. Basically these can be divided into two major categories.

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First one is conventional retaining walls there the backfill is natural soil and these behave as rigid structures. In conventional structure in these days you here of your geosynthetics and different materials, but in case of conventional retaining wall we do not use such type of material.

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– Mechanically stabilized earth walls: these have their backfill stabilized by inclusion of reinforcing elements such as metal strips, bars, welded wire mats and geosynthetics. These are relatively flexible and can sustain large horizontal and vertical displacement without much damage.

However, in case of mechanically stabilized earth walls we stabilize the earth, that is we stabilize the backfill soil with the help of metallic strips geosynthetics etcetera. So, you can see here in this slide that mechanically stabilized earth walls, what are they that, these have their backfill stabilized by inclusion of reinforcing elements such as metal strips bars welded wire mats and geosynthetics. These are relatively flexible and can sustain large horizontal and vertical displacement without much damage.

As I told you, that conventional retaining wall they are sort of rigid structures, so the displacement they cannot undergo a large displacement before failure; however, that flexibility is there in case of mechanically stabilized earth walls. Now, within the scope of this particular course we will be discussing the conventional retaining walls and that too mainly gravity retaining walls and cantilever retaining walls.

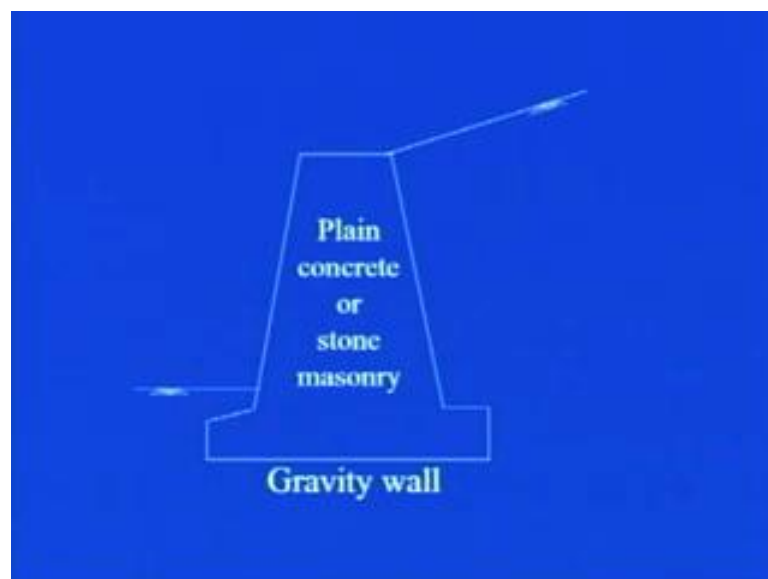
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However, various types of conventional retaining walls have been shown in this particular slide, that is first is gravity retaining wall, second is semi gravity retaining walls, third is cantilever retaining walls, fourth is counterfort retaining walls.

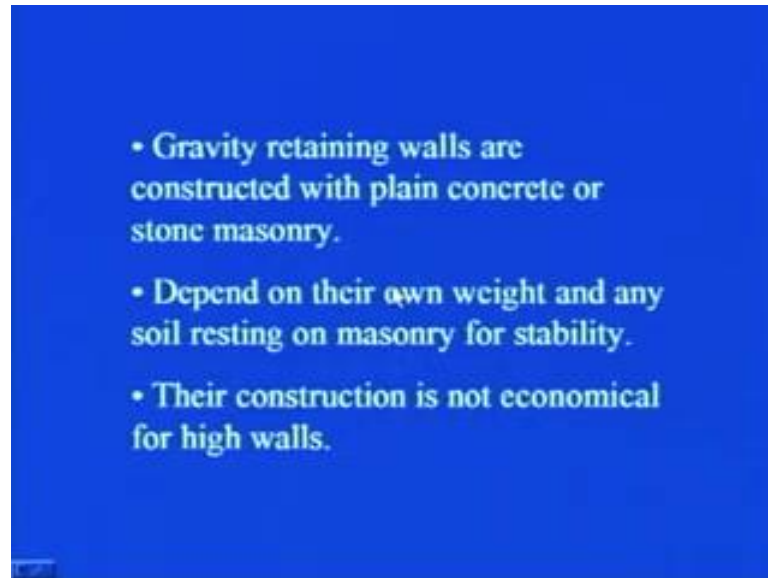
Let us try to have a look 1 by 1 that how one looks like and how one is different from another.

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This is sort of pictorial view of gravity wall, as you had seen that see here this is existing ground surface towards the backfill site. This is on the other side of the wall, here is this soil which was having the tendency to slide, we have to stabilize this soil.

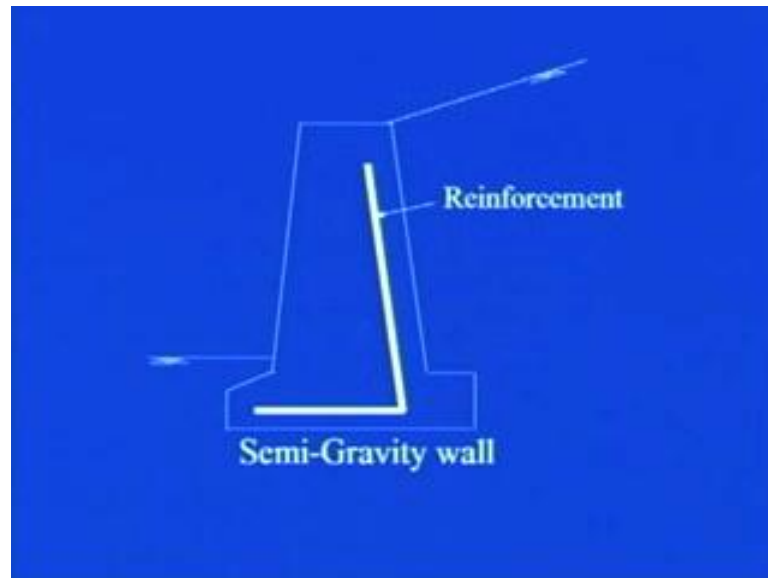
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Gravity wall is made up of usually plain concrete or stone masonry, what are the various features of this wall. See here gravity retaining walls are constructed with plain concrete or stone masonry depend on their own weight and soil resting on masonry for stability, so there is no reinforcement in this and nothing it is only its weight which is providing the stability to this kind of wall.

So, you can imagine that if you have to retain the soil and if you have to go in for gravity walls, how heavy they will be in their weight, to gain that particular stability. Their construction is not economical for high walls, because as, as soon as you increase the height of the wall, what will happen, since there is no reinforcement the masonry required or the plain concrete required will be quite high and so its weight. So, this becomes sort of a very bulky structures and it leads to uneconomic.

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Now, how to improve upon this gravity retaining wall, for that we introduce some of the reinforcement in the gravity retaining wall and we call that as semi gravity wall. All the things remaining same here, it is backfill here again in the soil and the reinforcement is placed by its construction.

So, what happen, some of the force or some of the pressure is being taken by this reinforcement and so that much reduction in the weight of gravity wall, you can go for and then that is how it is known as semi gravity wall.

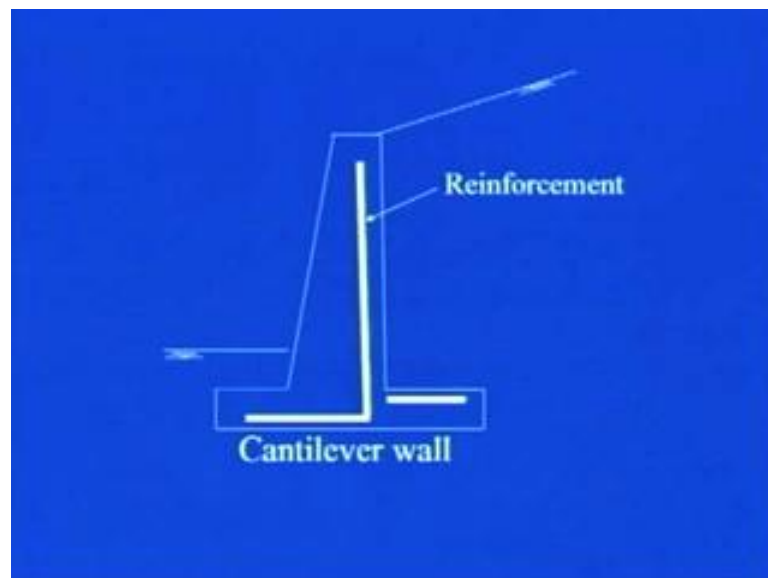
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- A small amount of steel may be used for the construction of gravity retaining walls to reduce the size of wall sections. These are referred as semi-gravity retaining walls.
- More economical as compared to gravity walls.

Let us try to see the main features of this kind of wall, a small amount of steel may be used for the construction of gravity retaining walls, to reduce the size of wall section. These are referred as semi gravity retaining wall, these are more economical as compared to gravity walls, because you can go ahead for higher walls as compared to gravity retaining wall.

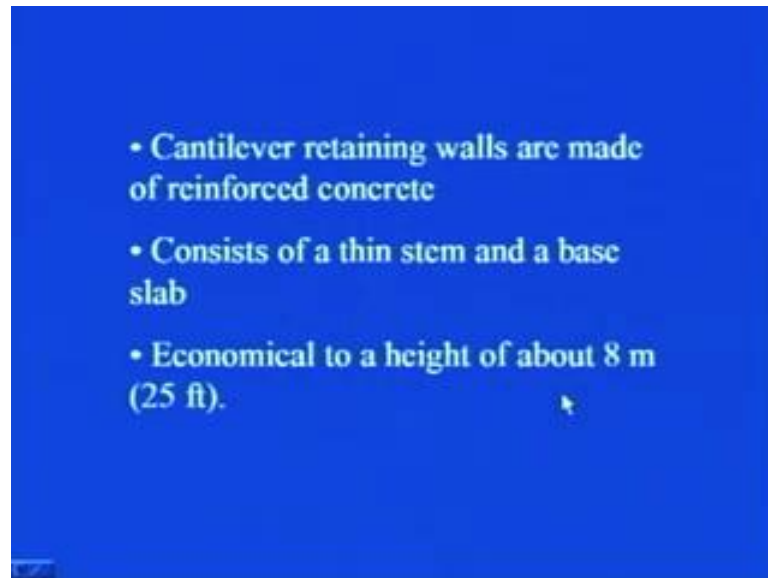
Due to the presence of the reinforcement, some of the forces, some of the pressures are sheared by that reinforcement and the force or pressure which is coming on the plain concrete or the stone masonry is become relatively much lesser as it was there in case of semi in case of gravity retaining walls. So, you saw gravity retaining wall and semi gravity retaining wall.

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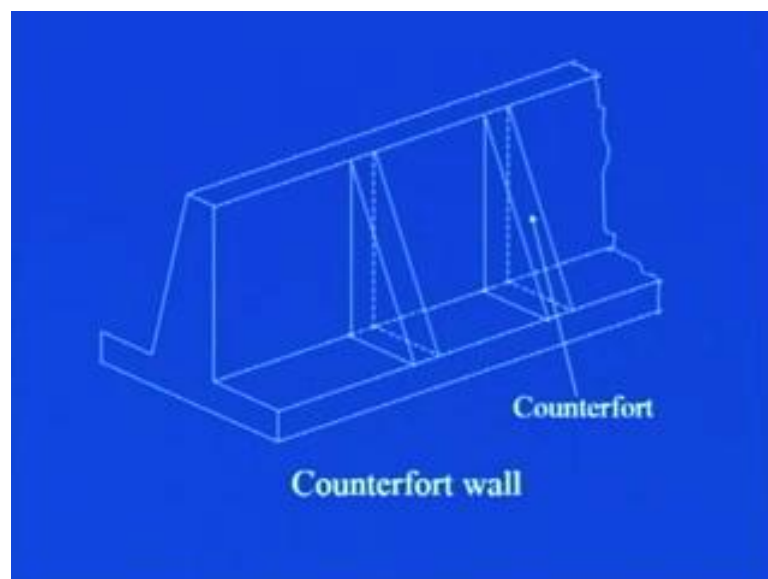
Now, let us try to have a look on the third type of retaining wall that is cantilever retaining wall which is little bit different from these two. It takes a shape of this kind such that it is this part it can behave as a cantilever part, this is what is your backfill soil the reinforcement which was there only this much in case of gravity wall. In cantilever walls some of the reinforcement is provided in this part also.

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Now, some of the salient features of retaining wall, these are made up of reinforced concrete. This consists of a thin stem and a base slab, it is economical to a height of about 8 meter or 25 feet.

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After that, now let us see, if the length of the wall or length of the soil retained if soil to be retained is too much. Then, going for a cantilever wall causes very large magnitude of bending movement and shear forces on the stem part of the wall which causes very bigger sections in design.

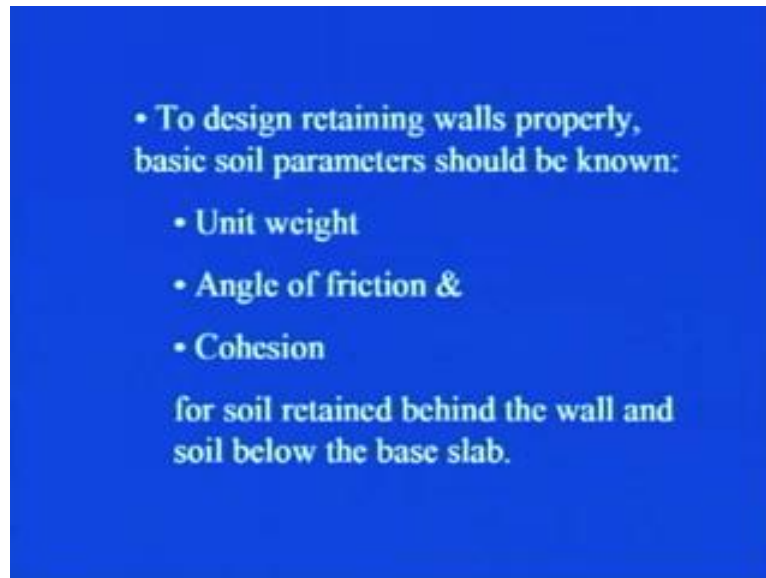
So, to avoid all these problems, what has been done, is that these kind of counterforts are provided at certain intervals, to provide the rigidity to this stem part of the wall.

You can see here is the three dimensional pictorial view of the counterfort retaining wall. It is a specific type of cantilever retaining wall, see this is what is the cross sectional view of retaining wall. This is the length direction in which it is extending to few meters or may be in some cases to few kilometers also and then to strengthen this particular part this kind of counterforts are provided.

You see, what happens by providing these counterforts, what happens, is the span is now this much only earlier, let us say in the absence of this counterfort if the span would have been this much with the presence of this counterfort, the span gets reduces to this much. And then, subsequently the reduction in the bending movement and the shear force is also there, which results in the economic design of the section on this particular cross section.

It is very much similar to cantilever retaining wall, as I just now told you at regular intervals these have thin vertical concrete slabs which are known as counterforts. These counterforts tie wall and the base slab together, the purpose of the counterfort is to reduce shear and bending movements. So, when you will be doing the structural design of these counterfort wall, then you will be able to appreciate more that to, what extent it reduces or it helps in reducing shear on the bending movement when you design the stem of any retaining wall.

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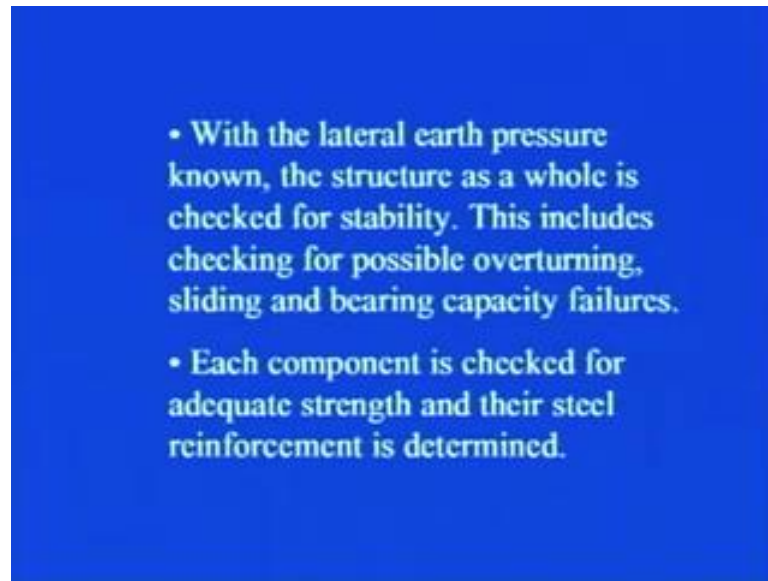
Now, these were the various types of retaining walls, to design the retaining walls properly some of the basic soil parameters should be known. As it was necessary, when we were estimating the lateral earth forces, what are those properties, they are unit weight of the soil angle of internal friction of the soil and the cohesion.

For the soil which is to be retained which is lying behind the wall and which is below the base slab, what happens is, many at times these two soils that is the backfill soil and the soil which is lying below the base slab, they are same. But in case, if they are different we need to take into account the difference and the different different properties of these different type of soils.

Now, knowing these properties of the soil behind the wall, all these knowledge it enables an engineer to determine the lateral pressure distribution for which the wall should be designed for. As you have seen, that to estimate the lateral earth pressures what you required is your γ c and ϕ that is cohesion and angle of internal friction. So, you have to have proper estimation of these particular parameters to have proper estimation of lateral forces.

So, there are basically two phases in the design of any conventional retaining walls, what are they.

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First of all, you have to proportion the structure, see before hand you do not have any idea that, what should be the stem thickness, what should be the width of the base slab, what should be the stem thickness, when the wall at the connection where the stem is getting connected to the base slab.

So, first we have to have some idea some preliminary idea about the tentative dimensions. And after that, once we fix up these dimensions tentatively then we go for checking the stability, that whether the wall is stable corresponding to these preliminary and tentative dimensions of the wall.

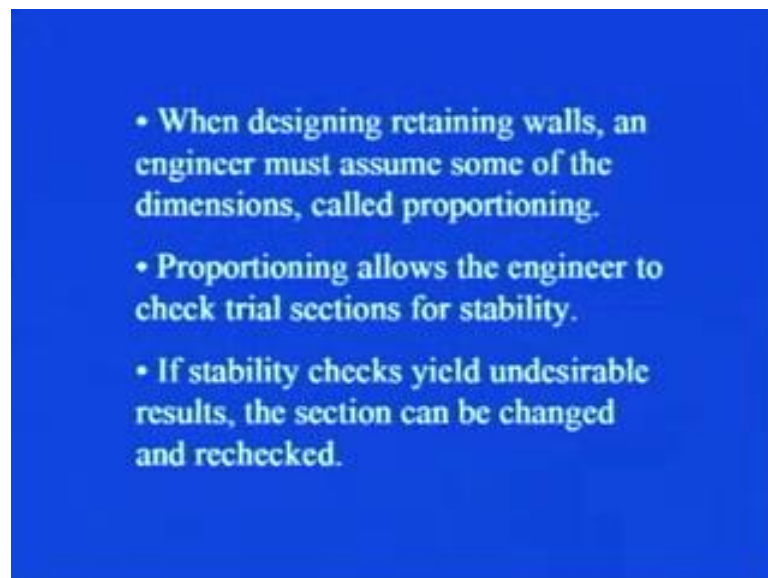
So, you can have a look here in this slide, that with the lateral earth pressure known the structure as a whole is checked for stability this includes checking for possible overturning sliding and bearing capacity failures. Each component is checked for adequate strength and their steel reinforcement is determined accordingly.

Now let us say that, I provided particular value of base, width of the base slab, now I checked for overturning sliding and bearing capacity failures it may happen that the wall is safe against overturning. But, it may fail in a sliding or bearing capacity, what you have to do, in that case you have to revise your dimension such that the wall is safe against all the three cases that is overturning sliding and bearing capacity failure.

Along with that this is, what is the overall stability, but as you know from your structural background that the stability as well as serviceability is an important criteria for proper functioning of any structure, so you need to provide the check for excessive settlements. In case, it may happen that a wall is stable against overturning it is stable against sliding and bearing capacity failures, but it may happen that the soil strata which is lying below the base slab is very weak or loose in nature.

In that case, it may cause excessive settlement, so that is not permissible as for as serviceability criteria is concerned, so that we need to take into account. But, for the purview of this particular course we will be emphasizing more on the stability checks of the wall.

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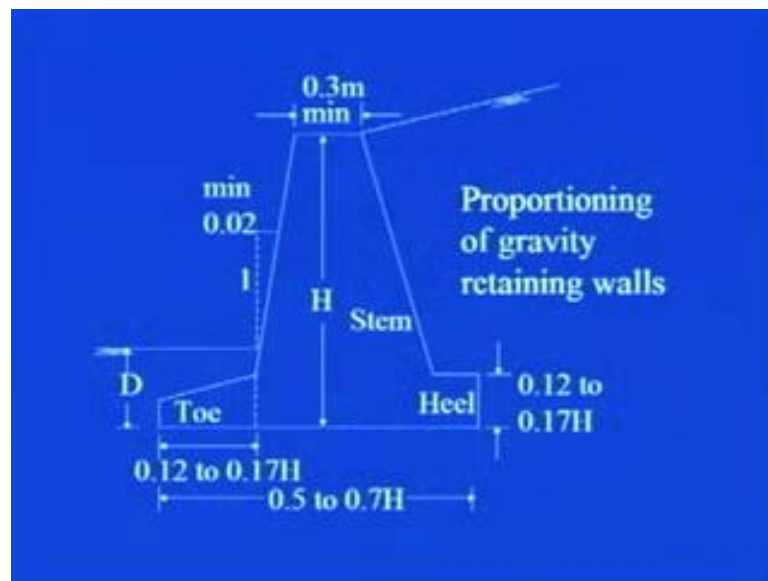


When designing retaining walls, an engineer must assume some of the dimensions as I told you and this procedure is called proportioning. This proportioning allows the engineer to check trial sections for stability.

Let us say, I took one tentative dimensions for all the sides and all the places, that is let us say thickness of the stem at the top of the wall, thickness of the stem at the base of the wall, then thickness of the base slab. Then, using these trial dimensions I have to provide the check for overturning for is sliding and for bearing capacity failures.

In case, if the wall is failing in either of these three criteria, you have to go for re-proportioning. So exactly in the third point, it is there that is if stability checks yield undesirable results. The section can be changed and rechecked, so we have to go on repeating this procedure till we achieve a proper stability against overturning sliding and bearing capacity.

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Let us, try to have a look in case of gravity retaining wall, see we will be emphasizing more on gravity retaining walls and cantilever retaining walls as far as this particular course is concerned.

So, let us start with proportioning of gravity retaining walls, here this is, what is your back fill, this is a soil. This whole soil is lying below the base slab also, this is the typical cross section of a gravity retaining wall. This particular part above the slab is known as stem, the part of the wall which is lying towards the back fill is known as heel towards another direction it is toe.

Now, usually it has been seen that if you keep the minimum of 0.3 meter at the top of the stem; that means, you cannot keep it to be 0.15 meter or 0.2 meter, you have to have a minimum stem thickness at the top of the wall as 0.3 meter or 300 millimeter. Now, if H is the vertical height of the wall from the experience and from the judgment, from the experience of different sides different construction of the retaining walls. Many research

workers and theoreticians they have given the some guidelines for proportioning the retaining walls.

Usually, the base width that is this much is adopted as 0.5 to 0.7 times H here H is your vertical height of the wall. So, you can take you if you want to have you can take any particular dimension in between 0.5 to 0.7 times H say if H is equal to 10 meters. Then, your base width can vary between 5 meter to 7 meters, you can go ahead you are in calculating or in providing the stability checks for the failure criteria.

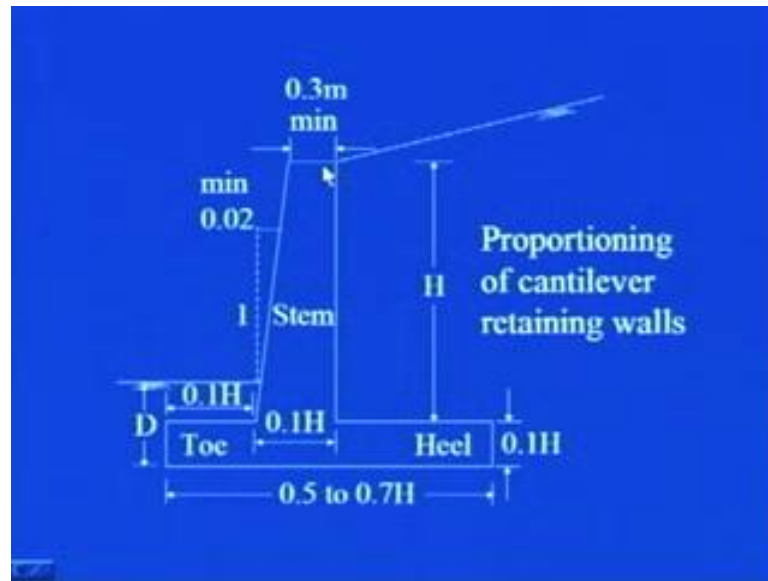
Width base width to be equal to say 5 meter 6 meter 7 meter and even more than that, but usually 5 to 7 meters for the height of the wall as 10 meter can be adopted. Then this part this is little bit tapered and the minimum 1 that you can provide is that 0.02 horizontal with 1 vertical.

So, this much slope you can provide, what about the thickness of this base slab, that can e kept in between 0.12 to 0.17 H. So, if height of the wall is 10 meters then the thickness of base slab can be of the order of 1.2 to 1.7 meters, again I will repeat here, again that the there is no hard and fast rule that you have to pick 1. 2 meter only or 1.5 meter only or 1.7 meter only as far as this thickness of the base slab is concerned. This gives you a rough idea rough guideline for deciding the tentative dimension

You pick any typical value provide the stability checks, if the wall is stable against overturning sliding and bearing capacity failures. Otherwise, you increase or decrease the usually you have to increase the base width and then you provide the stability checks again. And then, go ahead in case if it comes out be safe then you can confidently go ahead with structural design, otherwise again you have repropotion the whole wall.

Now, towards the toe, see this part you can take of the order of 0. 12 to 0.17 H, so if the wall height is 10 meter then this can be of the order of 1.2 meter to 1.7 meters. I hope that it is clear, always remember one thing that the thickness of the stem at the top of the wall should be kept as minimum 0.3 meters or 300 millimeters, base width should be of the order of 0.5 to 0.7 times the height of the wall.

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Now, let us see that how you can go ahead for proportioning, cantilever retaining walls. As it was there in case of gravity retaining wall, in this case also the top width of the stem should be kept as 0.3 meter minimum; that means, you cannot provide it 200 mm or 150 mm you have to provide 300 mm, again in this case, the base width should be of the order of 0.5 to 0.7 times H.

In this case, it is recommended that the base width that is this should be taken it is not the base width it is the thickness of the base slab base width is this. So, base width should be 0.5 to 0.7 times H, but the thickness of this base slab should be of the order of 0.1 times H. So, what you can do, is that let us say you have to construct the 20 meter high cantilever retaining wall, then 0.1 times H becomes 2 meter right.

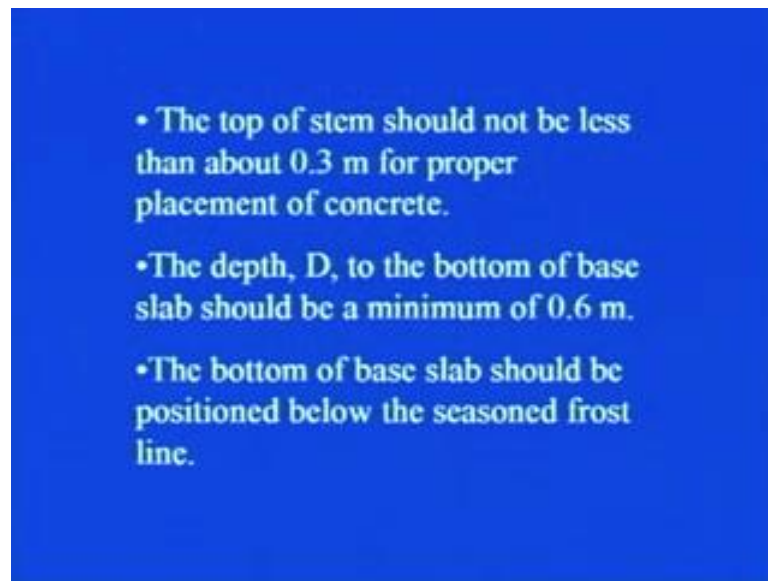
So, what you do is, that you first provide or you first assume this base thickness that is the thickness of this base slab to be equal to 2 meter. And then, accordingly you can choose all these dimensions carry out the stability check, if it is in stable its very good, if it is not a stable or if it is unstable in either of the case either of three cases, what you have to do, you have increase the base width or you have to reportion the whole wall altogether, again before you carry out the stability checks again.

In this case, again this you can keep this as tapered with this minimum 0.02 horizontal and with 1 vertical where the H is the vertical height of the walls from this point. D is the depth of placement of this base slab, below the ground surface, the width of the toe part

can be kept as $0.1 \times H$ and this width of the stem at where it connects with the base slab can be kept equal to $0.1 \times H$.

So, you can see that overall it gives you the rough idea about the proportioning of the wall. So, you can get first these trial dimensions and go ahead with the stability checks if it is coming out to be fine otherwise you re-proportion the whole thing and go for stability checks again.

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So, some of the guidelines that you must always remember while proportioning the retaining walls. The top of the stem should not be less than about 0.3 meter for proper placement of concrete. See if you go for 200 mm or 150 mm thickness you will not be able to place the concrete properly, so to make it easy during the construction procedure you have to have 300 mm thickness at the top of the stem.

The depth D to the bottom of base slab should be a minimum of 0.6 meter, (Refer Slide Time: 46:31) This D is the depth of placement of this base slab below the ground surface, this should be minimum of 0.6 meter. So, minimum 0.6 you have to give you can give even more than that if the construction permits.

The bottom of the base slab should be positioned below the seasoned frost line, that these are all the very general guideline that you must keep into mind before going for construction.

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- For counterfort retaining walls, general proportions of stem and base slab is the same as for cantilever retaining walls.
- The counterfort slabs may be about 0.3 m thick.
- Centre to centre spacing of counterforts may lie between $0.3H$ to $0.7H$.

For counterfort retaining walls general proportions of the stem and base slab is the same as for cantilever retaining walls. I already mention to you that the counterfort retaining wall is a particular type of your cantilever retaining wall.

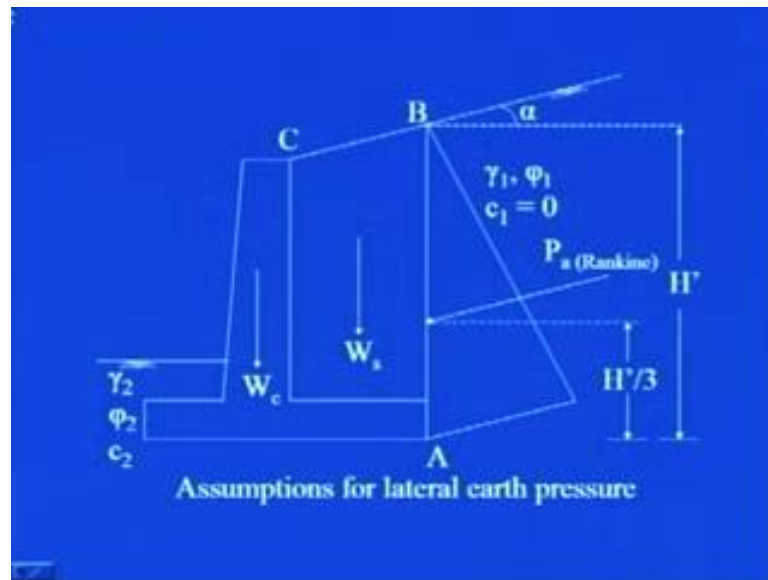
Now, how you can go for these counterfort slabs or how you can provide them. They there are various specifications which are available in relevant IS codes, but they are little bit more advanced studies, so it is beyond the scope of our codes. So, you just note down these guidelines.

The counterfort slabs may be about 0.3 meter thick, its centre to centre spacing may lie between 0.3 times H to 0.7 times H . So, if a wall is having a height of say 10 meter, then you can provide the counterforts at centre to centre spacing of 3 to 7 meters. Depending on what exactly is the stretch of the wall and what exactly is I mean, how you are able to achieve the stability.

Now, to use the lateral earth pressure theories in the design of retaining wall, an engineer must make several assumptions. So, because you have studied Rankine active earth pressure and passive earth pressure theory you had studied Coulomb's active and passive earth pressure theories. So, to go for designing of the retaining wall you have to assume some of the things.

Such that like in this case, in the next point if you have a look, in cantilever walls use of Rankine earth pressure theory for stability checks involve drawing a vertical line AB through point A which is located at the edge of heel of base slab.

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This is a point A which is located at the heel of base slab, so we assume that the failure is taking place like this along this surface AB; however, if you remember, when we discussed these theories, we assume a triangular trial wedge, but here it is not that case. So, this is a kind of assumption that we are making for the design or for providing the stability check for the design of retaining wall cantilever retaining wall.

So, it is from A to B a vertical line, that is this 1, this is the phase, now what are the various forces that you have to take into account, what are they, that is weight of the soil which will be lying on this particular area. The back fill is inclined at an angle of alpha with the horizontal the soil property is c_1 is equal to 0, that is it is friction less backfill, gamma 1 is the unit weight of backfill phi 1 is the angle of internal friction for this one.

Now, since the cantilever wall is made up of reinforce concrete, so it will have its own weight and that will be acting also, so this W_c represents the weight of the wall. For the soil which is lying below this base slab the properties are gamma 2 phi 2 c 2 gamma 2 is the unit weight of this soil c 2 phi 2 are the shear strength parameters.

Then, since it is inclined, you know that in Rankine's theory, for inclined backfill the earth pressure acts parallel to that. So, this P_a Rankine that is Rankine's active force, it is acting in a direction which is parallel to this inclined backfill, that is it is making an angle α with the horizontal and it will be acting at a distance of H' by 3 from the bottom of the wall.

Now, what is H' , H' I am calling as vertical height of the wall that is from here to here it was H , but H' is in this case is from this point B to the point A, that is this much height is your H' . And, this P_a Rankine will be acting at H' by 3 depth from the base of the wall or from the point A, these are the basic assumption that is the only assumption is that that if the failure is taking place along this vertical plane which is AB.

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So, you have to make an assumption that Rankine active condition is existing along the vertical plane AB, as I showed you in the previous figure. And then, subsequently you have the Rankine's expression you can use that to find out your Rankine active earth force which will be acting on the face AB.

As far as today's class is concerned, we studied the we started with the Coulomb's passive earth pressure theory we and then we studied the different values of K_p , how you can evaluate, for different values of β and α and δ and then I started with the introduction of retaining walls. We saw that there are four mainly types of retaining

walls gravity retaining wall, semi gravity retaining wall, cantilever retaining wall and a special type of cantilever retaining wall as counterfort retaining wall.

Then, we saw that how we can go ahead for the design procedure of these walls. First you need to have the proper estimation of the lateral earth pressure. And then, for that you have to have some of the initial dimension of the retaining wall to go ahead for the design procedure.

Once you assume, some of the preliminary dimension of the cross section of the wall, then only you can provide the corresponding check for stability. If that check is satisfying its otherwise you have to repropotion the thing and then we took the case of cantilever retaining wall and we tried to see that how the Rankine theory can be applicable while estimating the active force which will be acting per unit length of the wall. Now, this analysis we will be continuing in the next class

Thank you.