Ground Improvement
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Lecture 49
Soil Nailing (Contd.)

Hi everyone, let us continue to ground improvement lecture and we had completed initially ground soil nailing and then we have discussed about anchor, some part of it not fully and both are beneficial over conventional retaining wall, particularly soil nailing is particularly important for soil, advantageous over permanent retaining wall, whereas anchor mostly used for construction purposes and it is quite useful also.

And there are certain aspects there how it will fail and what are the different types of anchors and all we have discussed and today we will try to discuss the design step, failure mode already we have discussed and today this lecture today I will try to cover design, not really design step but not much design is there, design consideration what length, how much, etcetera, some guidelines we will discuss then there will be some strength of the materials is required, some guidelines are there those will discuss.

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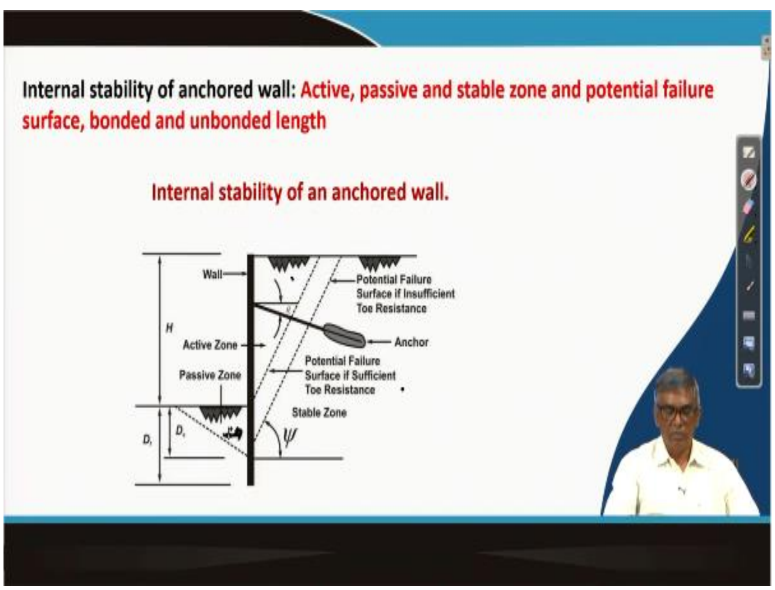

let me take the first slide that is the internal stability of the anchored wall, when the wall will be anchored, anchored wall it must be stable and then there are different zones are there, you can see here there is a this is zone called active zone, this zone is called passive zone and this is called stable zone and this will be this anchor is there and this anchor the unbounded length will be there on the active zone, whereas bonded length should be on the stable zone, that the resistance will develop here and that will prevent the movement of this active zone away from the wall.

And this will give you some toe resistance, that when it will be having tendency to pressure this side, it should not fail like this, you are pushing this side then also through this anchor you are pulling this side, then it has tendency to go this way, to prevent that movement there should be for this direction, this is passive, these are briefly I just mentioned various aspect of internal stability of the anchored wall.

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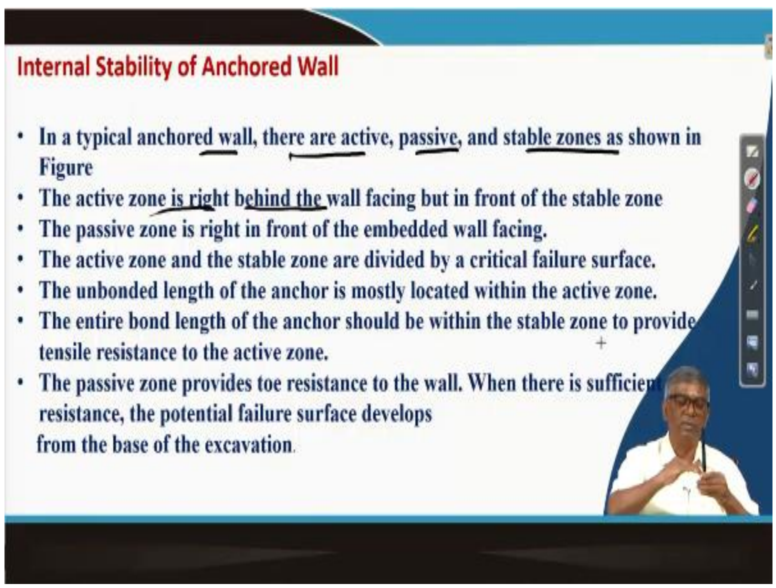

Now I will try to show you in detail listing and which I will be showing in the next slide, you can see that which I have already told I have listed here, typical anchor level, there are active, passive and stable zone which I have shown in the figure. An active zone is right behind the wall, this is the wall then just immediately after the wall is the active zone but in front of the stable zone.

Stable zone also behind the wall but there is a failure plane and between the failure plane and the wall that zone is the active and beyond failure zone that is stable zone, and then passive zone is right in front of the embedded wall which we have, this is the wall and then this is the passive zone which we have shown in the figure.

And active zone and stable zone are divided by a failure surface, which we have shown there also, I think I will not be not able to go back, that the entire soil behind the wall is that divided by failure line two parts, that is active part which is immediately behind the wall and the passive part which, sorry, stable part which is again behind the wall but after the failure zone.

That is already I have shown in the figure, then unbonded length of the anchor is mostly located within the active zone, so this is the wall and this is the anchor and this is failure plane, so unbonded length will be within the active zone, which I have also shown in the figure.

The entire bond length of the anchor should be within the stable zone, that is what if this is the failure plane and it comes anchored that the anchoring should be here only, so beyond the failure zone that the entire bond length of the anchor should be within the stable zone to provide tensile resistance to the active zone, active zone will try to put and then it will have, it will have some anchoring effect here. And passive zone provides toe resistance to the wall, toe can slide it can be horizontally or it can rotate so that resistance will be offered by the passive zone.

And when there is a sufficient toe resistance the potential failure develops from the base of the excavation, if the resistance is sufficient then if this is the bottom of the excavation, this is the bottom of the excavation then failure plane will start from here but if not sufficient there, passive resistance is there the failure plane go beyond, that is what I have not shown here, but these are the important observation for internal stability of the anchored wall.

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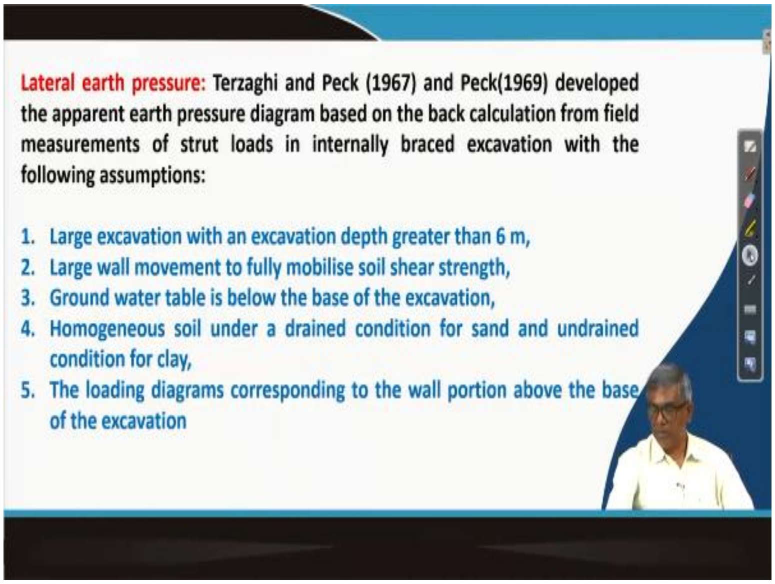

Next one that when there will be wall, then behind the wall there will be at pressure, earth pressure and when it is a conventional retaining wall, we have learned three different types of earth pressure, earth pressure at rest, active earth pressure, passive earth pressure and then we have also got the method to estimate active earth pressure, passive earth pressure or pressure at rest and also total how to find what is the total amount of active earth pressure or total amount of passive earth pressure or what is the total amount of at rest pressure, how to calculate that also we have learned in soil mechanics.

Now when it is a anchored and it is a excavated pond and in that case, that means during excavation work we generally provide seat pile and then simultaneously the anchor, so under this condition the earth pressure will not be same as what we have learned in the conventional cantilever or gravity retaining wall, here the Terzaghi Peck what they have done they have observed the pressure level and at different zone and then they have back calculated and they have given some pressure diagram and before giving to that they had also some assumption also and those assumptions are listed here.

Here Terzaghi and Peck and Peck both actually, two publications are referred here, develop the apparent earth pressure diagram based on the back calculation from the field measurements of strut loads in internally braced excavation with the several assumptions, those assumptions are here. large excavation with an excavation depth greater than

6meter, whatever the diagram etc., they have provided for calculation of earth pressure on the braced wall that will be applicable only when the large excavation and it is a depth is greater than 6meter.

And the large wall movement to fully mobilize soils shear strength, that is also another the wall movement will be sufficient, then ground water table is below the base of the excavation, if in between, if the base of the wall is here water table is here then this method of pressure diagram what they have given will not be applicable to find out the load, that will be different.

Then homogeneous soil under a drain condition for sand and undrained condition for clay soil, these two things, soil should be homogeneous and at the same time undrained condition for clay soil and drain condition for sandy soil this is the two assumptions also simultaneously taken.

And loading diagrams corresponding to the wall portion above the base of the excavation, so whatever diagram they have given base of the, above the base of the excavation this is the portion and the behind that they have given a typical pressure diagram, below that it is not applicable and not considered, based on this assumption they have given some diagram which we can see now.

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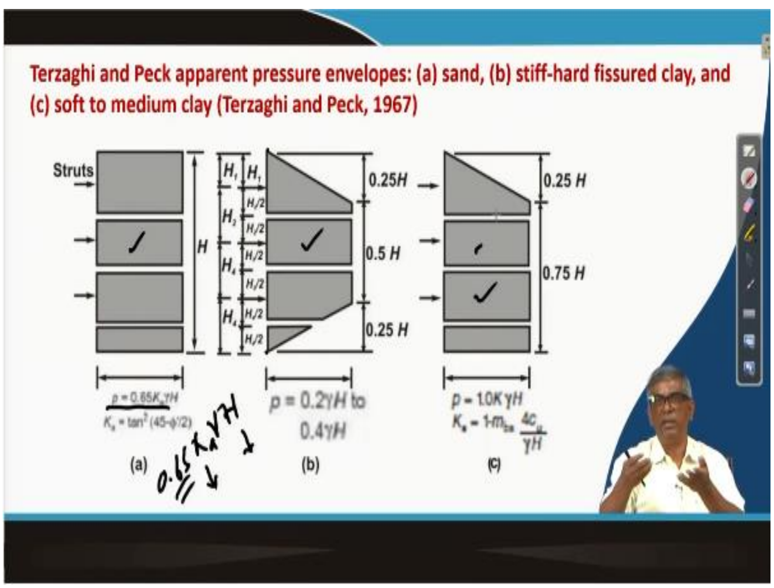

You can see here that there are two cases sand one diagram and then stiff hard fissured clay, this another diagram they have given and soft to medium clay there is another, so three, total three diagrams given so this is a, this is for sand, when the stand is excavated with support and then for the calculation of strut load one can assume the pressure throughout the depth uniform.

And with an intensity equal to point 0.65 Ka gamma H, where Ka equal to tan square 45 degree minus 5 by 2 that is coefficient of active earth pressure, so that means when the excavation is done on the sand and it is supported by the wall then if you want to find out the load on the wall then the pressure within the depth, entire depth can be assumed constant which is equal to ah 0.65 Ka gamma H, where H is the height of the wall, gamma is the unit weight of the soil, K is the active earth pressure coefficient and it is 0.65.

$$0.65 K_a \gamma H$$

$$p = 0.65 K_a \gamma H$$
$$K_a = \tan^2\left(45 - \frac{\Phi}{2}\right)$$
$$p = 0.2 \gamma H$$
$$P = 0.4 \gamma H$$
$$P = 1.0 K \gamma H$$
$$K_a = 1 - m_{cu} \frac{4 c_u}{\gamma H}$$

So normally at that depth if it is no excavation is there then the pressure could have been gamma H Ka is it not, so here actually 65 percent of that is taken and it is taken throughout the depth uniform. Similarly, for stiff hard fissured clay their diagram is taken, this is the diagram recommended, it is sort of trapezoidal diagram, initially at the surface of the ground surface is 0 and at the bottom of the excavation also zero, in between pressure will be maximum and that will be over a particular length.

And here you can see that the pressure will start from 0 and increasing linearly up to at a depth a 0.25 H it will increase to maximum and again it will be constant up to 0.75 H and then from there it will be decreasing and it will become 0 at the base of the wall and so that means there are three zones.

One is increasing at from the zero to some maximum value and then decreasing from maximum to zero at the base of the level, this trapezoidal diagram depending upon your start position and considering the zone of influence we can divide in number of simplified way beam like things and then we can find out the load, that I will discuss later on.

This is hard fissure clay and what will be the maximum pressure diagram 20 times of gamma H, so gamma H if I increase linearly it could have been gamma H but it is actually 0.2 gamma H to 0.4 gamma H, designer can choose in between, it can be 0.25 it can be 0.3, it can be 0.35 or it can be 0.4, so any value between 0.2 gamma H to 0.4 gamma H to be considered as a maximum, this is the maximum value and it is 0 and it is 0 and it start will be here according to the start position we can apply some method and then can find out what is the load on the start finally.

And if it is a soft medium clay then this is a typical diagram recommended and this diagram is that it at the surface it is 0 and it will be increasing linearly and will become maximum at a depth equal to 24.25 H and then it will remain constant up to the base of the wall and this what is the maximum value of the pressure, that pressure is given 1 Ka gamma H_2, 1 K gamma H_2, where K equal to 1 minus m 4cu by gamma H. So, these things we can see the reference, main reference exactly what it is given under and strength, the H gamma all those things are there, m is a coefficient depending upon soil type we have to take some value, all those things in there in the original reference.

Once you get so either so based on your soil type you can choose this diagram or this diagram or this diagram and then depending on the start position apply some simply one method and you calculate the amount of strut load, this is the way we do strut load and strut, when it is excavation and it is supported in this side and instead of both the, this is the one side of the excavation wall and this is one side.

And if it is supported like this then you are giving some pressure on the wall and in this direction but anchor is what this side wall is not there suppose, this is the only wall then from this wall connected another anchor behind and that anchor will be pulling, so almost similar whatever best or you can assume that strut in the front and whatever way you calculate similarly we calculate only it will install in the start it will go to the anchor, so that calculation only difference so that way we will see later on.

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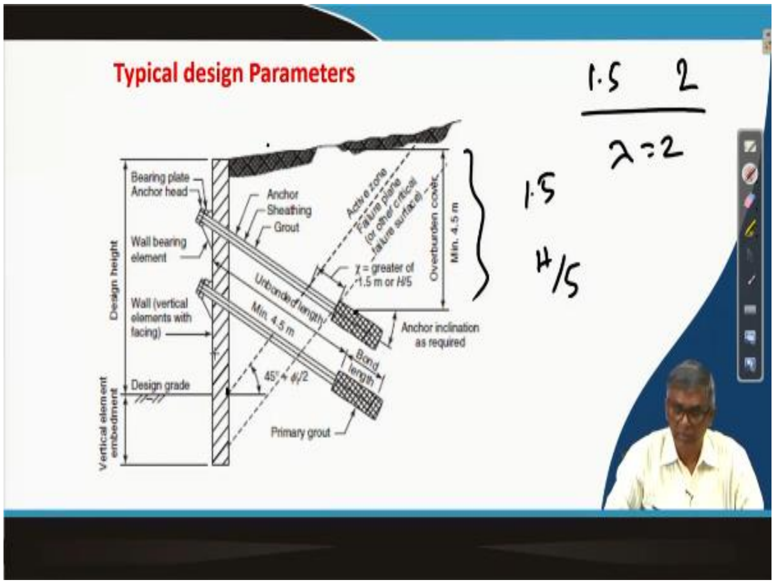

Let me go forward, so typical design parameters we have shown that now active zone, stable zone, passive zone all those things we have shown but now we have to what are what are the things to be designed. The things to be designed the total anchor length and to find out the anchor, total anchor length you can see that this bonded length to be designed, how much is the bonded length is required, which should be within the stable zone and then the unbounded length that it will be there fully on inside the active zone and beyond active zone also something some amount will be there.

$$\lambda = 2$$

$$\frac{H}{S}$$

And failure zone will be considered from your base of the wall and that your anchor should start at a distance from if this is the failure zone from here as a distance lambda, that lambda is equal to greater of either 1.5 or H by 5, if suppose 10meter wall then that means you have to compare 1.5 or H by 5 means 2. So greater of these two so lambda should be taken in that case 2.

So that means this length plus 2 meter plus anchor length, so that together will become the total length of the anchor and then the anchor should be some over should be under some wall pressure, what is the amount this should be at least 4.5, minimum 4.5 meter height should be there above the anchor, so that is another requirement.

So by and large these are the requirements, so again once again and this side there will be bearing plate, anchor head, wall bearing element and all those things are that, these are all typical design will be available and to be adopted, so let it whatever I have mentioned here same thing is listed also in the next slide which I will explain one by one and show you that is you can see.

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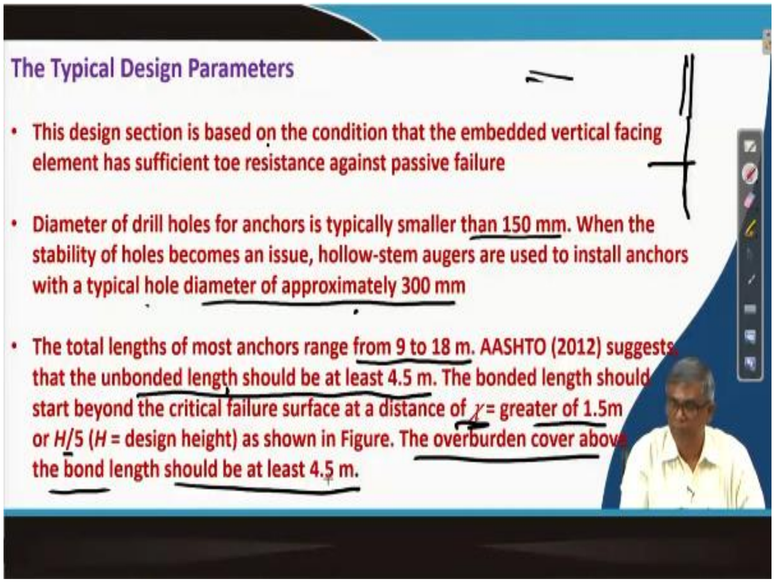

The design section is based on the condition that the embedded vertical facing element has sufficient toe resistance against passive failure, that means the design section should be, that means your wall, the section should be designed in such a way that it has sufficient storage, that if it is a depth of excavation, it should have some depth, so that it has sufficient resistance, that is one thing. And diameter of drill holes for anchors is typically smaller than 150 mm, that means for drill initially you have to drill the hole for anchor and that diameter is less than 150 millimeter most of the time.

When the stability of the hole become an issue the hollow stem augers are used to install anchors with a typical hole diameter approximately 300millimeter. This is another thing are there. And next whatever we have discussed already, the total length of most anchor ranges from 9 to 18 meter according to AASHTO 2012 the unbonded length should be at least 4.5 meter, which are shown in the figure also.

The bonded length should start beyond the critical failure surface at a distance, which you have shown in the figure, greater of 1.5 meter and H by 5, as which I have shown in the figure, and over bond, above the bond length also should be 4.5, which I have also shown in the previous figure. These are all some information required, details required for the design which I have shown in the figure also, some more are there let me see.

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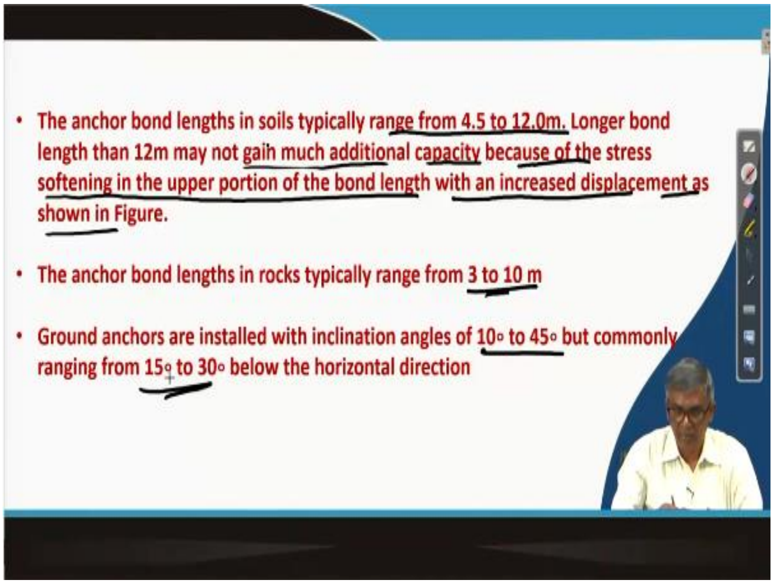

You can see here that anchor bond lengths in soil typically range from 4.5 to 12 meter, longer bond length than 12 meter may not gain much additional capacity, that means that limit is 12 meter if you go beyond that generally not much increase will be there, why that is also can be explained, that is explained here, may not gain much additional capacity because of the stress softening in the upper portion of the bond length with an increase this displacement as shown in the figures, which I will show in the next slide maybe.

And the anchor bond lengths in rocks typically again 3 to 10meter, here 4.5 to 12 and here it is 3 to 10, and ground anchors are installed with an inclination 10 degrees to 45 degrees but normally 15 to 30 is the common use, commonly used inclination.

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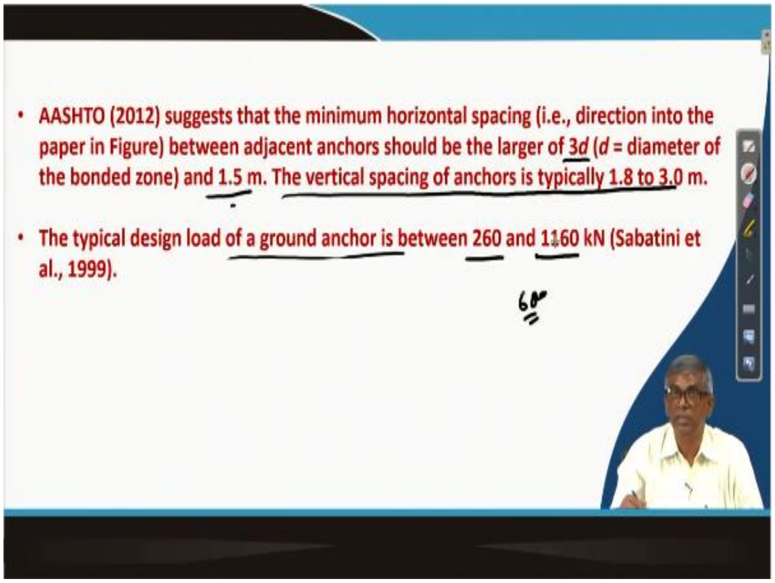

Let me give some more detail according to AASHTO 2012, minimum horizontal spacing direction into the paper, that means in this the horizontal spacing that one after another, between the adjacent anchor should be the larger of 3d and 1.5 meter, so if diameter is whatever is chosen you have to see three times of that if it is 200millimeter so it is 600 mm or 0.6 meter, so should be the larger up and then 1.5, so it will be 1.5 meter is the spacing.

The vertical special anchor is typically, that means vertical spacing that if this is the anchor wall, vertical spacing like this so that is 1.5 to 3meter so anchor will be if there is a supposed 10meter excavation is work is that then the wall will be there and behind the wall there will be anchor, that anchor will be horizontally spaced some distance, that means maybe 1.5 or 2meter.

Similarly, vertically also if there is a depth is 10meter then may not one anchor may not be sufficient, whereas if 5meter depth of excavation then one anchor may be sufficient, so with the increase of depth then vertical spacing with a vertical spacing you have to install the anchor, so that is what it is mentioned.

So vertical spacing 1.8 to 3 meter whereas horizontal spacing greater of 3d and 1.5 meter and typical design load of ground anchor between 260 kilo Newton to 1160 kilo Newton it can be in between anything.

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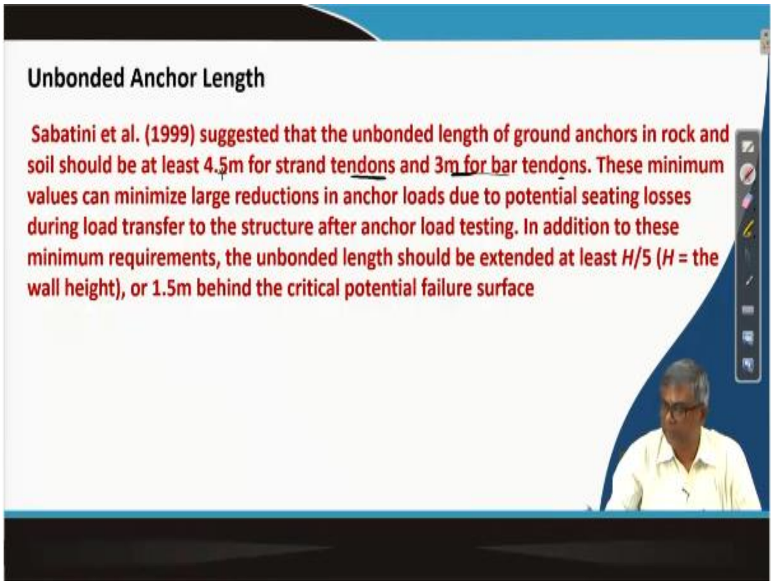

And unbonded anchor length this is within the active zone generally, unbonded length of ground anchors in rock and soil should be 4.5 meter for strand tendons and 3meter for bar tendons. There are three type, wear type and then there is a bar typical bar can be used so in the bar if you use 3 meter otherwise 4.5 meter and some justification is given here no need to read.

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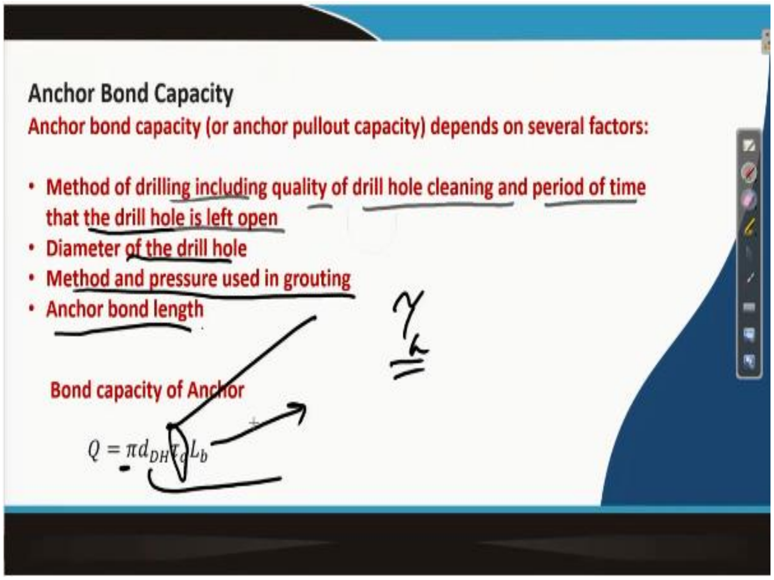

And then anchor bond capacity, the anchor bond capacity depends on several factors, you can see here that method of drilling including quality of drill hole, cleaning and period of time that the drill hole is left open, all those factors affect the bond capacity, anchor bond capacity. The diameter of the drill hole, method and pressure used in the grouting, that is also an important point on which the capacity depends, the anchor bond length, that is also important.

$$Q = \pi d_{DH} \tau_a L_b$$

All those things will be there, all will be included, all those effect will be included by this and bond length is this one last one is this and other things will be included in the form of tau, how much you are using so depending upon construction method, drilling method of drilling all those things tau is given in the table, so pi multiplied by DH, DH that means drill hole diameter, tau ultimate bond strength multiply the un bonded length, so this is bonded length this Lb, so by this one can calculate the anchor bond capacity.

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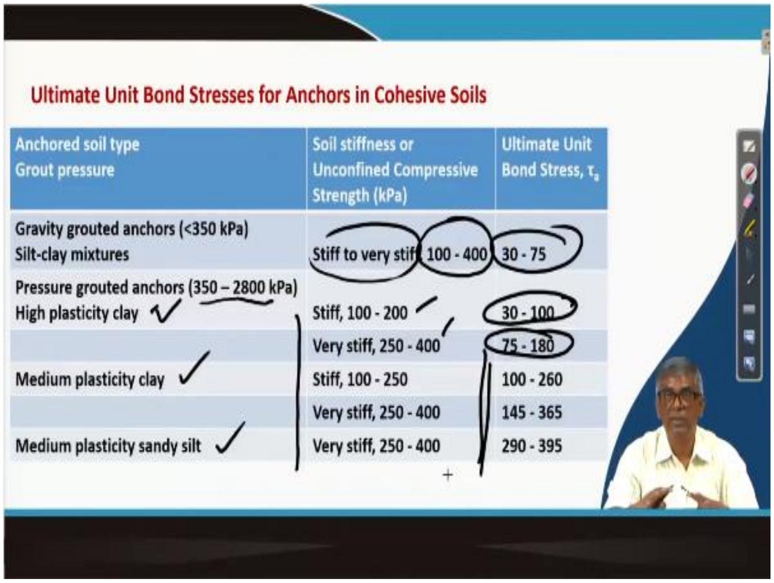

So let me take other aspect, so you can see here as I have mentioned the tau a depends on different factors, the anchor bond capacity depends on many factors and those factors actually included in the tau a itself. you can see here the in the cohesive soil and anchored soil type and grout pressure, so that means gravity grouted anchors with less than 350 kPa silt clay mixture and the consistency of the soil will be steep to very steep and unconfined compressive strength is 100 to 400, then ultimate unit bond strength can be taken as 30, between 30 and 75, so depending on the soil type all you want, designer can based on their judgment can pick up.

Similarly, pressure grouted anchors 350 to 2800 kPa pressure and high plastic clay then only use this and again it is stiff then this is the unconfined compressor, very steep this one and under this condition what will be the τ_u 0 to 100 and 75 to 180 and medium past plastic clay so pressure grouted anchors under high plastic clay, medium plastic clay, medium plastic silt sandy silt, so under three different categories.

And again, they are based on their consistency what will be the value of tau a is given here so we can be based on your construction, soil type all those things refer this table, see the range of value then try to take if the soil is to a softer side, then you can take lesser value, if it is steeper side take the higher value, like that one has to take the value for calculation.

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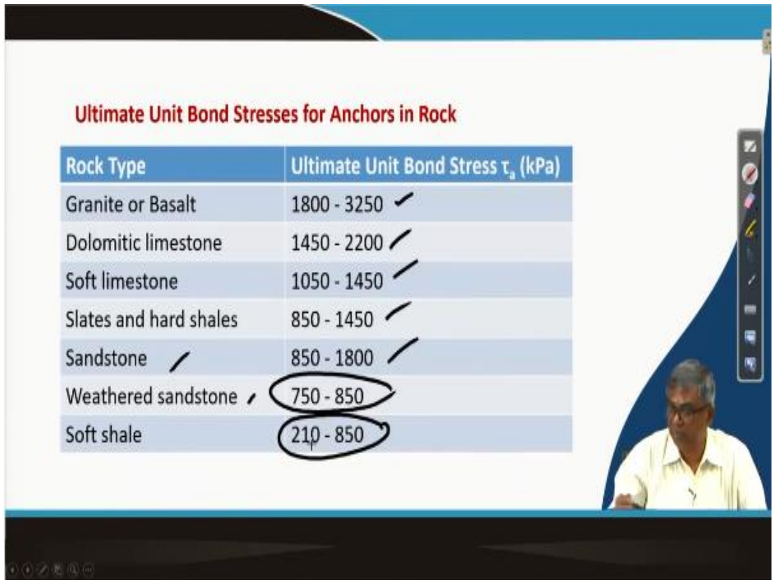

Similarly, there it will be there also for sand, now I have not shown here but it is there for a rock, you can see granite or basalt, the tau a will be ah you can see that 1800 to 3250, dolomitic limestone this value, soft limestone this value, slates and hard shales this value, sandstone this value, weathered sandstone this 750 to 850, soft shale 210 to 850. These are the different values of τ_a one can take for the calculating bond capacity in rock.

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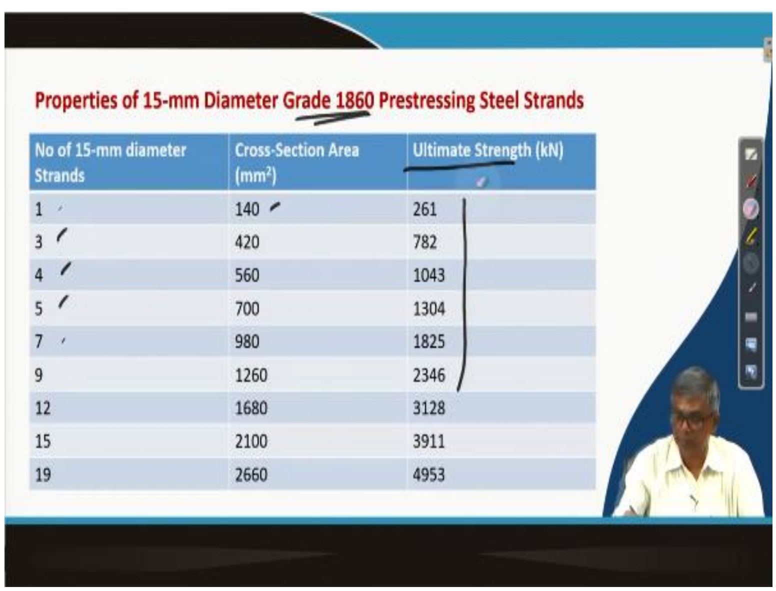

Then properties of 15millimeter diameter grade 1860 pre-stressing steel bar, this grade may be as per ASTM standard similar standard also there is IS which you can see I have not seen that, not referred. Otherwise, it will be similar table will be there for IS code also a number of studies 1, 3, 5, 4, 5 this strand can be used either one single, two or three so if you do that then accordingly cross-sectional area and then ultimate strength for those can be taken for the design.

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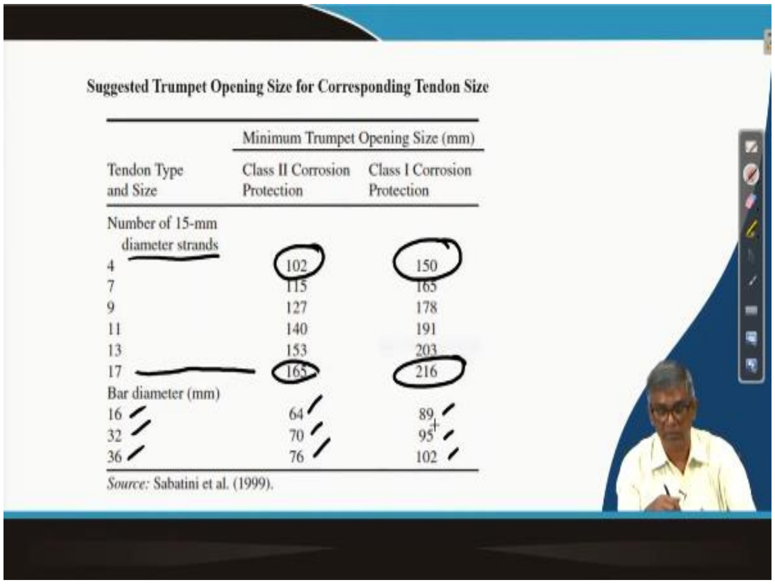

Then the suggested trumpet opening, there is a component trumpet for anchor and that opening you can see type and size number of 15 mm diameter strand, so 4, 7, 6 etcetera, will be there and again minimum trumpet opening size with class two corrosion protection, class one protection, class two corrosion protection is there the opening is 102, class one corrosion protection is there 150.

Similarly, if it is 17 taken then it is 165, where it is 216 and instead of that tendon is if the bar is used 16millimeter, 32millimeter, 36millimeter corresponding class two corrosion protection then your trumpet opening with 64, 70, 76. If it is class one corrosion protection is given then 89, 95, 102 opening is required, this is again can be taken from the list or you can say a table.

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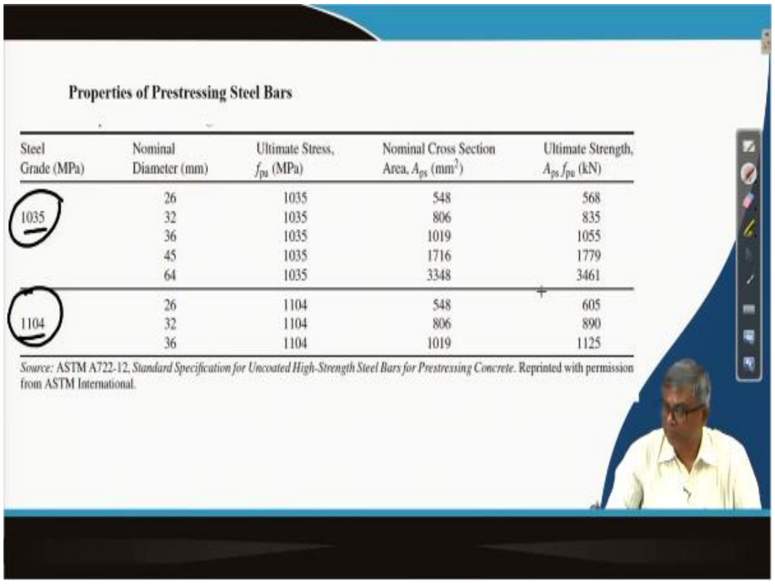

Properties of Prestressing Steel Bars

Steel Grade (MPa)	Nominal Diameter (mm)	Ultimate Stress, f_{pu} (MPa)	Nominal Cross Section Area, A_{ps} (mm^2)	Ultimate Strength, $A_{ps} f_{pu}$ (kN)
1035	26	1035	548	568
	32	1035	806	835
	36	1035	1019	1055
	45	1035	1716	1779
	64	1035	3348	3461
1104	26	1104	548	605
	32	1104	806	890
	36	1104	1019	1125

Source: ASTM A722-12, *Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete*. Reprinted with permission from ASTM International.

And then again properties of pre-stressed steel bars, again it is as per is ASTM, you can see steel grade, it is not there like in our case, so nominal IS standard can be seen corresponding, number nominal diameter etcetera will be there, ultimate stress will be there, nominal cross section will be there, ultimate strength also will be there and accordingly because according to our requirement we can pick up a particular steel grade, diameter a particular diameter can be picked up whether it is 32 or the 36 or it is 45 anything can be chosen from this to suit the requirement.

With this anchor detailed design too much of involvement is there and right now I do not think is essential, if you need you can refer the book that what book I have mentioned that is by Jie Han, Principles of Ground Improvement or exact title is given I will let you know once again, there you can see otherwise about the type of nails or soil or type of soil anchor, rock anchors and their categories and their various aspect like failure modes and all we have discussed.

Now I will be taking one question, one problem to understand or to explain how to arrive at the design, there are number of design parameters, how to arrive at those design parameters and I will take one problem soil nailing only, anchor I am not going to take any problem so because it will be too much of involvement will be there, better you can go through from the book and if you are interested, with this I will close here in the next lecture I will try to explain the problem, thank you.