Ground Improvement
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Lecture 47
Soil Nailing (Contd.)

Hi everyone, let us continue on this soil nailing, in the previous module we have discussed certain aspects of soil nailing utilities where it is suitable where it is not suitable and then other aspects like active zone and then resisting zone, there are various failure modes and all those thing information whatever you have given based on that you can design the soil nail wall and for that we need to discuss various aspects.

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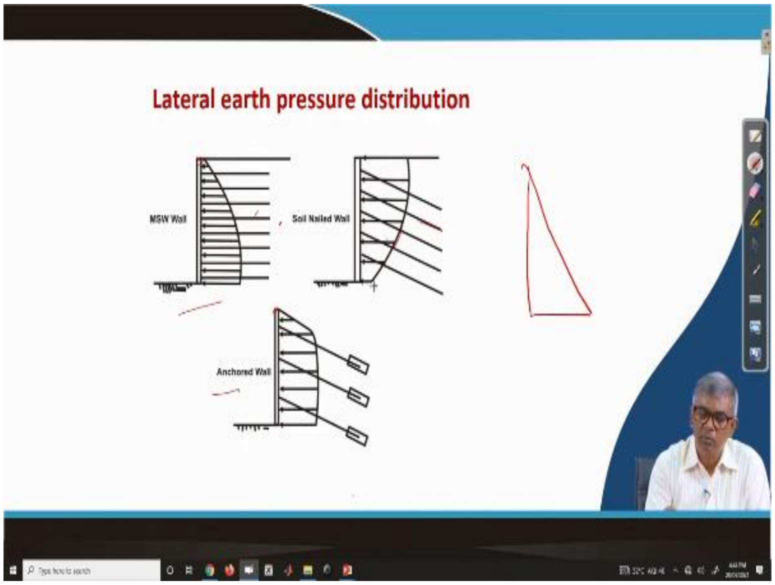

Let us take that one by one and you can see here, let us take your first slide here when ever with design wall, we have seen that in the soil mechanics or foundation engineering that we need to calculate that pressure, earth pressure and earth pressure when you do in the retaining wall, regular retaining wall generally we know that retaining wall earth pressure will be like that triangular.

And when it is then in the different cases how we take the earth pressure diagram you can see the MSW that is wall, so, in that case mechanically stabilized wall that means in short there actually you take diagram almost similar to that close to the surface zero and then towards bottom less but still we can use triangular diagram, but soil nail wall it will be more at this close to the surface and less at the base, so that is important the difference here.

And whereas, if it is an anchored wall again it will be similar to the MSW wall that it will be zero or the surface and it will be decreasing and that will be by a by a large will be assumed to be constant sometimes it will reduce also towards the bottom of the excavation. These are all different models of earth pressure distribution, which can be taken for calculation of earth pressure.

Because that soil nail wall when you design that whatever earth pressure will be coming that earth pressure has to be resisted by the nail. That is the design requirement, before because of that before designing, we need to know earth pressure, if that is the model of earth pressure, that is actually these are the soil nails and pressure diagram will be like the, what will be the pressure on each nail that can be calculated by some ways, that we will discuss later on.

These are all different models, but this is for basically mechanically stabilized wall or even a normal retaining wall, reinforced retaining wall, this is for anchor and this is for your soil nail and important difference in soil nail is that the grounds are based close to the ground it will be earth pressure is more and when you go towards the restoration, it will be reducing that is the only difference to be remember, an important difference.

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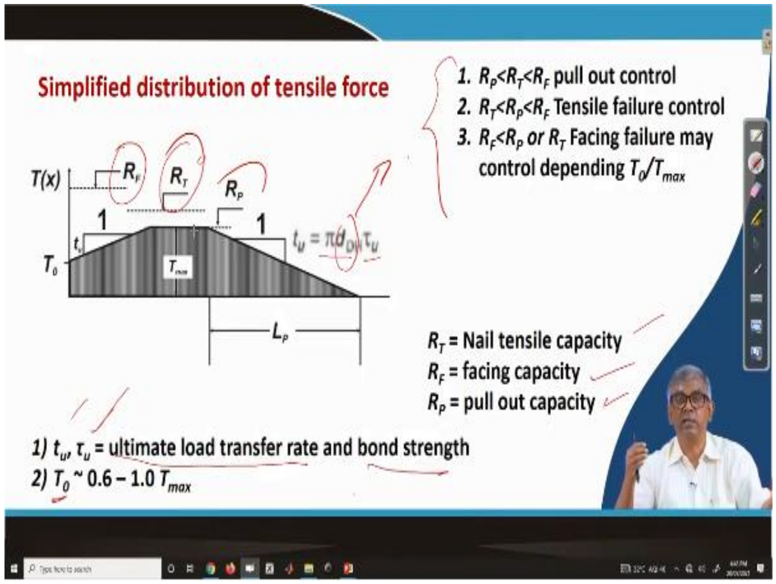

Again, then some simplified distribution of the tensile force. You can see though we have shown in the previous lecture module, that how the distribution of the other stress happens in the rod, we have seen that at the face, at the face there will be some value and then it will be increasing and then it will be decreasing and becoming zero. But here is then it will be curve continuously.

So then is difficult to calculate the value exact calculation of load or force will be difficult, so because of that, to simplify the calculation, it is decided to simplify the pressure distribution, you can see here that it is taken T naught at the face which is known and then it will be linearly increasing to up to some point and that will be a ratio τ_u versus 1, 1 vertical, 1 horizontal versus τ_u .

$$1.R_p < R_T < R_F \, Pull \ out \ control$$
$$2.R_T < R_p < R_F \, Tensile \ failure \ control$$
$$3.R_F < R_p \ or \ R_T \, Facing \ failure \ may \ control \ depending \ T_0 / T_{\max}$$
$$R_T = Nail \ tensile \ capacity$$
$$R_F = facing \ capacity$$
$$R_p = pull \ out \ capacity$$
$$1) t_u, \tau_u = ultimate \ load \ transfer \ rate \ and \ bond \ strength$$
$$2) T_0 \sim 0.6 - 1.0 T_{\max}$$

This is the ratio it will be slope and then over distance will be constant and then that is the T max and then again after reaching T max it will become zero with a decreasing flow which will be called t u actually 1 horizontal verses t u that is the slope, the same slope this direction or this direction, it will start, it will go longer distance because it started with zero here and T naught but it will go up to zero.

So, because this length will be longer than this length, but we can find out where it will be zero. So, this is the distribution will be taken and t u of course, can be calculated by this equation pi d DH multiple by tau u, tau u is the ultimate bond strength and d DH, d DH is this is nothing but drill hole diameter that is all pi is a constant and here and you can see there are three different forces will be there facing resistance, then tensile resistance and pull-out resistance.

There are three resistances will be there, all three will never be equal and because of that, there can be three different conditions, you can see here that R_P greater than less than R_T less than R_F. Exactly if the RF is if the maximum and R_T and R_P is less than that then of course, pull out will be the control, this is the list value pull out, based on pullout capacity you have to design, so that will control the design.

Similarly, if it is a R_T, R_P, R_F, if R_F is the less than RF value will control the design and if the R_F is less than RP or R_T then facing failure will occur that will consider, that has to be considered. So, this is actually because of these three different values we can find out what is the controlling mode of failure. R_T is the nail tensile capacity, RF is the facing capacity, R_P is the pullout capacity. That is what I have mentioned and t u and tau u, with τ_u is the ultimate load transfer rate and τ_u is the bond strength already I have mentioned and T naught is the 0.6 to 1 T_{max}.

Whatever T max actually is there and that actually will not be fully transferred to the connection, connection will have little lesser value which will be ranging between 0.6 to 1 T max, T_{max} is the maximum value which can happen tension actually at the rod., this is a simplified diagram which can be used for the design purpose.

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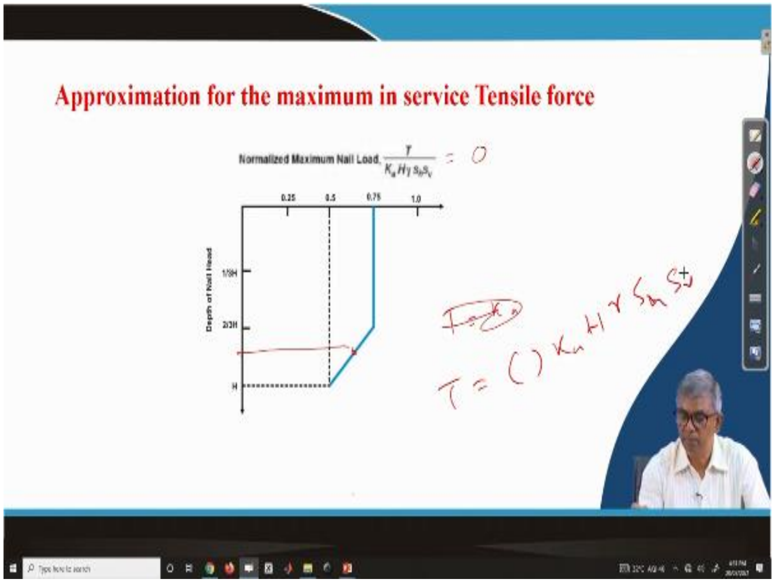

Then this is as we have mentioned that diagram, earth pressure diagram, so normalized maximum nail load and what about different height that is given diagram here and this will be up to two third H it will be constant and from two third H to H it will become reduced to a value 0.75 to 0.5 so this slope can be automatically obtained. So this is a guideline to depth of nail head to normalize maximum nail load, so that this is the diagram is given, can be utilized.

And here normalized you can see, here this is nothing but a sorry, this is nothing but you can say lateral earth pressure if you can see H gamma, H gamma H, SH SV and then multiplied by K, that means nothing but gamma H is nothing but the pressure at that point and then you multiply by SH that mean horizontal facing and vertical facing, that means the range or the domain for which that nail will work.

Then and then multiply by K that is the total force divided T over this is the normalize, then you can find out T from actually we can find out based on depth, we can find out these ratio and if you know this K, H, SH, SV then we can find out T from there, I hope it is clear, from base on the direction or the depth we can project on these and then you can see here you can find out, what this depth up to two third is constant but beyond these each little bit less.

To find out that value, suppose this is a depth, sorry, suppose this is the depth so what is the value we can find out and then from this value what is T, T equal to Ka value actually we are getting this is this equal to some value then you can find out T equal to that value multiplied by Ka H gamma SH SV, this is the way on that find out.

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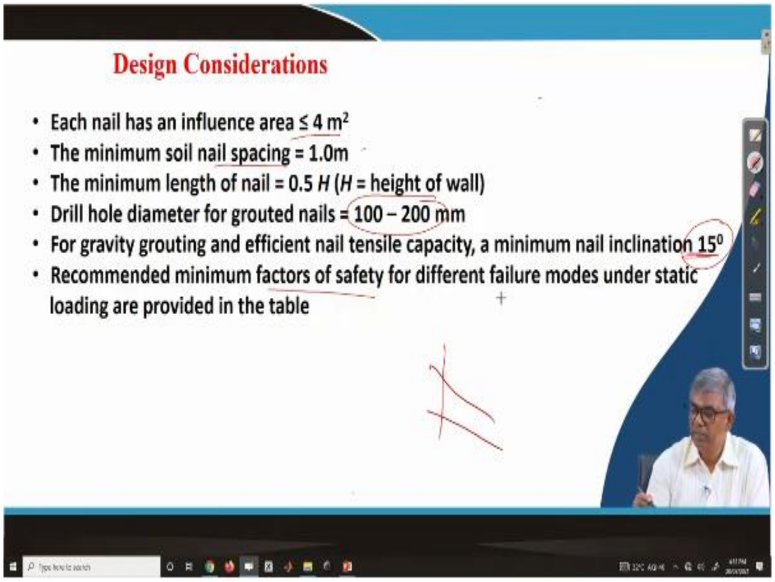

Let us go to the next one and design consideration you can see here number of things, each nail has an influence area less than equal to 4meter square, this is the some charts I will be discussing, that is the things to consider, each nail has an influence area less than or equal to 4 meter square, the minimum soil nail spacing will be 1 meter, minimum spacing it should be more than that, otherwise it is minimum spacing is considered 1 meter.

The minimum length of nail 0.5 times H, if the height of earth or height or wall is H is then 0.5, so minimum nail length and it can be more than that, that is what is taken, drill hole diameter for grouted nails, if it is grout and drill hole diameter is taken between 100 to 200 this will work and if it is more than that or less than that, this design will not work, then for gravity grouting and the efficient nail tensile capacity a minimum nailing inclination is 15 degrees, to make efficient, nail inclination whatever we are showing like these like this, this inclination will be only 15 degrees.

A recommended minimum factor of safety for different failure modes under static loading are provided. That mean recommended minimum factor of safety for different failure modes will be different, which I will be showing in the next slide. These are all different requirements based on which design is developed and finally, given in the form of chart which we will discuss at the end today and you can see these and then next one what I wanted to show you that the factor of safety for different condition.

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You can see here that external stability and internal stability, there are two groups and under this external stability there can be global stability then long term, global stability short term and sliding that there can be bearing. External stability so there are four global, sliding and bearing, out of three again global can be long term and short term and again the symbol is taken as a global FS_G, both in this both are FS_G and when the sliding FS L, one of the bearing capacity FS_{BC} and temporary structure it is temporary purpose of construction after construction you can remove it if that happens then the factor safety is 1.35 whereas, if it is permanent then it has to be 1.5.

Similarly, for global stability short term temporary 1.2 to 1.3 but permanent is also since it is short term 1.2 to 1.3, then sliding a temporary it is 1.3 but the permanent is 1.5. So, bearing capacity again for temporary is 2.5 and permanent it is 3, now nail pull out, internal stability you can see nail pullout, nail tensile, these two are important. Nail pullout that symbol is FS_P and it is nail tensile failure FS_T and then if it is a temporary structure then this value factor of safety should be 2 and if it is a permanent structure the factor of safety also should be 2, that it should not nail pullouts should not happen then it will not work, it will not useful.

The tensile failure even if temporary is 1.8 and permanent it 1.8, with these two are important actually in the nailing, so because of that here whether it is temporary or permanent factor of safety will not change because if this failure happens immediately will happen, even temporary means it will not for a one hour or temporary means that three months, six months, so that will not also happen. Because of that nail pullout and nail tensile based on these two it will be stabilized they are there is no compromise, factor of safety has to be both cases equal.

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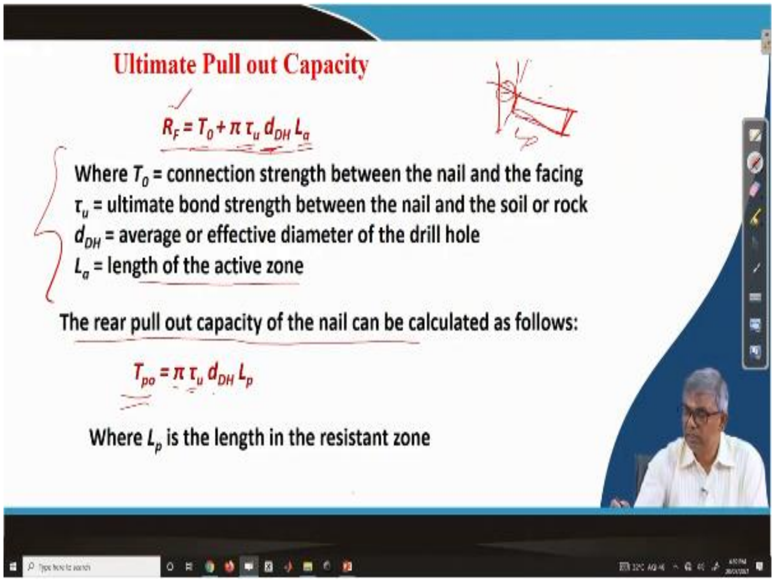

And ultimate pullout capacity it can be calculated R_F, R_F equal to T naught is the face connection, then pi is a bond strength, this is the diameter of the drill diameter, La is the length in the active zone and you can see this is RF and then this is not pullout capacity, pullout capacity is this one, this is R_F, R_F that we have seen R_F then R_P and R_T, so this is the calculation how to find out R_F, actually when there is a wall and this one an active zone is like this, this portion whatever friction develop that is pi τ_u d_{DH} L_a, this is the length, this length is L_a, so these plus T naught is R_F, facing resistance.

And then so here this equation there or whatever quantity T naught is a connecting strength between the nail and the facing, connecting strength and tau is the ultimate bond strength d DH is the average of the effective diameter of drill hole and La is the length of the active zone, so I hope it is clear. So, this is the facing resistance and then rear pullout capacity of the nail that can be calculated a T_{po} that is symbol to the T_{po} and here actually pi tau d_{DH} so that means, from here to from here to hear this distance to consider actual pull out, because when this one is in this force is greater than this, then actually pull out will happen.

This pullout capacity to one has to estimate this pullout T_{po} will be pi tau u d_{DH} into L_p, so this is our way on both can we, where L_p is the length in the resistance, this is the resistance zone, this is this distance L_P. So, these two forces can be calculated by facing resistance and pull-out resistance can be calculated by this.

$$R_F = T_0 + \pi\ \tau_u d_{DH} L_a$$

Where $T_0 =$ *coonnection strentgh between the nail and the facing*

$\tau_u =$ *ultimate bond strength between the nail and the soil or rock*

$d_{DH} =$ *average or effective diameter of the drill hole*

$L_a =$ *length of the active zone*

The rear pull out capacity of the nail can be calculated as follows:

$$T_{po} = \pi\ \tau_u d_{DH} L_p$$

where L is the length in the resistance zone

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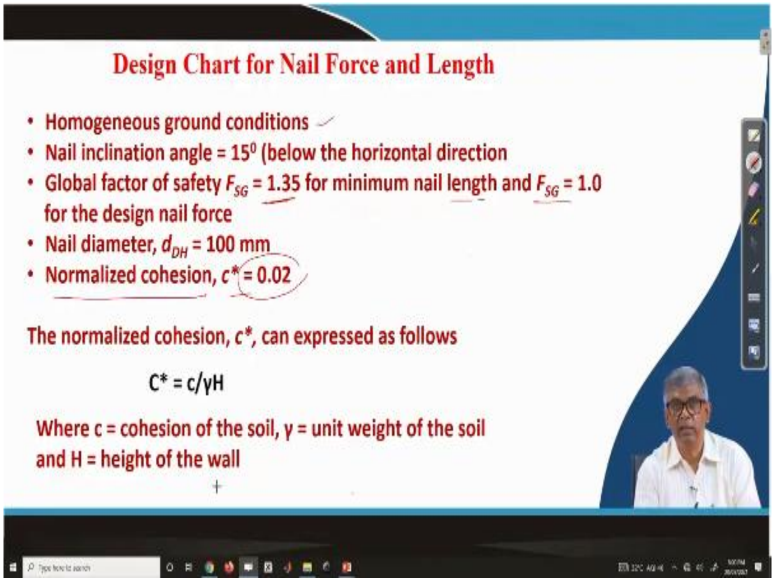

Next one is the design chart for nail force and length as all of our basic information is given based on that numerically they are analyzed and then there are some charts are given which can be utilized for the design purpose and what are those important assumptions are made in that chart preparation, homogeneous ground condition. So, ground behind the where nailing will be done, it has to be homogeneous, it may not be reality, but assumption is.

Nail inclination is 15 degrees and if it is more or less or more some modification may be required, nail based on this 15degree inclination that chart is prepared, global factor of safety F_{SG} is taken 1.35 for minimum nail length and F_{SG} 1 for the design nail force. So, these two things are taken and nail diameter taken 100 and if it is more than that then correction factor how to do that we are also given.

Normalized cohesion c star is given as 0.02 whereas c star is express c by gamma H, this is non dimensional and where c is the cohesion, gamma is the unit weight and H is the height of the wall. So, these are the basic things input given in the analysis.

$Homogeneous\ grooound\ conditions$

$Nail\ inclination\ angle = 15^0 (below\ the\ horizontal\ direction)$

$Global\ factor\ of\ safety\ F_{SG} = 1.35\ for$ minimum nail length and $F_{SG} = 1.0$ $for\ the\ design\ nail\ force$

$Naildiameter, d_{DH} = 100mm$

$Normalized\ cohesion, c^* = 0.02$

$The\ Normalized\ cohesion, c^*, can\ be\ \exp ressed\ as\ follows$

$c^* = c / \gamma H$

$Where$ c=cohesion of soil γ=unit weight of soil and H=height of the wall

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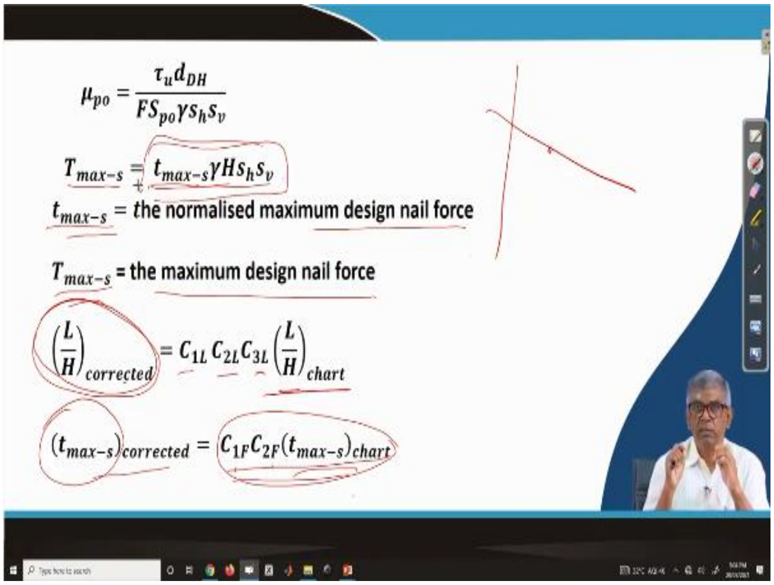

And next there are a number of terms that are used this is mu po the non dimensional factors which is used in the chart. So, this is actually tau u d DH divided by a factor of safety po, that means factor of safety against pullout, then gamma Sh Sv and T max s is the tensile force maximum equal to T max s multiplied gamma H Sh Sv, so when there will be a nail, so if I found out T max at that level, how to find out the actual value, so you have to gamma a gamma times H, you have to find out gamma times H Sh Sv and then T max s, so this can be taken.

T max s is the normalized maximum design nail force, and T max is the maximum design nail force, maximum design force and this is a normalized maximum design nail force, this is this is normalized that means, ratio between two, that means non dimensional, this is normalized maximum design nail force and this is actual.

And in the design chart there are one side that is two parameters from there can calculate since, you can see that you have to find out the height and so that and one side actually L by H as you can find out from the chart and T max s you can find out the chart and whatever we are getting L by H based on certain input data based on which that analysis was done, but actual design may be different.

So, because of that something, some correction is required from the chart whatever L by H will get from their L by H is corrected if you want to find out then it will be C 1l, C 2l multiple C 3l L by H chart so, L by H chart from the chart you can obtain and you can multiply by three factor to get the L by H corrected. So, once you get the L by H corrected from there you can find out length required, multiplying by H.

Similarly, you get from the chart t max h from the chart and then actual corrected so and t max chart whatever you are getting that is that chart was prepared based on certain numerical values, but your actual design may be different. So, if you want to correct that one then you have to multiply by C_{1F} and C_{2F} and then C_{1F}, C_{2F} you have done if we multiplied by from the chart then you will get t max s corrected and once you get t max s corrected then you multiply by this, then you will get that tensile, maximum tensile force in the nail. So, this is actually by a large design step using the chart.

$$\mu_{po} = \frac{\tau_u d_{DH}}{FS_{po} \gamma s_h s_v}$$

$$T_{\max-s} = t_{\max-s} \gamma s_h s_v$$

$$t_{\max-s} = \textit{the normalised maximum design nail force}$$

$$\left(\frac{L}{H}\right)_{corrected} = c_{1L} c_{2L} c_{3L} \left(\frac{L}{H}\right)_{chart}$$

$$\left(t_{\max-s}\right)_{corrected} = c_{1F} c_{2F} \left(t_{\max-s}\right)_{chart}$$

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And then whatever we have seen ultimate bond strength tau u for different soil and rock with the different that is what is given you can see material here the material is a rock and construction method is rotary drill and rock type marl, limestone, then your ultimate 300 to 400, Phyllite 100 to 300, chalk 500 to 600, soft dolomite 400 to 600, fissured dolomite 600 to 1000 like that, the value of tau u, actually ultimate bond strength what can we use in the design that we taken from this table.

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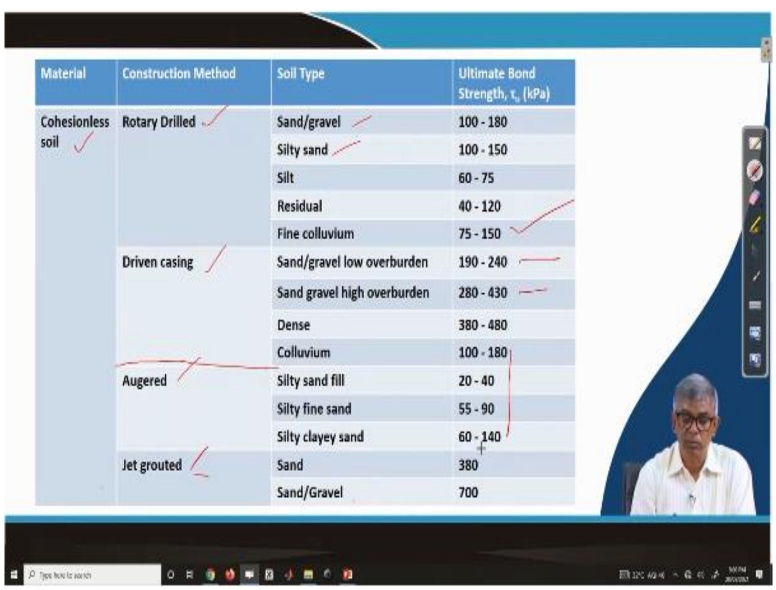

So, it is for rock, let us go for soil and when it is soil again, soil can be cohesion less and cohesive. So, for that again two different charts will be there you can see here that material is cohesion less soil and again construction of method rotary drill driven casing, augured and jet grouted and again rotary drilling can be sand gravel then 100 to 180, silty sand 100 to 150, like that up to this and then it will driven casing, then sand gravel low overburdened, sand gravel high overburdened again 192 240, 208 to 430.

Augured again can be dense under, sorry, up to these it will be yes, I think it is from here only. So augured will be silty sand fill, silty fine sand, silty clay sand, so there are values are given, jet grouted sand and sand gravel 300 to 700 actually, the tau u can be taken in that design. So, this is a one when are we designing so these values can be taken from this table for cohesion less soil.

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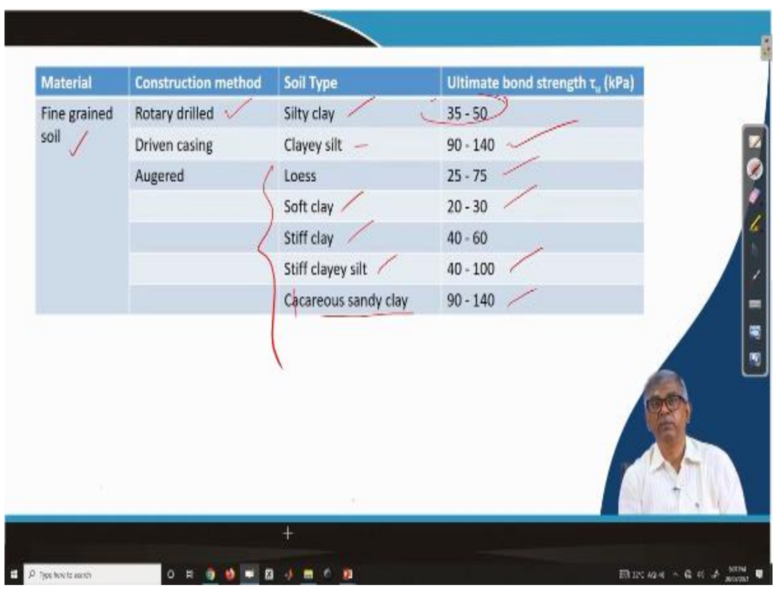

Similarly, if it is cohesive fine grained and again you can see that material is fine grain soil and construction method rotary drill in that case a rotary drill is used silty clay and value will we can see very less 35 to 50, driven casing clay silt will be used this method and ultimate bond strength is 90 to 140, if it is augered it can be used there are so many different types of soil loess, soft clay, stiff clay, stiff clayey silt, calcareous sandy clay all those types of soil, augered nailing can be done.

The value is actually 25 to 75, 20 to 30, 40 to 60, 40 to 60, 40 to 100, 90 to 140. So these are different values of ultimate bond strength are given rock, cohesion less soil and then fine grain soil, three different categories charts are given this can be used for the design to take the ultimate bond strength value.

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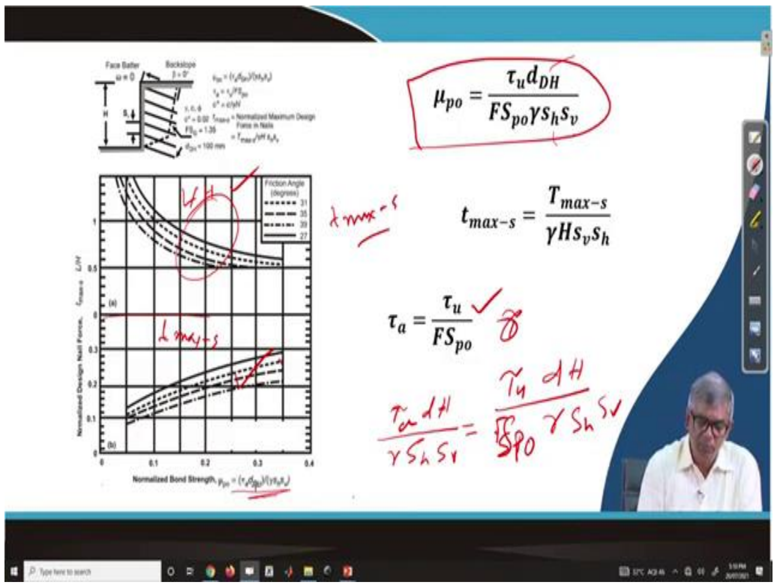

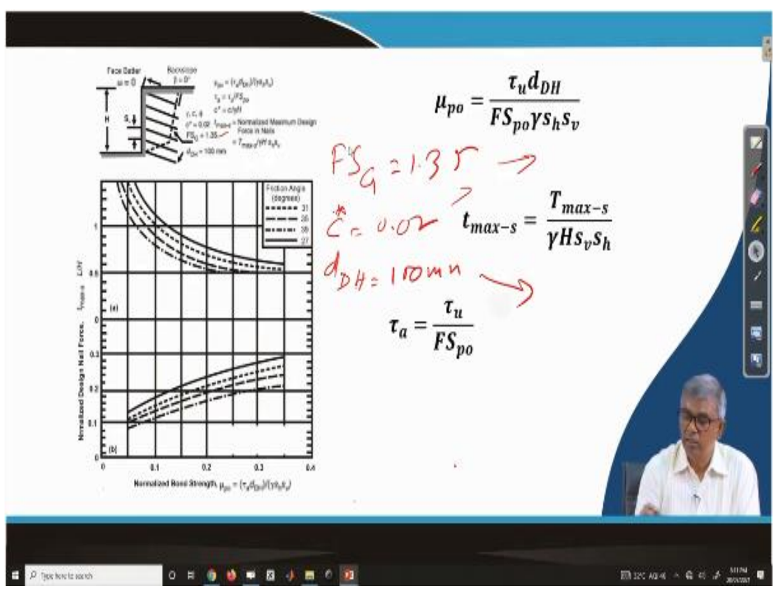

Now, I was talking about the chart and you can see here the chart is given one direct normalize bond strength mu po, mu po can see it is given as tau a, it is given as tau a dH divided by gamma Sh Sv and tau a is nothing but this one. So, ultimately if tau a if you substitute in this is nothing but tau u dH divided by FS, FS_{po} and then gamma S_h S nothing but this one, so it is to make a shorter instead of τ_u, τ_a expressed here otherwise it is either these or these the same, one axis is this, other axis is actually t max small t max s, this one or L by H.

$$\mu_{po} = \frac{\tau_u d_{DH}}{FS_{po} \gamma s_h s_v}$$

$$t_{\max-s} = \frac{T_{\max-s}}{\gamma \mathrm{H} s_h s_v}$$

$$\tau_a = \frac{\tau_u}{FS_{po}}$$

$$\frac{\tau_a dH}{\gamma s_h s_v} = \frac{\tau_u dH}{FS_{po} \gamma s_h s_v}$$

So, L by H from here to this part L by H is this part and t max s, t max s is this part this part and L by H is this part. So, you can calculate mu po that means, if you know the factor of safety if you who know the ultimate bond strength, you know the drill diameter and if you know the gamma, if you know the S_h S_v then the mu po can be obtained and from there you get some value suppose 0.2 and again there are some angles, friction angle is given based on that you can read here, and project on these axis then you will get t max value some value from here, that t max can corrected later on by using C_{1F}, C_{f2F} etc.

Similarly, based mu po you can find out projecting on these and for different soil condition what is the L by H from the chart and these two things can be used and then for correcting L by H and corrected t max s, so this can be obtained so this is by a large the basic information which will be used in the chart so, you have to calculate this mu po and that is only parameter and then you will project on these two charts and you will get t max s and L by H.

So, this is the only job to be done from this chart, once you get these from this chart and then you have to correct it for different values because this chart is provided for actually can see here it is mentioned also FS_G 1.35 and you can see c star equal to 0.02 and another thing is given a d_{DH}, d_{DH} equal to 100 millimeter, but your this diameter may be different this c star also may be different, this will also be different and because of that three different corrections are there.

$$\mu_{po} = \frac{\tau_u d_{DH}}{FS_{po}\gamma s_h s_v}$$

$$t_{\max-s} = \frac{T_{\max-s}}{\gamma H s_h s_v}$$

$$\tau_a = \frac{\tau_u}{FS_{po}}$$

$$FS_G = 1.35$$
$$c^* = 0.02$$
$$d_{DH} = 100mm$$

I will discuss only one correction, so these things will later on we will see. So, let me go to the next slide and you can see the chart is given for three different conditions, you can see here that this chart is both backfill is horizontal and wall is vertical, so omega is zero beta is zero and you can see that next figure everything else is same.

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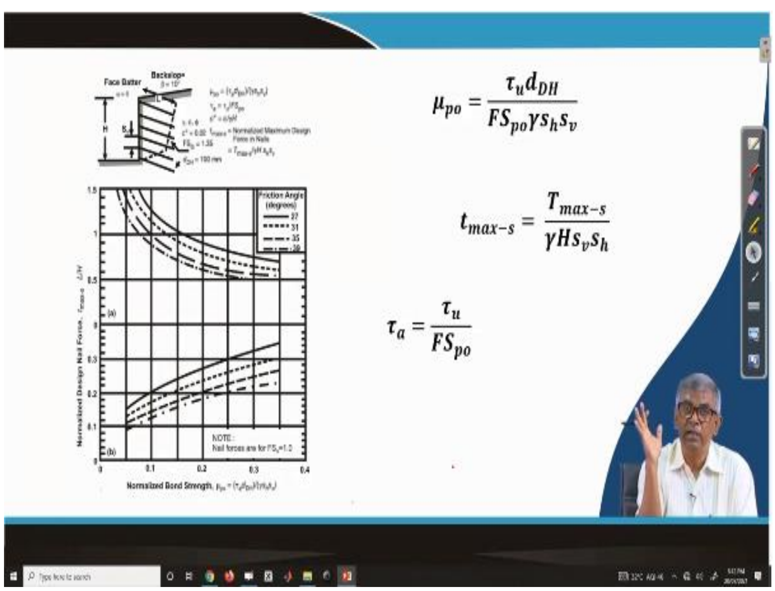

Everything else is same only you can see that omega is zero, but beta is 10 degree that mean vertical wall inclined backfield otherwise the rest of the things are same.

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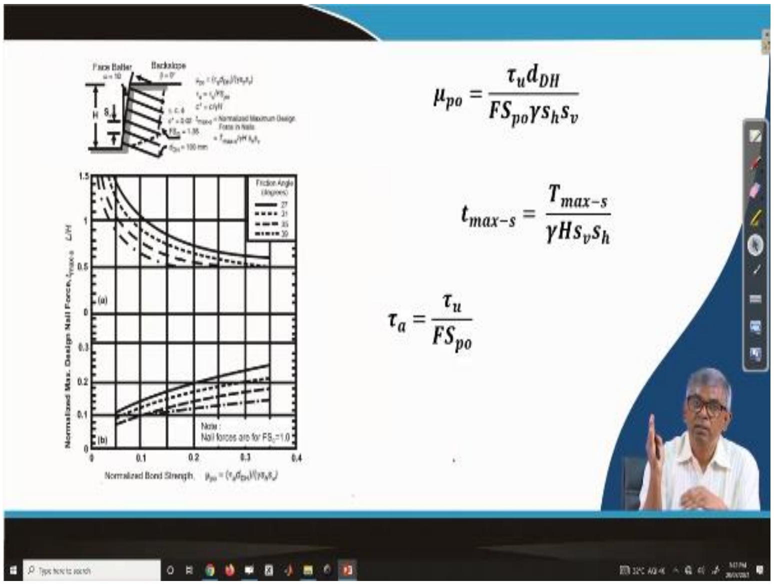

Next figure you can see that horizontal backfill but inclined wall so omega has some value beta is zero. Otherwise, everything is same.

$$\mu_{po} = \frac{\tau_u d_{DH}}{FS_{po}\gamma s_h s_v}$$

$$t_{\max - s} = \frac{T_{\max - s}}{\gamma \mathrm{H} s_h s_v}$$

$$\tau_a = \frac{\tau_u}{FS_{po}}$$

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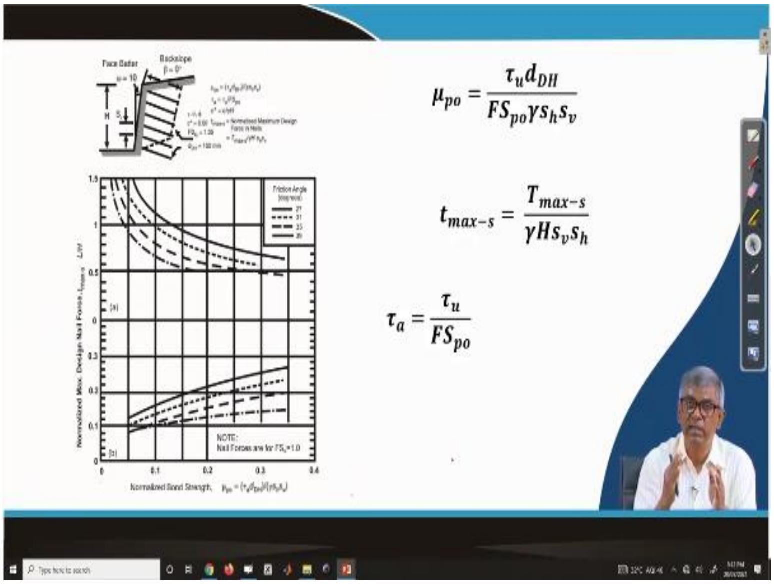

Next figure you can see that omega has some value, beta also some value that means inclined while inclined backfill. So otherwise in the show all four graphs, the method of use actually same, only different that based on your site condition how it will be whether it is inclined wall or vertical wall, whether inclined backfill or horizontal backfill based on that out of four you can choose any of them and after choosing that you have to find out t max s or no you have to calculate the mu po, from there you can find out t max s or L by H and then you can apply correction.

$$\mu_{po} = \frac{\tau_u d_{DH}}{FS_{po}\gamma s_h s_v}$$

$$t_{\max-s} = \frac{T_{\max-s}}{\gamma H s_h s_v}$$

$$\tau_a = \frac{\tau_u}{FS_{po}}$$

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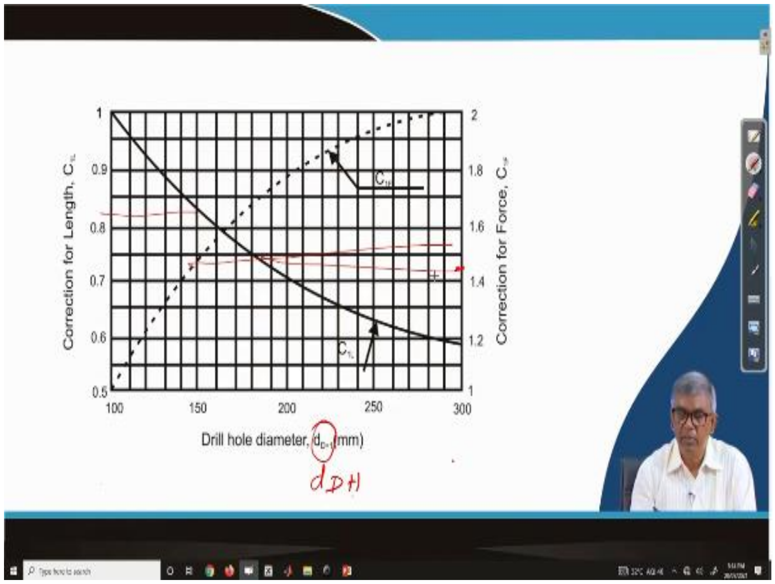

And you can see that for correction you can see that $C_{1\ L}$ and this is this is of course, not d plus 1, d_{DH} drill hole diameter, drill hole diameter d_{DH} millimeter. So, generally as you have mentioned that the chart is given for 100millimeter, but this when you are actually drill hole diameter is 150 or 200 or 250 then accordingly suppose is 150 then you can find out $C_{1\ L}$ $C_{1\ F}$ both correction value we can find out. So $C_{1\ L}$ you can read from this side height, so this is C1 L, so you can see 150 you can project on these and read this one.

And similarly, 150 and if C 1F is these, that project is, designing project on this side and read the value those values can be multiplied. Similarly, for other factors also there is a chart given and can be accordingly applied and corrected.

like this finally has to be designed so I can take one design example to illustrate how different the slope condition and wall inclination condition, then the different diameter of the different soil properties can be incorporated in the design, that different spacing, all those things I can explain with the help of one example problem, which I will take later on, not immediately after this maybe I will complete some details of anchor now and then at the end I will give you the example for illustration of this design, how to design whatever chart is given by using that how to design it with this I will close here, thank you.