**Ground Improvement**
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**Lecture 50**
**Soil Nailing (Contd.)**

Hi everyone, once again let me welcome you to this ground improvement lecture class and I am towards the end of the module 10, that is your ground, module 10 is actually, sorry module name is not written here, module name is actually your soil nailing and already we have discussed soil nailing, soil anchor, what it is and what is their different design requirements.

What is the failure mode, how to find, how to do some analysis, what is the pressure diagram etc., all those things we have discussed over four lectures and now I thought it would be a good to show one numerical example to explain how to do soil nail design, soil nail wall design and for this purpose I have taken one problem.

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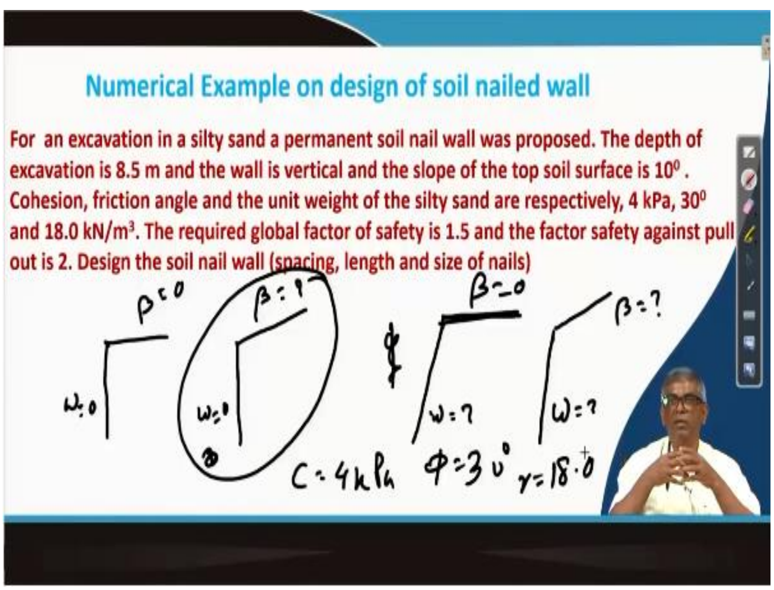


Let me go to the problem and then see the method of solution and, this is the problem, you can see here that problem is given like this for an excavation in a silty sand, a permanent soil nail wall was proposed, and the wall will be permanent. So, if it is not permanent the anchor could have been there but since the soil nailed wall permanent so it is, nail is there and depth of excavation is 8.5 meter and the wall is vertical and the slope of the top soil surface is 10 degrees.

And the slope of the top soil surface is 10 degrees that means, we have discussed four different problem or in the form of design chart we have given for soil nail wall and we have given wall something like this it is vertical and horizontal soil and then there is another vertical wall and inclined soil and this, this inclination is W, this in inclination beta, this inclination is W, this is beta and then we have done another, did not this one inclined wall and horizontal soil.

This is here actually W equal to zero, beta equal to zero, w equal to something and beta equal to also, w equal to zero and beta equal to some value, here w equal to some value and beta equal to zero and third one this is slope and this is also sloped, so W equal to some value, beta equal to some value, there are four different conditions given according to the problem, the wall is vertical that means, this one and the slope of the top soil surface is 10 degrees, this is this one. This is the time the case two actually is the problem, in our problem.

Cohesion, friction angle and the unit out of the silty sand are respectively 4 kPa is a C is the 4 kPa, C value is 4 kPa and your Φ actually is 30 degrees and your unit weight γ equal to 18 and the required global factor of safety is 1.5 and the factor of safety against pull out is 2. Design the soil nail wall spacing, coming to design the soil nail wall means the height is known, now what you have to do you have to provide nail and so while providing nail you need to provide the spacing both in horizontal direction and vertical direction and also size of the nail size of the nail means diameter.

If you can find out the load and a particular steel if you can choose ultimate tensile strength of the steel is known, then from there we can find out the area requirement and from the area requirement we can find out what is the diameter required, that is the by and large design procedure.

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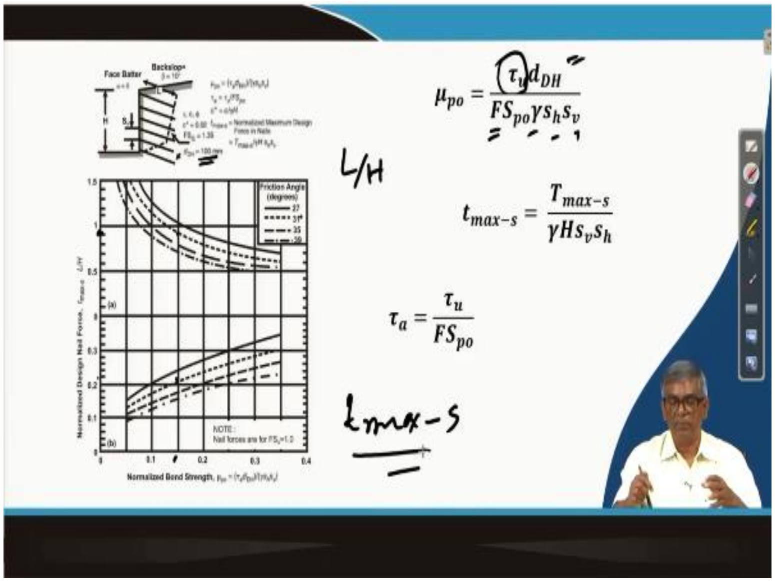


let us go back to the typical problem as I have told you that it is a case two, that means this is the one, this case actually with β = 10 degree exactly and W is zero and you can see that this chart is prepared for global factor of safety equal to 1.35 and so, because of that what you have to do you have to apply correction and this chart is prepared for drill hole diameter is 100millimeter.

But in our problem, I think it is not given but we can select and then the accordingly we have to apply correction and then c star value c by gamma γ H is given here, all those things are okay. So, that means drill hole diameter and global factor of safety two things are there, so because of that you have to apply correction.

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

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

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

So, what you have to do based on given soil properties you can calculate tau u maybe given tau u is not given, but you can assume do my method of installation and soil type is known if that particular type of installation is there with a particular soil type then from the least you can find out tau u and factor of safety of pullout actually given, d diameter can be assumed or you have to design finally, and gamma $S_h$ $S_v$ again in the any design actually if $S_h$ $S_v$ is not given you have to choose some value of $S_h$ and $S_v$ and see that whether it is satisfying or not.

Of course while choosing $S_h$ $S_v$ you have to follow the guidelines and how we can choose, there should be minimum, there should be maximum you cannot use a spacing of 10 meter up in soil nail, it can be 1 meter it can be 1.5 meter, it can be 2 meter, 2.5 meter like that 3 meter, not more than that or less than that.

So, the justification you have to choose $S_h$ and $S_v$ and then you had to calculate mu po, and mu po or whatever value suppose it came 1.15 and then you can see for different values of friction angle of course, all values are not there, it is given from 27 to 39 in between can be interpreted and below 27 degrees it may not be suitable also. So, here actually if it is this one and suppose I choose a 31 degrees soil, so 31 degrees means this one so I can project on these, then I can find out from these what is the value of t max s, t max s value I can find out from here something close to 0.2.

Similarly, from here again I can project on this, this is L by H, so this one I will put on these and L by H can be read from here, so I will be going here, maybe somewhere here, maybe somewhere here, the value is very close to 1 so maybe 0.9 or 0.95 from something like that. So, that means we get L by H from for the mu po calculation, you get L by H from the chart and you get t max s, this to get from that chart. Once you get from this chart, then what you have to do, you have to correct for that your actual diameter is different, actual global factor of safety is different, so you have to apply correction for those and then you can find out L by H corrected and t max s corrected, so all those things tapes I have discussed.

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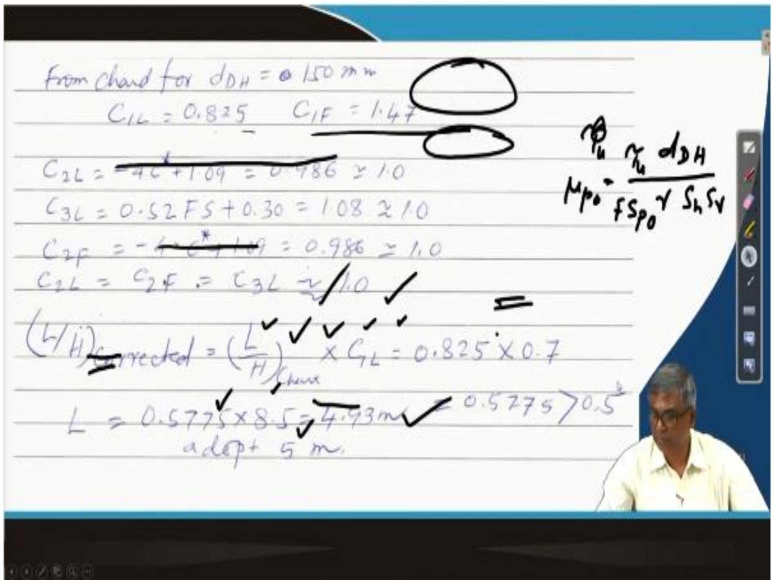


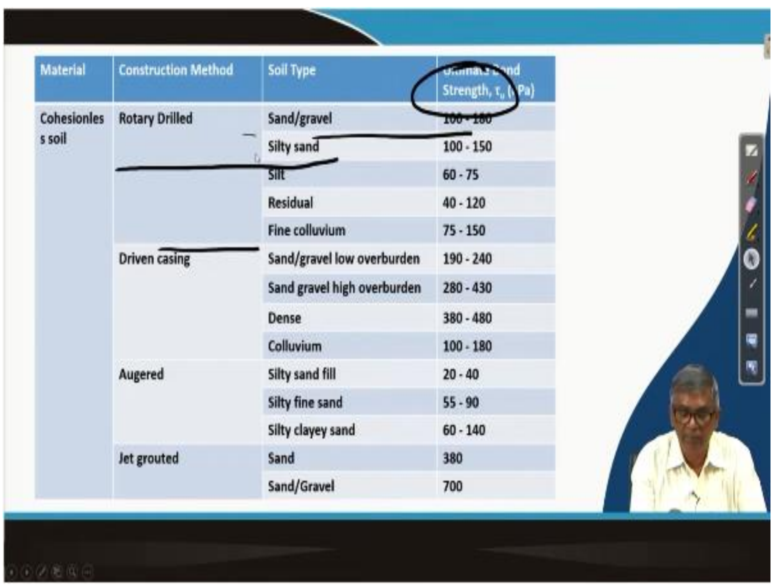

| Material | Construction Method | Soil Type | Ultimate Bond Strength, $\tau_u$ (kPa) |
|---|---|---|---|
| Cohesionless soil | Rotary Drilled | Sand/gravel | 100 - 180 |
| | | Silty sand | 100 - 150 |
| | | Silt | 60 - 75 |
| | | Residual | 40 - 120 |
| | | Fine colluvium | 75 - 150 |
| | Driven casing | Sand/gravel low overburden | 190 - 240 |
| | | Sand gravel high overburden | 280 - 430 |
| | | Dense | 380 - 480 |
| | | Colluvium | 100 - 180 |
| | Augered | Silty sand fill | 20 - 40 |
| | | Silty fine sand | 55 - 90 |
| | | Silty clayey sand | 60 - 140 |
| | Jet grouted | Sand | 380 |
| | | Sand/Gravel | 700 |

$$
\begin{aligned}
&\textit{From chart for } d_{DH} = 150mm \\
&C_{1L} = 0.825 \\
&C_{1F} = 1.47 \\
&C_{2L} = -4c^{*} + 1.09 = 0.986 \approx 1.0 \\
&C_{3L} = 0.52FS + 0.3 = 1.08 \approx 1.0 \\
&C_{2F} = -4c^{*} + 1.09 = 0.986 \approx 1.0 \\
&C_{2L} = C_{2F} = C_{3L} \approx 1.0 \\
&\left(\frac{L}{H}\right)_{corrected} = \left(\frac{L}{H}\right)_{corrected} \times C_{1L} = 0.825 \times 0.7 = 0.5775 > 0.5 \\
&L = 0.5775 \times 8.5 = 4.93m \\
&depth = 5m
\end{aligned}
$$

$$
\mu_{po} = \frac{\tau_u d_{DH}}{FS_{po} \gamma S_h S_v}
$$

But once again I will show you this is already done. You can see that we are considering since many things are not there, assume diameter the drill hole 150, so it is not given so you have to design, assume install by rotary drill method at an inclination of 15 degrees. So, these are important actually so we can design, you can assume anything, suppose let us assume this, the ultimate strength of when this is sealed a rotary drill method is applied then we can find out the particular or is that the tau a, so ultimate bond strength between the soil and the nail can be taken 125, that I can show you.

I can show you or this is the one, you can see here, here rotary drill method and silty sand and the value is given here, sorry, value is given here 100 to 150. So, the designer can choose based on the adjustments, a particular value says about 125 is taken. So, let us take that, so that is what is shown, you can see 125 is taken here and then assume both, now horizontal spacing and vertical spacing we can choose definitely different but here for as a first trial let us take the horizontal and vertical spacing be 1.5 meters.

And then the expression for mu po just what I have shown, this is tau u, sorry, not the mu po equal to tau u multiplied by $d_{DH}$ divided by $FS_{po}$ gamma $S_h$ $S_v$ and you can see here then if you put the value then this tau u is 125, drill hole diameter 150, 0.15, factor of safety pull out that 2 and gamma is 18 and $S_h$ is 1.5, $S_v$ is 1.5.

If I calculate these then we are getting a value equal to 0.231 and C star will be C by gamma H, from there actually we are getting 4 by gamma 18, is the gamma H is 8.5 we are getting 0.026. mu po equal to 0.31, phi equal to 30 degrees and W equals to zero degrees and beta equal to 10 degrees and then if you go back to chart so, I am not able to let me go to the end.

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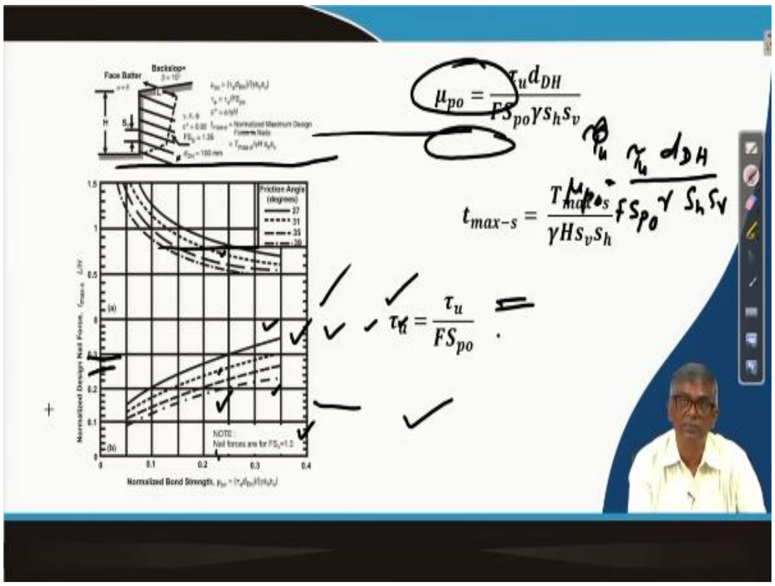


Yes, this is the chart. So, you can see 0.231 somewhere here, somewhere here, sorry, somewhere here this is actually 0.25 and that means 0.23 will be somewhere here and then if you project on these and project on these and then you get corresponding values of L by H from chart and t max s from the chart.

$$\mu_{po} = \frac{\tau_u d_{DH}}{FS_{po}\gamma S_h S_v}$$

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

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

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

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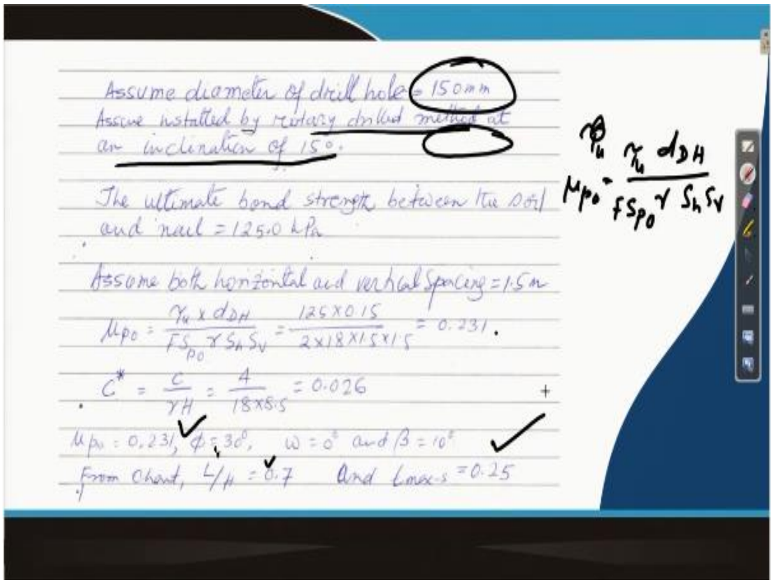


So, if I do that, and that is what we have noted here you can see here from the chart you get L by equal to corresponding to mu po, sorry, mu po corresponding to mu po equal to 0.231 we are getting L by H from the chart 0.7 and t max s from the chart 0.25. So, these are the things we are getting.

$$Assume\ the\ diameter\ of\ the\ drill\ hole = 150mm$$

$$Assume\ installed\ by\ \mathrm{r}ortary\ drillied\ method\ at\ an\ incliation\ of 15^0$$

$$The\ ultimate\ bond\ strength\ between\ the\ and\ drill = 125.0KPa$$

$$Assume\ both\ hoorizontal\ and\ vertical\ spacing = 1.5m$$

$$\mu_{po} = \frac{\tau_u d_{DH}}{FS_{po}\gamma S_h S_v} = \frac{125\times0.15}{2\times18\times1.5\times1.5} = 0.231$$

$$C^* = \frac{C}{\gamma H} = \frac{4}{18\times8.5} = 0.026$$

$$\mu_{po} = 0.231, \phi = 30^0, \omega = 0^0 and \beta = 10^0$$

$$fromchart, \frac{L}{H} = 0.7 andt_{\max-s} = 0.25$$

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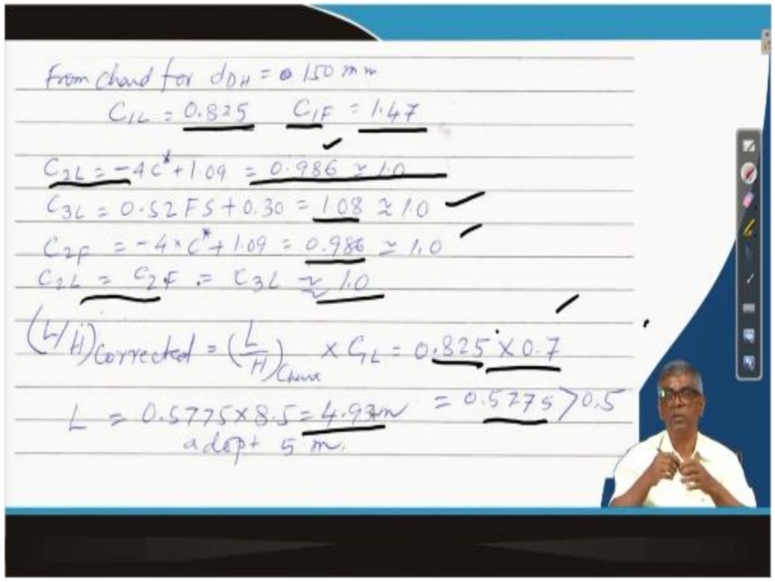
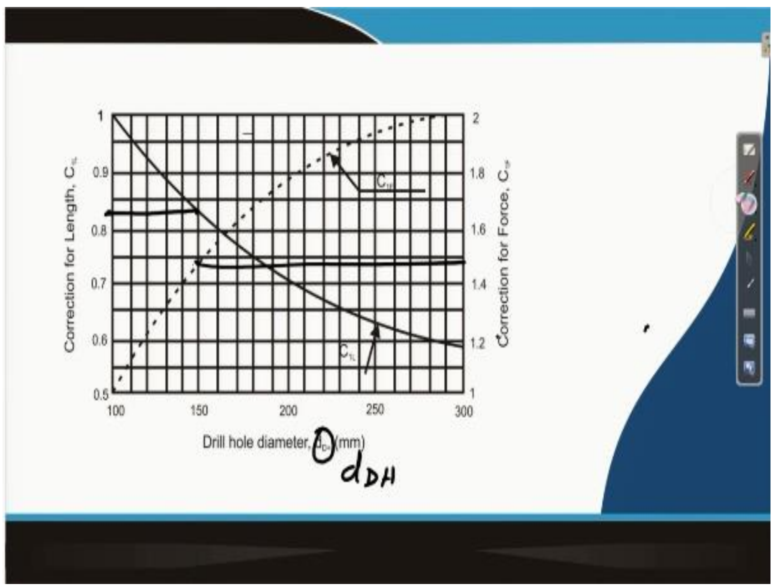

From chart for dDH = 150 mm
C1L = 0.825 C1F = 1.47
C2L = -4C* + 1.09 = 0.986 ≈ 1.0
C3L = 0.52FS + 0.30 = 1.08 ≈ 1.0
C2F = -4 × C* + 1.09 = 0.986 ≈ 1.0
C2L = C2F = C3L ≈ 1.0
(L/H)corrected = (L/H)chart × C1L = 0.825 × 0.7
= 0.5775 > 0.5
L = 0.5775 × 8.5 = 4.93 m
adopt 5 m.


Correction for Length, C1L
Correction for Force, C1F
C1F
C1L
1
0.9
0.8
0.7
0.6
0.5
2
1.8
1.6
1.4
1.2
1
100
150
200
250
300
Drill hole diameter, dDH (mm)
dDH

$$From\ chart\ for\ d_{DH} = 150mm$$
$$C_{1L} = 0.825$$
$$C_{1F} = 1.47$$
$$C_{2L} = -4c^{*} + 1.09 = 0.986 \approx 1.0$$
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$$C_{2F} = -4c^{*} + 1.09 = 0.986 \approx 1.0$$
$$C_{2L} = C_{2F} = C_{3L} \approx 1.0$$
$$\left(\frac{L}{H}\right)_{corrected} = \left(\frac{L}{H}\right)_{corrected} \times C_{1L} = 0.825 \times 0.7 = 0.5775 > 0.5$$
$$L = 0.5775 \times 8.5 = 4.93m$$
$$depth = 5m$$

Now, next step will be to correct it and you can see here from chart for d DH 150 millimeter that there is another chart, this chart actually you can see that when $d_{DH}$, this is actually $d_{DH}$ drill hole diameter when is 150 then $C_{1F}$ can be calculated from here C 1F actually you will be reading from here and $C_{1L}$ will be this curve, we will be reading from here. So, these two values if you read and then that will be the $C_{1L}$ and $C_{1F}$.

So let me go to there now, let me go to that page. So let me you can see here that that C 1l actually from the chart equal to 0.825 and $C_{1F}$ is 1.47 and $C_{2l}$, $C_{3l}$, $C_{2F}$, these are all actually empirical equation is given which I have not discussed before. Once again I am writing $C_{2l}$ minus 4 C star plus 1.09 and if you calculate it comes 0.986 which is close to 1, $C_{3l}$ actually 0.52 FS plus 0.3 and if you do this it is coming close to 1.08 which is close to again 1 and C 2F again minus 4 C multiplied by C star plus 1.09 you put the values again we are getting 0.986 it is close to 1, other than $C_{1F}$ and $C_{1L}$ other parameters are constant generally or factors come very close to zero.

If you do not require very accurate calculation, generally those value constant can be taken as 1, so that is why I did not discuss that time, but in the exam generally if it is there, only $C_{1F}$ and $C_{1l}$ will be given other thing can be assumed as 1. So, if you do that so that is what the I have mentioned here $C_{2l}$, $C_{2F}$, $C_{3l}$ equal to 1 then L by H corrected will be L by H chart multiplied by $C_{1l}$, so again L by H from the chart actually have got 0.825 multiplied by 0.7, we are getting some value which is equal to 0.5775 and that should be minimum 0.5. So, since it has come more than 0.5 so you have to give provide 0.57, so whatever exactly came so 0.575 multiplied by 8.5 it comes actually 4.93 so nail length actually coming 4.93, we can choose actually length equal to 5 meter.

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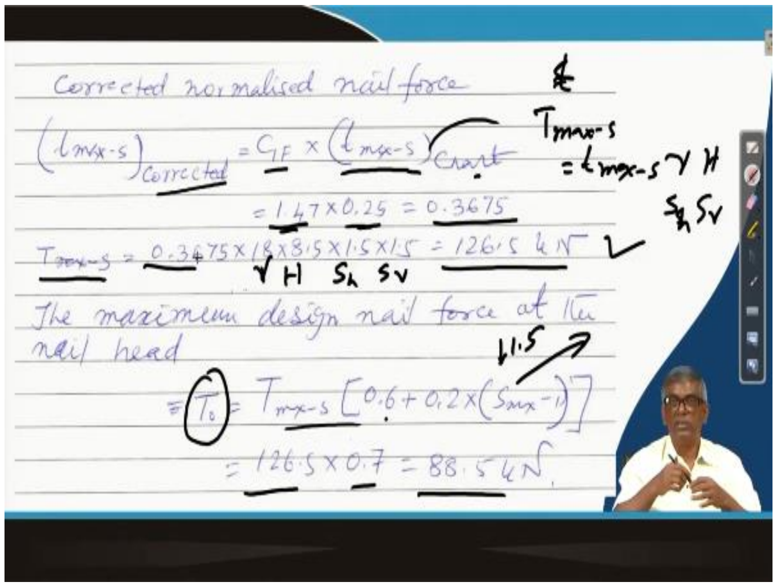


Let me go to that next and then you can see that t max s from the chart we have calculated and we have to get now t max s corrected, so corrected normalized nail force t max s corrected will be equal to $C_{1F}$ multiplied by t max s corrected from the chart and this is $C_{1F}$ we have got 1.47 and t max s we have read from the chart 0.25 if the value comes 0.3675.

So, tmax s actually then from the equation actually 0.3675 that means, t max s and this is actually gamma H, this is actually gamma this is H and $S_h$ $S_v$ actually t max s, actually T max s will be equal to t max s multiplied by your gamma H and then $S_h$ then $S_v$, so all those things are applied and then you are getting that this value is coming 126.5 kilo Newton.

The maximum design nail force at the nail head, we have mentioned that nail head and on the nail is different, so nail head actually force designated as T naught and which is given in the form of this equation. t max s multiplied by 0.6 plus 0.2 multiplied by S max minus 1. This is the expression and this S max actually what if I use different spacing for horizontal and vertical direction the which one is the greater one that means, the horizontal spacing support two, vertical spacing support 1.5 in that case s max will be two, if the vertical spacing is 1.5 meter, horizontal spacing also 1.5 meter then your S max will also become 1.5 meter.

Since our problem we have assume $S_h$ equal to $S_v$ equal to 1.5 meter. So, 1.5 can be taken here 1.5, 1.5 minus 1 it will become 1, 0.5, 0.5 multiplied by 0.2 will become 0.1 and 0.1 multiplied by plus 0.6 is a 0.7, so 126.5 multiplied by 0.7 it is coming at 88.54 this is the nail head.

$$\textit{corrected normalised nail force}$$
$$\left(t_{\max-s}\right)_{corrected} = c_{1F}\left(t_{\max-s}\right)_{corrected}$$
$$\left(t_{\max-s}\right)_{corrected} = 1.47\times 0.25 = 0.3675$$
$$T_{\max-s} = 0.3457\times 18\times 8.5\times 1.5\times 1.5 = 126.54$$
The maximum design nail force at the nail head
$$\mathrm{T}_0 = T_{\max-s}\left[0.6+0.2\times\left(s_{\max}-1\right)\right]$$
$$\mathrm{T}_0 = 126.5\times 0.7 = 88.54$$

These two things actually for nail head design required and t max s will be required to find out the diameter actual what is the anchor and then the form of nail in the form of that in enforcement the soil nail to be decided, if a particular grade of steel is used and you know maximum tensile stress and based on that you can find this is the required load and this is the stress load divided by stress you can get the area and that area, from the area you can find out what is the diameter required, this is by a large actually steps of design in your soil nail wall design.

This is the way actually to be, design means what exactly you have to give what technology to be used for making the nailing and accordingly based on type of soil and the technology to be used then you can find out the front chart what is $\tau_a$ that is one thing, you have to select a diameter of hole and then all based on this you can find out actually mu po.

And of course, to get mu po before that again you have to choose the spacing of the nail, both horizontal and vertical direction and then you calculate mu po and then you have to choose the out of four charts which is matching exactly with your problem and then accordingly you have to choose that chart and on that chart you project mu po on two curves, one for L by H another for t max s, to get the from the char t max s and L by H, then you apply correction to L by H and t max s both for different corrections will be there, only one correction, C1 correction to be applied.

And once you apply that you will get the length, you will get the t max, you may get T naught and if a particular grade of steel if you use then we can find out what would be the area required and then from the area you can find out diameter required. So, this is the process of the design.

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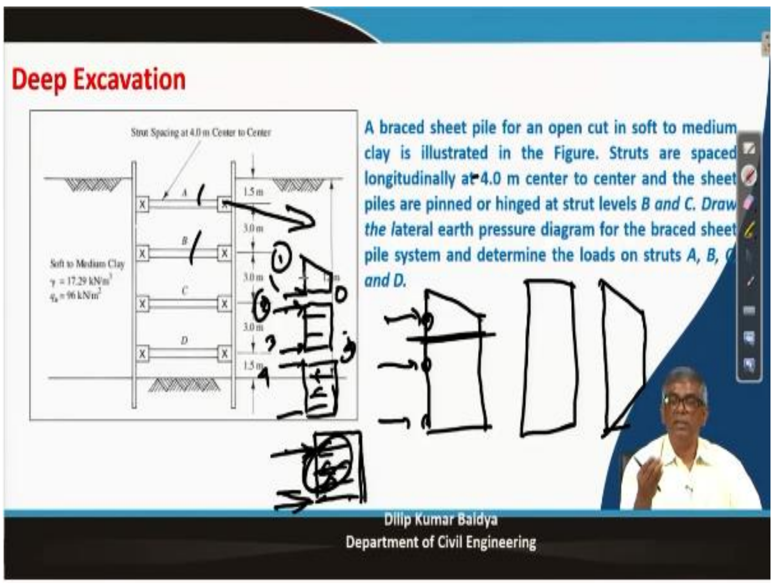


I have not had a plan to do any design on anchor but typically in the lateral excavation of the supported, lateral supported wall that is called struts actually, these are the struts. Force comes here and when it is in pressure here and that means it is giving pressure in this direction and when does it stop these if the anchor is there, pressure is this the anchor also direction in same direction.

Because of that what we can do similar type of arrangement, the anchor is there suppose, this is the wall anchor location is this, anchor location is this, anchor location is this then we can assume support here, assume support here, assume support here and then you consider the pressure diagram either this or it can be constant this or it can be something like and like this.

If you choose any of the pressure diagram and then tributary for these actually will be made up to meet point of this and so if I do this, then I can simplify method which we have done before, similar we can do suppose I can do that this part I can separate it like this, one support is here, another support is here, so this is we can consider a simply supported beam like and with a uniformly distributed load.

And then summation of these two reactions will be equal to the pressure coming over this and then to find out what one take moment with any of the with respect to one on support and take moment with respect to one support then we get the load, one reaction in this, once you get the reaction in one, then reaction two reaction equal to the load then from there actually can get load divided by load minus one reaction will be the reaction on the other two, other one.

like this actually we can do and generally it is not done like this, I did one mistake we generally hinge method, we do is not like this, it will be hinged actually that we are to assume that it is, so like this it has to be considered and at this level again it has to be like this and then of course if I know the intensity here I can find out these two and again I can find out what this load equal to this load. This support will be this, this reaction one and this is two, one plus two will become this, this reaction.

Similarly here actually three and here it will four, three plus four will be here actually this loading, so the reaction at this point, like those reaction whatever you will get from these can be considered as the, if you stop this support instead of this strut if the anchored same load can be considered it is there also and that based on that loading, you have to find out the bond length etcetera, etcetera all that we have discussed, so like these it can be entire design can be done. I am not taking any problem because a lot of things will be there to consider. So, it will be too lengthy, so I am skipping this one because this module in five lectures it cannot be difficult to cover more than that. Because of that I will just stop here and of course, there are two more modules will be there but two modules together actually only one module.

There actually will try to discuss about the application of enforce or geo synthetics and various application of ground improvement of erosion control etcetera. Application of geo synthetics so there will be as a as a reinforcement, as a protection, as a barrier for something like that, then there are drain so number of ways actually geo synthetics can be applied.

And so, initially the few lectures we will discuss about the application of geo synthetics more broadly different, different applications without any analysis, detailed analysis, later on a few applications, where that geo synthesis is used as reinforcement or something else, there are some analysis, I will try to consider that we can have on design or problem also.

This geo synthetics and the application of geo synthetics in ground improvement problem, there are two modules together will be one module. I will try to take one hub mostly discussion and application of geo synthetics in various areas briefly, later on one or two topics, analysis, exact analysis, how to design how like a nail or anchor or something else whatever we have done similar way some design also to be taken. So that will be I will start in the next lecture.

That is the only thing is pending we will try to discuss that. Of course, whatever is coming in my mind I am trying to cover, you may have some difficulties or some question in between and of course, when the course will be running that time of course there will be some living session, that live session, that time you can raise those question also you can raise some question on the forum, time to time will respond to those and with that, actually, maybe it will be benefitted to you.  with this, I will close here, thank you.