Ground Improvement
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Lecture No. # 33

Soil Nailing

So, what I do is, now I talk about soil nail wall. This is another elegant technique that the that is because of the principle of reinforced soil that came up and the principle is quite simple. What we do here is that in the case of reinforced earth wall, you construct from bottom right you just take a, you clear the ground and then you put some this thing and put the facing first then put the back fill then put the reinforcement. Like that you know you have a sequential construction it go from bottom to top.

Here that is you are constructing a wall. Here also you can construct a walls, but, for an excavation say for example, excavation what you do is that you come from top.

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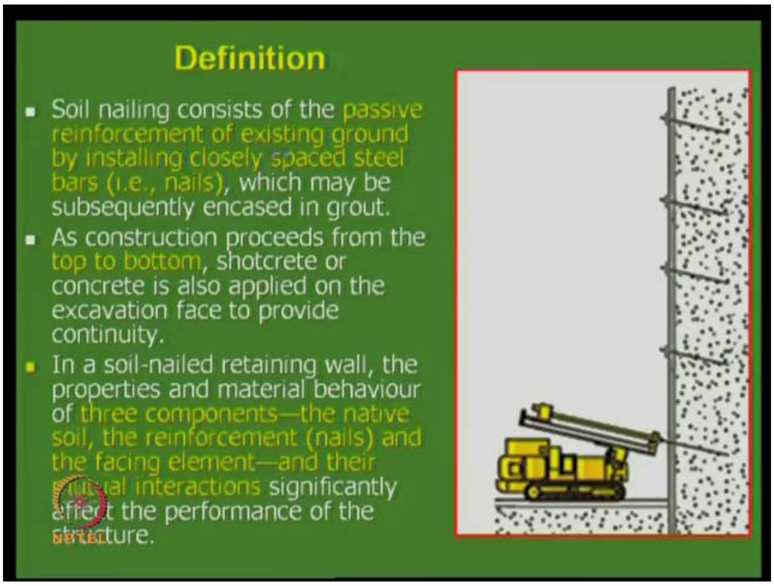

The soil nailing consist of passive reinforcement of existing ground by installing closely spaced steel bars which may be subsequently encased in grout. What we do is that, we sequentially you know make a cut make some little bit of excavation, put a nail you know. It can be a nail means reinforcement bar and it has some, what you call the passive inclusions in the sense you know the grout is there all round and this is another one. Like that it sequentially do that. So, the construction proceeds from top to bottom and we put either a just a shotcrete or a shotcrete is applied to provide stability. The soil nailing retained wall, the properties of these materials, native soil you know like what soils can be used for nailing is another important thing because soil is there and you need to strengthen it.

It is in the r u wall you you get a back fill and then reinforce it here you have to deal with the existing system. So, native soil is there you have to, reinforcement is there and facing element the three things that are important and the way the three things interact you know, like nailing, facing and the native soil. the that That effects the performance of the structure.

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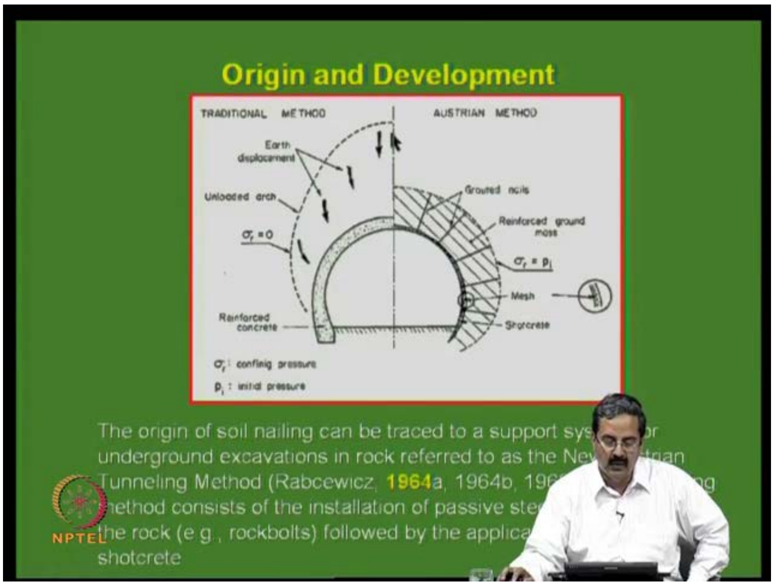

So, if you want to get the maximum benefit out of this; yes you should understand three of them. I want to tell how the technique came. Actually you know this technique came from in construction of tunnels. Actually when you construct a tunnel what happens? You make a small opening and then there will be earth you know because of the opening there is a tendency for collapse and the failure zone is like this. you know failure zone is like this.

So, you try to design by means of arching action to retain this much amount of soil you try to provide some reinforced concrete lining. That is a principle where you know like sigma r equal to zero the Rieger stress line and all that you do this some traditional method that is what people do.

Ah That is what that they were doing, but, you know in some in Austrian method you know it is called new Austrian tunneling method what they did was that you know many of the workers, you know the thing is that you put some nailing you know short nails so, that it is stable then put some simple cover. So, what is happening is that, you did not allow this much of material to the, you know, acting or you know you have not designed for this much of pressure. You only designed for this much of pressure because this is actually yeah this is the, that pressure and all that.

So, the advantage is that you are immediately able to you know you did not allow the failure planes to develop the moment you excavated here you just put some nails such that all that vertical forces that are coming they are able to interact between the because of the interaction between the soil and the this thing nail; the load that is coming like this was much less and you can have a thin thin facing. Is it not? That is very interesting.

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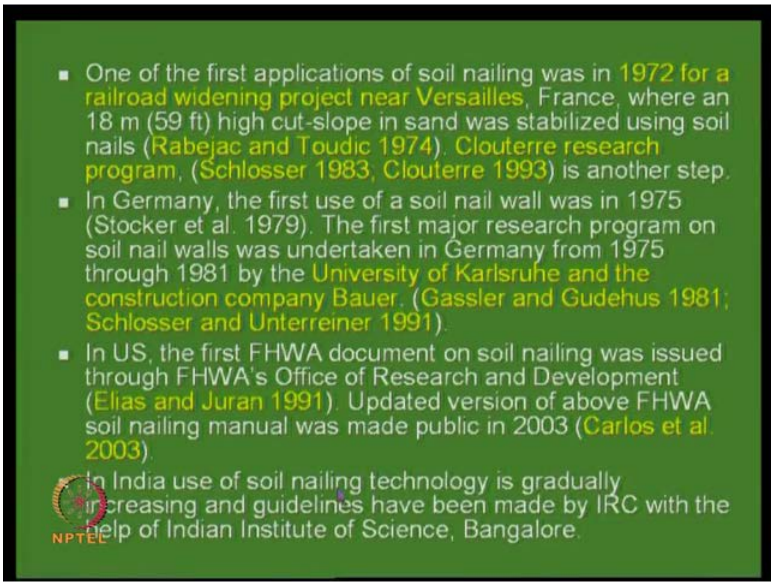

And in fact, first nailing application was in 1972 for the road railway road project in France. Eighteen meters is the high wall you know you can see its eighteen meters is very big and it was.

Then in France you know they started a big research program it is called Clouterre. Terre means soil in French and cloud means nail. So, soil nail is what is called. So, they started a big research program in in the in 90 and 80 they worked about very long time say for example, about ten years and come out with lot of guide lines. That is in the case of Germany. And in the case of you know the France and in the case of Germany they also did in 1975, one soil nail wall and lot of research work was done again in the University of Karlsruhe and other places. And there are some companies that are doing even now very well actually German soil nailing you have to see, it is excellent.

And in US you have federal highway document in soil nailing and it was again you know Juan and all there are persons who came from France and then they helped them and you have an updated version now you know. So, federal highway is also very active and even in India we have been able to develop guidelines based on the some of the above and Indian roads congress is has made it available. In fact, we prepared I prepared actually and we did that.

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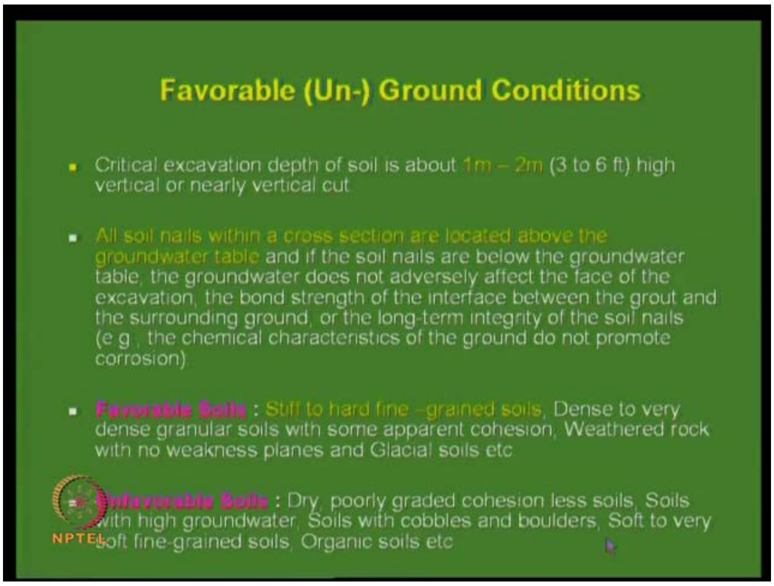

So, what is this favorable conditions and unfavorable conditions for nailing? Actually you know the thing is that you excavate, but, if it collapses it is a problem. So, you do not want it to collapse right so, but, then you have to put the nailing also. So, if you can if the soil can stand on its own for about half a meter or one meter before the nailing is nail is put then its fine. So, you can do that sequentially. That is what we try to.

So, critical depth is about one to two meters and if it is there its fine. Second thing is all soil nails within a cross section are located above the ground water table. That is one thing that one should be very careful. And. So, favorable soils are that stiff to hard and fine-grained soils dense to linearly with some cohesion and all that and unfavorable soils like a poor graded soils like you know, it can which can start collapsing like that or even were water table and very you know gravelly material where its not even possible to you know, The thing is you are trying to provide a grouted soil nail you know. The thing is that you make a bore and then put a grout and put reinforcement and if you cannot make that in the gravelly deposit then it is difficult, organic soils all that.

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What are the advantages? It is so effective that it can be used you know with some space availability is quite less, construction is less disruptive to traffic, causes less environmental impact, relatively fast in construction uses a typically less construction materials and hence economical then occurrence of utilities may place restrictions on the location, inclination, length of the nails.

What happens in most of the cases? Suppose you were doing nailing in town you know important you know urban area you have pipes, service lines you know electrical cables, water supply lines and all that. So, that may put a limitation on the length of the nails in the upper areas you know. Then you know when water table is there again it possess a problem. Then it also needs specialized construction people you know. You need to have experience otherwise it is very difficult you know. The thing is the moment it collapses see you wanted it to be stable, but, if it collapses what is the use?

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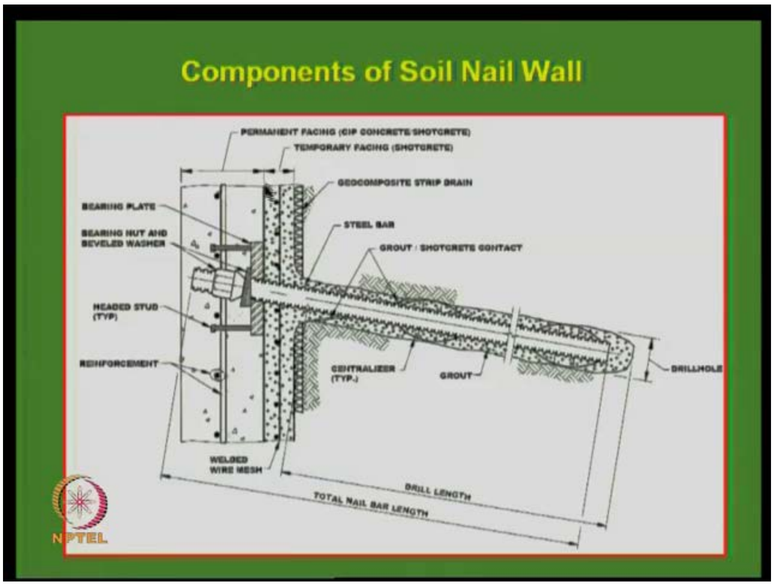

So, it looks like this you know you have a reinforcement rod then you have the grout also here all round. Then you can even have you know, there are some materials which is called all grout. Centralizes is just to keep that in position you know, the thing is that there is a small centralize centralizers to see that whole thing is in position and then you have a geo composite drain that can be used for drainage purposes. And then this is the thickness of the temporary facing is about say for example, 75 mm or something that one can have. And then this is the permanent facing. there are All this things are done and what we do is that we can just after putting the nail and it can be covered like this that is what it. So, it becomes like a permanent wall.

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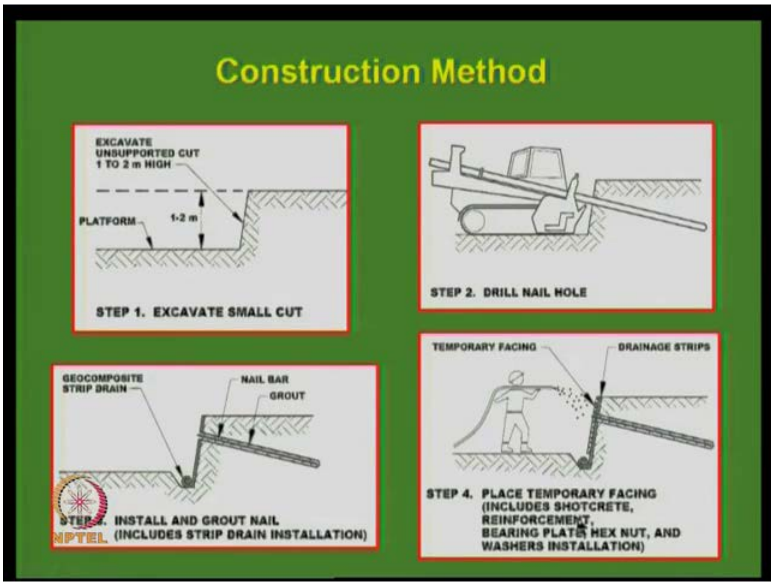

So, as I just mentioned what are the steps. Go to some depth then drill this equipment with some, it is called wagon driller and then put this nail bar and grout and then this one. Then shotcrete temporary shotcreteing and go to the next level placement of temporary facing all that next level.

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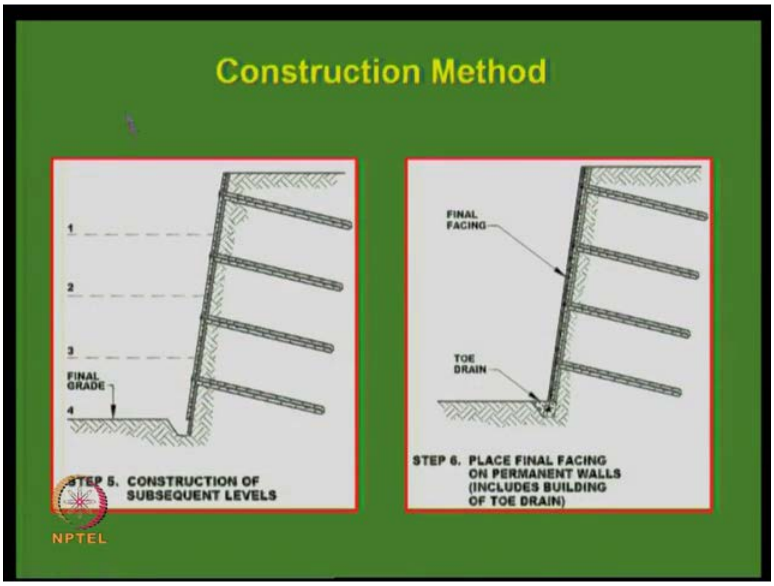

Then, one, two, three, you can keep on going. Then put this that is it that is way we do it. So, these are all some applications of slopes.

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You can see here you know big retaining wall structure then because of the bridge embankment you can see all round apartments here, but it was nailing is possible.

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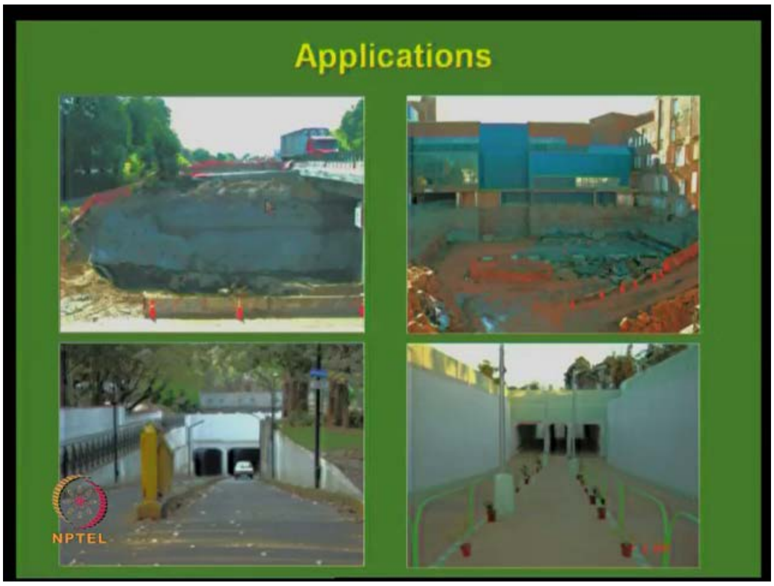

In fact, I owe I did couple of projects on these lines. This is our own an under pass IISC under pass where you know, these are all nailed walls on either side. And the beauty was that if you have gone for a regular retaining wall; all the trees that were there here you know 16 trees you have to cut them. But, then because of the nailing we you know it was there intact.

It is another structure that we designed for the ministry of defense you know, about seven meters high wall shotcreting and nailing was done and it was a very successful project which was finished in you know whole structure was finished in a very fast time. It was very good. So, it received lot of appreciation and awards as well.

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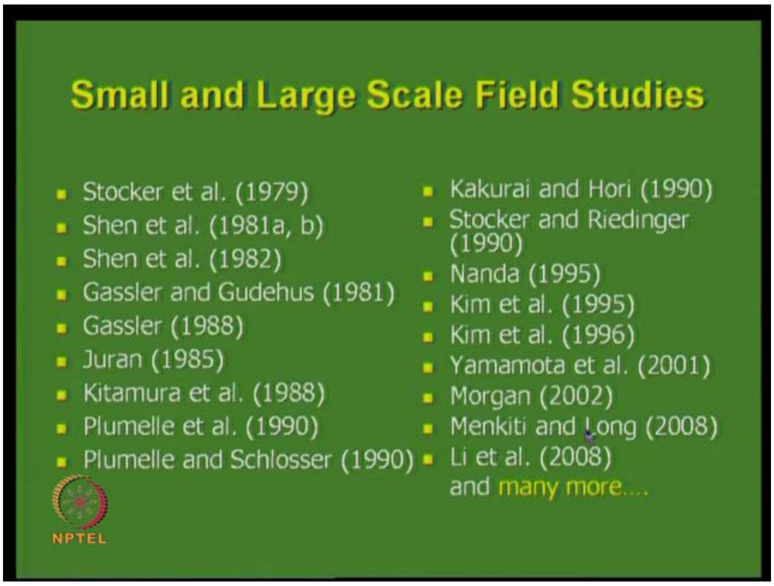

So, the soil nailing technique has been you know well studied. In fact, so, much so, that you know you have you can classify them in field studies and there was. So, much work by different people here.

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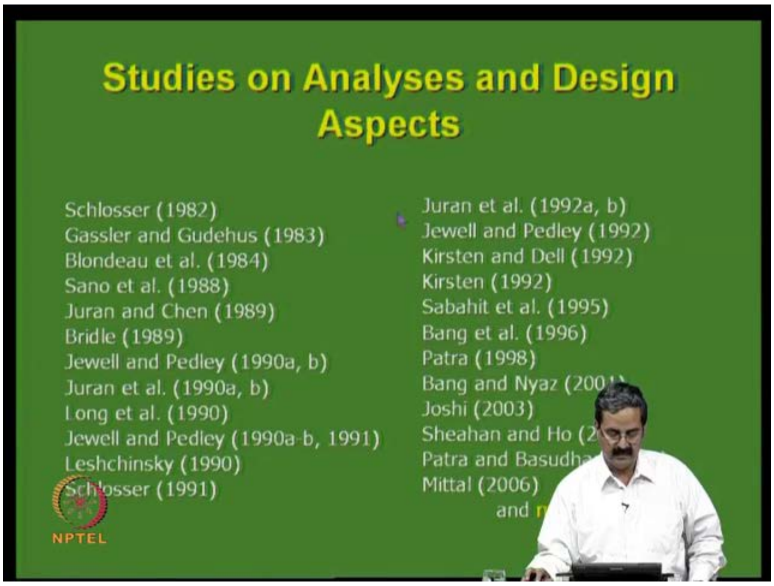

And people have started lot of analysis; like analysis and design was well established well studied and Schloseer many people have studied Juan and in fact, there many people have done lot of analysis Jewell and Pedley. There were very good work was done there are many more.

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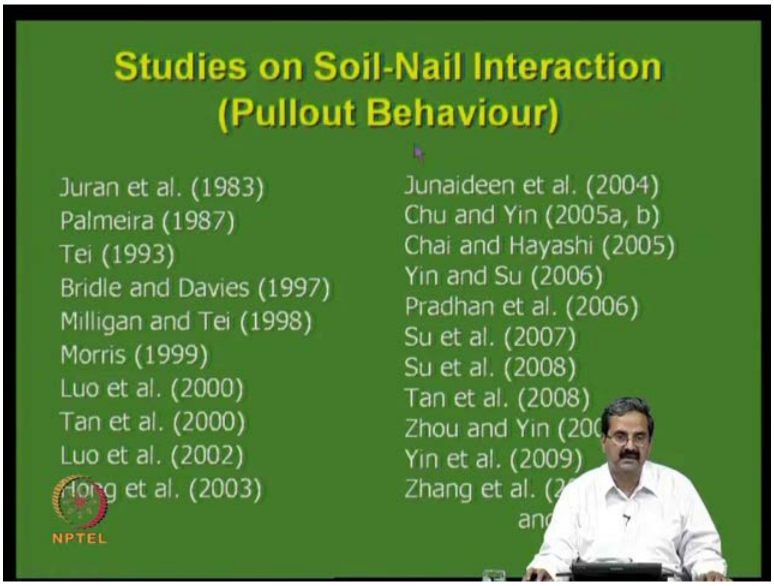

And soil nail interaction was also done like you know; how the soil interaction nail is there you know, how does it respond, you know. Pullout behavior you know, as I said pullout in as also very important, very important actually.

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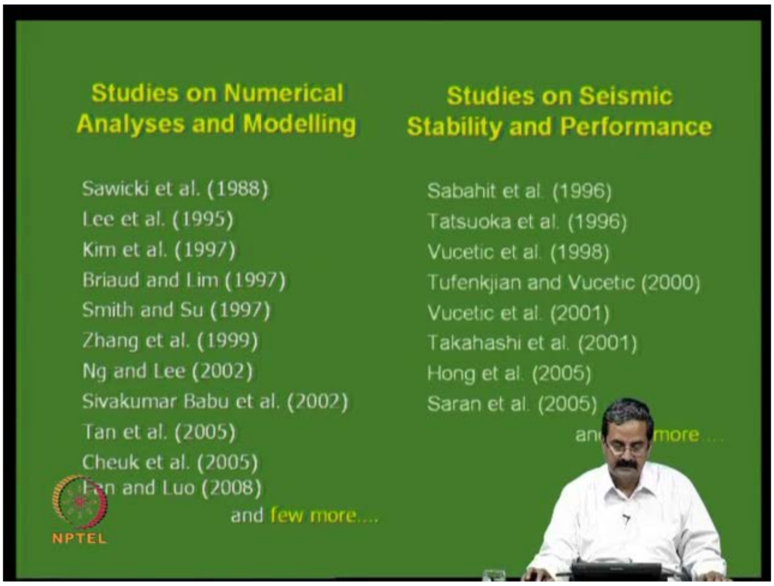

Then studies on numerical analysis and modeling and you know. In fact, there are so many papers. In fact, in some of the papers we studied you know the effect of construction influences there are some studies we did in this particular publication. All are very well thoroughly studied papers are there and again some more work and case studies we have and reliability analysis is also done.

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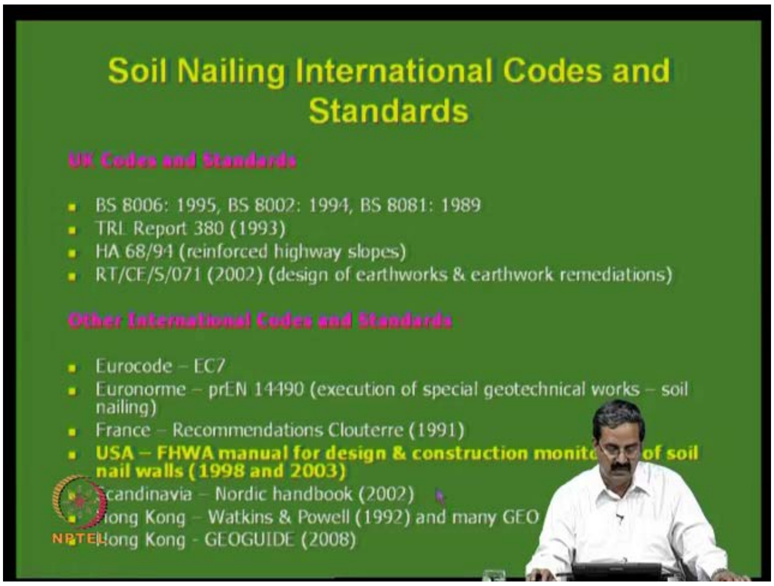

So, you also have lot of codes BS 8006 here are. So, many codes available on these lines. Federal highway code and all that.

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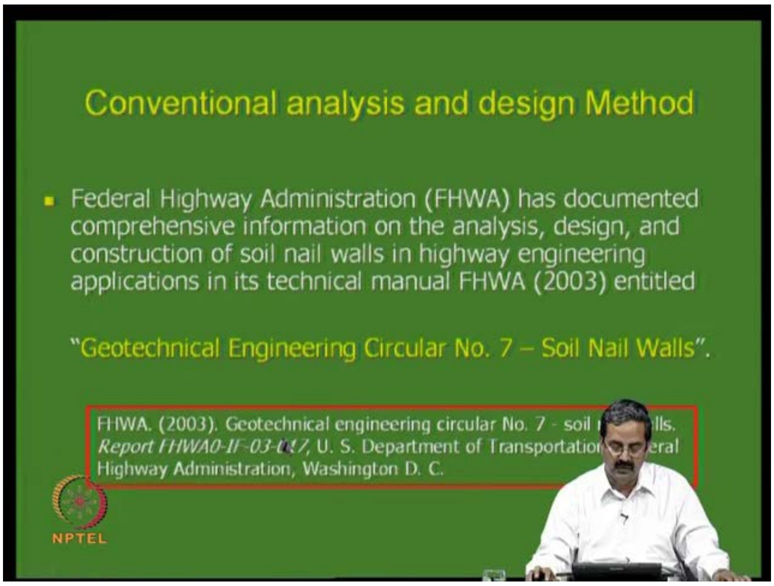

And I will just describe what is presented in the federal Highway Code you know so that you can understand how you can go about design that is what I would like to see.

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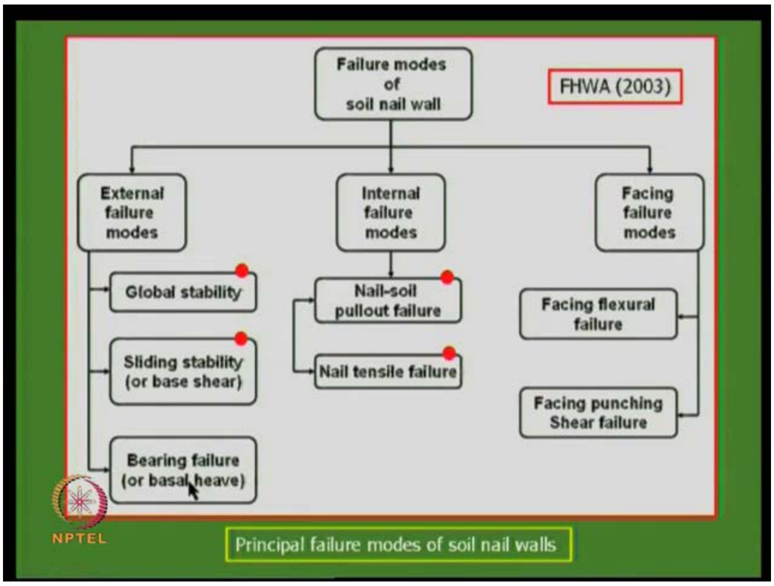

So, if you want to design a soil nail wall; we should understand what are the failure modes? First thing as we know it is all external failure modes we have to look for global stability we should, sliding stability then bearing pressure similar to any of the retaining walls or r u walls or anything then internal failure modes. It can pullout pullout nail can come out or it tensile capacity can be poor that is too are possible. Then the facing failure is also possible like you know the, it can bend then it can punch all that is possible like we will see some of them.

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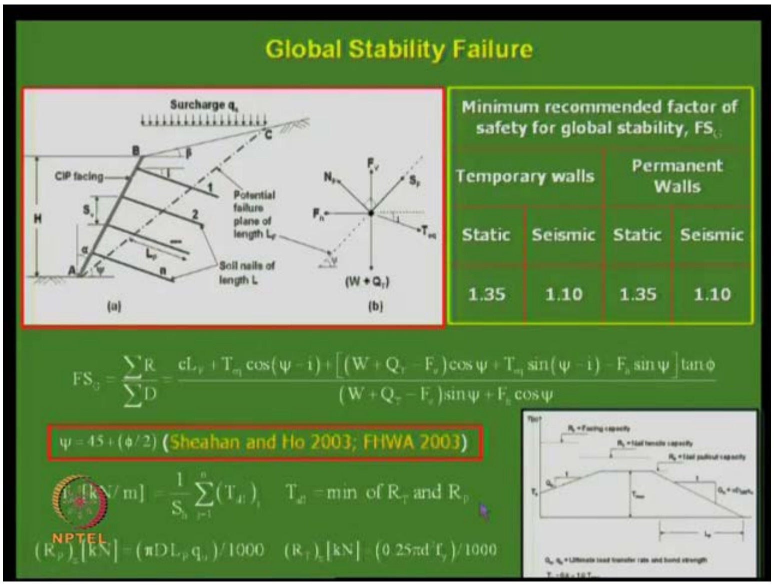

So, global stability what it means? Say for example, we studied you know the if this is a failure software's and this is a surcharge here and you can you know you assuming that this is a failure surface one can derive an equation for equilibrium in terms of factor of safety global right. If you know the length c and then L F is the length of that and reinforcement force required and all that, one can gave get that

And based on this one can derive that and then the tensile force is distributed among all this reinforcement members, the horizontal components and the allowable tensile force is the two resistances here, resistance in terms of the tension pullout and the resistance in terms of the pullout is nothing, but, you know pullout is nothing it is a surface area right.

If you are putting a circular thing pi D L pi D L p into q u. q u is the bond stress divided by 1000 whatever it is just that. Then it is a tensile force resistance tensile force is nothing, but, its pi D square by 4 right into F y you know. So, that is the total R T you know tensile force.

And the other important thing is that, this is what the we assume you know particularly the code assumes some sort of the distribution of forces on the nail like it varies from T naught to like this and you know it comes to this the length L p is here and so, we try to classify in terms of the R p is one term that is called facing capacity.

Then R F is a nail capacity and nail pullout capacity. There are three terms that we have and so, this is one important variable and minimum factors of safety for global you know temporary walls if it is static its 1.35. You include earth quake force into consideration and then you do that it is 1.1, permanent walls factor of safety this is 1.35. Of course, there is no difference.

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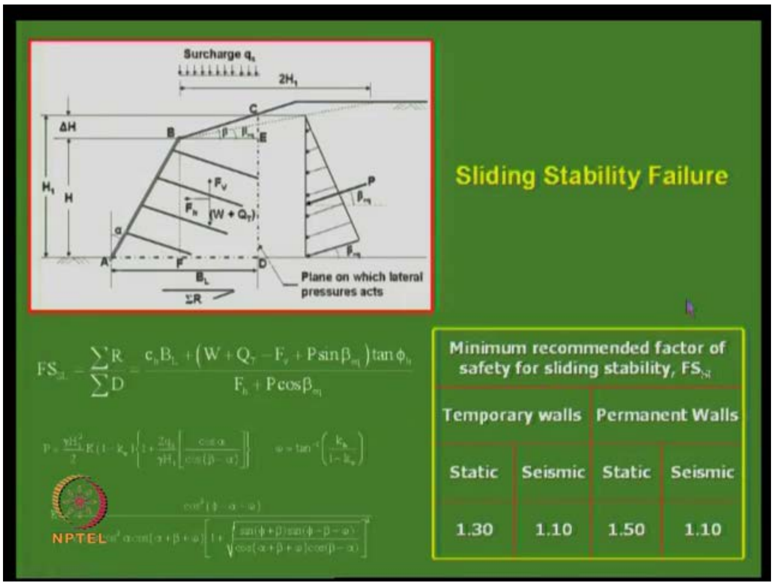

Then what is sliding stability? Like what the horizontal component of the this you know the forces and then this sliding force. It is a the sum of the ratio of resistances to driving forces one can derive a simple equilibrium equation and you know say for example, you say here p equal to gamma H square by 2 into like we that already p into gamma H square one minus k v if you have surcharge it comes like this. And this in terms of the earth quake force and k is a if it is a inclination right, because it is a somewhat sloping. So, you have this factor of safety again you know 1.3 1.1 something like that right.

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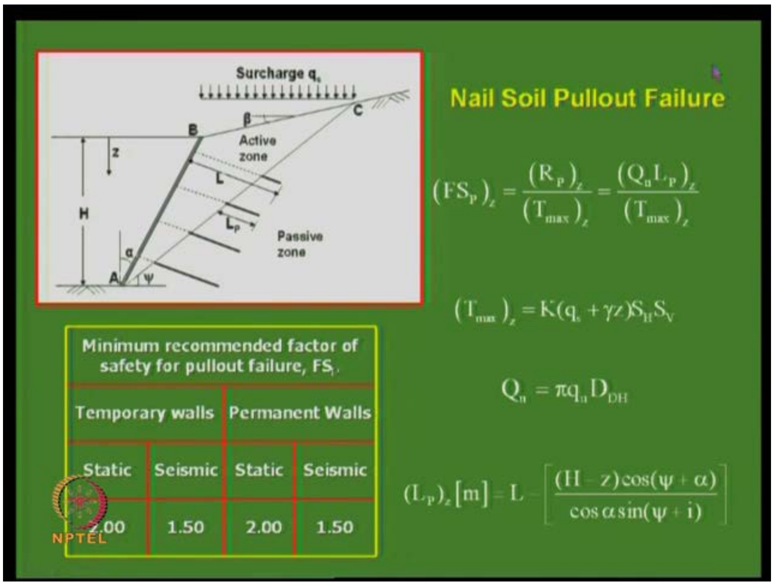

We are discussing these failure mechanisms of nail walls as I just mentioned, external stability is an issue and apart from external stability we need to address some of the internal failure mechanisms. Say for example, soil nail soil pullout failure means if the length of the nail you know say for example, this is the active zone and we call it this is a passive zone. And if the length is not adequate here then the possibility is that the nail can come out easily. We do not want to have such problems

So, what we do is that we try to have adequate pullout resistance which is given by this like R p you know, which is nothing, but, the bond stress and the length of the length of pullout at a depth z and divided by the maximum tensile capacity at that particular layer. So, this is what we do and we see that, we know that at the T max certainly depth can be calculated in terms of the k into surge Q s plus gamma z into s H into s v. This is very clear and Q u is nothing, but, pi D q into the drill hole diameter diameter say for example, the grout hole diameter is say 100 mm or 75 mm.

We have actually drill bits which you can you know drill that and then put the nail. I just showed you the diagram in which you make a drill hole and put that grout and also this say equalizers are there. The equalizer, nail and then both will be, they will hold both of them together and then there they they just see that nail you know it should be at the centre right. To keep the nail in the centre that centralized centralizers are used. So, this is what we do and the length is nothing, but. So, once you know this one can get this L p is nothing, but, if this is an expression because we use this failure mechanisms like this we assume and once you get this, the factor of safety has to be in temporary walls static and dynamic its two and permanent wall it is two whatever minimum minimum factor of safety recommended.

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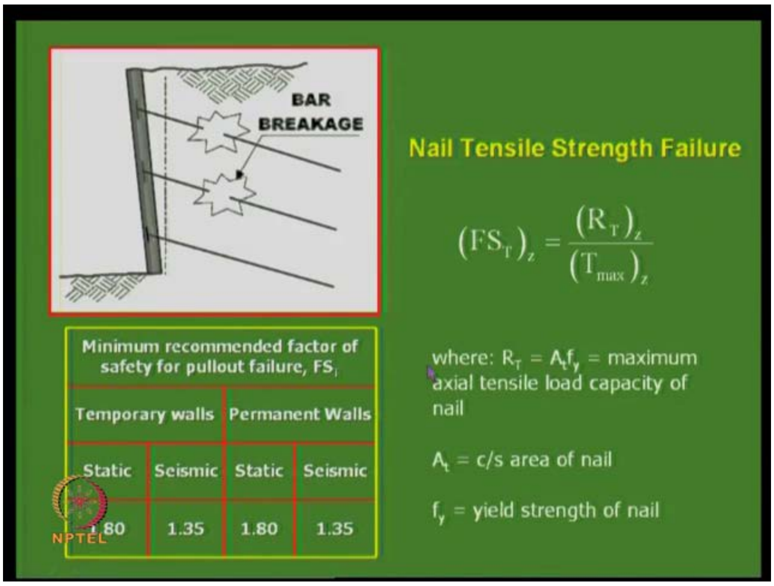

Then the other one that one can expect is tensile failure like the factor. Say for example, the resistance, tensile resistance available and then the tensile force mobilized. So, it should be always more than one whereas, R T is nothing, but, the area of cross section of that and this is the simple right. So, once you know that, the again you know you have to see that the factors of safety of at least one point or maintained in static conditions and whether it is permanent or temporary or whatever you know.

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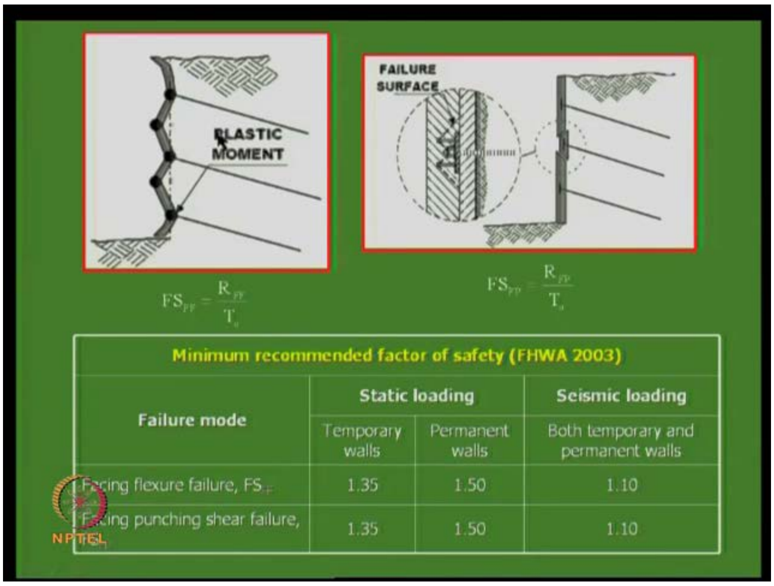

So, one should see that tensile failure and the breakage should not occur. Then the other one is that the what you call the flexural modes you know the facing failure modes right. Failure modes are nothing, but, this you know this sort of plastic movement formations you know, if it is too thin it is possibility to have and even this sort of punching mechanism can occur you know. That is one possibility in the case of facing failures you know.

Soil nail walls should be stable in external conditions, internal stability considerations as well as facing considerations, facing stability. These two are facing stability and so, you have to see that the factors of safety are ensured and this factor of safety against facing failure is given by R F F divided by T naught we will see that. And here the, this is another one is given by this expressions. We will see that what is the tensile force. That comes on to this that what we have to see we will see that.

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I just want to illustrate this with reference to some example here, seven meter high wall. In fact, I have lot of examples on this in which we did even ten meters, twelve metes fifteen meters and all that and this is a simple example. And I want to tell you that there are two types of nails that we use in Bangalore or in India; one is called a driven nail in which the nailing is done using a jack hammer. It just, put it to the jack hammer and then you know drive nailing you will only it is just a reinforcement rod it just gets into the soil where as a grouted nail is you have a driven nail that is there and also the grout is there on surround it.

The difference is that the in the case of a driven nail it is very easy to do because you know cost and simple operations that is what many people do in Bangalore and whereas, grouted nail is much more you know rigorous and you know it needs some what little expensive then the driven nail.

And in this case I am just using a driven nail and the spacing is horizontal to vertical spacing is 0.5. In fact, our soil nail wall in IISC campus is made out of this, driven nails and spacing is like this. Then, the inclination sometimes people were using it can be twenty five degrees is the actual one because that is what is an optimum degree, but, in some places in what we use is just horizontal because it is easy to drive a nail horizontally. Then the soil nail material is grade F E 4 14 and this is what it is.

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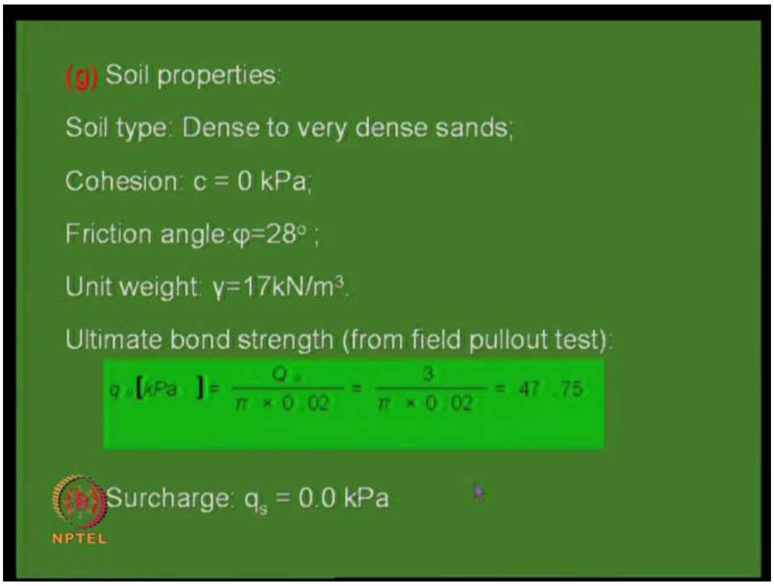

Now, in fact so, soil type is dense to very dense sand and cohesion is zero and friction angle is like this unit weight is this one and ultimate bond strength. Actually, in one of the locations in fact, I conducted a very field pullout test which is very low value that I got and I am just trying to use it for demonstration purpose. Actually that it is in Ahmadabad area where it is just that very it can easily one can pullout the nail you know. The soil is so, poor and the diameter is 20 mm. So, I used and then the bond stress is nothing, but, Q divided by pi into this. So, you get 47.75, surcharge is not there.

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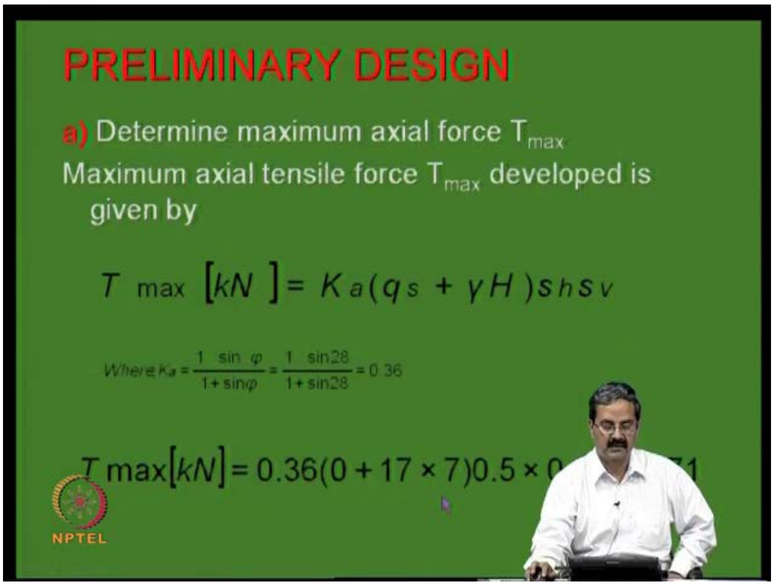

And the maximum force is given in terms of the k a into this particular factors. this is the. So, you can see that it is 10.71 kilo Newtons is the force required for this spacing right at a maximum spacing maximum depth of the, you know it is a small number.

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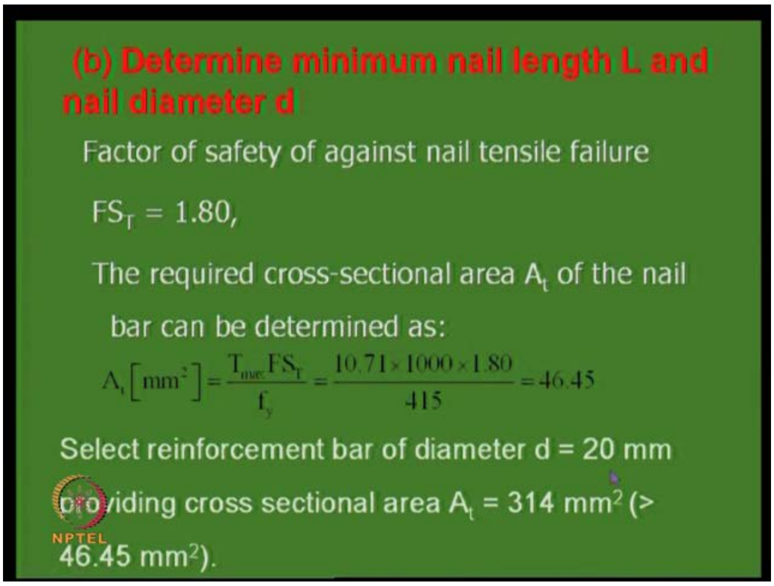

Now, the factor of safety for nailing tensile failure is 1.8 is what the code says. So, the required area of cross section is 46.45 you know. You can calculate what is the area of cross section that you need to provide using these simple expressions with factor of safety and 415 grade and all that. And normally you choose a 20 mm because it is easy to drive you know I can choose a smaller one, but, I cannot see 16 mm is also possible. So, you just provide this and you know the area of cross section is much higher than this very much higher one can. In fact, 16 mm also can be done you know, but, 12 mm is very difficult to drive you know, it is it can bend it. So, if it is very you cannot bend it you cannot drive it you know it is there is, people have to hold in with some sort of arrangement.

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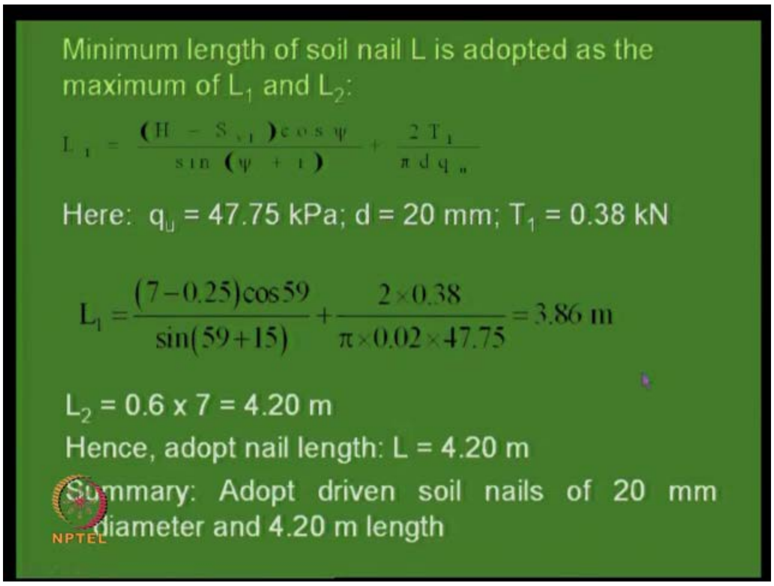

So, minimum length of the soil nail is adapted as an L 1 and L 1 2. There are two considerations here and. So, if you just use that and you know at the top and 0.38 kilo Newtons and length in that you should provide it is about 4.2 and. So, the 4. 2 meters will be the length of the nail you know it is a 7 meter high remember that. So, 0.6 is a one that you are using and this is a normal thing that we provide actually. You assume that if 10 meters is a height 0.7 times into height. So, 07 meters it is 7 meters here. So, 0.7 into 0.6 actually 0.6 is also used 0.6 into7.

So, there are some variations is there reference to this length you know people are very like you know if you are using you know stiffer material like soil nailing it can even go for 0.6 Geordies 0.7. So, there are some guidelines available, but, you know in this case it is 0.6 into 7 is used and so, the length of the nails and this is adopting a driven nails of 20 mm and all that this work fine.

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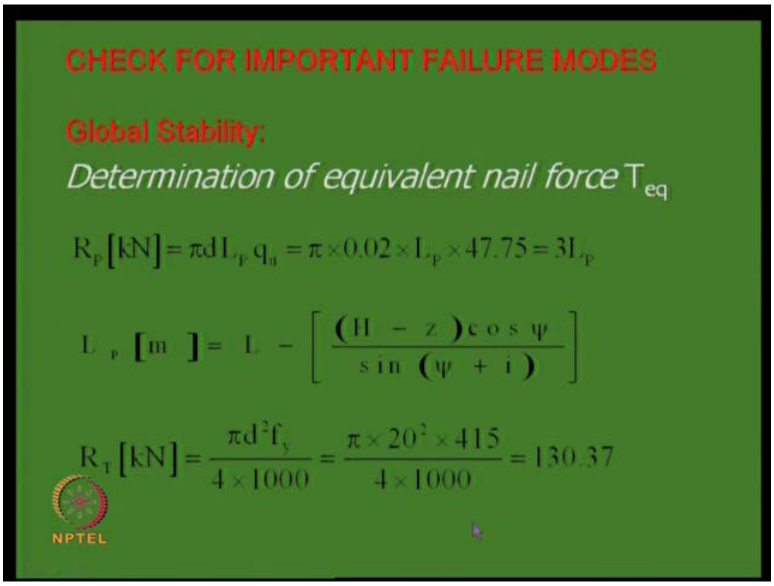

Now, the resistance against pullout is what you calculate and L p you calculate and at any point and this is another thing R T resistance due to tension is what you have provided 130 because it is another force that you 131 kilo Newtons is there in each you know, 20 mm rod that is what it means.

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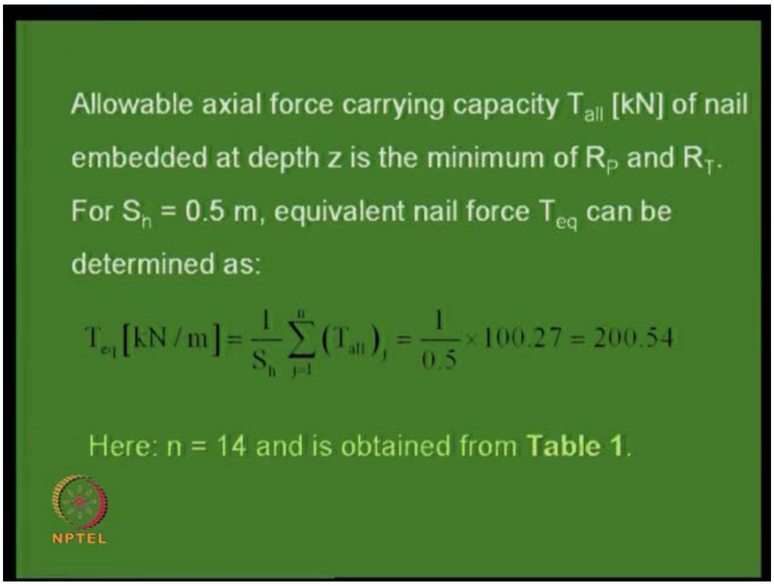

Now, the allowable tensile force carrying capacity of all of the nail embedded at a depth z is the minimum of R p and R T and for s is equal to 0.5 spacing the equivalent you know calculate the depending on the spacing you know what is that equivalent force. So, since we are providing for 7 meters 0.5 spacing fourteen length of the nails is 14 right and at any section.

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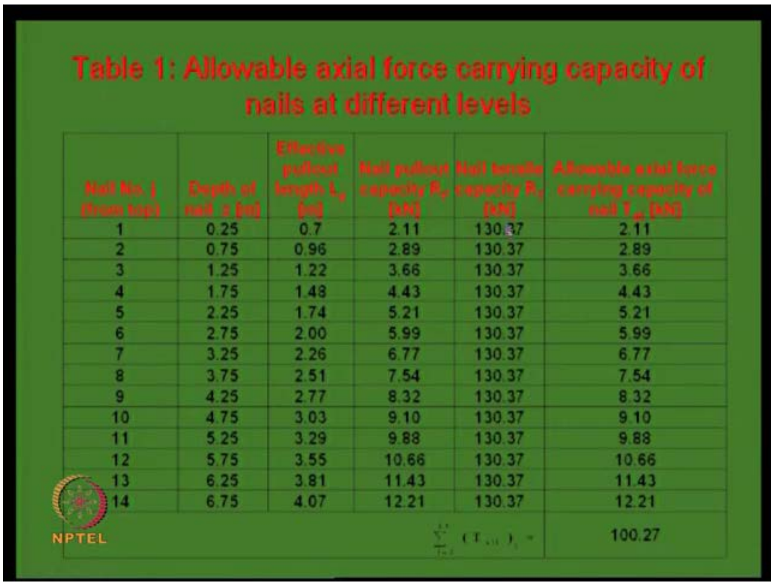

Table 1: Allowable axial force carrying capacity of nails at different levels

Nail No. j (from top)	Depth of nail z [m]	Effective pullout length L_e [m]	Nail pullout capacity R_p [kN]	Nail tensile capacity R_t [kN]	Allowable axial force carrying capacity of nail T_{aj} [kN]
1	0.25	0.7	2.11	130.37	2.11
2	0.75	0.96	2.89	130.37	2.89
3	1.25	1.22	3.66	130.37	3.66
4	1.75	1.48	4.43	130.37	4.43
5	2.25	1.74	5.21	130.37	5.21
6	2.75	2.00	5.99	130.37	5.99
7	3.25	2.26	6.77	130.37	6.77
8	3.75	2.51	7.54	130.37	7.54
9	4.25	2.77	8.32	130.37	8.32
10	4.75	3.03	9.10	130.37	9.10
11	5.25	3.29	9.88	130.37	9.88
12	5.75	3.55	10.66	130.37	10.66
13	6.25	3.81	11.43	130.37	11.43
14	6.75	4.07	12.21	130.37	12.21
				$\sum (T_{aj})$ =	100.27

And. So, this is a location you know you start with 0.25, 0.75 like that. Depth you can see 0.25 0.75 1.25 6.75 like that. And the effective pullout length also one can calculate. It is you know, at the top it is very less you know because failure wedge is just projecting and nail pullout capacity is quite low. Nail tensile capacity is very high and the allowable axial say this is a 2.11, it comes here tensile the pullout capacities right.

So, like that, one can get all this the tensile capacity is same here because 130 and this is the pullout capacity as a function of the depth it changes because it is then you have this number and then you sum up all of these numbers see summation of all this 100.27. So, what we do is that, I think I will show you the previous one.

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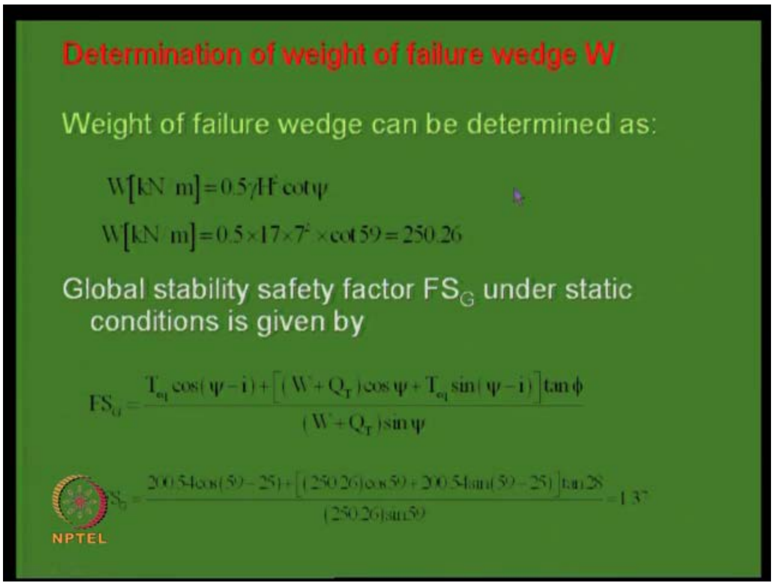

So, this is what we have done. I mean it is double of that actually there is no problem. Now, the weight of the failure wedge is 0.5 into gamma H square cot psi. All these numbers are given. Global stability factor you have an expression here. So, use all of that equivalent tensile force and all that variables, you get a global factors of safety of 1.37 which is okay.

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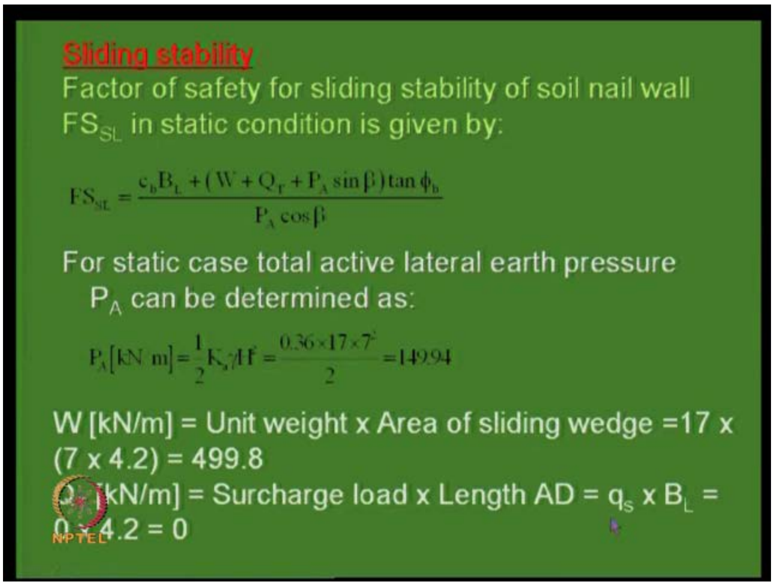

Then the sliding stability that one can get is, something again there is a expression is there wherein and then you know active at pressure half comma H square weight and all that you have.

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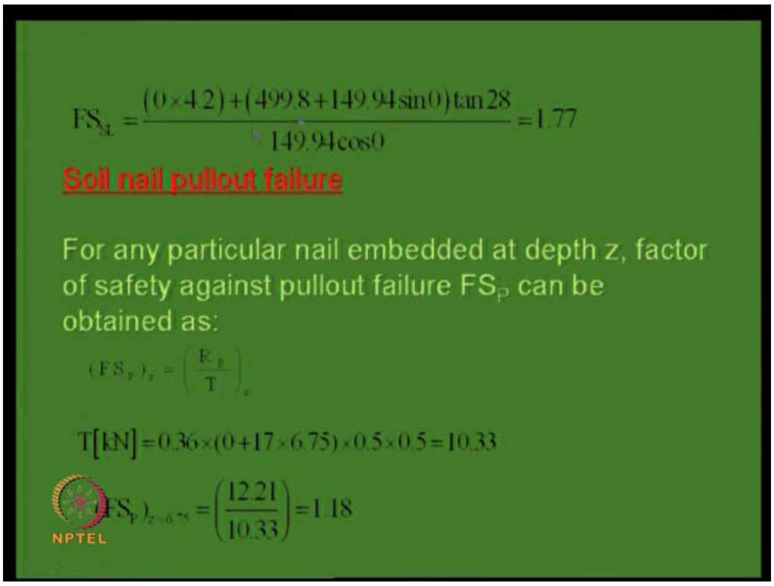

And the sliding factor of safety is 1.77 that all that then the soil pullout nail pullout failure at any depth you have to see that and this is the expression for factor of safety and T N is nothing, but, this expression we have that, k a into the time 10.33 with factor safety it say for example, at 0.75 meters depth level is then given by this expression 1.1.

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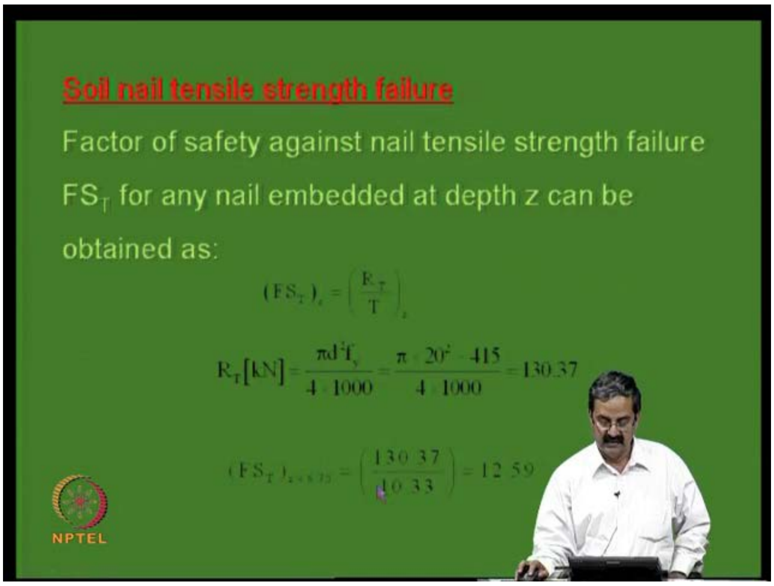

You know it is the top most point you can see that. yeah Actually it is less less then the it is a lower actually less than the one point three specified actually is close to one. I mean it is there is one thing we will see later.

Soil nail tensile strength failure you know the factor of safety against tensile strength is again to be calculated. This is that resistance available because of the area of cross section divided by tensile force mobilized. This 130 is the capacity of the nail and then at each level say for example, at 6.71 meter what is the tensile force developed? 10.3. 130 is available and 10.33 is what is required. So, factor of safety is about 13, 12.59 like that.

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Table 2: FS_P and FS_T of soil nails.

Nail No. j (from top)	Depth of nail z (m)	Factor of safety against pullout failure FS_P	Factor of safety against nail tensile strength failure FS_T
1	0.25	5.51	Very high
2	0.75	2.51	Very high
3	1.25	1.91	Very high
4	1.75	1.66	Very high
5	2.25	1.51	Very high
6	2.75	1.42	Very high
7	3.25	1.36	Very high
8	3.75	1.31	Very high
9	4.25	1.28	Very high
10	4.75	1.25	Very high
11	5.25	1.23	Very high
12	5.75	1.21	Very high
13	6.25	1.19	13.6
14	6.75	1.18	12.59

Like that one can calculate and then you know the tabulate all these results and depth and all that. Only this two are little higher and these are all very high you know tensile capacity it is very, you know there is no problem because you saw that what is required is just 10.10 or something. What is required is what is provided is 131or something.

So, except here, you know at the top layers you know there is factor of safety is little less for the pullout. Somewhat it is, little pullout is somewhat lesser here because of that load that you have added there. You know what is the load 300 kg's are very low load you know which is something will be unusual, but, you can see that if it is little higher you know if you just make I just show you that.

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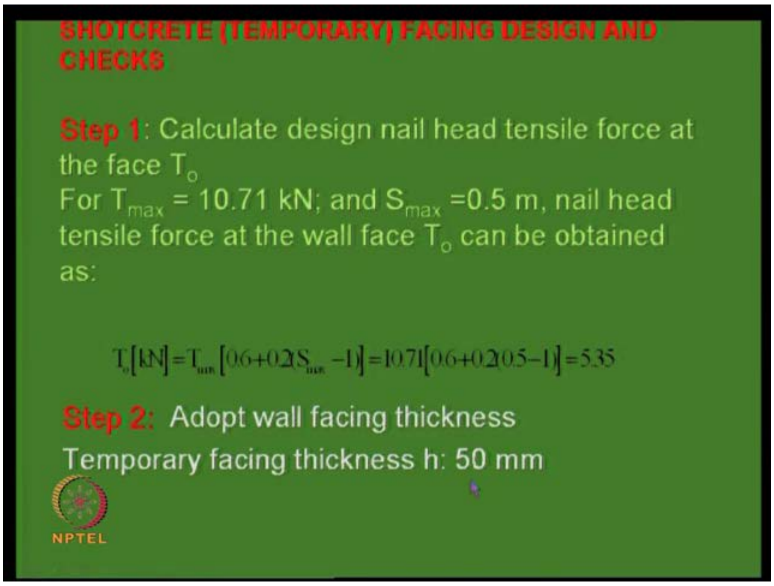

So, that is one important variable we will see then what about a shotcrete temporary facing design and checks calculative design in nail at tensile force at facing T naught? Actually T max at that point is 10.71 and maximum spacing is point s max is 0.5 So, there is an expression for the tensile force at the nail head it is nothing, but, this expression 0.6 into this simple expression is here. So, 5.35 is a load that the facing should take care. See some force gets transfer to the facing this is the force that it can it has to take care. So, you have an adopter wall facing off from about 50 mm.

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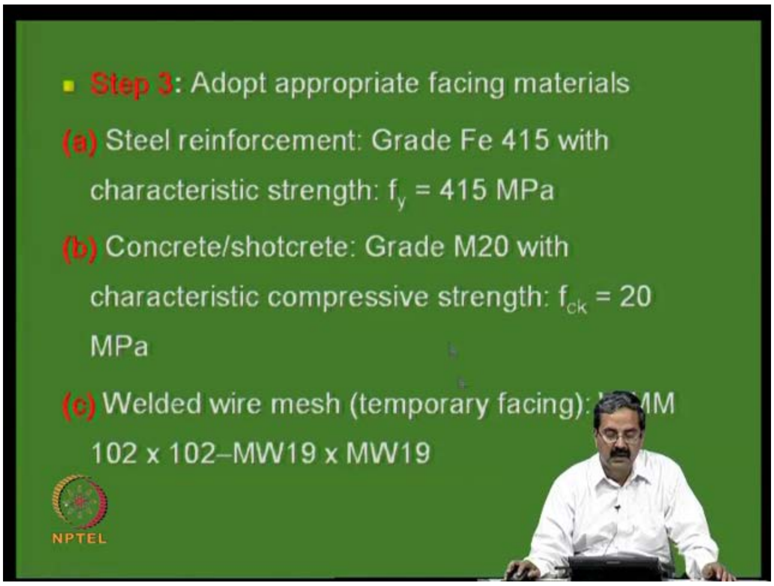

And you know f y grade and m concrete and all that FCKwire, wire mesh you know the thing is that we put a wire mesh. See the thing is shotcreting first thing is the nails are there nails are there, weld mesh is there which is say for example, one naught two into one naught 2 into 19 mm thickness you know some gauge wire mesh. So, there if you weld it and then shotcreting is done. So, that is what we do in our all structures and many places it is done like that.

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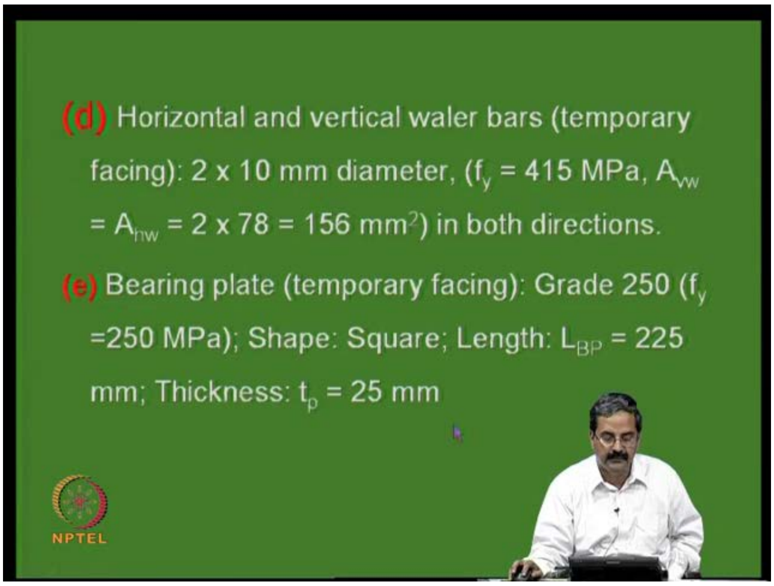

So, once you have that, this is also another horizontal you know, the bars you know horizontal walker bars temporary facing again we provide like you saw in some places where are beams being provided.

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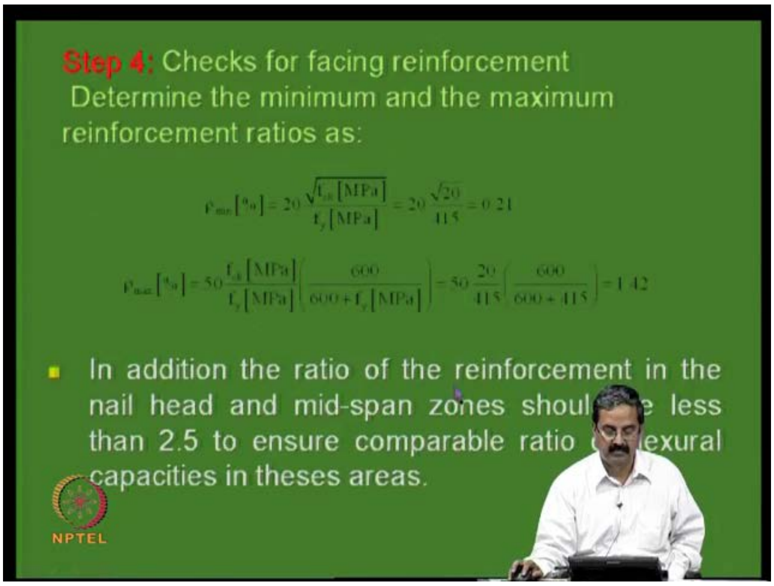

And bearing plate is another one that we provide. So, what we do is that checks for facing reinforcement; the minimum steel reinforcement is provided it is in terms of 20 into square root of f c k into f y 0.21. So, this is another one that we provide like in terms of the. So, maximum value it is minimum and in maximum. It is say the reinforcement ratio it is 1.42 it varies from 1.42 to 0.21 again. So, these are the two expressions.

In addition the ratio of the reinforcement in the nail head and the mid span should be less than 2.5. That ratio between the nail head and a mid span zone should be compatible ratio of the flexible capacities in these areas.

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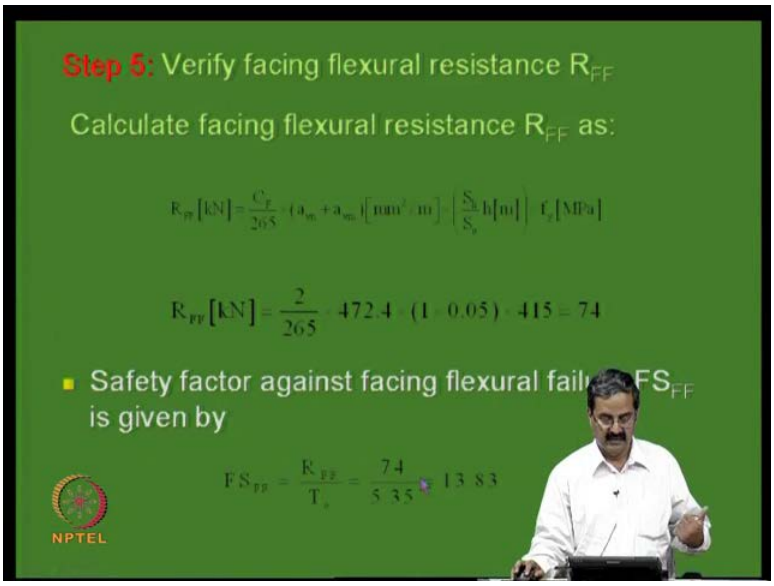

So, that also, show verify the facing flexural stiffness R F F. We just calculate the facing flexural stiffness is another expression that you have in the federal code. These are all little empirical, but, at the same time you know, they are all based on the, you know ah. So, R F F you have the due to flexural facing you know resistance is what you are trying to calculate safety factor again is nothing, but, F S. F F is nothing, but, this is a four seventy four divided by the 5.35 is how you got was that we will go to the previous step.

The force that we have yeah 5.35 is a force that you got from this expression right. This is actually as I said if you connect the nail to the facing weld weld mesh is also is there. So, this material should be designed because all the, some force gets transferred here because of the connection. So, how much of that force is what is this? You know this is an equation that you know I just mentioned about a triangular the distribution of the tensile force and all that this is what you get.

And the force that you know that can be used here, say 574 is a force that you based on the spacing and R F F you know there is an expression here that you have to use and you will get this and based on that the factor of safety against flexural failure is like this.

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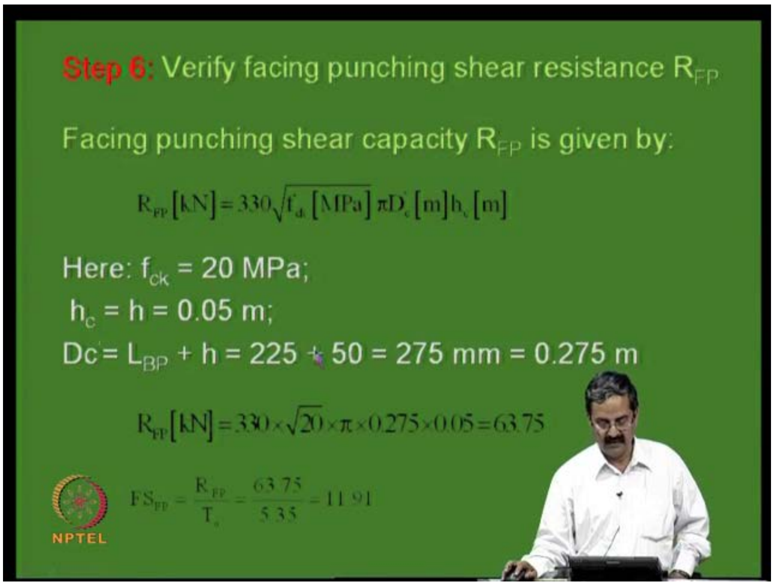

Then punching failure is again there is an expression, simple expression for punching which they have done based on mechanics conservations and here also again same thing you will get 11.91. So, the flexural stability of temporary facing is all right because the factors of safety are quite high and you are essentially using these two expressions here; one is this one and the previous one another thing I showed.

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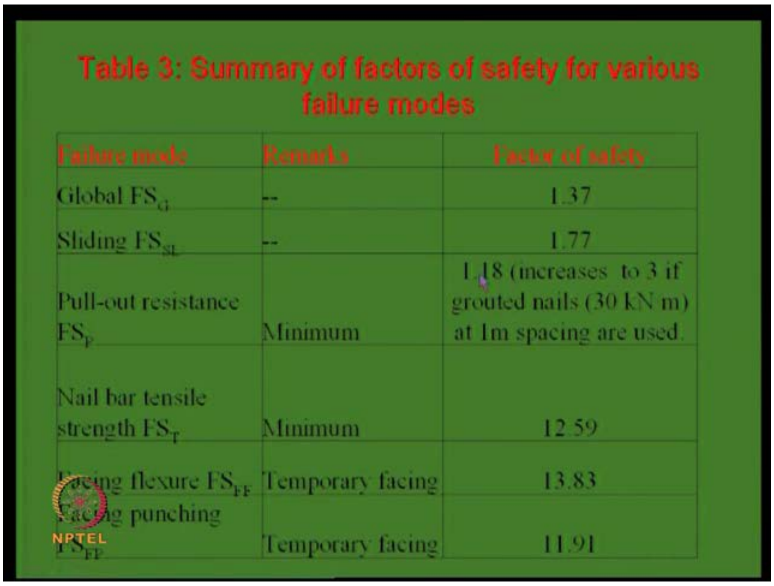

Failure mode	Remarks	Factor of safety
Global FS_G	--	1.37
Sliding FS_{SL}	--	1.77
Pull-out resistance FS_P	Minimum	1.18 (increases to 3 if grouted nails (30 kN m) at 1m spacing are used.
Nail bar tensile strength FS_T	Minimum	12.59
Facing flexure FS_{FF}	Temporary facing	13.83
Facing punching FS_{FP}	Temporary facing	11.91

So, the way that it looks like is that as I said, the facing flexural stabilities are quite good temporary facing and they menu nail bar tensile strength you know, the reinforcement it is very good right. It is an excellent thing there is no problem. And global stability see the thing is global stability is one point three seven is closed. One point three and sliding is also all right and the factor of safety against pullout you know, if you put a driven nails it is one point one eight right we saw that.

Because I took some 300, but, then the factor of safety increases to 3 if grouted nails with 30 kilo Newton per month at one meter spacing I used. Like I did work out revise all these calculations just for only that because the pullout resistance is low there the best way is to use the grouted nail.

You know as I just mentioned assuming that I have you know 30 kilonewton per meter length of the nail you know it is just an if what is the length of the nail here it is 4.2 meters if I just. So, 4.2 into 30, is the total pullout load like you know, if I just do a pullout test in the field like pullout that nail I will get the maximum load that I am expecting is 30 into 4. So, 4.2 right. So, about 124 or whatever right. 30 into yeah 30 into 4 is 120 plus close to the point. So, it is fine.

So, suppose I get the pullout load more than this I am very. So, I do a field pullout test which we have equipment and it gives I get a load of say 100 kilo Newtons I will be very happy why because it is more than say for example, 200 kilo Newtons I get total load. So, 200 kilo Newton divided by length is 200 divided by 4.2 which is quite higher than what I used. So, it is fine. So, what I want to say is that the factors of safety can be increased wherein I mean like you know you need to design on this lines. So, that way this design has a global stability issues are satisfied, pullout resistance is satisfied, tensile capacity there is no problem at all and then the facing stability is ensured.

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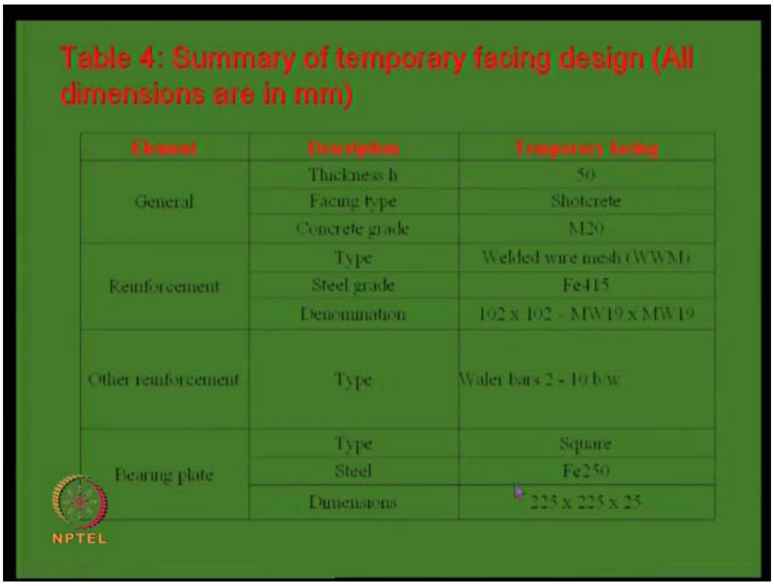

Table 4: Summary of temporary facing design (All dimensions are in mm)

Element	Description	Temporary facing
General	Thickness h	50
	Facing type	Shotcrete
	Concrete grade	M20
Reinforcement	Type	Welded wire mesh (WWM)
	Steel grade	Fe415
	Denomination	102 x 102 - MW19 x MW19
Other reinforcement	Type	Waler bars 2 - 10 b/w
Bearing plate	Type	Square
	Steel	Fe250
	Dimensions	225 x 225 x 25

So, what is that you have to provide? So, thickness of the shotcrete is about fifty mm and then m twenty grade of concrete and weld wire, welded wire mesh and steel grade F F 415, this grid size you know thirteen this is a small thing and the other reinforcement walker beams one can provide and bearing plate this is another thing that one can provide you know that what I showed you in the beginning.

And once you provide this that is fine you know. So, it is like what we do is that. That constitutes a soil nailing design and what I want to illustrate to you to you is that you know the there are so many you know the you know features in the soil nailing technique that you have to sequentially do the things right. See this is a simple design which is a conventional method.

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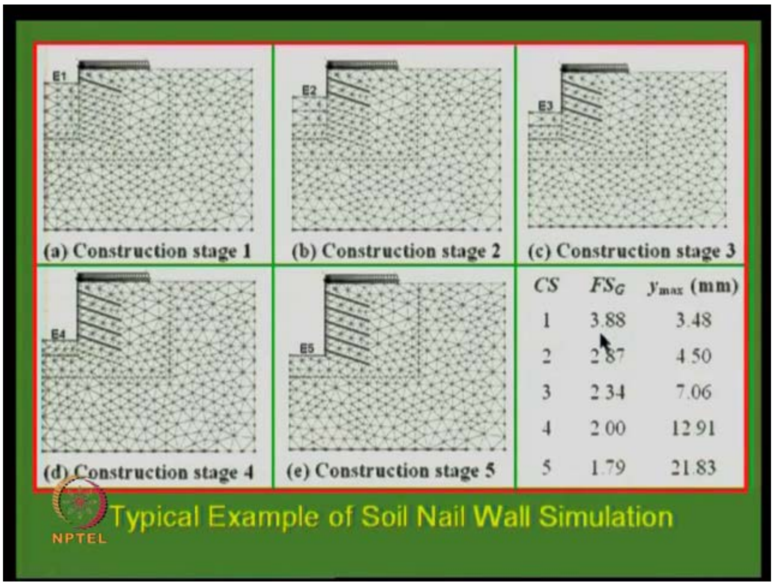

But the best way is to like as I said, the effect of this nailing can be obtained, understood better in terms of finite element analysis. So, what I did was that we did a sort of finite element analysis like typical example what we do is that excavations like I told you know in the beginning like excavations e one, excavation e two there are the different stages you know, e 1 e 2 e 3 e 4 like that you know you just remove that.

So, what we try to do in this is that you try to simulate using you know you can use flack or plastics or something and design this nail you know. What you do? Excavate a bit like say for example, you are putting half and your spacing is 0.5 meters right. So, space half a meter excavate then simulate that. What happens? There will be some plastic deformation zone stabilize and you can still find out. So, after that put a nail and then check what is the tensile force mobilized allow it to equilibrium and all that one can do a simulations all that. So, you can do sequentially and excavation stages you know e 4 e 5 are all the excavation stages and complete this nailing.

So, in this case you can see that, you know the factor of safety is global factor of safety we are looking at it. The, you know, the construction stage one two three four five right. So, the factor of safety is very high you know this is a small cut you have made you know it is not like say if it is five meters you know is assumed that five meter just one meter is removed the factor of safety is still one high deformation is small. Then, you know go to the next stage and the factor safety comes down.

So, finally, the at final stages you know, you have what is called strength reduction technique in plastics or even flack you will get this number factor of safety and also deformations also one can calculate and see you as you go down the deformations also increase right. So, this is an interesting example of how you can get because in conventional thing you do not have any information about deformation right. If you want to get deformation information and you know the thing is that the, you are assuming a failure mechanism there right you are assuming what type of failure mechanism? We assume a wedge there it can be a logarithmic spiral it can be a circle.

So, what we want to do is that here in this finite element analysis and numerical analysis you allow the failure mechanism to develop on its own and form forms the failure surface. So, that is much easier and much more better than assuming a failure surface and then doing the design. Of course, both are correct, but, then the advantage is that you will get some information about deformations the influence of construction sequence at every stage of excavation and all that.

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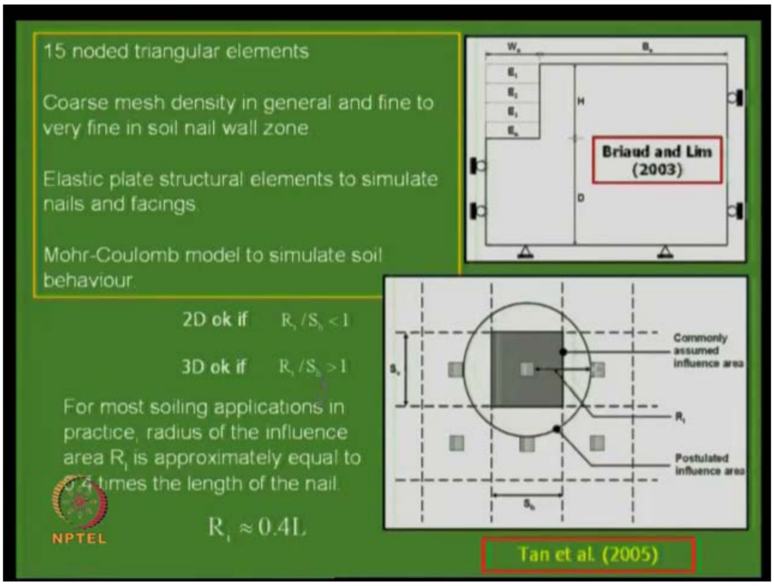

So, this is what an example here is. So, fifteen nodded some sort of examples we have taken and you know the effect which is a fifteen nodded triangular element and Mohr-coulomb model is used and soil soil is a Mohr coulomb model and there is some criteria for the simulation of nails as well all that we have used.

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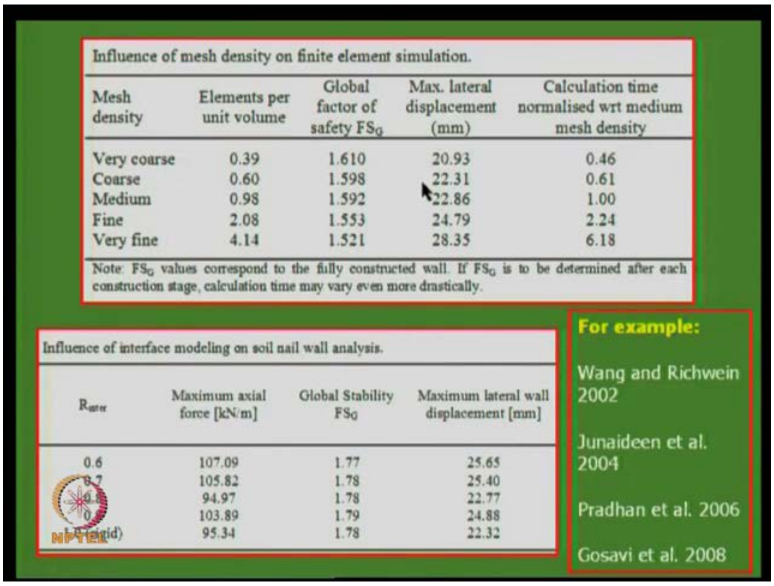

And we just want to give an example how the mesh density as a role you know. So, if it is coarse mesh and a fine mesh you know what happens? The global factor of safety there is1.61 so, elements per unit volume is also is used as a criteria. So, the factor of safety varies from 1.61 to 1.52 maximum lateral displacement 20 to 28 and a calculation time normalized with respect to medium mesh density. You have take with respect to medium mesh density what is the calculation the thing is if you make a very fine mesh what happens? The calculation will take more time. So, it is 6.18 times compared to this one you can see one and coarse one it is half of it fine mesh this much.

So, possibly you know you should take a balance you know if have numbers of and then see the accuracies involved like you know 1.59 to 1.52 or you know. So, you have to see that differences. Definitely if you want to go for good deformation in predictions you must go for fine mesh. There is no doubt about it right. So, this is very important that this gives an idea of the role of numerical simulations in soil nailing. Interface is also given interface modeling and how interference will affect the displacements and factor of safety. You can see that as the interface becomes rigid; the maximum horizontal force little comes down and then you know then the, this will increase marginally 1.7 and 1.78 deformation will also come down marginally right.

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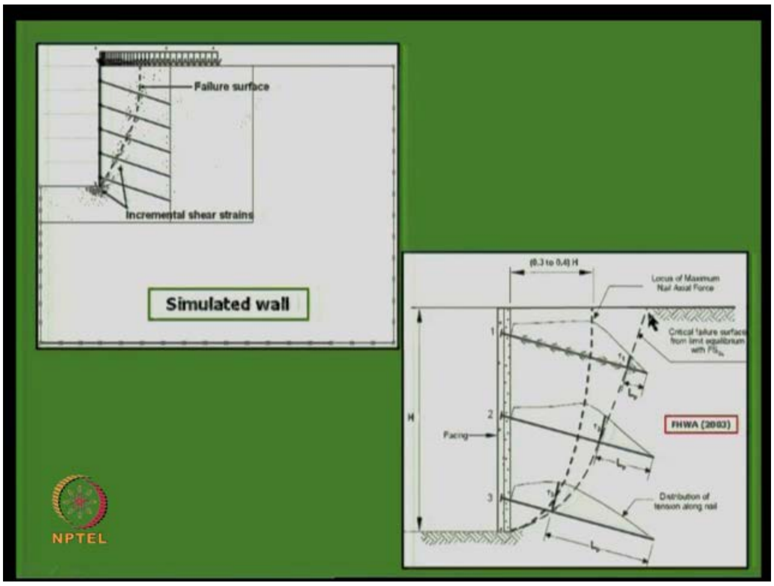

So, as I just mention this will use an essentially a, strength reduction technique which is given in the standard text books and advantage is that the, why as I just mentioned this is the failure surface right simulated wall. And in the federal high way we assume a distribution like this. Critical failure surface from limit equilibrium this is the failure surface whereas, from numerical analysis it is like this, which is like you know 0.3 to 0.4 H of that and this is a tensile force maximum tensile force you know the way the distribution of tensile force is developed. And this is another important variable and this at facing this is a wire mesh inside. This is the nail and those things are welded right.

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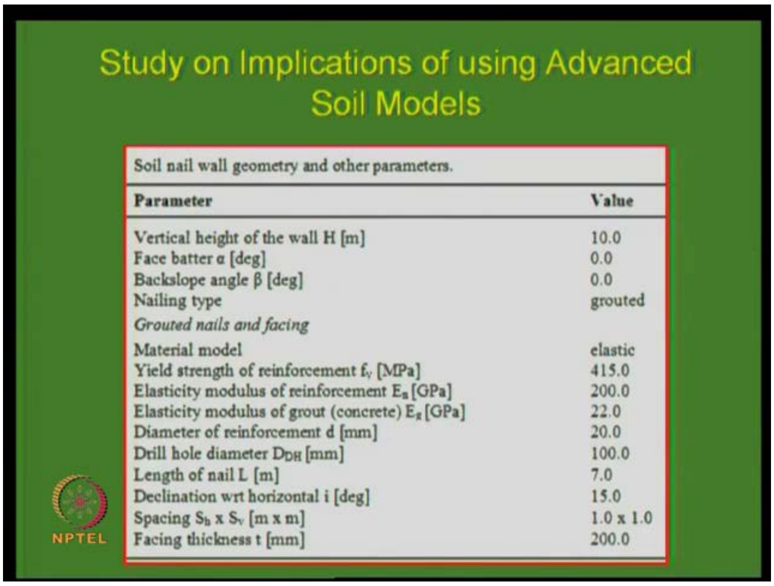

Other thing that I want to highlight to you is that the importance of using correct constitute I mean appropriate constitute models. Of course, this is not course on numerical analysis, but, at the same time I felt one should understand the influence of numerical modeling in ground improvement techniques. This is just is taken as an example. For example, the height of the wall is 10 meters and grouted nails then the spacing is also there like 7 meters is the length of the nail because I said 0.7 times height length is some 15 degrees, spacing is one meter by one meter facing thickness and elasticity all the properties are known.

So, now actually the thing is that why this constitutive models are very important is that you know normally we are using c and 5 for representing soil, but, when you are trying to do an excavation; the problem is that you are there is a bottom heave that comes out you know there is a movement that takes place. So, there is so, many, so, many like you know if you do not predict this deformations properly the building that is next to that will have a problem. So, it is important that one should apart from using a conventional method of calculation of nailing stability or anything you know for that matter in ground improvements technique.

One should calculate using even you know if you are capable of doing it one should do using numerical methods as well like close form solutions are fine, but, you need to really you know much go beyond that and check because this will give a range of values.

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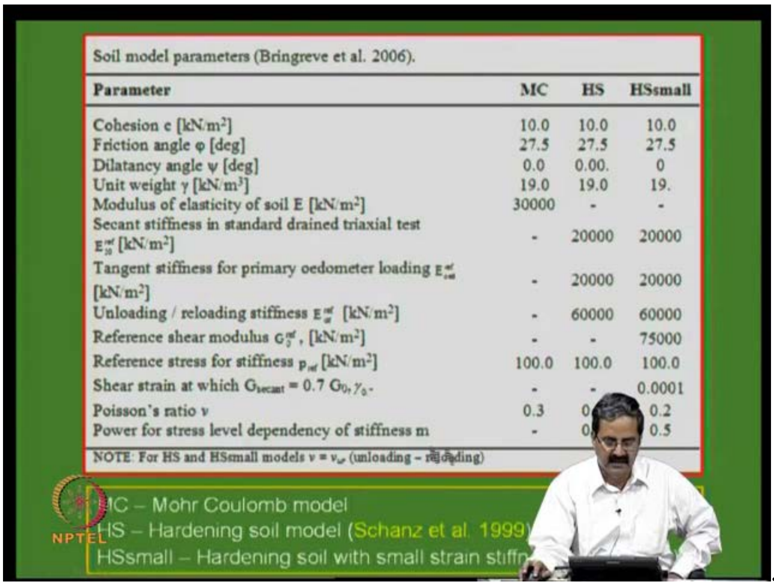

So, soil parameters you know the thing is that, there are three types of models that suppose if I use plastics I have three types of models which I can use what is called Mohr coulomb model the other one is called hardening soil model. Hardening soil model is similar to you know in the sense that the some of the problem associated with soil are not just see and you know the soil parameters not c and phi alone. Soil has also the stress and strain effects it hardens and there is an the confining pressure dependent behavior is there like you know higher is the confining pressure higher is the strength all that things are there.

So, if you want to capture them hardening soil model is one thing and then to capture the small strain you know the thing is strain starts at not what you see in trials and testing. It starts at a very small level you know two shear displacements of two soil particles. Consider that they have, what is called hardening soil model which is given in that small. It is called hardening soil model with small stiffness and if you are using a flack also you have Mohr coulomb the modified cam clay model and all that. Then can that can be done.

So, these are all some parameters that have been used to get some information about the properties like you know as I said the soil has an unloading and loading loading and unloading behavior is different right. So, to represent that you have what is called unloading reloading modulus. Say for example, we know that compression index is say for example, c c is some this thing you have unloading unloading there is another modulus. So, its five times less actually. If you get a compression index of some say 0.4. .4 divided by five roughly will be the recompression index you know actually why because the soil is elasto plastic in the first stage when you unload it is only elastic.

So, it cannot completely recover all the plastic plastic deformations cannot be recovered. So, what we do is that that gets reflected in this compression and recompression lines and the even you can calculate them in terms of the stiffness and these are all some parameters that we should use and even the stress dependency. This is another parameter that you need to have no these are all one can understand.

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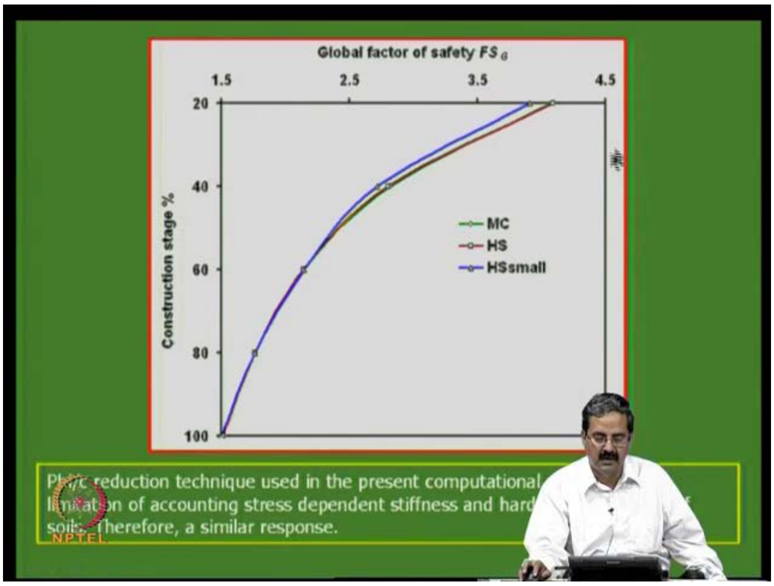

And the thing is that the as a function of construction stage, what happens with different models was seen in terms of the global factor of safety. Like as you saw that the factor of safety is like little higher like three point eight and then it comes down to one point five or whatever right when the construction is complete as a factor of safety somewhat in this range. And there is not much difference between the models used when you are trying to calculate factor of safety global.

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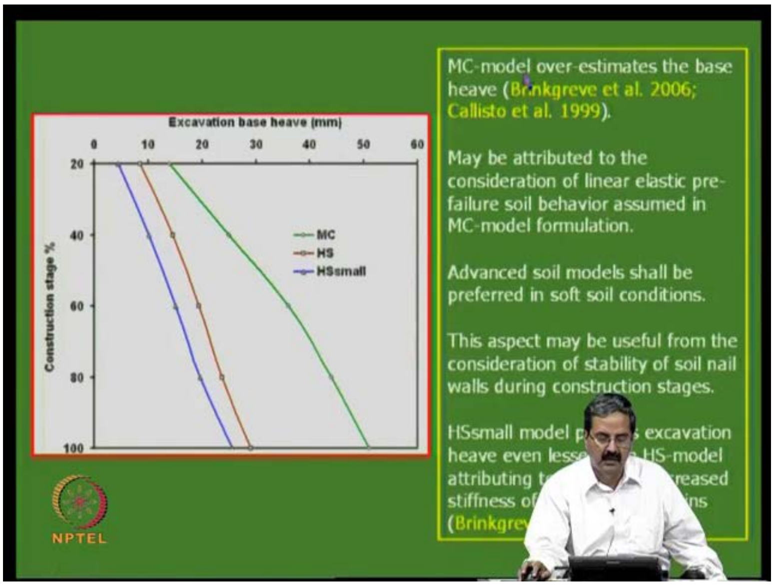

But when there is a deformation right there is big difference. I want to highlight to the that point that you have Mohr coulomb model like this, hardening soil model like this and the another model like this. What it means is that you are not estimating the deformations properly that point I would like to highlight. That is it. So, Mohr coulomb model estimates the base heave like these are all what people have observed and normally you know we should use good constitutive models otherwise there will be a serious issues of prediction of deformations in a wrong way like this. That is what I want to highlight

So, yeah you can see that yeah what I want to Mohr coulomb model; deformations are very high let me repeat and this is hardening soil model and the small strain model it is like this. So, what I want to say is that, if you use see most of the time the people use Mohr coulomb model for prediction purposes, but, then the problem is that you know the, if you do not take care of the non-linear the soil properties like stiffness and small strains and all that this deformations are over estimated. That is what I want to highlight and and when deformations are critical one should use properly.

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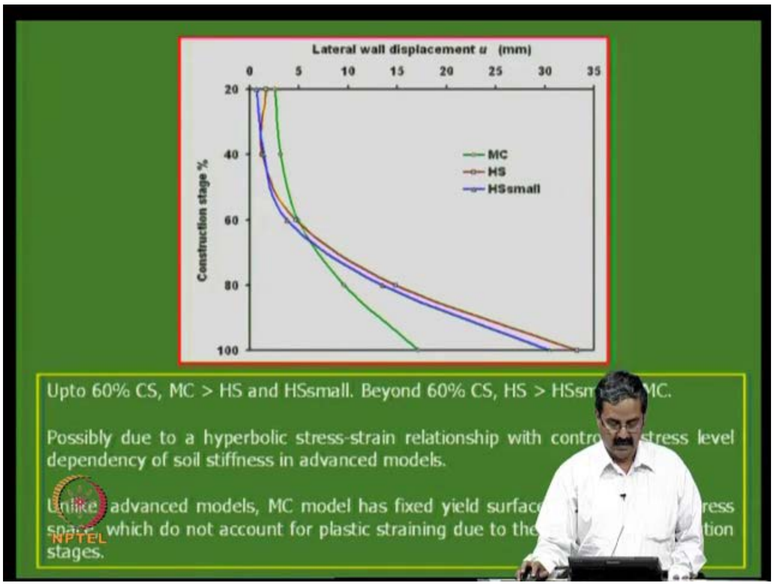

Then, the lateral displacements also the same like you know you can see that like this is another one that gives some information. So, these are there are some reasons for this some of them you know these are all referred in some papers.

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And another important thing that I would like to highlight to you is that you have a tendency to calculate using k a gamma z into s v into s H right. How you calculate the tensile force? Use this expression and then get tensile force. So, if you plot like this, this is a line you get right. Then the thing is that this is from the depth of excavation. So, what happens is that if you really do from numerical analysis you can plot them what is the maximum tensile force. It is like this for different models may be for Mohr coulomb model this little less, but, for other two models it is a little here.

But then it is not the same as what we assume for design. It is less here, it is I mean it is less here, it is more here. That is a very important why because the, it is soil is not see there is no soil is the thing is it is not like a hydro static pressure distribution. What is that gamma H k in it? It is a hydrostatic pressure distribution which cannot be like this.

So, this is just a conservative assumption, but, one should be careful at the top where one should be you know provide large pullout lengths and all that to avoid this problem of you know tensile forces are high you know compared to what you assume here what it means is that there is a possibility of you know pullout failure and you know that possibility is there. So, you have to provide normally reinforcement will not fail by tension it is only by pullout. So, the if you provide short length and divided by tensile force instead of using this tensile force actually the actual tensile force is this much. So, there is a possibility of pullout failure. So, one should provide longer lengths here. That is what it means ok.

So, this is about in terms of the construction stage you know in terms of the percent comes like when it is hundred percent it is tensile force you know about 30 kilo Newtons is what you have like 30 kilo Newtons what you have. So, other thing that we have you know we have what is that length of the what is the capacity of the 20 mm steel rod I said? It is 131 kilo newtons right we have seen that pi d square by 4 into f y and all that if you do you get that

So, that 131 you can just make it as a thin sheet and you if we are trying to do a plane strain analysis you have to use equivalent stiffness right. So, the movement of that bending stiffness has to be converted properly and you can calculate how much is the tensile force and the factor of safety.

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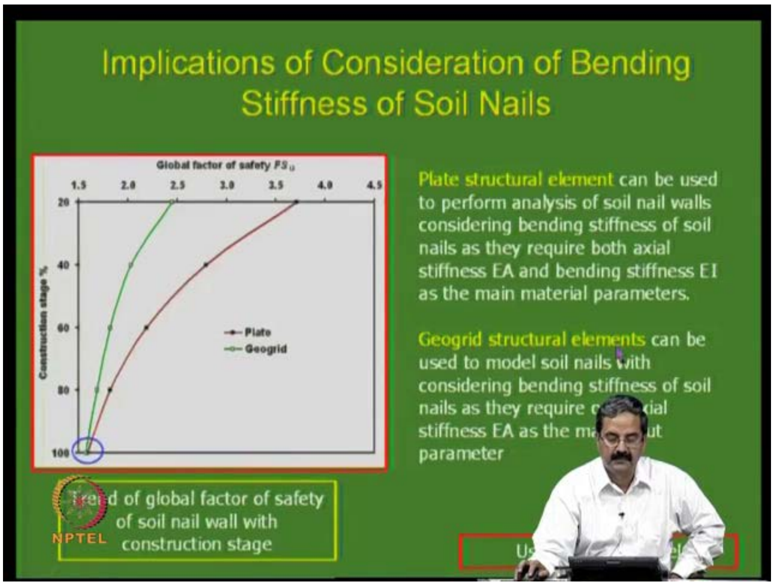

Then other thing that I would like to you know, the just I mention earlier in the beginning you know when I trying to talk about the reinforced soil walls; stiffness of the material is also important like you know if you are using a geogrid yeah it can be a bendable material you know it is only acting as a tensile element. But, if it is a nail or some stiff reinforcement like steel reinforcement it is it has more bending stiffness. So, how do you understand that?

So, for example, in this particular program if I use a plate element it takes care of bending movement. So, you have to, you bending movement and shear force are obtained based on that whereas, if it is a just a Geogrid element which means it is can only tensile element then, it can see that the factor of safeties are somewhat different. So, we use a, what is called plate structural element can be used to perform the analysis of soil nails considering bending stiffness of soil nail as they require both axial stiffness and bending stiffness. Both axial stiffness and bending stiffness are required here whereas; geogrid elements can only have the axial stiffness.

Axial stiffness is, there are two stiffness that we have to give and based on that and using the Mohr coulomb soil model you can see clearly that. The factor of safety in the case of plate element is somewhat higher particularly when you are trying to talk about in the beginning stages like it is stiffer right. Instead of 2.5 the factor of safety is little higher which is a useful consideration.

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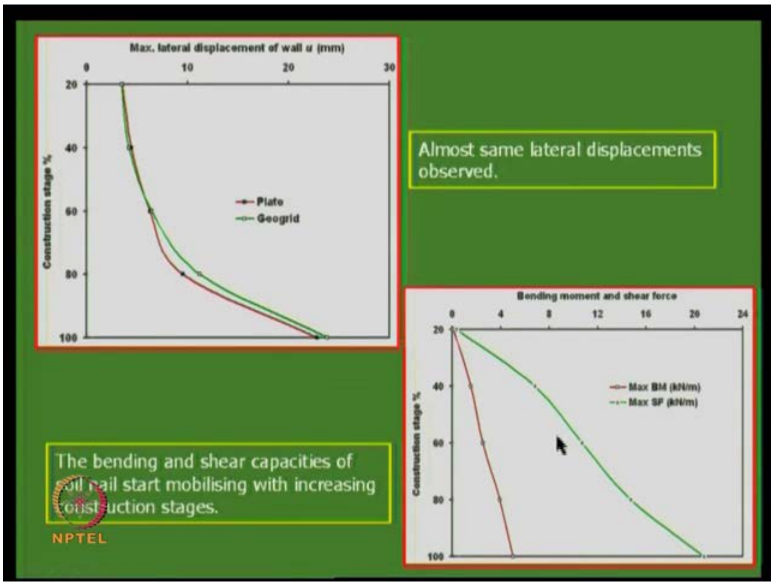

The same thing that you have like particularly in the case of bending movement and shear forces this is another one. It is only in the case of plate element right and displacement is another, displacement should not be much different.

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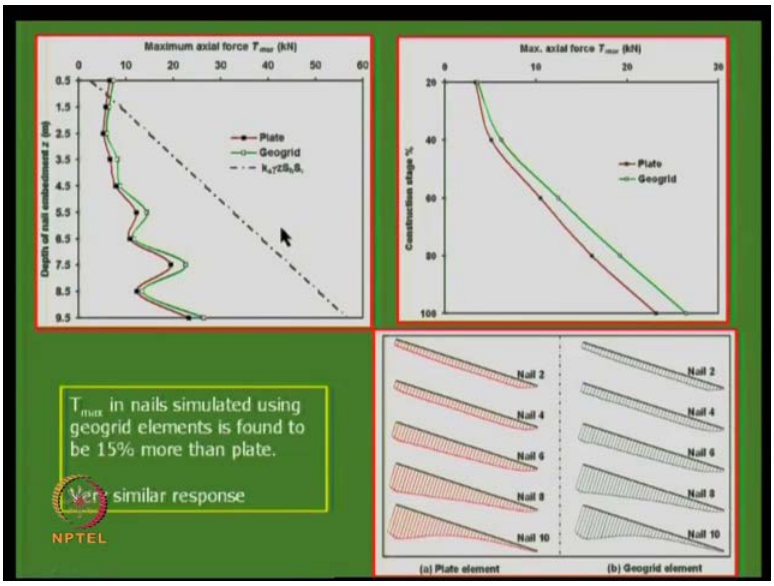

And that is what you observe and even that particular maximum force you know like you know k a into gamma H you can even calculate like this and see that you know, why this is you know the difference you will get it you know if you do the simulations. And then

T max in nails simulated using geogrid elements is found to be fifteen percent more than that in plate and then there. So, this is all distribution of tensile forces.

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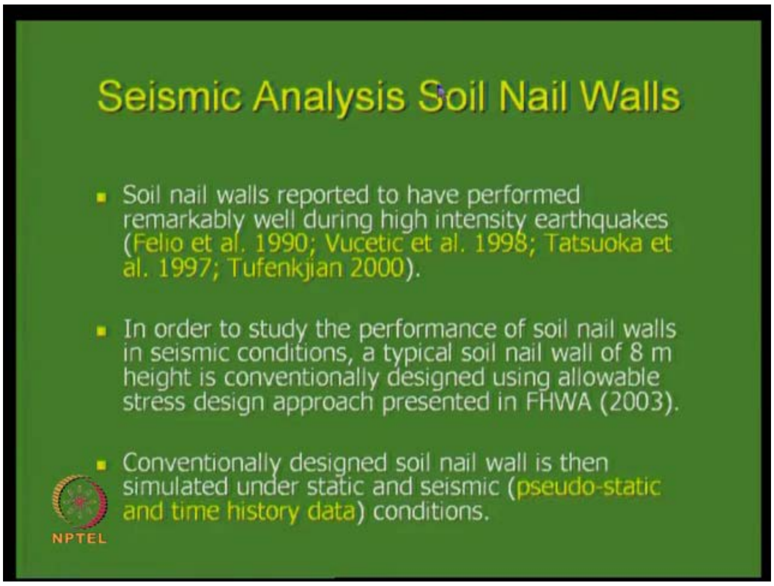

So, what you have seen is that what is, the use of the numerical analysis compared to conventional analysis. I even want to go one step ahead because what people have seen as a soil nail walls are supposed to be very good in earth quake conditions and when they are you know like we have seen some earth quake earthquake coefficient specifications by federal high way and all that and I in this example I would like to show you you know one is called you know the pseudo static method the other one is called you know time history you know you can give the acceleration time history of the earth quake itself. What happens when you just do for any for soil nail wall no. This can be done for any structure, but, this is just a soil nailing is an example to highlight to you the role of numerical analysis in ground improvement.

Because particularly why I have taken the soil nail wall so, that we do not have good guidelines on soil nail walls and the fact is that they have which should the many earth quakes they are doing the many earth quakes of high intensity; the soil nail walls withstood the earth quake and places like you know in north east, in India and all that we need good stable structures. That is a reason why we thought we should investigate.

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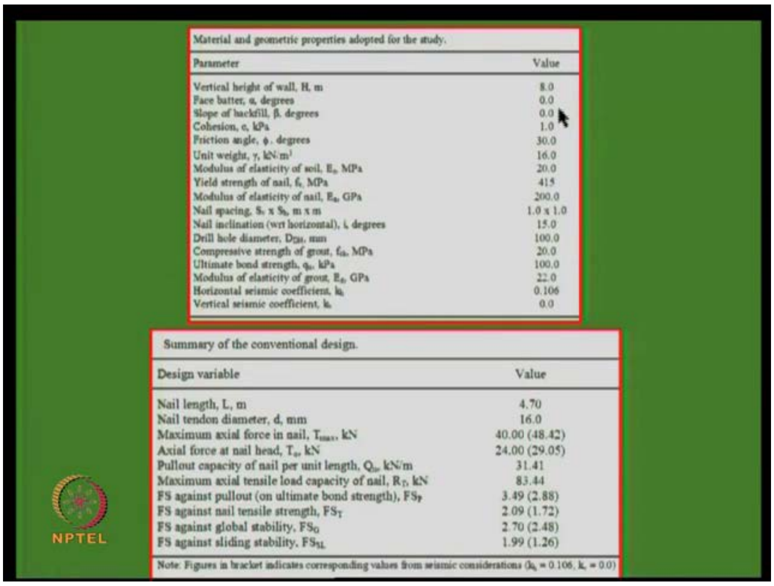

Material and geometric properties adopted for the study.

Parameter	Value
Vertical height of wall, H, m	8.0
Face batter, α, degrees	0.0
Slope of backfill, β, degrees	0.0
Cohesion, c, kPa	1.0
Friction angle, ϕ, degrees	30.0
Unit weight, γ, kN/m^3	16.0
Modulus of elasticity of soil, E_s, MPa	20.0
Yield strength of nail, f_y, MPa	415
Modulus of elasticity of nail, E_n, GPa	200.0
Nail spacing, S_v x S_h, m x m	1.0 x 1.0
Nail inclination (wrt horizontal), i, degrees	15.0
Drill hole diameter, D_{DH}, mm	100.0
Compressive strength of grout, f_{ck}, MPa	20.0
Ultimate bond strength, q_u, kPa	100.0
Modulus of elasticity of grout, E_g, GPa	22.0
Horizontal seismic coefficient, k_h	0.106
Vertical seismic coefficient, k_v	0.0

Summary of the conventional design.

Design variable	Value
Nail length, L, m	4.70
Nail tendon diameter, d, mm	16.0
Maximum axial force in nail, T_{max}, kN	40.00 (48.42)
Axial force at nail head, T_o, kN	24.00 (29.05)
Pullout capacity of nail per unit length, Q_u, kN/m	31.41
Maximum axial tensile load capacity of nail, R_T, kN	83.44
FS against pullout (on ultimate bond strength), FS_P	3.49 (2.88)
FS against nail tensile strength, FS_T	2.09 (1.72)
FS against global stability, FS_G	2.70 (2.48)
FS against sliding stability, FS_{SL}	1.99 (1.26)

Note: Figures in bracket indicates corresponding values from seismic considerations (k_h = 0.106, k_v = 0.0)

And for the typical case we took about eight meters high wall which is used conventionally designed, using allowable design procedure like you can see that eight meters and space cohesion and spacing is one meter and drill hole diameter hundred mm. All that calculations are given and when you do the conventional design the length is four point seven meters because the length is 8 8 by you know that ratio is maintained diameter is 16 mm nail force all that calculate factor of safeties sliding all that we have.

So, once you have all these numbers; then the figures in the bracket indicates corresponding value from seismic conditions putting k H equal to 0.106. Some k H value you have to put and what happens to the maximum nail force? Instead of 40 it becomes 48, nail head 24 becomes 29. The factors of safety slightly come down 3.49 to 2.88 right. All these are well understood right.

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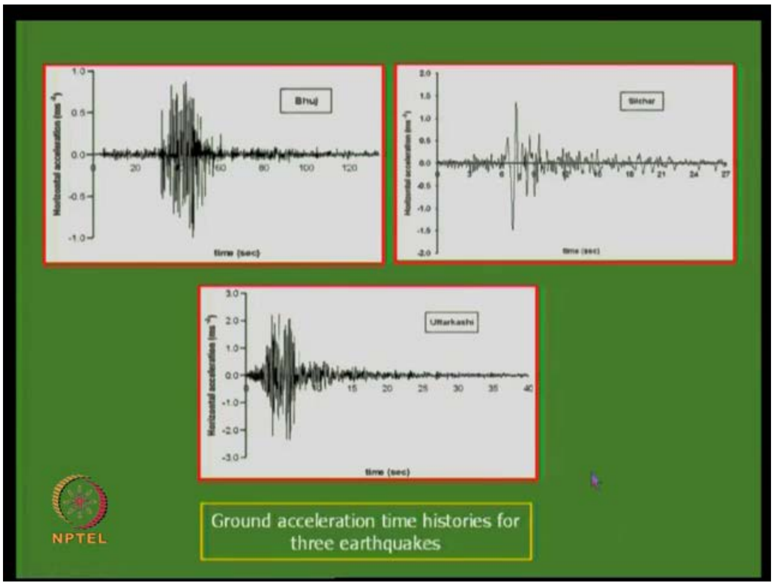

Now, what I do is that we have earth quakes in our country which we have, which can be represented in terms of the time history horizontal acceleration versus time. So, what one can do that this is in Silchar and this is in Uttarkashi.

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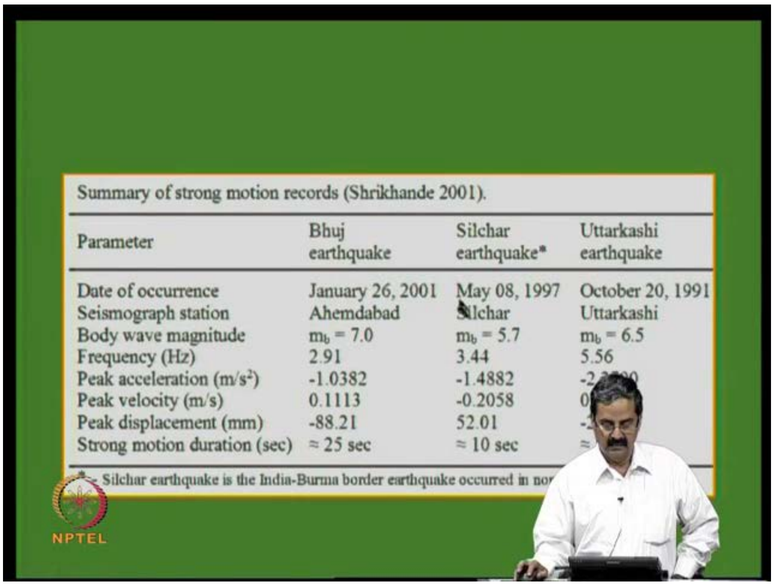

Summary of strong motion records (Shrikhande 2001).

Parameter	Bhuj earthquake	Silchar earthquake*	Uttarkashi earthquake
Date of occurrence	January 26, 2001	May 08, 1997	October 20, 1991
Seismograph station	Ahemdabad	Silchar	Uttarkashi
Body wave magnitude	$m_b = 7.0$	$m_b = 5.7$	$m_b = 6.5$
Frequency (Hz)	2.91	3.44	5.56
Peak acceleration (m/s^2)	-1.0382	-1.4882	[illegible]
Peak velocity (m/s)	0.1113	-0.2058	[illegible]
Peak displacement (mm)	-88.21	52.01	[illegible]
Strong motion duration (sec)	≈ 25 sec	≈ 10 sec	[illegible]

* - Silchar earthquake is the India-Burma border earthquake occurred in nor

So, these are all these data available and data earth quakes and frequency and all that right.

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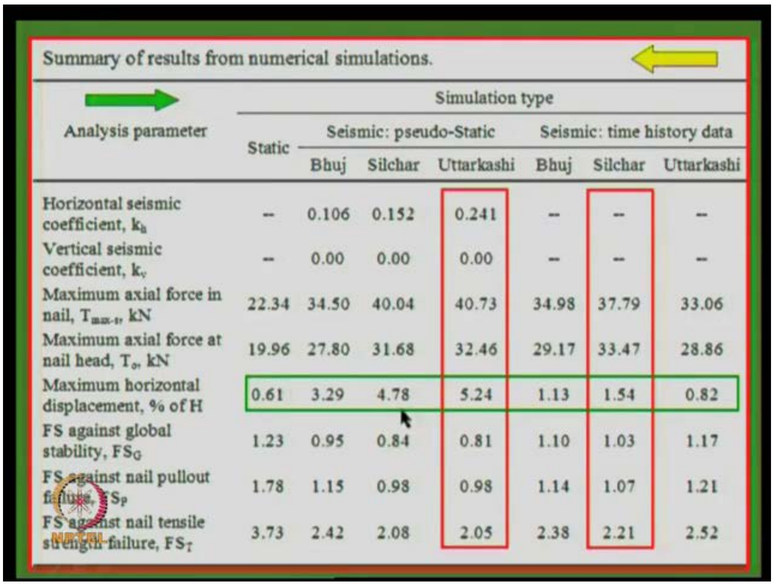

Summary of results from numerical simulations.

Analysis parameter	Simulation type						
	Static	Seismic: pseudo-Static			Seismic: time history data		
		Bhuj	Silchar	Uttarkashi	Bhuj	Silchar	Uttarkashi
Horizontal seismic coefficient, k_h	--	0.106	0.152	0.241	--	--	--
Vertical seismic coefficient, k_v	--	0.00	0.00	0.00	--	--	--
Maximum axial force in nail, T_{max-s}, kN	22.34	34.50	40.04	40.73	34.98	37.79	33.06
Maximum axial force at nail head, T_o, kN	19.96	27.80	31.68	32.46	29.17	33.47	28.86
Maximum horizontal displacement, % of H	0.61	3.29	4.78	5.24	1.13	1.54	0.82
FS against global stability, FS_G	1.23	0.95	0.84	0.81	1.10	1.03	1.17
FS against nail pullout failure, FS_P	1.78	1.15	0.98	0.98	1.14	1.07	1.21
FS against nail tensile strength failure, FS_T	3.73	2.42	2.08	2.05	2.38	2.21	2.52

So, what we saw is that so, we have static analysis, we have seismic analysis which is in terms of the pseudo static analysis and also the time history data. You can see that for example, the static case the displacement is 0.67 you know, what is the maximum horizontal displacement in terms of percentage height? .67. Now in the pseudo static case it is 5.3, 0.29 in the case of Bhuj, 4.78 in the case of Silchar and 5.24 in the case of Uttarkashi and time history data 1.13, 1.54, .82.

You can clearly see that the deformations are over predicted. Is it not? You can see instead of 3.29 here its 1.13 here. Why? You know k H analysis assumes that the earth quake is continuous and you know time history is constant whereas, there is a time history complete you know, it is that force is somewhat you know it does not act you know there is a dissipation. You know this earthquake occurred for a certain time right some it has that. So, you can see 4.78 0.82.

You can clearly see that a time history analysis of the earthquake and using it as an input for the horizontal force due to an earthquake is a better way of doing that and of course, best is to do a conventional analysis. Actually you now because the thing is that we should always do this and do that you know. This gives always a safer you know to protect our self. But, yes I have used this method and it is I am giving a safe value, but, this will tell you how safe you are to some extent if these calculations are correct. If you are wrong here then it is very risky right, but, at least you cannot be wrong here because in conventional method it is just calculations.

But in finite element analysis; you can give wrong in numerical analysis and boundary conditions one should be very careful. You may end up declaring you know the one. So, one should always see that if you completely do this sort of analysis it is possible to say where the numbers are falling.

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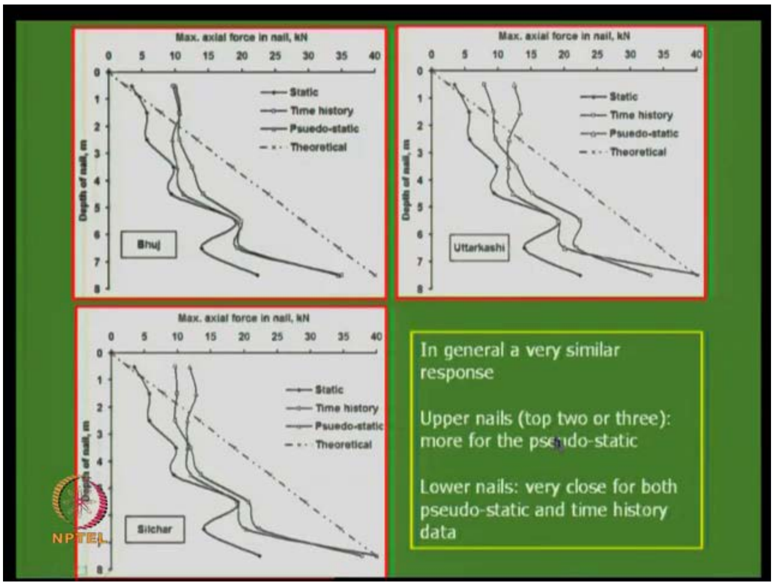

So, this is a typical analysis. In the Even in the case of static and time history in pseudo static and theoretical of course, this is theoretical and Uttarkashi and all that this is Silchar and all that.

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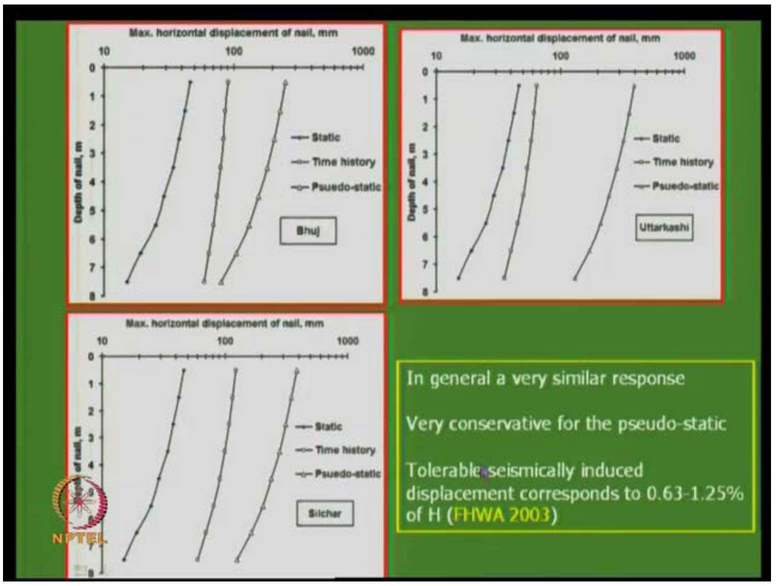

Response is similar that is fine. yeah Displacements you have seen that how they are different in different loading conditions if you take static it is much lower and time history its little better, but, pseudo static gives somewhat higher. That is what you have seen.

And very importantly the tolerable seismically induced displacements like in the range of 0.632 to 1.25. How do you say that this (( )) structure is safe? In fact, I was telling you about r u wall design in which there is horizontal force tolerance you know, service ability requirements it is about one percent of the height of the wall or some sort of thing given that there is this some factor and all that. Based on that if you can even say that yeah if the even after the earth quake is subjected to and if the deformation is in this range then it is fine you can. In fact, measure it is in some cases you know if it would have failed right

In some case you go to some earth conditions, I have seen r u wall failures are there ru soil failures are there. If the deformation is there yeah it would have failed and you can prove that yes the deformation is much more than this one percent. So, it has failed you can say that right. Ah. So, the other one that I would like to you know, here the factors of safety are .81 right. Global factor of safety is .81 right. It is a somewhat then, .98 against pullout failure and then this is another. So, this two are somewhat what about the sliding? We will just see that.

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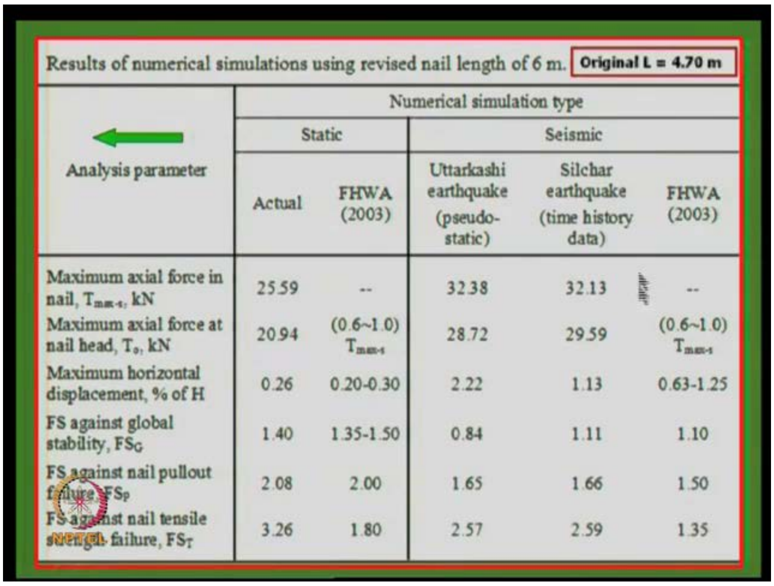

Results of numerical simulations using revised nail length of 6 m. **Original L = 4.70 m**

Analysis parameter	Numerical simulation type				
	Static		Seismic		
	Actual	FHWA (2003)	Uttarkashi earthquake (pseudo-static)	Silchar earthquake (time history data)	FHWA (2003)
Maximum axial force in nail, T_{max-t}, kN	25.59	--	32.38	32.13	--
Maximum axial force at nail head, T_o, kN	20.94	(0.6~1.0) T_{max-t}	28.72	29.59	(0.6~1.0) T_{max-t}
Maximum horizontal displacement, % of H	0.26	0.20-0.30	2.22	1.13	0.63-1.25
FS against global stability, FS_G	1.40	1.35-1.50	0.84	1.11	1.10
FS against nail pullout failure, FS_P	2.08	2.00	1.65	1.66	1.50
FS against nail tensile strength failure, FS_T	3.26	1.80	2.57	2.59	1.35

The length of the nail I just was trying to see, original length is 4.7 and this is all the factors of safety, actual and federal high way codes are like this and in some cases it come down right. So, what is recommended is1.1, but, it is 0.84 here.

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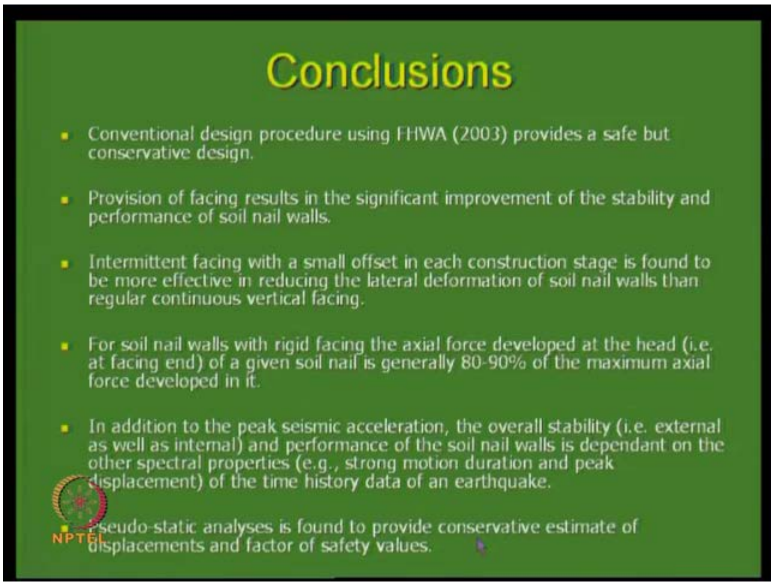

So, one can really alter that length and see what can be done you know see original. So, can always change that and then get the improved length and it can be done. So, one can, what I want to highlight to you is that the design issues that we have. So, the design issues are very important.

And in most of the cases you know, whether it is conventional design procedures for r u walls or soil nailing they are they provide safe and conservative designs in some cases it is true, but, in some cases you know like one should be careful that is why lot of research is required to what extent this federal highway guidelines are complete and you know, in terms of telling you know, we talked about r u walls where the stress distribution is like this and one is to two and is it correct for a r u wall type of structure, all that can be examined.

Ah Provision of facing results in significantly permanent stability and performance of soil actually deformation particularly its quite important. Actually I was showing you one more example earlier in the my previous class where I was telling you about providing an offset at every level, at some level also helps in effective effective in reducing the lateral deformations. And then the for soil nail walls with rigid facing, the axial force developed at the nail head is generally eighty to ninety percent of the maximal force developed.

So, in fact, the what is the percentage of the nail force that comes to the facing is another important variable that you have seen and the in the dynamic analysis we have seen that the spectral like time history analysis is somewhat very useful and pseudo static analysis is gives somewhat a conservative estimate. So, what would I like to say is that soil nailing has been quite effective. In fact, I must tell you that there are number of case studies that we did. Like the other case that even I have see while there is one embankment structure like it is a water water reservoir and like where the water is removed from the tank.

And what happened was that when water is removed from the tank you know because you know water is full in some season, but, then the village needs that water you know tank actually the town actually it is not a village it is a town that needs that water when the water is withdrawn, the you know the embankment dam has a clay core and a cover you know. So, that clay cover the cover was coming out it happened once it failed actually. The thing is that the so, what people felt was that when the water is removing that cover it means that the cover soil was erodible, like the erodible soil is somewhat erodible and the possibility is that it can easily come out. So, people brought non erodible soil and then try to mix that soil and then used it.

Second time again it failed. What happened was that, between the clay core and cover of the dam there are some the interface shear stresses and when the forces are withdrawal like that the you know it is just coming like that and if you are able to stitch you know I have seen that with the nailing you know, if you are able to stitch that clay cover as well the core of the dam it was working. In fact, that is a very unique case study that we did about four years back and we stitch that clay cover with a core you know, with some overlap about five meters nails at some spacing and it is working very well even now about even after four five years of construction. Earlier it failed in 2004 and again 2005 and people had lot of difficulties. So, because they did not understand that the withdrawal also creates lot of forces and there should lot of to resists those shear forces you need to have proper nailing force resistance for shear and which can be provided with proper nails. So, with this, I would like to conclude. Thank you.