Ground Improvement
Prof. G. L. Sivakumar Babu
Department of Civil Engineering
Indian Institute of Science, Bangalore

Lecture No. # 27
Factors Affecting Reinforced Soil

In this lecture, we would be talking about the factors affecting the behavior and performance of reinforced soil.

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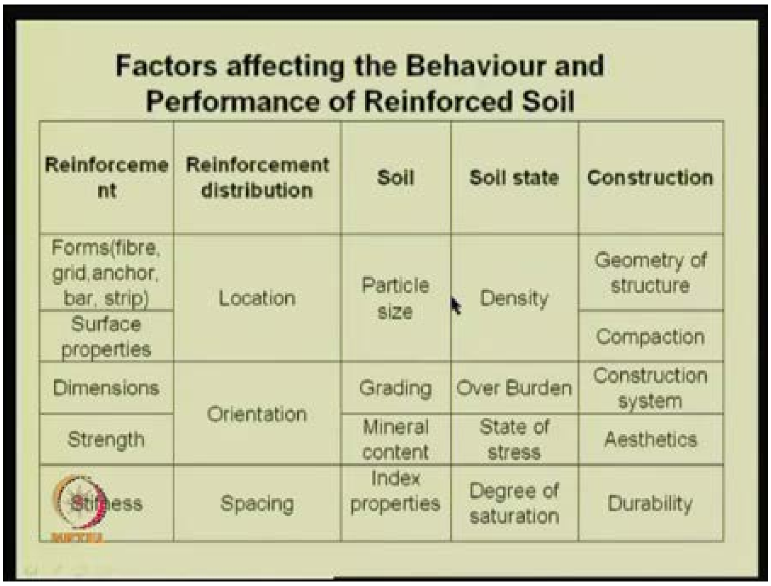

Factors affecting the Behaviour and Performance of Reinforced Soil

Reinforcement	Reinforcement distribution	Soil	Soil state	Construction
Forms(fibre, grid, anchor, bar, strip)	Location	Particle size	Density	Geometry of structure
Surface properties				Compaction
Dimensions	Orientation	Grading	Over Burden	Construction system
Strength		Mineral content	State of stress	Aesthetics
Stiffness	Spacing	Index properties	Degree of saturation	Durability

As I just mentioned, reinforced soil technique is one thing that took the whole geotechnical construction by storm. And the fact that, you see so many flyovers constructed with reinforced soil technology; and particularly, in many other applications of pavements and other cases, it has been possible that one can say that this has been very important technology for infrastructure.

So, there are different factors that could affect the behaviour of reinforced soil; one is in terms of the reinforcement - the way that reinforcement distribution is done, that soil type, the soil state in construction. In this reinforcement, you have different types of forms, fibers, grids anchors, bars and strips, surface properties are important, dimensions are important, strength properties of the geogrid important, stiffness are important.

We will see some of many of these all the factors, like say for example, reinforcement - its location is important, orientation is important, the spacing of the reinforcement is important, particle size, gradation, many of these factors are quite important; and we will see how they are important in the case of reinforce soil.

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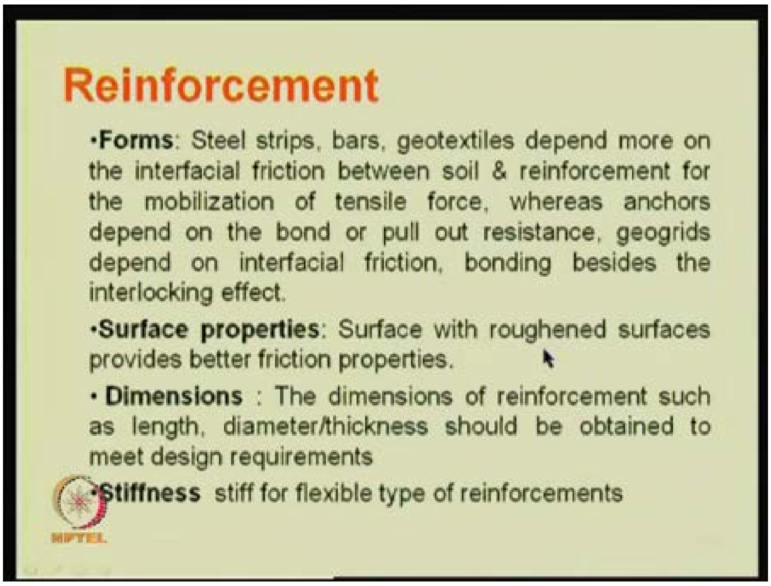

As you just mentioned the forms, it can be many things like steel strips, geogrids, geotextiles, and why is it important is that, some geotextiles, you know, as I said friction is an important component of reinforce soil. Geotextile is essential only a frictional behavior, like because it is a continuous surface, and there is a friction between a soil and the reinforcement, that is that is required for mobilization of tensile force. Whereas, say for example, if you are putting anchors, like you know, you have a reinforcement and then you have an anchor at the end, the anchor will give you the pull out resistance; see as I said the two components - one is called frictional resistance and bond resistance. If you put a reinforcement and then a one bond, like you know, a some sort of anchor, it will have a combination of both friction as well as anchor.

So, like that, people have done different types of or the forms of reinforcement, and say for example, geogrids another type and they are very they have both friction as well as bonding effects. Then, the surface property is very very important; smooth surface will have less friction whereas, roughened surface will have better friction.

Dimensions of the reinforcement are very important, because the length, thickness, diameter, should be obtained; you know, we have to have, say for example, you have to see what is required for you so that, you can get from manufacturing agency, and then put it. They come in some standard lengths; stiffness is also a very important.

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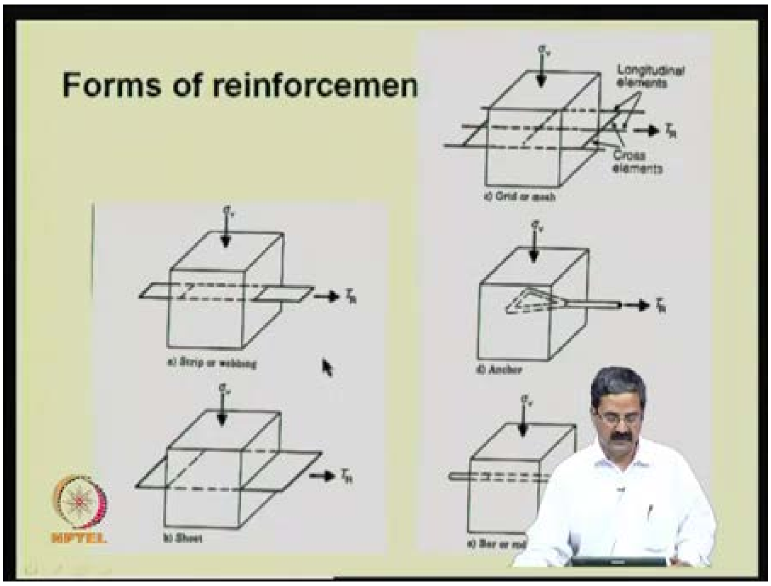

So, forms of reinforcement as I said, it can be a strip, it can be a sheet, it can be a grid, like I will just show you; there it can be a anchor, like you know, you have a reinforcement, you can put an anchor inside; you can be a just a simple bar like a reinforcement bar.

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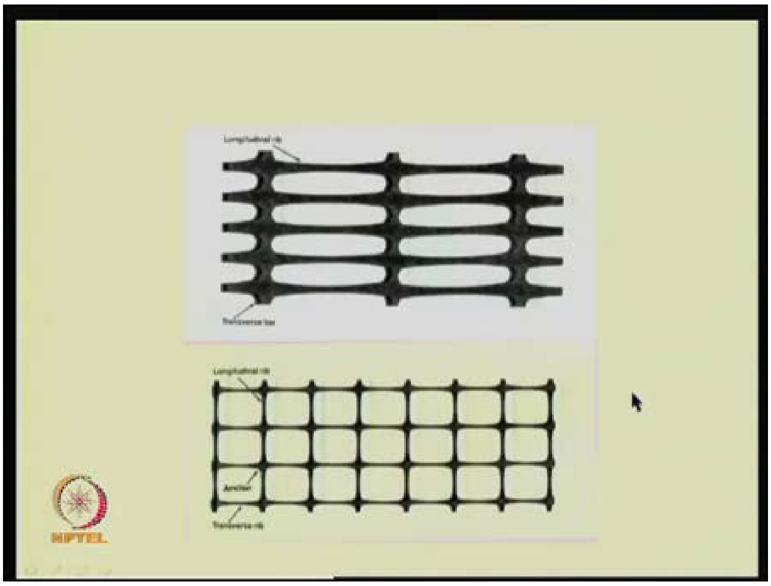

It can be like as I just mentioned, it can be a geogrid. This is most of the time we use it for reinforced slope applications or retaining wall applications. This was used for bearing capacity and pavement applications, like say the thing as I just mentioned here, this is a geogrid and these are direction of axial force, and there is a contribution of grid.

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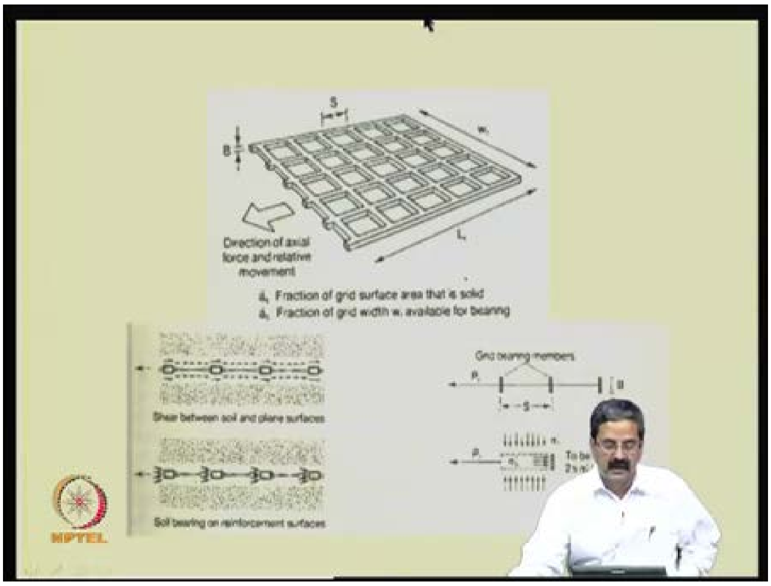

There are two things here; the interaction takes place between the soil to soil, like you know, here say shear between the soil on plane surface, like you know, here you have. Then, you have bearing also like this, like you can see that, you know when you pull a reinforcement like this, the resistance is along this line and also like this; number of bearing elements are there, ok.

So, there are, say for example, in this case, in this meter length, there are 1 2 3 4 materials that are providing bearing. So, this is something like this, like say, you have a spacing here, you have a b here. So, if you apply a force, there is some sort of bearing resistance, that is mobilized and to satisfy this roughness to be fully rough, you know, its there is a simple relationship that is given in terms of this simple equation. So, the shape and the form of the reinforcement is quite important.

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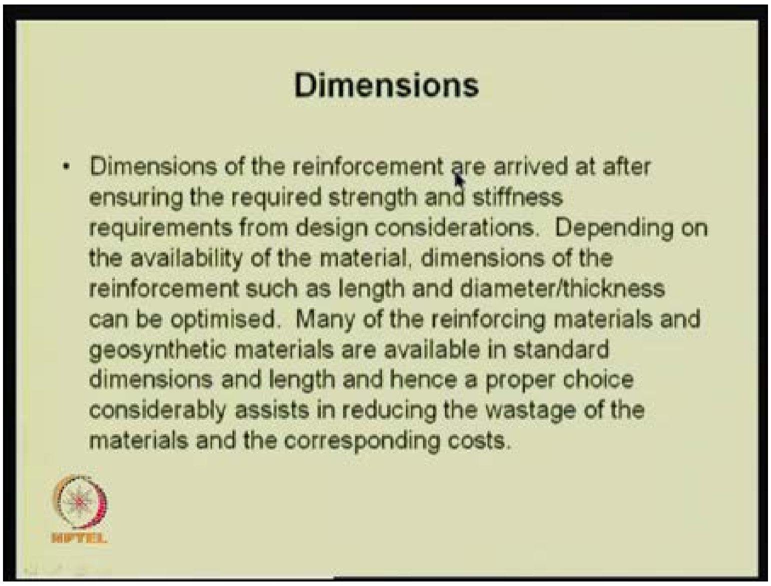

Then, dimensions actually, you know, the way that we design is that, we just first get some required strength and stiffness from design, and say we try to check, if it is available; say for example, tensile strength is a 30 kilonewton per meter and we should know what length it is available, because I need if 7 meters is a height of retaining, say for example, 10 meters is the height of the retaining wall, 0.7 times is the length of the reinforcement required.

So, 0.7 times the height will be the length of the reinforcement in every point and then you also know the spacing. So, I will know the total quantity of the reinforcement required, because you must be able to optimize on the dimensions actually. Essentially, if you get lot of material, you should be able to, say for the you should be able optimize them.

And another important thing is, you can even, see the other day just I was mentioning, you have a geocomposite also. Geocomposite means it has a tensile properties as well as a drainage properties also. So, depending on the application, we must be able to so, but then it may come in a different shapes. So, many of these things they come in roles, and you need to have you know how much how many number of roles are required; say for example, if you ask company, he ask you, sir, how many roles you need? He will not ask you, say for example, you know what is your design and all that. He would be only interested in something number of some numbers of roles required and also he will give you what application.

Say for example, if I say I have a reinforced soil application for retaining wall, he will give you all that retaining wall specifications using their product and also how to install the product in the field using for their product, and what is the care you should take, all that he will give.

So, essentially this is a function of dimensions. So, the design is very one should be careful and also one should be able to optimize, because you should not waste too much of materials also. I will show you later an example, in other class in the subsequent classes of how it can be optimized.

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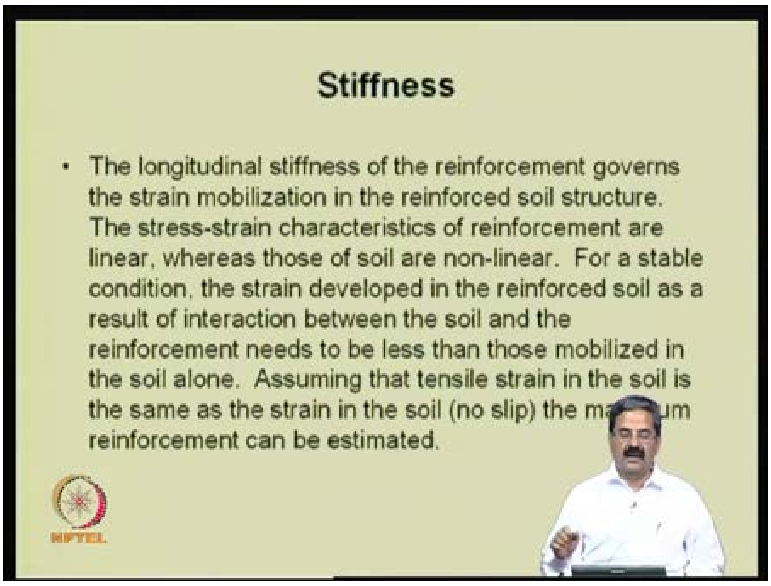

Then, stiffness is a very important parameter, like you know, we have two types of thing; you know, geogrid is somewhat stiff, geotextile is flexible, whereas a steel reinforcement is very stiff. So, the stiffness is required for strain mobilization reinforced soil structure; this stress strain characteristics of reinforcement are linear, we know that, whereas the soil are of non-linear in nature. For a stable condition, the strain developed in the reinforced soil as a result of interaction between the soil and reinforcement needs to be less than those mobilized in the soil alone.

So, for example, why you are putting a reinforcement in the soil is essentially to reduce a strains, because lot of strains are taken care over the reinforcement and not the soil. So, that way, what you have to expecting is that, the there is no slip between the soil and reinforcement; say for example, if you apply a some load, now strains are mobilized both in soil and reinforcement, ok. So, they must work together, like you know, we they move together, like you know, soil should have some strain and reinforcement also will have the same strain, because its what is called strain compatibility, ok.

So, we say that, there is no slip that occurs. So, this is very important concept and so we calculate the corresponding stiffness’s. Soil can be very less in stiffness, but reinforcement is very good in stiffness. Both of them together will give you the composite stiffness. So, that how much of stiffness is there from reinforcement. In fact, it is a very important point like e value, right.

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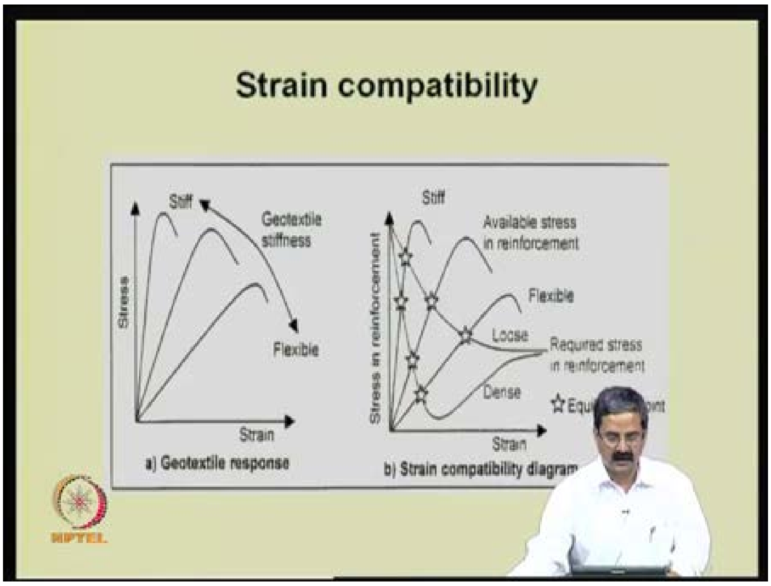

This is what I just mentioned; it can be a very flexible one like a geotextile, it can be a very stiff one, it can be a like a geo, this is a geogrid it could be, it could be a steel reinforcement also, like steel has very stiff and that helps, you know, like you know, as I said the other one I was talking about that state of the soil also; I was telling about the strain compatibility earlier, where this is a loose soil, this is a loose soil, this is a dense soil. And actually, this is a available force in the reinforcement, because the available force in the reinforcement; its the stress strain curve is very steep in the case of stiffer material, it is like this and its all of them like this.

But in the case of loose soil or a dense soil, there is a difference. So, when they strain together, then the possibility is that, as I just mentioned in the other case, like you take this case; in the case of dense material, the strain required is quite less, whereas in the case of loose material, the strain required is quite little more, right.

So, this is what I was just mentioning, that this is an important concept, say, even you can take the other way that, say, this is an important concept in terms of understanding a what is the strain required and all that; this will see some more information on this.

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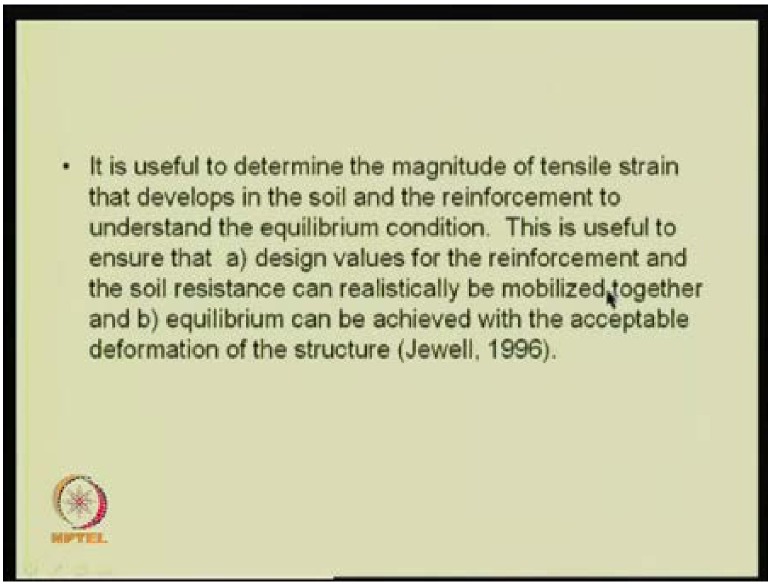

Why this is very important, because it is very useful to determine the magnitude of the tensile strain that develops in the soil and the reinforcement to understand the equilibrium condition. This is useful to ensure that the design values for the reinforcement and the soil resistance can be realistically mobilized together, and equilibrium can be achieved with the acceptable level of deformation of the structure.

What you are looking for is that, say for example, in the case of if the compaction is very good, say like, then definitely you have a behaviour like this, you know, dense material behaviour like this. And you can expect that, you have the available force in the reinforcement you know you have a, say for example, a stiff reinforcement it is like this. So, you have a denser material, so you have the force which is quite good. Stress in the reinforcement right stress in the reinforcement is like this. So, in the same thing, you know, this is one thing, fine.

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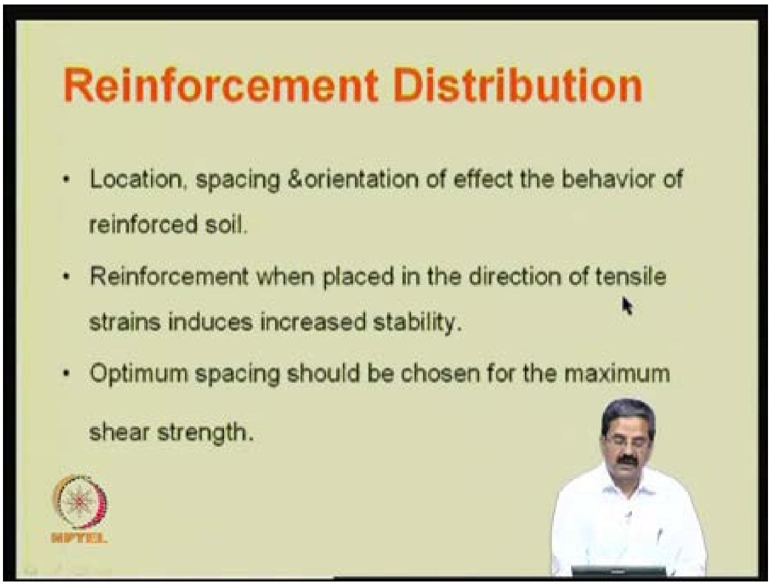

So, reinforcement distribution is another important factor. We have seen that, say for example, if there is a load applied on the footing and failure planes develop like this, so you put reinforcement in the horizontal direction. So, the possibility is that, the reinforcement will intersect the shear planes and then it increases the bearing capacity.

So, the location, it all depends on the type of failure, say for example, in the bearing capacity, you can just put below the foundation level, but whereas, in the case of reinforce slopes, for example, if the failure is occurring like this, you put like this, right. So, once you put, say for example, nailing, you can put like this and then it prevents the failure occurring.

So, location, spacing, orientation of the effect of the behavior, they are quite important; and what we have to see is that, the reinforcement should be placed in the direction of tensile strains, like as I just mentioned, you apply some load and block moves, there is a tensile strain mobilization in this direction, the compressive strains are mobilized in this direction. And that is the way one should see that and then optimum spacing should be chosen for maximum shear strength, like one should be really judicious in this.

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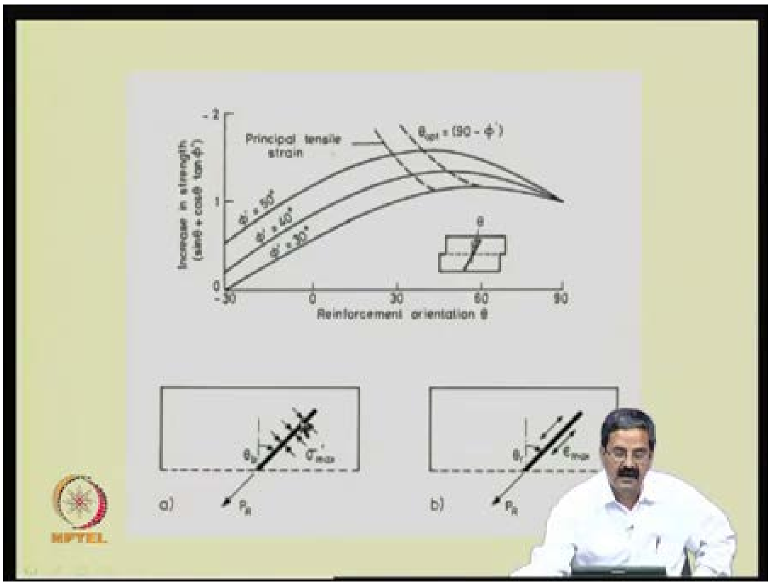

And as I just mentioned, I was talking about the orientation the other day, that like I will just gave you this simple expression, which is nothing but the strength in reinforced soil, because of the orientation, like sin theta plus cos theta into tan phi; this is what I just discussed.

And it is a, like you can see that, if the orientation is at an angle say 30 to 60 degrees with respect to its the failure plane, you know, this is a failure plane, right, in a dia shape box say for example; this is a dia shape box; this is 30 to 30 to 60 degrees if it is there, you are getting a very good effect.

What it means is that, if you want to get a maximum effect out of the reinforcement, you should be able to incline the say for the reinforcement in that angles. So, you take the case of a bearing capacity application, the failure surfaces develop like this; and if you put a reinforcement, the angle at which the this particular angle is about 30 to 40 degrees, in case of bearing capacity; even in slopes also, roughly it is same. And the fact is that, you can see that between 30 to 60 degrees, little flat it is, is it not?

So, it is a very important advantage, that see for many of the soil engineering applications, if you put a reinforcement, this is a very useful thing to apply for increasing bearing capacity slope stability and all that, because it is naturally the way that we put a geotextiles or geogrids is giving these angles, ok.

You do not need to really do something else to really get these angles, see because they the moment you apply load, the failure surface are developing like this. You are just putting a geogrid, and if you really understand what could be the probable failure surface and what could be the angle, it will be in this range, and definitely you can be very sure that it is going to be effective.

The other one that I would like to highlight you is that, if the reinforcement is in the direction of tensile strains, like this is a very important concept here. If the reinforcement is placed in this as a same direction here, you have a very good effect, but then other point is that, the what is called bonding; see, the there are two things that we need - one is that reinforcement should be very force should be developed well in the reinforce soil, that is only possible when the it is in the direction of tensile strains.

And the other one is the bonding, see this is actually, this is see, this is actually pullout resistances, you know, this is a like you know, you have a reinforcement here and there is a maximum stress acting and this thing. And if you pull out like this, what happens is that, if a maximum stress is more, then you cannot pull out, right.

So, from bond considerations, I want to give a simple example, if the angle at which the bond is going to be maximize is 90 degrees actually. So, if you apply a vertical load, you the bond resistance is very high, but that is actually the preferred; see, this is a reinforcement direction, if you want to get the maximum benefit out of from the bond, the vertical load should be will applied like this; the sigma maximum stress should be applied like this. So, it is 90 degrees, right.

So, that is one thing; the other thing is, if tensile force is in this direction or the tensile strains reinforcement is going to be a very effective. So, here the angle is 0, in terms of the tensile strains, and in the form terms of in the terms of the bond, it is 90 degrees, like if you want to get a very good bond, you should have this angle as 90 degrees actually, ok.

Though I am showing you some angle here, the angle ideal is 90 degrees here; if it is want to be in the direction of tensile strains, it is just 0, but both are not possible, you have a in between angle, say for example, 45, 30 to 40 degrees like you have here, so which means that, there will be a small correction, lesser, you know, it is not either in the direction of this to get the maximum benefit out of the tensile action or it is not in this direction to get the maximum benefit out of the this bond action.

So, still it is in a via media, which is somewhat reasonable satisfactory what. So, what you should do is that, the increase in shear strength will be slightly less; the only consequence is that, it will be, you may say that, you will get a maximum effect like this. But this angle, this because of this small minor things, there'll be a minor reduction, that is it. So, that is what we should understand.

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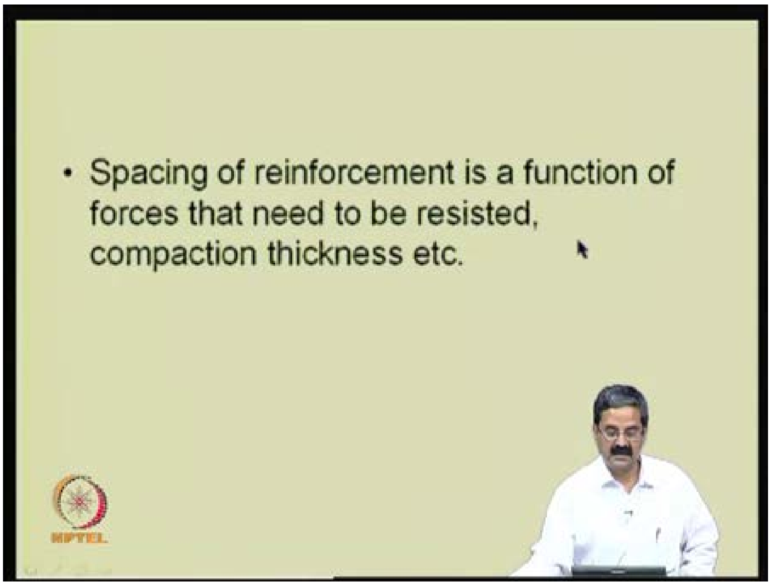

So, these are all in terms of the orientation effects, in terms of the reinforcement. So, spacing of reinforcement is a function of the forces that need to be resisted, compaction thickness, etcetera. What it means is that, you have a earthquake force or you have a some horizon force that is coming up, now you have the friction between the soil and reinforcement should act in the opposite direction. So, higher is the force, higher is the space, lower is the spacing required; say for example, you take the reinforce at retaining wall, maximum pressures are at the bottom, like you know, we say k a gamma h square by 2, right. So, k a gamma h square by 2 is the maximum pressure.

So, that resistance should be given by this geogrids or a reinforcement only, and if the spacing is closer, they give a higher the higher force right. For the same one meter length, you know, you calculate at the bottom 1 meter what is the actual active force, you balance out by this; that is what we are trying to do.

So, spacing is an important factor and then compaction thickness is another important factor; say for example, as I just mentioned, many of these geotechnical constructions we do have to do soil compaction and we have to do for maximum density and all that. So, when you do that, it has some thickness; it can be, like you know, 50 centimeters, it can only be 25 centimeters.

So, you have to place in terms, say for example, if I get a spacing of 50 centimeters from force considerations, I have to use two lifts, like 25 centimeters one lift, 25 centimeters one more lift, put a geogrid or a geotextile. Then, in some other case, say for example, I get only say the in terms of compaction lift techniques only I should discuss, because that is a way that I can place the reinforcement; otherwise, I cannot put a geogrid; say for example, ten centimeters I cannot put, it is not you know, we should be its uneconomical.

So, what you should do is that, you should just get a geogrid, which satisfy that requirement also. So, you have to come out with some number of combinations, because the companies will have different geogrids varieties, you know, grades, like it can be 80 kilonewton, it can be 100 kilonewton, it can be 120 kilonewton. So, if 120 kilonewtons is suitable and it gives somewhat reasonable compactive thickness, it is fine for you. So, there is a combination that we will see in the examples. So, then see the backfill properties are very important.

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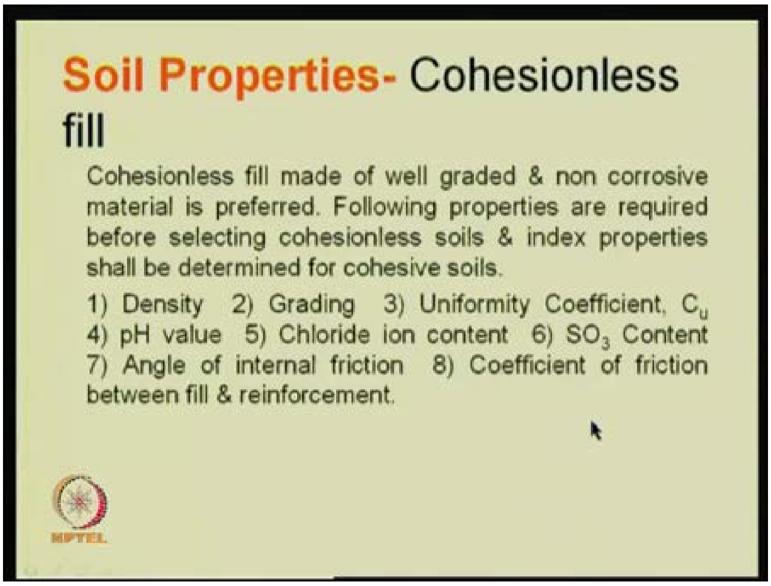

And see the normally in codes, we specify well graded non corrosive material, and we need to have the following properties like density gradation, uniform coefficient, ph value, chloride ion content and all that properties are required, and coefficient of friction between the soil and reinforcement are required.

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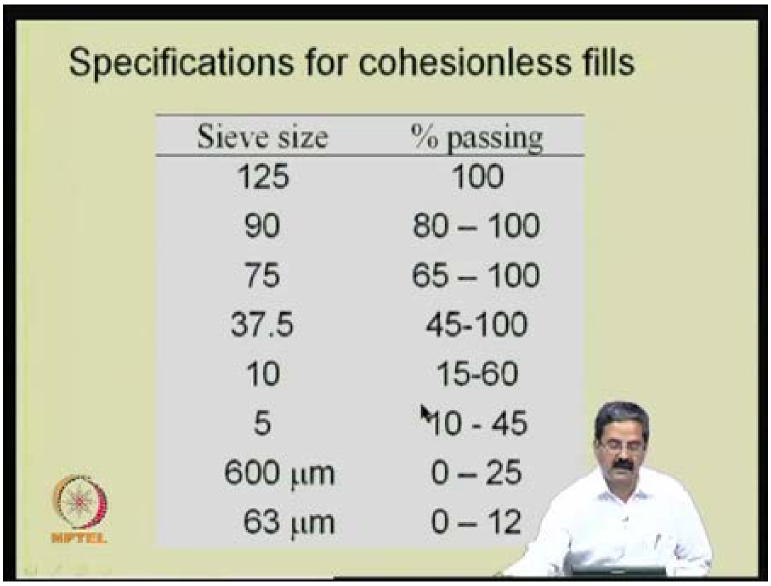

In fact, we say that, say the friction angle should be not less than 25 degrees or something, and like you know, you can see IRC specifications, we have Indian roads; congress specifications, we have bs 8006; UK specifications, we have NCMA specifications which are followed internationally. Internationally, there are two types of specifications that are normally followed: one is called NCMA specification and then the BS specifications. And in India, we follow IRC specifications. So, they specification for cohesionless soils and both cohesive soils also, like you know, they give a specification like this ok.

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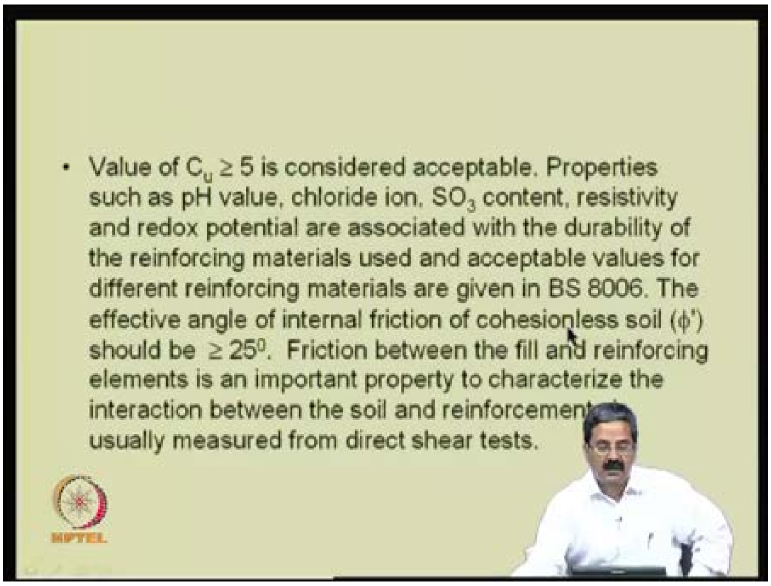

Say for example, what it means is that, the sizes you know it can be 100, the size you know sieve size should be it is 87, size you know that gradation material 65 to 100 is 45 15. So, it depends on that.

The drainage purposes, we know that the coefficient of uniformity d 60 by d 10, right; it should be acceptable more than five. Properties such as all these things are also important and the effective angle of internal friction of cohesionless should be more than 25 degrees. Friction between the fill and reinforcement elements is an important property to characterize interaction between the soil reinforcement, and normally measure from direct shear test, as I told you that there are number of test that one can do. We would discuss that how it can be done; we have to subject it to three normal stresses and pull out the I mean you can shear the reinforcement across it. So, you will get, right.

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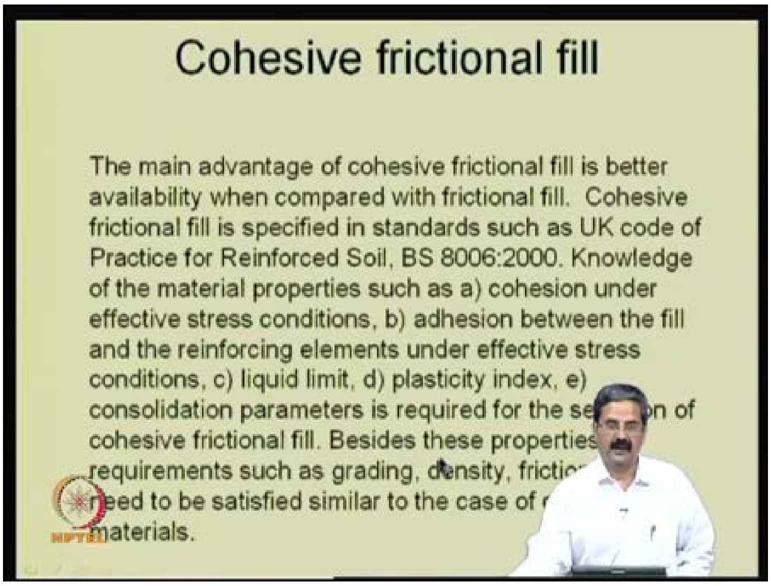

Sometimes there is a tendency for, you know, if you sand is not available, then there is a cohesive soil is also acceptable. But then there are some requirements, that it should not have too much liquid limit and plasticity index, some specifications that are given. And again, all of these things are standard, say for example, you should find out c and friction angle and all those parameters, and make sure that, that will not lead to any other difficulty; say for example, you cannot take an expansive soil as a backfill material. You have to choose a backfill material, that has small cohesion and also gives enough frictional properties.

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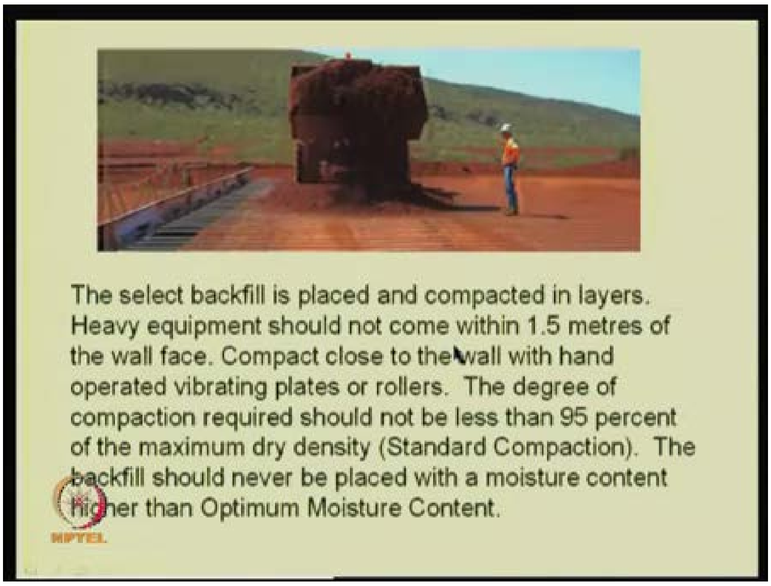

This is what I was just mentioning; for example, a simple example that I thought I should show you, that this a type of reinforcement that they are trying to place, here in this case is a steel strips, ok. It can be even there are many types of materials here, and then this is the way that it is done. And after that, it is compacted; you can see how nicely it is there, you know, layers in compacted. So, once the sand is the material is dumped, it is called backfill material, right. So, this backfill material should be in placed and compact in layers, and heavy equipments should not come into 1.5 meters of the wall face.

Say for example, this is a wall face, you should not you know bring in any of the heavy equipment here; it should be only limited to this side, because if you have lot of lateral, because of the compaction if you induce lot of lateral pressures, the facing will get disturbed. Then, there is also some specification, that it should be 95 percent of the standard compaction and all that, and the water content also we have specification; one should be very careful, one should follow these specifications very strictly.

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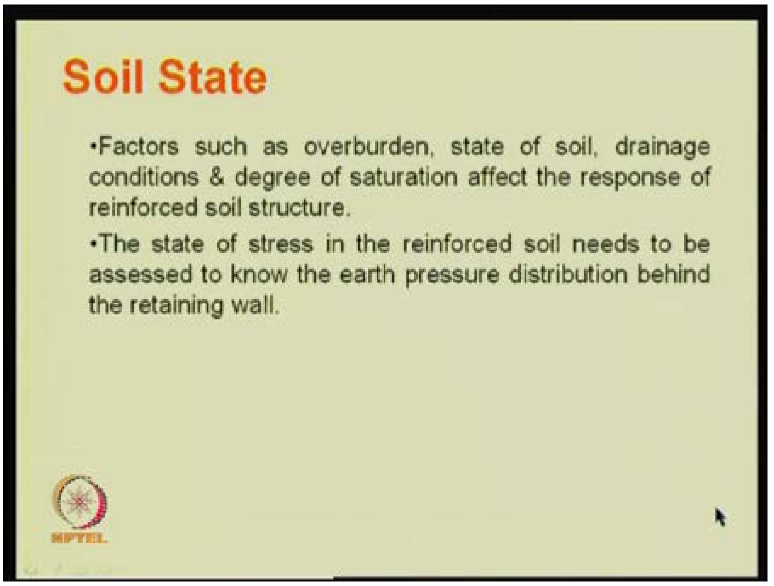

Then, the soil state, see there are number of reasons here; one is, say we said, the we said cohesive soil is also ok and then we also said sand is fine, but then soil alone is not sufficient; soil state, what is the state of the soil and how does it respond. So, for example, at pull out over burden, you know, so for example, in a retaining wall, you have 1 meter, 2 meters, 3 meters, there 3 or 4 depth of over burden is there you know or in an excavation depth of over burden is there.

So, the state of the soil is very important, why because, the I mean the over burden is also very important, like say for example, as I just mentioned, as you go down, the pullout resistance is going to be higher for a reinforcement and then a active force is also going to be higher, but in the top layers of layer reinforcement, the force coming is quite less, but then the pullout resistance is going to be higher, why because, I will just its easy to pull out a member with a less over burden, like you know, if then the length is short, it can easily come out. So, you need to because over burden is something, say for example, at 1 meter level, it is only gamma by into height, its low, whereas down, it is much higher. So, over burden is important factor.

State of the soil - in fact, is it active state or a k naught state is another important factor, because some soils see it depending, even it depends on a type of reinforcement also, because stiff reinforcement you have seen, it needs they need very very minimum strain very very.

So, we can say that the soil is in a state of k naught condition, means, coefficient of at pressure at rest. So, the state of the soil is at rest, but whereas, a geotextile or a geogrid, they need some sort of deformation, which means that, the state of the soil is active condition. So, the state of the soil is very important, why because, in design if you are trying to, actually people have develop design methods also based on this.

So, if somebody is using a steel reinforcement, they say if you want to calculate earth pressure, you say k naught into gamma h, but if you are using a geotextile reinforcement, they say use k a into gamma h. So, that is the difference it could make, in the case of state of the soil. And soil state of the soil is also that, it is like, see, is it a dense as is it a loose, like we have seen that, it should be very dense material, why?

Because the it has a tendency for development of pore negative pore pressures; you know when this density is quite high or the you know there is a possibility of what you call the negative pore pressures, it will increase the effective stress. Then, drainage conditions - so, we normally calculate effective stress parameters, which are based on proper consideration to drainage. So, degree of saturation is also an very important parameter, say for example, in slopes, if degree of saturation is say, it is it is a dry slope, then the earth pressure is less.

But if it is partially saturated, what is happening? Earth pressure is going to be higher; earth pressure is going to be higher, because there is a water pressure partially saturated, and say for example, there is a seepage pressure imagine. So, all these things lead to they affect the performance of the reinforce soil.

As I just mentioned the state of the stress in the reinforce soil needs to be known, to assessed also, to know the earth pressure distribution behind the retaining wall. So, earth pressure, how do you that? it is k a into gamma h. We assume that, it is a hydrostatic distribution in fact, is it not? We assume that the pressure is hydrostatic, like it is like a water force acting, ok.

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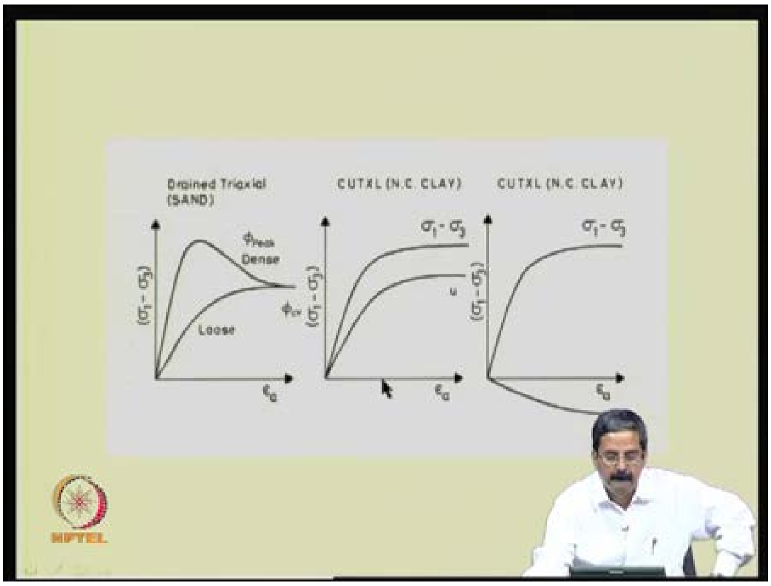

So, these are all some typical stress strain curves that we see in the case of test. So, this is in the case of peak, we have a similar response here, like essentially this is a pore pressure response; and this is in the case of drain test, this is a volume change, ok.

These are typical stress strains, responses that one should understand, and one should get this effective stress parameters from triaxial testing only; why I am asking is, in a direct shear test, we cannot measure effective stresses. If there is provision for measuring effective stresses in a dia shape box is fine, but normally we are conventionally use triaxial testing, right.

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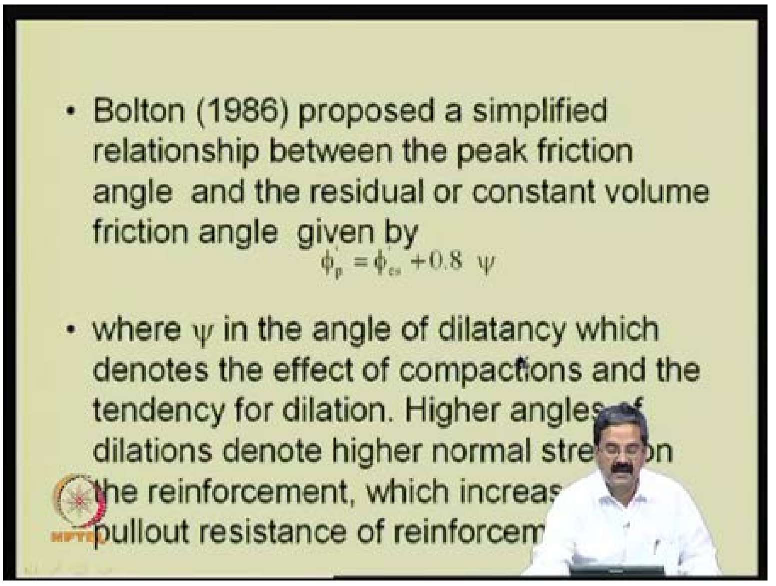

Then, there is another thing important I would like to highlight to you is that, see this stress and curve we have seen of the soil is like this, loose sand it is like this; if you have a reinforcement, it will be like this - much steeper - it will be like this.

If you just plot the reinforcement combined soil plus reinforcement, it will be like this, much higher than any of these two, because it takes a load, right. So, why is it is going to be affective, and one more thing is that, there is a always a question that is it how is that the peak angle is related to the constant friction angle, I am I am sure about this.

I hope you are aware of this three terms, that say for example, when you do a directional test or a triaxial test, you will get ah friction angle using peak values, like using residual values and there is what is called angle of dilatancy; the angle of dilatancy is an important parameter in reinforce soil, because like if you are trying to take peak response, what do I just mentioned that reinforce soil will be like this; it will not it will not it will not reduce, this strain softening will not be there in the case of reinforce soil.

So, to calculate the parameters, what you should do is that, there is a. So, what is that parameter you can take; there is some equation that is given in terms of the phi dash peak, is nothing but you have a constant strain angle phi from residual angle and also point 8 times psi.

The psi is that the angle of dilatancy which denotes the effect of compactions and the tendency for dilation. Higher angles of dilations denote higher normal stress on the reinforcement, which increases the pullout resistance.

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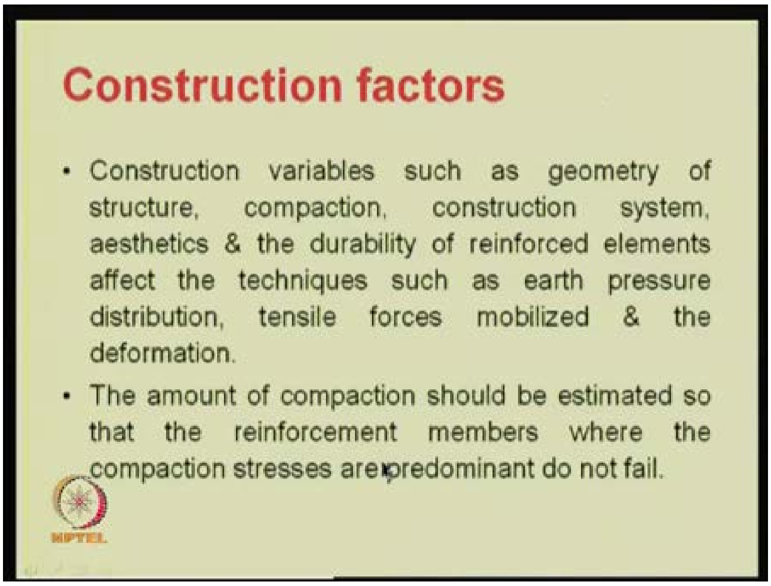

Actually what happens is that, to pull out, when there is a good dilation is not easy, because you know the compaction induces what is called dilation tendency. The dilation is there, dilation tendency is there, but then it cannot dilate, and because in that process, what happens? It holds that reinforcement much much stronger, because effective stress is more now. See the dilation tendencies will induce more effective stress, right.

So, because of that, you have some ideas on effective stress plus the effective stress component into dilation tendency, you know, which is not dilation is not allowed to take place. So, that pressure extra pressure is also added. Then, there are some important variables that we should see like. So, we have seen we have discussed about the type of reinforcement, I mean, the reinforcement and its types, then its distribution, we talked about the properties of the soil, like you know, we should be loose or dense, or it should be clay or sand and all that, and we also discussed about its orientation.

And we also discussed about its some other features, and I must tell you that construction factors play very significant role in reinforce soil, why because, technique it is a technique actually. The way it constructed is an important thing; if you do not construct a technique, the implement the technique properly in the field, then the possibility is that it may fail. So, technically may be nice, but the way it is done is not good.

So, one should understand that, that there are number of factors such as, geometry of the structure, compaction, construction system, aesthetics and durability of reinforcements. They all affect the earth pressure distribution, tensile forces mobilize and the deformation. Actually, see, you want all these parameters, and finally, they are affected by the technique itself.

The amount of compaction should be estimated, so that the reinforce members where the compaction stresses are predominant do not fail, like as I just mentioned, the compaction should not be too close to the wall. If it is too close to the wall, there is a possibility that, because of the compaction, there is a high lateral pressure. And if it fails, that the phasing may deform also, its all that we do not want to have. So, that is one thing, one should know.

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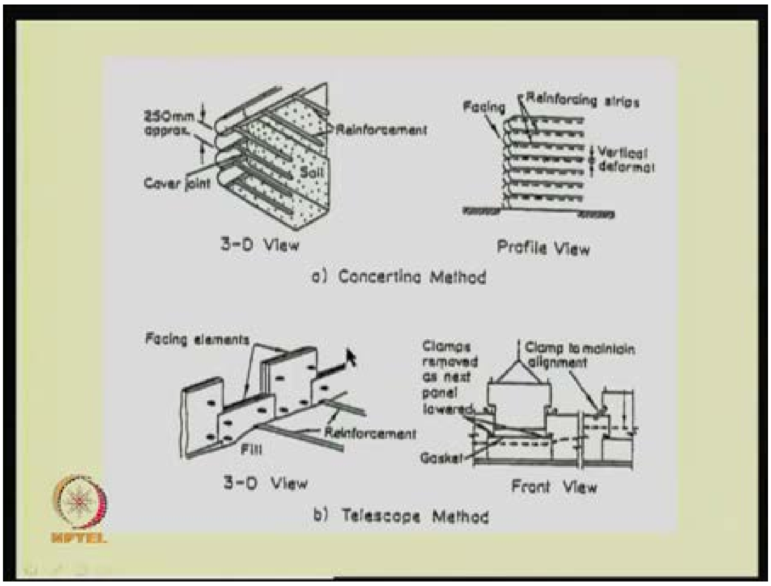

I will give you small examples, how is that as I said construction methods are there are so many, right, like what the way that we do is that, it can be constructed with a simple reinforcement like this and put a simple what is called a sheet like this; you know you come from, you know, you put some, you have a cover, first you put a cover like this, then put a backfill, then put this, bring… see for example, you have this is a area, put the first put the geotextile layer, then put this material, put this material here, then again put one more one more layer of geotextile put like this.

So, you keep on doing like that. Here, what is that it is special the soil is actually the geotextile is somewhat flexible right. So, the earth pressure will be in the k a condition, because the it is not stiff - geotextile is not stiff – then, it may be more have a more tendency for deformation. So, it is one thing. So, it is like this, you know, it may undergo lot of horizontal moment as well as vertical moments; this is one simple example.

Whereas you take another case, where you have a steel reinforcement like this and it is connected to the phasing panels. In such a case, what happens is that, as I said, because of the connection between the reinforcement and the panel, some force of some force gets transferred to this. So, which means that, the one should design the phasing's properly.

In this case, phasing is a simple geotextile material, right; you do not have any simple problem and then you just put a you can put a simple layers of geotextiles; keep on putting it to some height, and then, if the tensile forces are taken care of by the geotextile tensile strength, it is all right. Length is also should be, say for example, as I said that, if 10 meters is the height, 0.7 times a length of the should be the length of the reinforcement.

So, you can just do that, and if you satisfy that condition and then see that, the material stands like you can make a 80 degree or 90 degree geotextile slope like this; keep on doing it, take a soil, put the material, take a soil, put the geotextile like that; compact it, of course, you have to compact all that. So, you can do that, instead of conventional 1 is to 2 slope.

You know sorry 2 is to 1 slope, where two is a horizontal and one is vertical, like which you do right. In a embankment problem, we do that we need a 2 is to 1 slope, which has a because a slope factor of safety is cannot give you that steeper slopes, but here geotextile you can achieve that steeper slope.

What is happening here is that, the difference is the material; material, the way it is done you know geotextile. So, the way it is constructed is important factor here. So, you have different types of joints also, like you know, this is actually the way that is done. In fact, in the field, the way it is done is that, it is like, you know, you bring that phasing panel; see you construct first half panels like this, this is one half panel, this one half panel, this is another one, then you put the next one, they keep on doing, you can observe them in the field.

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I would like to just illustrate some of these important points with reference to a case study that we did. This is our own under under pass (( )) of science.

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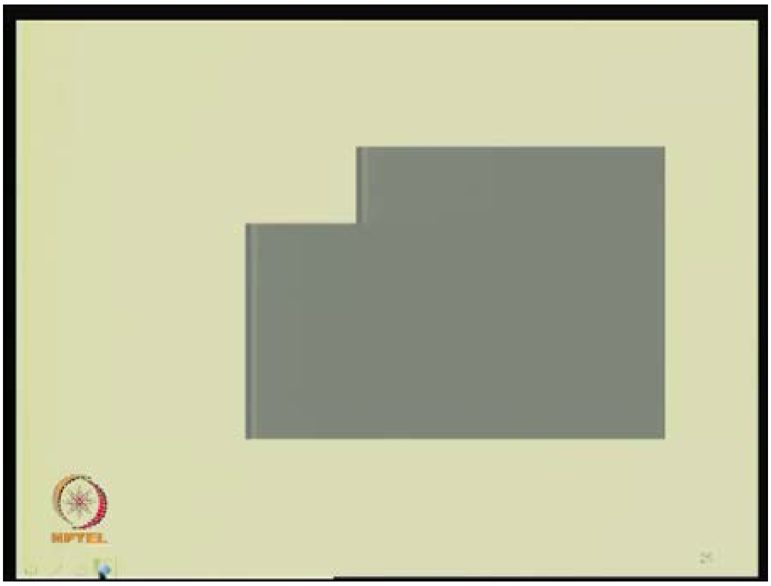

I would like to just illustrate you how it was done; it was done with a soil nailing. Soil nailing is that classical reinforce soil technique, where you do not need a backfill, in-situ soil has to be stabilized. And the way it is done is you make an excavation, just excavate about some say 1/2 a meter or a something or 1 meter, put some reinforcement like this.

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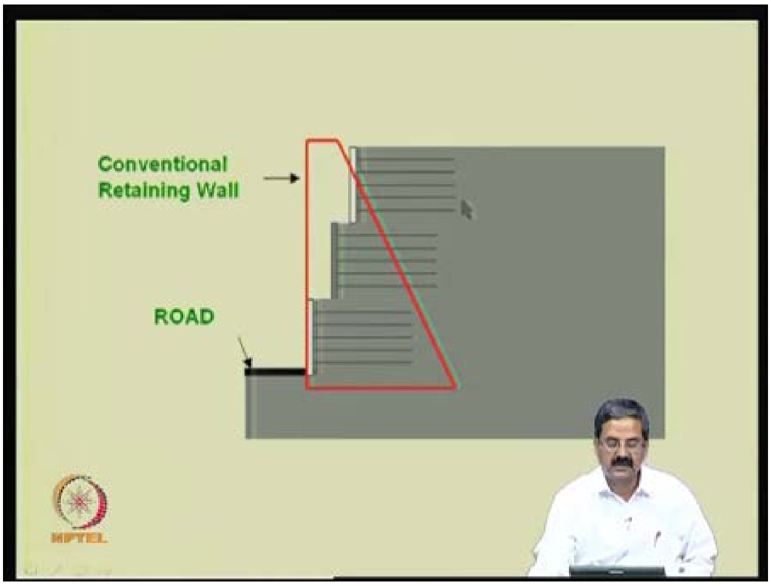

This is a road, this is a typical structure, right. So, the advantage is that, instead of having a big retaining wall like this, you have a simple reinforcement structure like this, where you have simple systems like this. So, it is much cost effective and you do not need to worry about the backfill material for this retaining wall and all that, and it is easy to construct also in an excavation, right. So, this is a very simple advantage.

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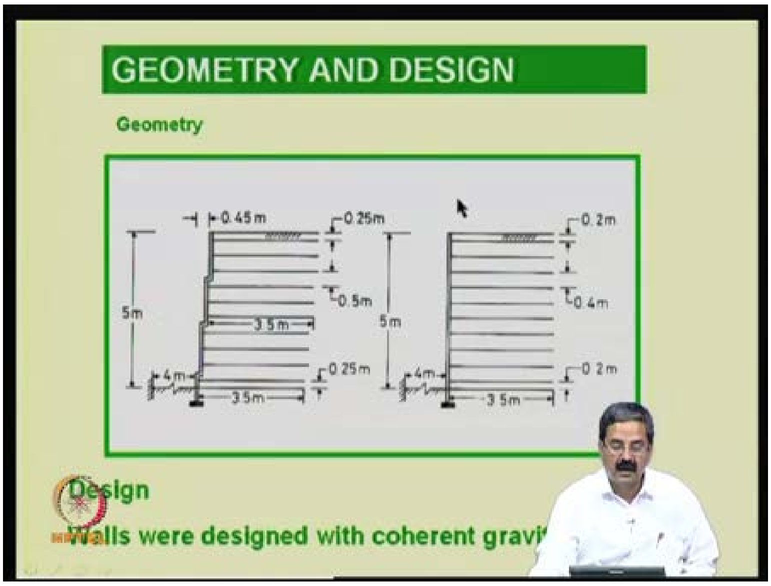

The way that we have these walls is that, in one case, you have a five meter wall with this type of phasing, right, and it has this 3.5 meters is the length of the nails. Other case we have vertical one. So, the difference is that, you have a stepped phasing, which I say like 15 centimeters at every place 15, 15, 15. So, 45 centimeters is the total difference. Why is it done was that, if you just incline little bit, the earth pressure will be less. If it is inclined wall, the earth pressure is very high; if it is little inclination is there, the earth pressures are little marginal less, right.

So, that we wanted to do that here and the second case was that it is vertical, because the earth pressures are maximum, when the wall is vertical. And we use the steel reinforcement, which is nothing but steel rods. So, it is a stiff reinforcement and we call it, we use the k naught gamma h. So, we call, we have a design method based on that, which we call it coherent gravity method, like once you put a reinforcement like this, what it means is that, this wall behaves like a coherent mass; that is why we say that it is a coherent gravity design method.

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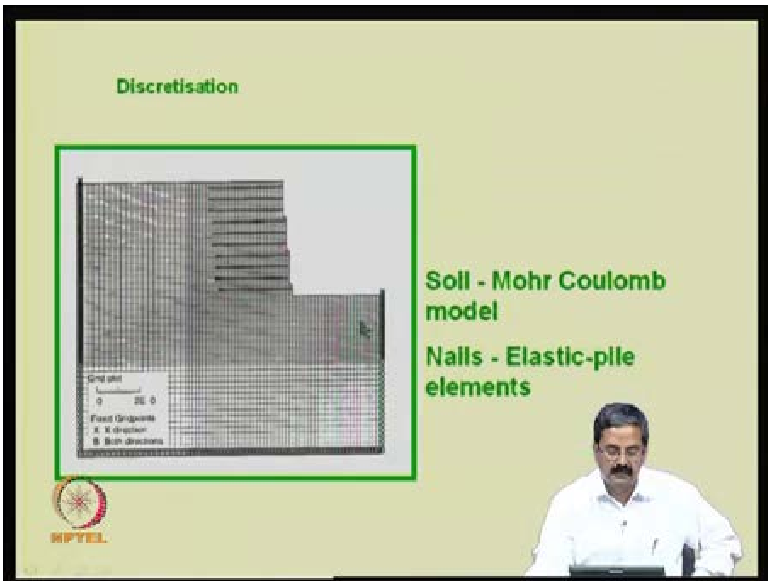

So, actually you know you can design this, the way that I told you like you know how to calculate earth pressure k naught into gamma h, and see, that is earth pressure acting right. So, k naught. So, how do you. So, what is the pressure that you have to resist, how do you get it.

It is nothing, but you can the friction between the soil and reinforcement you have to calculate. How do you get that? T, t should get; you know tensile force in the reinforcement. How do you get? It is nothing but the you know friction force around the reinforcement 3.5 meters and s v into s h. What is that frictional force? It is nothing but k naught into gamma h again, right.

So, that is earth pressure is coming. So, you have to calculate the frictional force and see that the spacing, and vertical and horizontal spacing, and such a manner that, the tensile force that is there is transferred back to the system.

So, there is an earth pressure that is coming here; if you put reinforcement like this, there is a friction develops. So, all that forces again transferred back to the system. So, there is what we do, and if you want to analyze that, conventionally we can design it, like as I said, we have some rules where it should be some based on that earth pressure you can calculate s v and s h, and length is also it should be 0.7 times h; that is what we can see; what is the length here? 3.5 by 5.7 times. So, and, but if you want to analyze that properly, we have to do a numerical simulations only right; for that, we have done it here.

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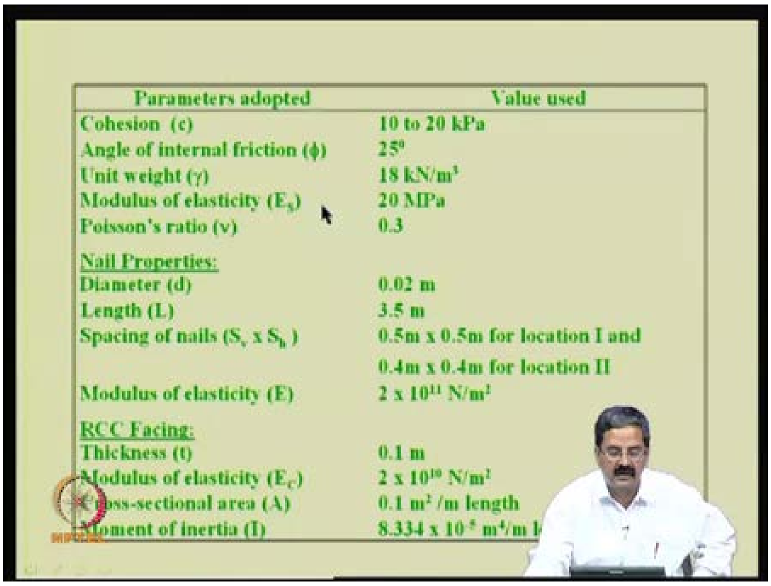

The cohesion is about varying cohesion is there, friction angel is 25 degrees, unit weight and all poisson's ratio is all there, e s is 20 mpa. Nail properties is a 20 mm diameter, length is 3.5, spacing is 0.5, 0.5 in one place and 0.4 in other place, modulus of the steel is this much, r c phasing we have and these are the properties.

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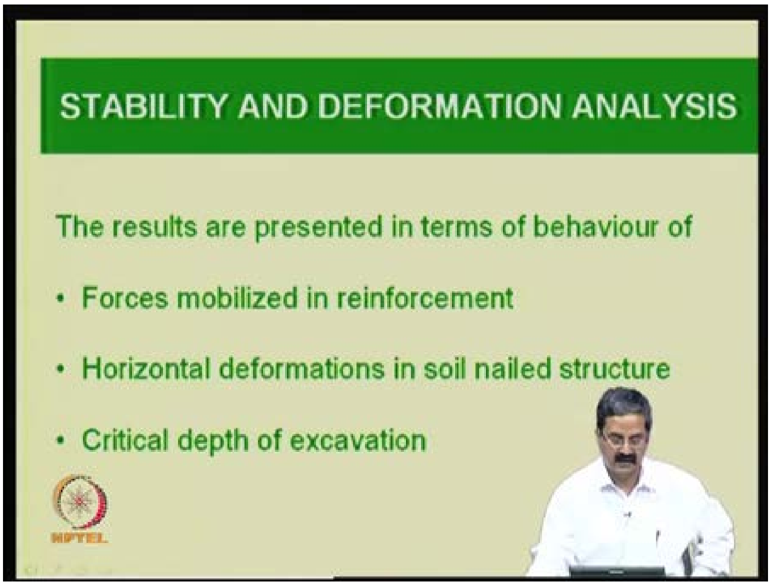

So, once you do that, how do you understand the effects of construction here; let us see that.

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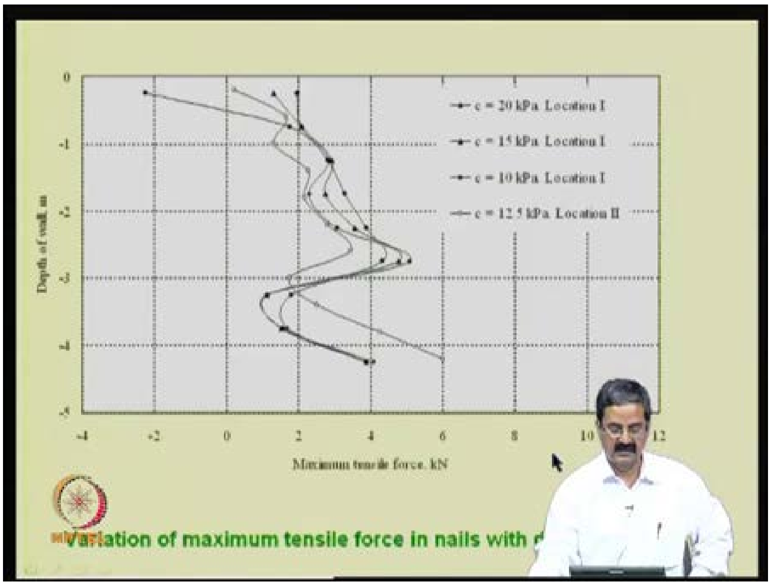

Actually, so, the maximum, see the thing is, the way that, see, in a numerical simulation, the way that we deal was that, you just excavate a bit and then put reinforcement, right; excavate ah reinforce excavate a soil and then put reinforcement. So, same thing can be modeled also in the numeric analysis, that you excavate and allow it to equilibrium; you know, in the flack or finite element analysis, you should just see that, what happens? Then, shear contours will, shear contours will develop and all that. And you can calculate, what should be the, keep on doing the same, put reinforcement and what is a force mobilized in the reinforcement; you know you can calculate what is a tensile force mobilized in the reinforcement also you can calculate.

You can see that, say for example, here its when you excavate up to minus one, there is something like you know minus 2 kilonewtons. Then, you come to minus 2 or minus 3 or minus 3 meters like that, you know, there is some change, is it not? So, what is happening is that, depending on location, like you know, the though the design is based on the same lines, depending on the location, because the small changes in earth pressure are there and c values are also different. So, you can see that, the pattern of tensile forces is different; it is not like a triangular or something like that, it is not a like we assume some you know see that. So, this is another one; the variation of maximum tensile force in the nails.

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Summary of critical depths of excavation

Cohesion (kPa)	Critical depths of excavation (m)		Location of maximum horizontal deformation	Critical Depth improvement factor
	Without nailing	With nailing*		
10	2.5	5.0	3.81 m depth	2.00
15	4.0	7.0	5.31 m depth	1.75
20	5.0	10.0	7.90 m depth	2.00

(* The critical depths of excavation are arrived based on the maximum horizontal deformation exceeding 1%).

What we did was that, some sort of analysis was done, where without nailing, it is able to stand for about any with c equal to 10 k pa, it can stand about 2.5 meters without nailing. So, after that, it collapses. So, then, what is a depth that which it collapses? It is we got like this. The critical depth of excavation is arrived based on the maximum horizontal deformation exceeding percent, like you know, what is happening? There is horizontal deformation that occurs, and in literature, we have seen that about, if the deformation is for stable walls, there is some sort of criteria that is given; we followed that criteria and we got these numbers you know; it can be even 0.1 also, 0.1, 1, whatever; some criteria has to be has been fixed up and we got these numbers.

So, a for 10 k p a about 2.5 meters, it can stand without nailing; if it is 15 k p a, it is 4 meters it can stand, and 20 k p a, you do not need nailing at all, but the fact is that it is all cohesion. cohesion cannot be (( )) you know it is a sandy material, suppose in then it can collapse, right.

So, what you should do? You should have to supply some sort of what you call cohesion - pseudo cohesion - which is in terms of the soil reinforcement. That is what I just gave you in one of the fundamental principles, that the advantage of the soil is that, it can give apparent cohesion which is permanent, whereas this is I am just doing a parametric study. So, I use this, then, another thing is the location of maximum horizontal deformation also we got. So, this is all depth improvement factors, is nothing but 5 by 2.5 is 2 4 by 7 and these are all the numbers.

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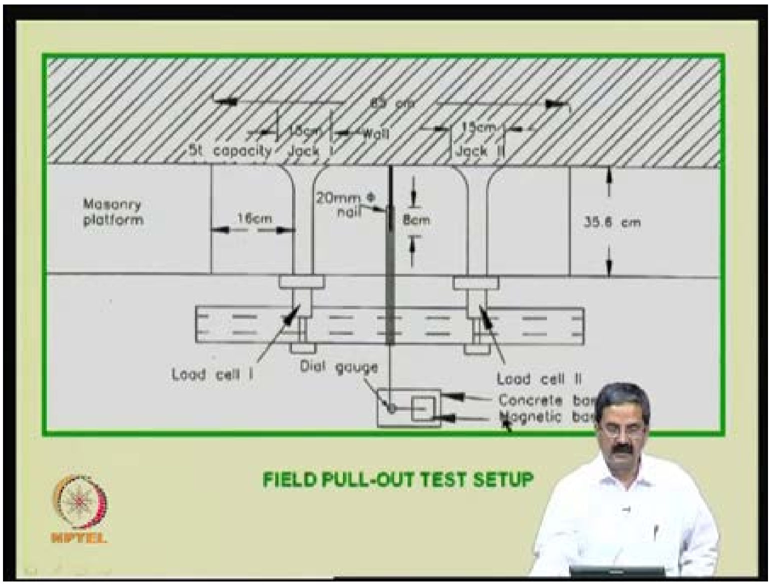

And we also did some sort of pull out test, that we in one of the for the nails; nail was pulled out and using some simple equipment that we have, some masters program.

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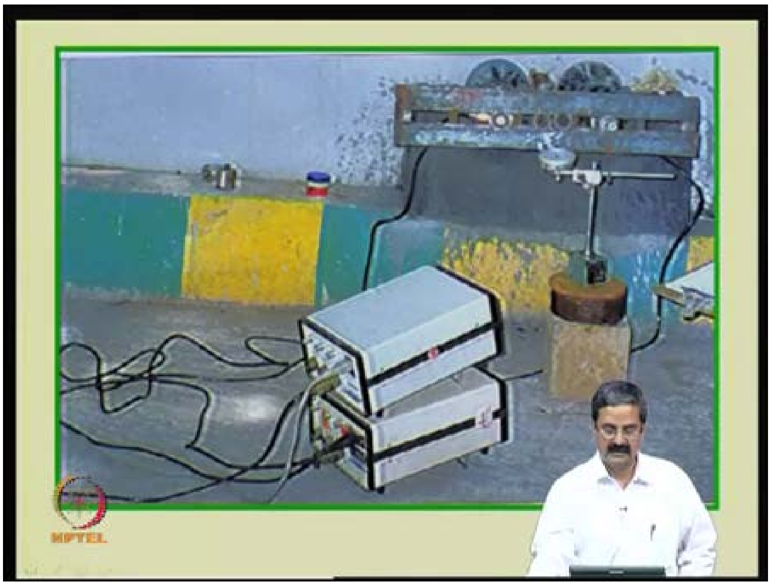

This is how you can see the nail was done.

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And this is another arrangement that we have seen

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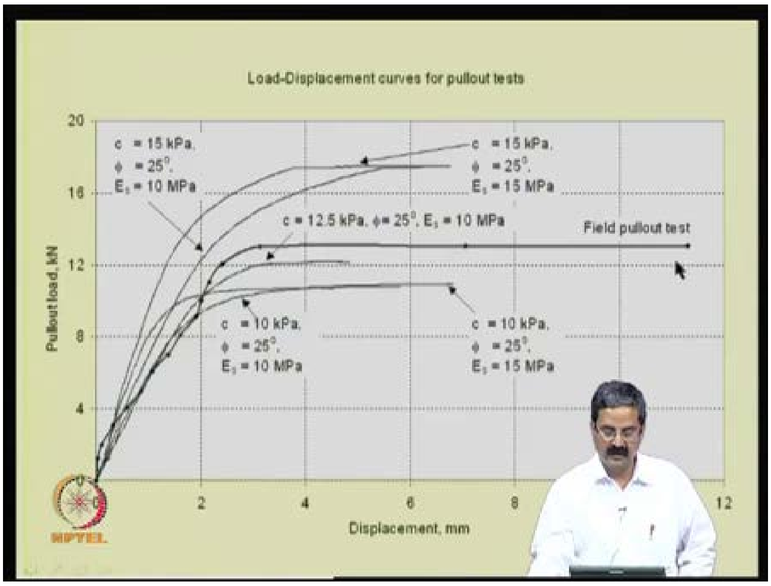

And this is a field pullout test result, and for you know, because we have assumed various values of c and phi, you know, because there are some variable values, where you know this is like a field pullout test, we could match this field. What are the values that this pullout field pullout test represent one can calculate? c and phi are more or less constant, but e 1 can change and you can get the number.

So, what it means is that, this particular, you know, field pullout test is an important parameter, because when you have so many variables, it is important to calculate what should be the representative c and phi, and it gives that using a pullout test.

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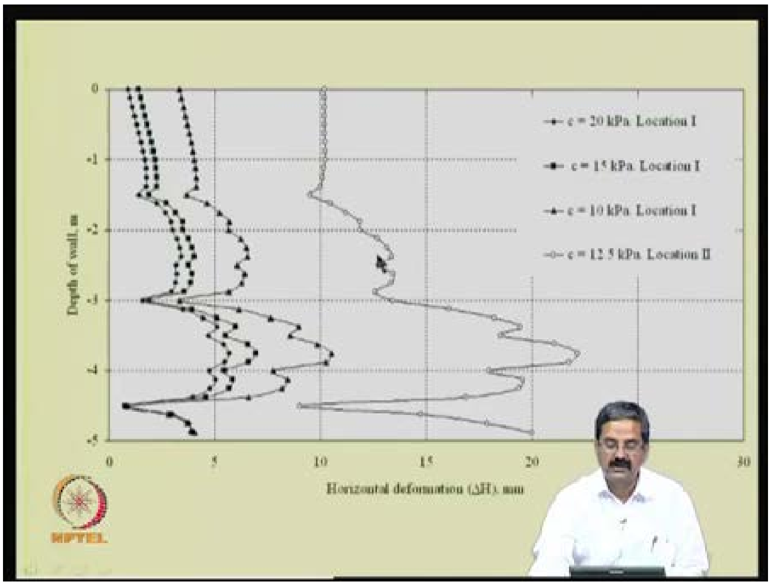

So, as I just mentioned, now what is the consequence of once you know this properties, how the horizontal deformation will change with respect to different cohesion values, like you can see that, at this, it is so high here. And in other case where you know, say for example, in the location 1, say this all the 3 points correspond to location one; depending on the say c is a lowest here, so you will have a higher deformation here.

So, like that why this thing is, why is it like this is because of the way it is done, we are exactly simulating the same thing in the field. When the numerical simulations also like, I excavate, then allow the soil to equilibrate, and then find out stresses. Then, put the nail also and calculate what is the deformation and what happened, all that I calculate, and then sequentially, if I do, if I plot all these deformations, I will get like this.

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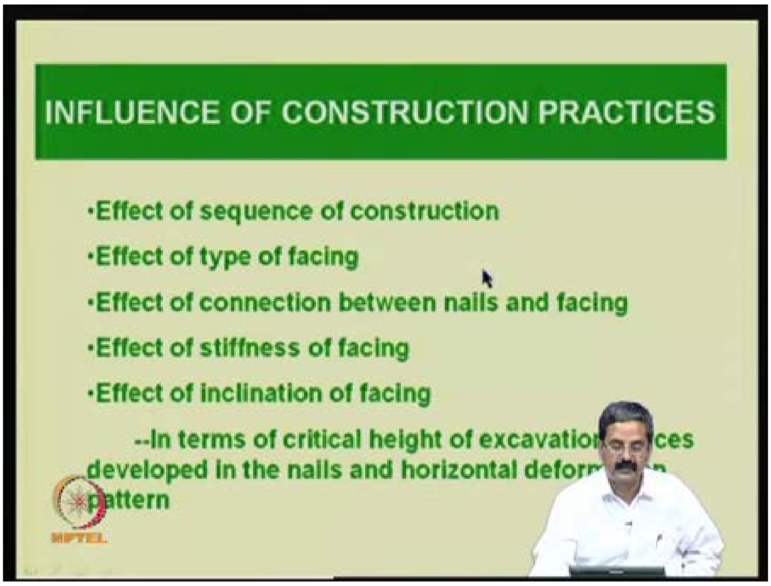

So, once you have these sort of information, one can understand as I said construction practice how is that it is influencing here. So, sequence of construction, type of phasing, connection between nails and phasing, stiffness of the phasing, inclination of the phasing also, we will just see that.

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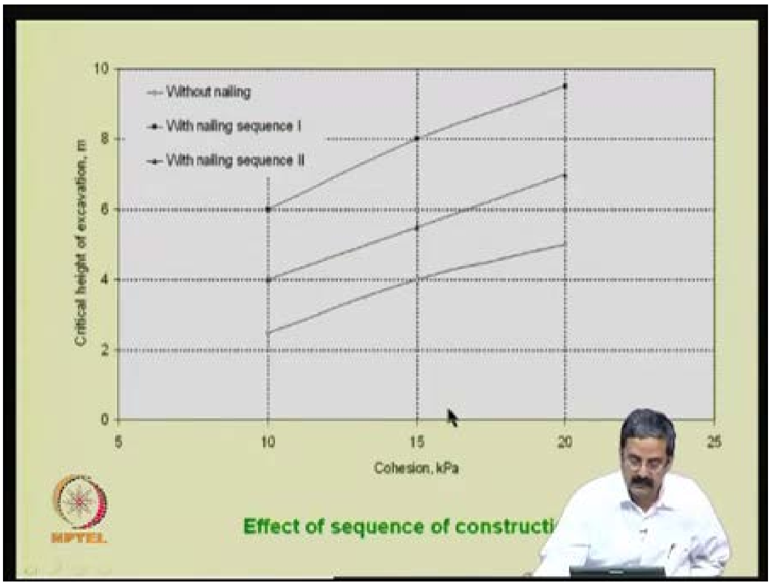

Actually there are two sequences one we had; one was that, you know, 1.5 meters you excavated see actually the total height is 5 meters, right; 1.5 meters can excavate, again 1.5 meters one can excavate and 1.5 meters one can excavates. Why is that 1.5 meters is required is, 1, 2 persons, 3 persons can stand and nail it. So, the average height is 1.5 meters. So, 1.5 meters one can comfortably excavate and then start nailing; that is what we thought.

And second sequence is, the other sequence I want to say, half a meter excavation, put a nail, half a meter, again nail, half a meter, again nail. So, which is better? Actually the things is, in the first case, where you are putting in 1.5 meters and then putting nailing, already there will be some deformation that get stabilized. So, putting nails later will not be that effective, at least in terms of the deformation like that.

So, we did some sort of analysis; based on that, you can see that, critical depth of, see, like without nailing, it will be lowest for depending on the c value. The moment I have a sequence one, which is nothing but 1.5 meters, and doing like that it is much better than that, the best was 0.5 meters and put a nail, 0.5 meters put a nail like that. So, this has a better stability than compare to others.

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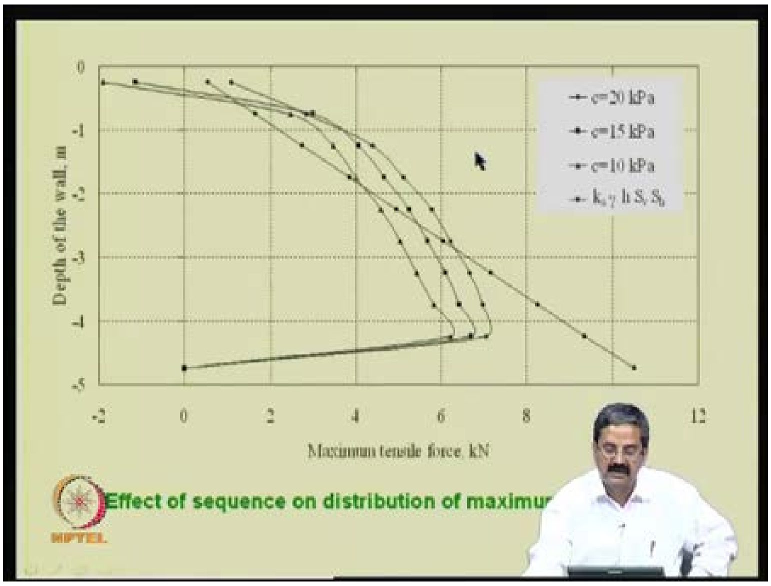

The same thing is also, like you know, the other important plot that we should see is that, I told you that how do you get the tensile force, k a gamma h into s into s h or k naught also you can have you know, depending on if you assume that the soil is yielding, you can put 1 minus sine phi by 1 plus sine phi, or if it is not yielding, 1 minus sine phi. So, this is how it is different than what you assume.

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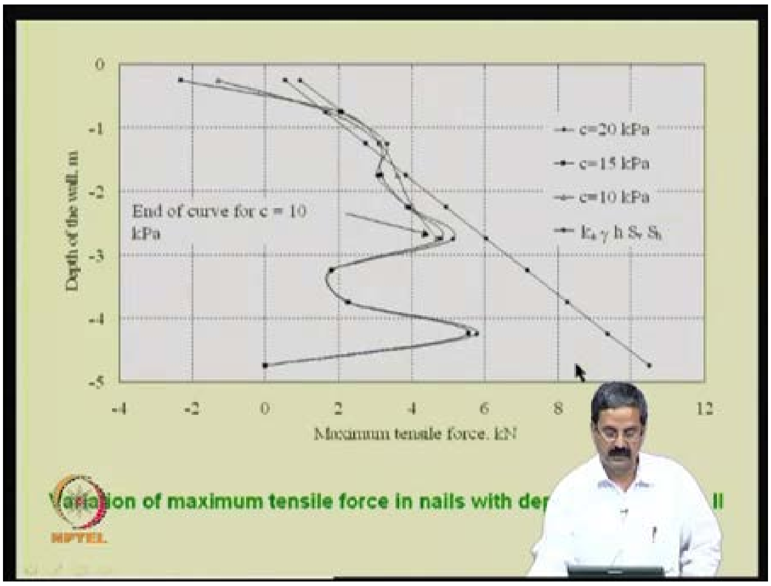

This is the type of other one that we have.

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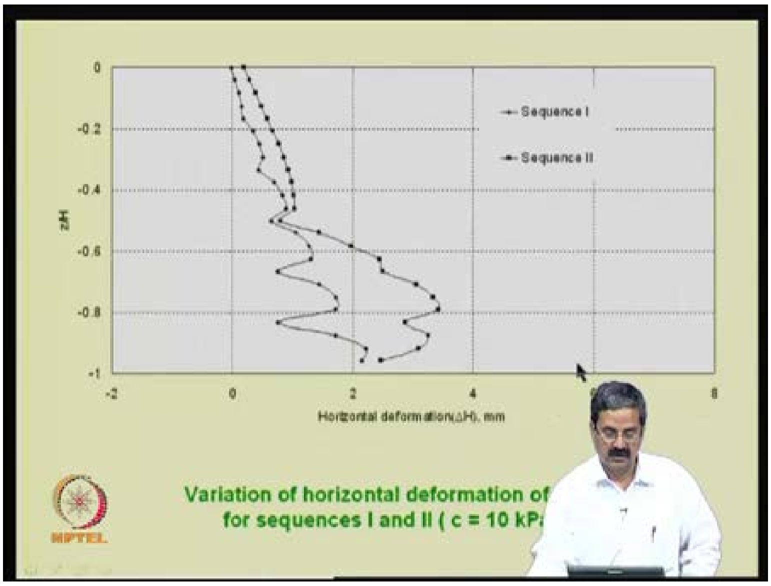

So, this is what I was telling you the difference between the sequence one and sequence two.

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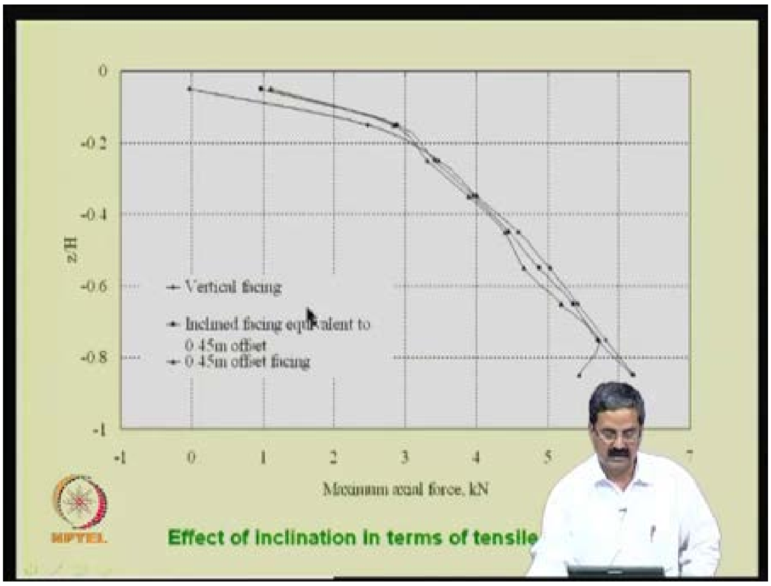

This is another type effect of inclination.

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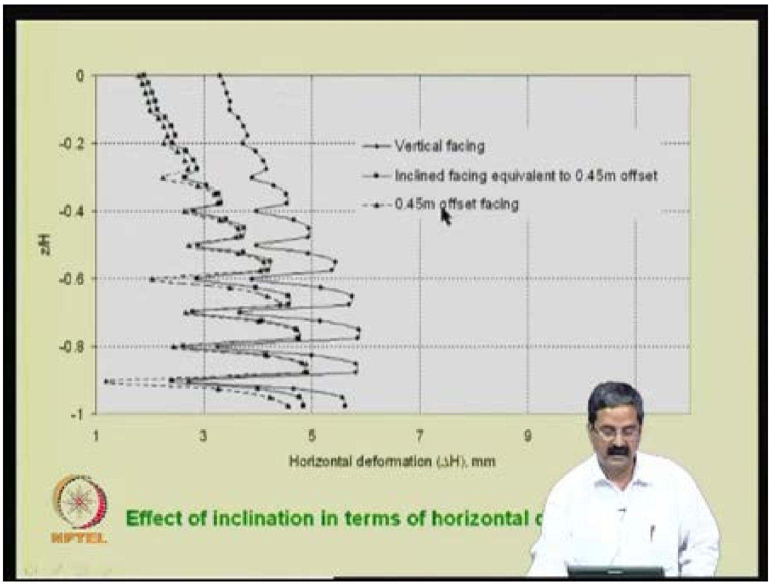

This is again in the type of vertical facing, it will have maximum deformation compare to other deformations, like you know, we will see that is what we are seeing.

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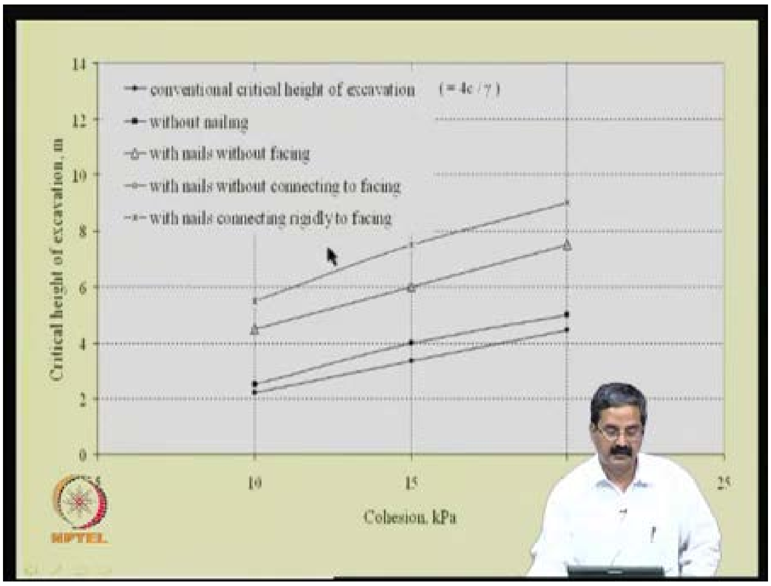

This is again same thing, like if you do connection, what happens? When you do with connections, what I just observed was that, it will be having higher critical depth of excavation, which means that, the forces are little transfer to that. And also actually we have seen that, the failures surface the shifts towards the facing and the mass of the soil, that creates earth pressure is going to be less.

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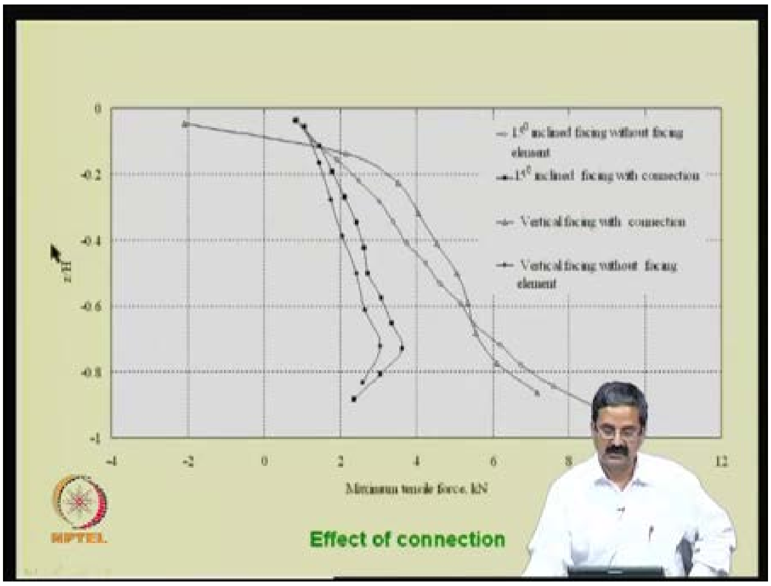

So, this is again about the effect of connections, where the vertical facing without this thing will have the highest pressure, like you know, yeah without facing this

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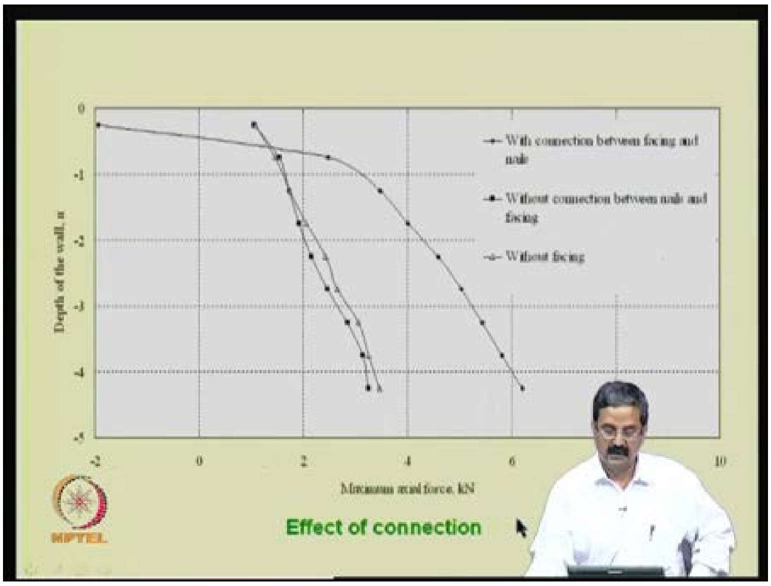

This is another one.

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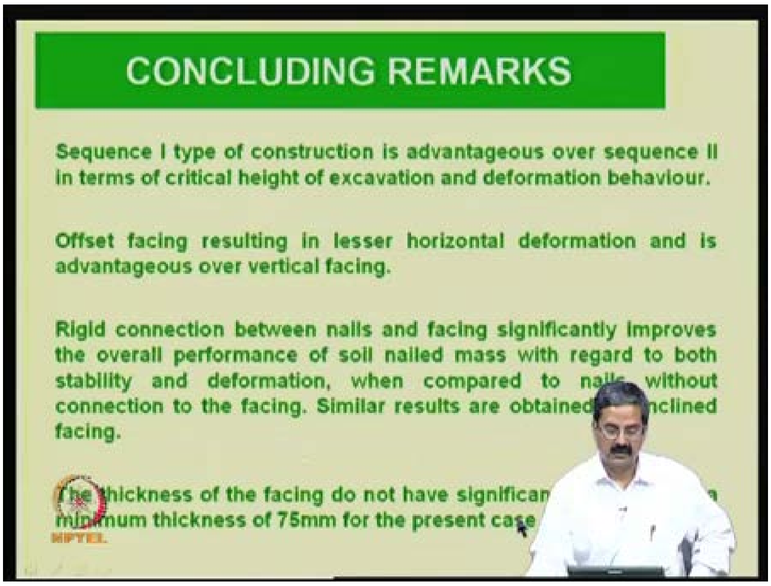

So, what I would like to just summarize is that, effect of sequence is very important and these are all some observations that we saw. Rigid connection between nails and facing improve the stability of the soil mass, both in terms of factors of safety or even deformation and all that.

And thickness also does not have a significant effect. So, is it 100 mm is ok or 75 mm, it is always a question. And codes - some codes - recommend some numbers, but then it is important that we have some analysis also done for that.

Thank you.