Ground Improvement
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Lecture No. # 25

Reinforced Soil Principles and Mechanisms

In this lecture, we would be talking about Reinforced Soil, its Principles in Mechanisms. As I just mentioned in the ground improvement, we have the use of inclusions; inclusions means, whatever, you know, say for example, a steel rod or anything that can be introduced to give a reinforcement effect that helps in increasing the bearing capacity, reducing the settlements, and increasing stability in whatever manner you want and all that. So, this is one of the significant aspects in the soil mechanics, where reinforced soil has proven to be a very useful technique in many geotechnical problem solving approaches.

I would like to just introduce, what is this stabilization, and stabilization by external means and what is a stabilization by internal means. We are all familiar with retaining walls, say for example, cantilever walls or a gravity walls and all that. There is some force acting, say, because of earth pressure or because of the earthquake force and all that; we try to reduce that or nullify that force by, you know, putting some sort of a material, say for example, gravity wall; the weight of the gravity wall itself will take care of the pressure acting.

So, we use an external system. You have a soil, soil creates a pressure; to withstand that pressure, we have a gravity or some sort of a retaining system which can stand against that forces. What we do is that, we try to... the other way of finding that is that, you have a soil that is creating pressure; so, put some sort of reinforcement inside, because of which all that forces that are coming on to that retaining system or minimal or negligible; and to that extent that it is very stable also.

So, what we say is that, this is an externally stabilized system and the other one is internally stabilized system, in which we have reinforcement introduced, and they intersect the failure mass and failure surface, and deflect the failure surface beyond higher, you know, beyond certain failure zones; and there, there will be a higher shear resistance mobilized along the failure plane, and that helps in having higher factors of safety.

So, for example, there is a, say, you have excavated 1 meter of soil, and then what happens is that, if you excavated one way, 1 meter of soil, there is a type of a wedge formation that can come; there is a tendency for it to slide. So, one way is to see, that you put some sort of a member, external member to see that, that is stable. So, you should be able to calculate what is the horizontal force is, and you should see that you should also calculate, so that, one meter excavation, some weight, that can stand that horizontal force. The other one, other way is that, you do not allow that force to develop, put some reinforcement inside, so that, the force coming on to the external surface, the outer surface is minimal.

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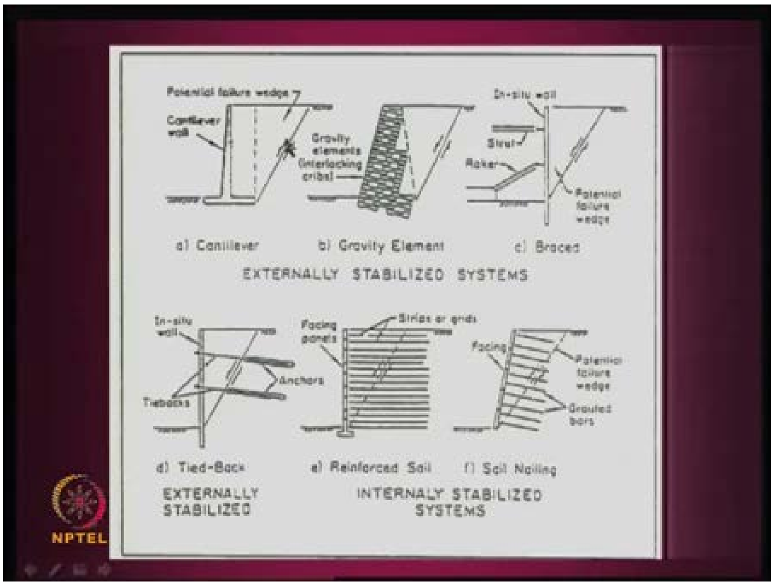

So, this is what we do. Like, just some examples of the externally reinforced soil systems, like we are familiar with a cantilever walls or even gravity walls like this, where you have a, say for example, you have a potential failure surface, and then you design all this retaining wall for the weight of the soil here, then the earth pressure acting here and all that. And what we do is, other way is that, we have a braced excretions; sometimes this is a failure, soil failure mass, then we put some sort of braces; like you have a collapse, say, we must have seen for pipe, the digging, you know, for pipe lines, the pipe lines. Say, there may be a 2 meters of pipe you would like to put there. So, you have to just excavate little bit of 2 and half meters on either side or 2 meters pipe you are trying to place there. So, that excavation should not should not cave in.

So, you try to put some sort of struts like this tensile members and then at the bottom also like that you know you try to create some system where this a retaining wall is stable. The other way is, that you try to put some there or, you know, this is what you call externally stabilized systems. The other way is that, we see that you have a tied back like this, is a failure mass; we know this is a weight of the failure mass, we try to put some sort of anchors here, and these are all tensile elements; we call them as tiebacks, tie, tie is tension member, that we know; and the tie tension member holds this wedge.

Say the two reinforcements in this wedge will hold this thing, and this, we anchor it here, you know, this is called anchor you know. Anchoring means holding it like, this is a tensile element and then it is hold here, because, you know, there is a bond resistance is higher here, it is held here. Then, once you do like this, then the pressure coming on this is quite less; so, is an in-situ wall. This is called tie back wall, the second thing what we do is that same as it is a actually nothing, but the reinforced soil like we are trying to put all this reinforcement in successive manner, that the earth pressure, say for example, k a gamma h or k naught gamma h, whatever depending on the state of the soil, whether it is close to earth pressure, activated pressure or its k naught.

Say for example, if the depth is not going to be very high, it will be k naught; but, if the depth is going to be large, you know, there is a tendency for the soil to been active condition. Then, there is a movement; when the movement there is a movement, the pressure gets lessened.

So, this is what is called reinforce. The technique in which, see, you try to, if this a failure surface, you try to put all these sorts of reinforcements, and this is one actually one should he may wonder why there are only 2 members here. There are many numbers here; the difference is that, actually, you know, the here, the tensile force requirement will be very high, but the same tensile force is distributed here; that is very important. And this is, this is, somewhat in terms of the construction; this is somewhat little expensive compared to this one; that is what people have seen.

The other one, the most classical case that we have been very familiar with this, is a soil nailing, in the sense; this is a failure surface and you put a series of nails like this, so that, the earth pressure is not developed. So, the moment the earth pressure is not developed, then you do not need anything here. So, put simply, some sort of facing and then it is alright.

So, this is all called externally stabilized systems; these three, and this is called internally stabilized systems; and over a period of time, we have seen that, the stabilizing the soil using some of these techniques is much cheaper compare to this, and as you increase the height, say for example, beyond 3 meters or 4 meters or even say, for example, I was taken the case of 10 meters or 15 meters, definitely they are going to be 30 percent cheaper, is easier to do. And, for example, here, as you the increase in height is, there may be, you have to go for counterfort retaining wall right? Here, that distinction is not there; whether it is 10 meters or 20 meters or 30 meters, same technique; but you have to stager it in some sense.

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So, that is the factor of safety, needs to be calculated properly. How this soil reinforcement technique came is that, actually, it is, people have been using this soil reinforcement for a time, from the time immemorial like, you know, people say that even when you make Ganesha idols, you put some sort of fibers, so that, the shrinkage cracks are not there and all that.

Here, the same thing like this is a typical diagram. The soil reinforcement technique in the recent times was discovered by one Henri Vidal. He is actually a French engineer, working in a, you know, in l CPC France, where he went with his daughter to play, you know, on the beach, and his daughter is a quite young girl, and the job, her job was to take the sand, construct a small heap like this; like this, you see the heap, then jump on it.

Then, what happens? It collapses, right? But then, what she does was that, what she did for some time was that, she took all sorts of pine needles there, again jumped; what happens? This will not collapse. So, he finds it very interesting, and then he, why he is he was wondering, why is this thing is happening like, you know; the thing is that, you can even construct, you know, the base width, say for example, we know that the soil angle, repose angle, of reposes 25 degrees.

So, which means, that you cannot construct a slope beyond 25 degrees; but, in this case, if you put the sort of material, you are able to construct slopes up to 50 degrees, which is quite interesting. Then, even the height is also more sometimes. So, for the same base width, height can be more or you can use, an angle of repose can also be more, so, that is very interesting. So, then, he finds it very, then very challenging, and then goes back to laboratory, and then finds that the friction between the soil and, say for example, the sand here, he is, and then the reinforcement is responsible for this stabilization.

Why is that you have an higher angle of repose or, you know, higher? The height is more; it was able to understand, that it is because of the friction between the soil and the reinforcing element, and then, that leads to some sort of tensile force mobilization; because, the moment there is a friction between the soil and reinforcement. There is a tensile force mobilization, and as long as a tensile force is operating, like, it is alright, you know, you are stable. So, he, after that, he goes back to laboratory, does lot of research on many varieties of reinforcement elements like, you know, it can be many things like, you know, steel rods, then strips rod, many shapes of metals, and all that and comes up with a design procedure to resign a retaining walls and to control landslides or the slope stabilization problems. In fact, the first application of reinforcement technique was in 1966 or 1969, when the first wall was built. In fact, you can see some of these figures in my book which is soil reinforcement and Geosynthetics.

And, where the first time, they had did, that is, thing, and then they found it; he developed a design procedure The design procedure is again very simple; we know that the retaining wall has to be safe against a external stability; first, external stability in the sense, that bearing capacity failure, then sliding failure and rotational the over turning failure; all these things are there, that is a standard procedure. Now, you have a reinforcement element, and since you have a reinforcement element, you should not lead to stability. So, he was looking at... so, tensile; see the thing is, now as I just mentioned the force, tensile force is mobilized.

So, the reinforcement will have some tensile capacity; as long as this tensile capacity is more than the tensile force generated, the system is safe; so, that is a factor of safety. Like, you know, say, the tensile capacity is say, 100 tons and the tensile capacity in any member is say, 50 tons, so, 100 by 50 is a 2 factor of safety like, there is a lot of capacity, but factor of safety is 2 now. Similarly, that material should not come out; say for example, this is stable, but I should not pull it out; if I pull out, what happens? The pull out resistance is low, so, even the pull out, the tensile force generated, should have a, you know, like as I just showed in the diagram; the anchoring, it should be anchored. So, it should have some, you should not come out. So, that is called... there should be sufficient length of reinforcement; say for example, if there is a short length, and if it comes out, there is not; it is going to collapse, it does not mean anything. Say for example, we have small fibers here, they may be little helpful, but it is not going to be so much helpful. So, this is one important thing.

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So, he finds that actually, this is the origin of the reinforced soil technique, and after that, he develops that as I was just mentioned went back, to laboratory and perfected this technique. This another small example, you put some layers of reinforcement, you know, anything and you just stand on it. Definitely, this becomes like this, you know, you cannot you, say, already you can see that his leg is embedded in soil and the they have equal height, weight, volume; everything is same except that you have a reinforcement here; everything is same except that the they have reinforcement. Here, you can see that it is able to support his whole weight, but here, it is not that. So, this is actually why it is. Because, this reinforcement element is, you know, taking care of the friction; I will just show you that.

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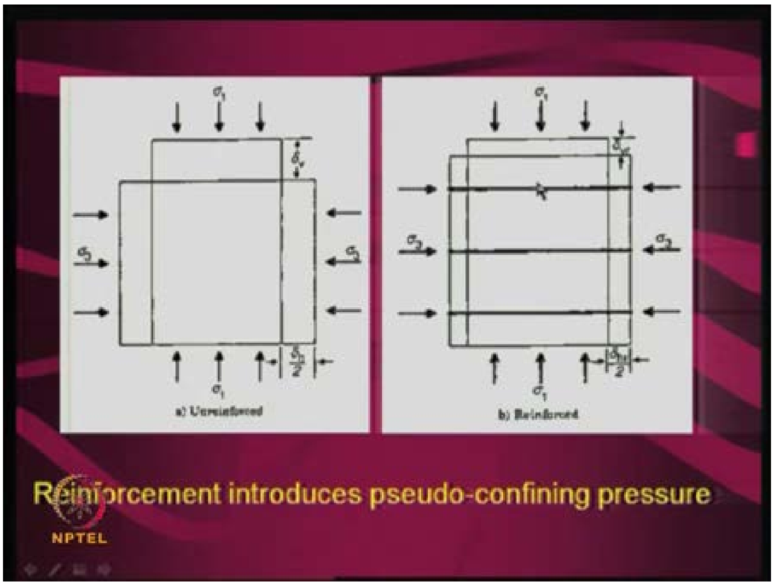

You can see in this figure that see, you have an element, and you apply some load sigma 1, and it attains equilibrium; it goes to sigma 3, right? So, you have vertical displacement delta sigma v, then horizontal displacement delta sigma h by 2 on either side. So, this in the case of unreinforced system, like I just mentioned like this, you have a system like this, and what happens? The moment I put the reinforcement, there is an applied load like this; it starts acting like this, then there is a resistance here, the opposite direction.

So, it does not move at all; not so much, you know. There is a small movement, but, you know, the thing is, to generate a friction, it has to move little, small movement is required; you can just see that it is a delta v r delta h r by 2; you know, it can be very small. So, but then, we can see that, there is a, you know, it does not collapse at all like we have seen that particular figure. So, this is a principle reinforced soil, in which there is what is called this reinforcement. It is like, you know, you are applying extra pressure, confining pressure on the other side, so that, whatever is a vertical force, there is a lateral force that is coming here, right?

So, that much, that is what I meant by pseudo-confining pressure. So, there is, because of the friction between the soil and reinforcement, some sort of pseudo-confining pressure is introduced, which makes the system stable; unlike this case, where there is a total collapse, right?

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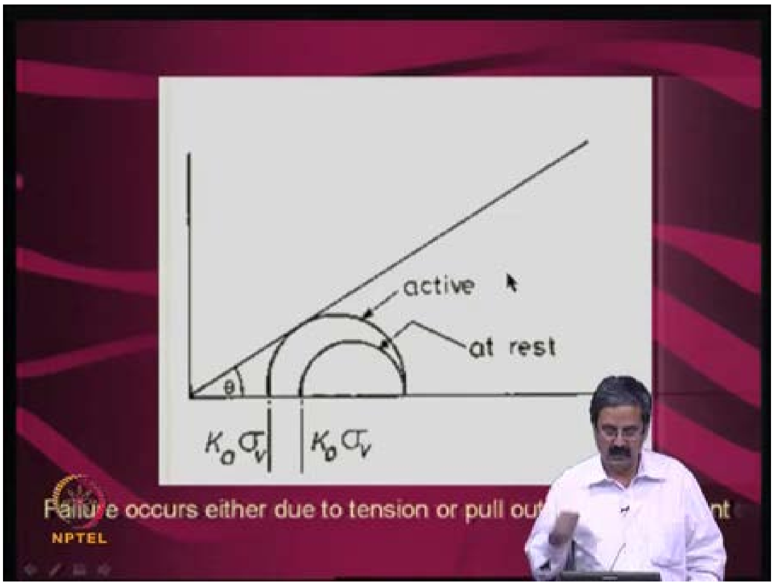

So, this is a very simple principle, and to operate it, a very effectively, some more requirement is there; that here, another example like, suppose the soil as I just said, it is at rest. So, this is actually, this is a Mohr circle, you know, this is a normal stress, this is a shear stress and this is a friction angle of this; and actually, you know, this is as long as, you know... In the previous diagram, we have seen that there is a vertical force and then there is a confining pressure developed, which is nothing but, as I just said, extra confining pressure, which you can say, is k naught time sigma v; you know, lateral stress is k naught time sigma v.

So, as long as k naught is there, k naught means earth pressure at rest; the soil does not move, but as the movement, there is a small yield like, if say for example, if the pressure increases, there is a yield; what happens? So, this is actually, this is a sigma 1 k naught; sorry, sigma v; this comes like this. So, as long as the Mohr circle is here, below this line, there is no failure, right? So, you apply some more force, sigma v, it again mobilizes equivalent pseudo confining pressure k naught sigma v like you know I may just increase a sigma v and then again there is one more circle that can come here and it k naught sigma v.

So, as long as the circle is within this, below this line, it is safe; but then, there is also a possibility of little yield, if there is a friction between the soil and all that it may touch this thing. So, essentially, our objective is to see, that these two conditions like, you know, essentially, you should not or it can even get chopped off, you know; tensile failure, you know, it can be because, you keep on applying higher normal stress. Say for example, if there is a slip circle here like, you know, you keep on increasing k naught, k naught into sigma v, then the failure surface, if it is within this, is alright. But, if it touches and then there is also a little bit of yield, then it leads to some sort of, it may touch this line. So, our objective is to see that these conditions are avoided, like tensile failure should not happen and as well as the pull out failure should not happen; that is the whole principle.

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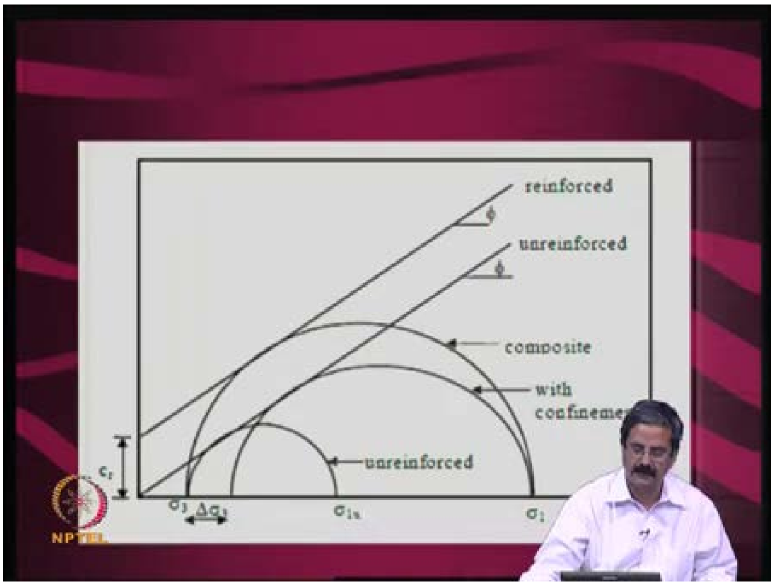

And this, another example that we would like to mention; like, what happens if you put reinforcement? Say for example, sigma 1 u, under reinforced soil, and then this is sigma 3; and, if you put, so, like... So, this is at, and then you have 2 circles, actually both are under reinforcement. So, what we say is that, if you put confinement or, you know, reinforcement, it behaves similar to a composite. Earlier, you have a reinforced soil of only, you know, for these 2, you know, it is a friction, is there, which is on the, for an corresponding to under reinforced soil. And, by this process of additional confinement, what we have done is that, there is a cohesion, that gets developed, that gets mobilized. We try to say that and it is called pseudo-confining, pseudo-cohesion.

So, like, with introduced some sort of pseudo-cohesion, earlier it was only c 0 and 5, equal to some number, say 30 degrees. Now, because of this, like, you know, the failure, you know, the thing is earlier, there will we have 2 circles now. For the same sigma 1, you have a higher normal stress taking; I hope you can understand that. It is a sigma 1 without reinforcement. Now, sigma 3 is same; then, what did I do? I put some sort of reinforcement and I applied load.

So, it yields at a point called sigma 3, right? It yields at a point called sigma 3, and so, how do you? Now, you know, I can get a tangent here, I can draw a tangent. So, this extra confining, this is what is called, you know, c cohesion; you have this advantage. So, for the same normal stress, it is able to, because of the higher, you know, we are trying to represent the effect of reinforcement by this cohesion; that is what it means.

What you are trying to do is that, we are trying to characterize the effect of reinforcement; that is what we are doing here. Because, if you are trying to design a reinforced soil, what is that? One understanding is that, yeah, it increases cohesion. So, in a factor of safety calculation, if you know how to calculate c using reinforcement, so, c equal to 0 phi equal to 30, say, it gives the factor of safety of 1.02, then put c equal to 10, 20 Kpa and phi is same, then, the factor of safety could be 1.08 or something. That is may safe, so that, cohesion can calculate here, this, what earlier people were doing. So, the advantage, you know, people have realized that reinforced soil technique is going to be a very effective.

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So, it has three components; one is a reinforcing element like a strip or a grid or a sheet or you know anything. Then, facing units to prevent soil from erosion; it can be pre-cast concrete panels that we see; metal sheets and plates, gabions, welded wire mesh, shotcrete, wrapped sheets of geosynthetics, anything. Then, backfill soils, you have some specifications here; that, we will discuss. You can have local soils, marginal materials; even fly ash can be used. In fact, I used fly ash and many of at least 2 projects.

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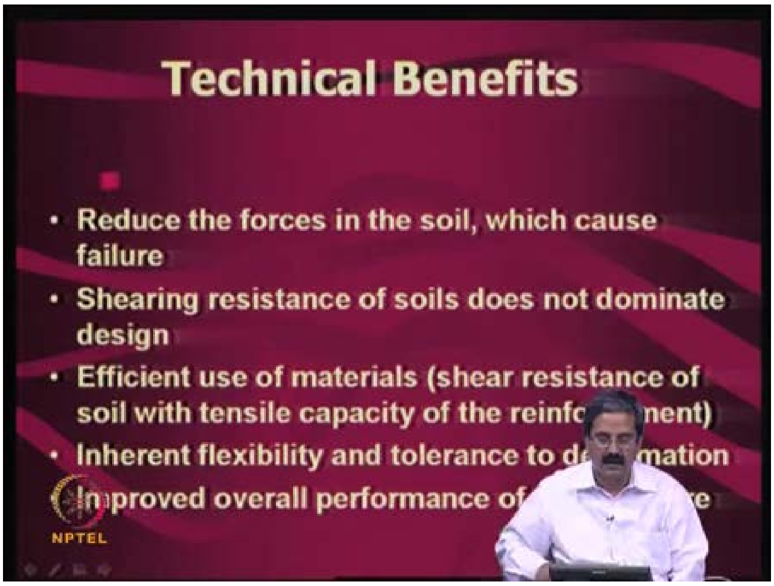

Why is it, the technique has been effective? Actually, the thing is that, we should see, why the reinforce soil is effective, and from technical angle and as well as economic angle. In terms of the technical advantages, see, if there is a force like it reduces forces in the soil, which cause failure like, you know, there is a disturbing force and earthquake force in the opposite direction, which means, that it reduces the forces in the soil, which causes failure.

The important thing is that, shear resistance of the soils does not dominate the design like, earlier, we had only c and phi. For example, if the c is not there, it is only a sandy material, it fails; that is, because, if you just do any stability calculations, c will have a very big effect than friction, you know, between the two. Like in any stability calculation, use any slope stability program, you have to give c, you have to give phi, you have to give gamma. So, gamma has a minimum naught, so much effect; but friction has good effect and cohesion has a highest effect.

So, but then, suppose, you take a sandy material, cohesion is very low, then it gives a problem; you know, the factor safety is less. Now, with reinforced soil, you are able to give cohesion, and now, you see shear resistance of the soils alone does not dominate the design. We do not need to bother about it; whatever is a shear resistance is available, is now, you are putting a reinforcement and increasing the shear resistance; that is an advantage to whatever you want.

So, that way, the shear resistance of the soil does not dominate the design. Then, efficient use of materials say like, you know, the soil is poor in tensions, so you are trying to mix or add some reinforcement elements, which will make soil as good tensile, carrying tensile, tensile force carrying materials. So, you are trying to make an efficient use of materials which is called, say for example, the both soil and, you know, reinforcement, they have an excellent combination of properties.

In fact, he must be knowing about, in soil mechanics, strain hardening and strain softening. If you put same sort of reinforcement, strain softening will not occur; I mean, it reduces. Actually, we will see that in some later lectures. The thing is that, there is a very nice combination of materials that leads to very synergetic improvement. Like synergetic improvement, means, in an association with soil alone is weak; reinforcement alone you cannot do anything like; so, by combination of these 2 materials, there is an excellent advantage. Then, the other important point was the inherent flexibility and a tolerance to deformation; because of this advantage, it is much more flexible, and the earth pressures, they get adjusted themselves and there is a deformation tolerance is very high.

See, in some cases, the deformation could be, as they cannot, some retaining walls cannot take deformation, it may collapse. But here, there could be deformation; but then, it could stand. In fact, I was seeing one case where the height of retaining wall is about 42 meters and the deformation that was coming was about 450 mm. 450 mm in a regular wall is imposable, even the height of the wall is 42 meters; it is impossible to construct an RU wall; I mean regular wall with 42 meters, because it needs heavy, I mean, lot of concrete quantities and steel quantities are required.

There, there is the reinforced soil technique, is a very tolerant deformation. So, reinforced soil structures are very useful; then, improved overall performance of the structure, the structure perform is also overall improved. Like, I will tell you the classical example of a permanent design. If you put some reinforcement in a roads, definitely the overall performance of the road will be very good, why? Because, the way it acts, say for example, you know, as I said load distribution, load distribution of the what is the concept in payments is that, if there is a load, traffic load that is coming, it should be well distributed.

So, how do you do that in the field? Actually, it is because you have various layers of materials that are putting; but instead of that, you put a geo-grid there, excellent. There is no problem at all. So, the performance is, its number one, the thickness of the payment has come down; number two, there is a overall performance of the, you know, say, load dispersion characteristics. And all, by somehow, with this process, it improves the overall performance; that is a very important advantage.

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Then of course, the economic benefits like, one is the cost savings relative to other alternatives time, and again people have seen that these techniques are going to be very, very effective and very economical. Then, these will enable the use of locally available materials and poor quality fills also. Like as I just mentioned, fly ash could be used, bottom ash could be used, in many any materials could be used; but one should do proper quality control test and see that, that is alright.

The other one was a land acquisition. Because, you know, in many cases, I showed in the previous case, you know, like a railway line is there, land acquisition caused; on either side, you have to construct big slopes. Say for example, 1 is to 2 slopes, like 2 horizontal to 1 vertical, 1 vertical to 2 horizontal; if you just want a 10 meter embankment, 10 meters plus 20 meters on the either side. You have to say that 20 meters is required on either side of the road.

And suppose, you think that they are paddy fields; it is not. So, paddy fields are gone or if the thing that they are buildings, it is not possible to do at all. So, what is a best way? You make it vertical using this technique; you know, you do not need to really make it; whatever is tolerable, say for example, make it 85 degrees vertical; that is nice, so, their land acquisition cost could be minimum. And another advantage was, less construction time on projects. Say for example, there area, many, this as I said, it involves a use of precast elements, you know, precast elements everything fabricated like in RU.

In reinforced, retaining walls, you have to cure 21 days and 28 days. There are a lot of other things; here you have a precast element which you bring reinforcement. You assemble, put compaction, and it starts; you know, you can do very fast. I have seen many projects where the cost of construction, you know, is very well controlled, and you know, you can accelerate projects to keep up the times that are specified.

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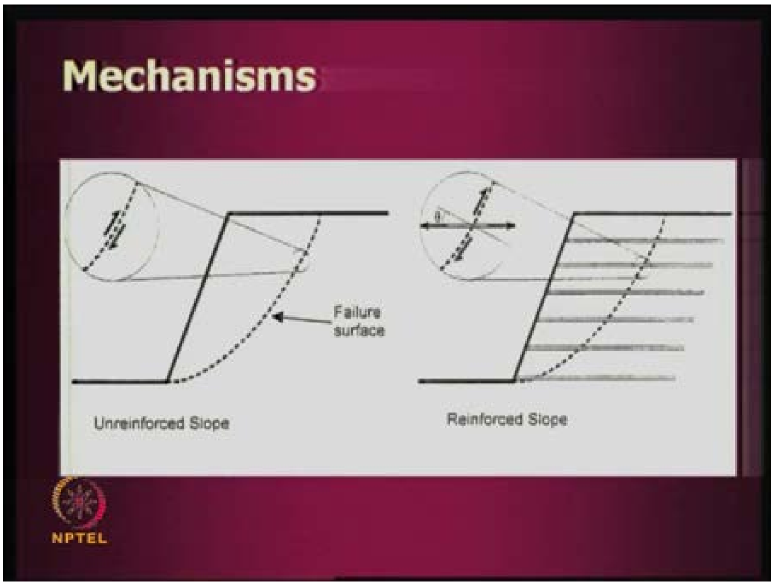

Now, what is a mechanism? Some more, what we saw is that, we have seen some idea, how reinforcement can be affective? We will understand it further. This is a under reinforced soil slope; this a shear resistance and the failure surface; and, you know, on the either side, you have a, you know, you know, it tends to fail; and then, there is a resistance along this line and all that. Now, you are trying to put a reinforcement here 1, 2, 3; there are 1, 2, 3, 4, 5, 6 layers of reinforcements, and they have an inclination at some theta degrees. You have a to the failure surface, you know, this is a failure surface; and then, it is an angle theta, this reinforcements are placed.

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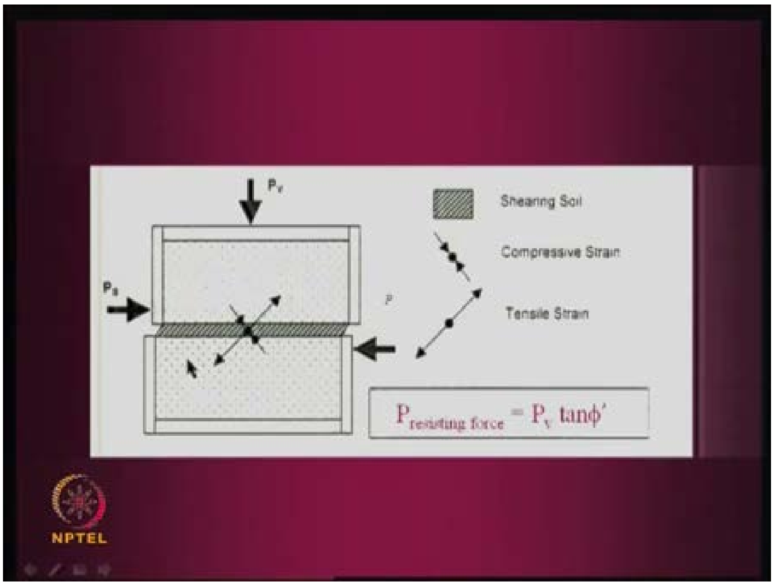

So, how does it act? We have to see and quantify, we will see that. See, this is analogous to a direction of box, you apply some vertical force, there is a shear force, right? And, what happens? This is a soil without reinforcement; and in this soil element, which is under sheared, there is a compressive force like, you know, because of this movement, in this direction, there is a, you know, its compressed in one sense like.

So, there is a compressive strain, there is a tensile strain; like in this direction, it is a tensile stress is acting; and in this direction, there is a compressive stress acting, both are perpendicular. And, how do you get the shear force? Shear force is nothing, but I assumed that it is sand, c plus sigma tan phi, right? Or p; resisting force is nothing, but p v tan phi. You know, we know, then friction angle of the soil and say like, you know, shear stress, shear strength equal to sigma tan phi; it is not strength know, it is just a force only, because we know the area of cross section.

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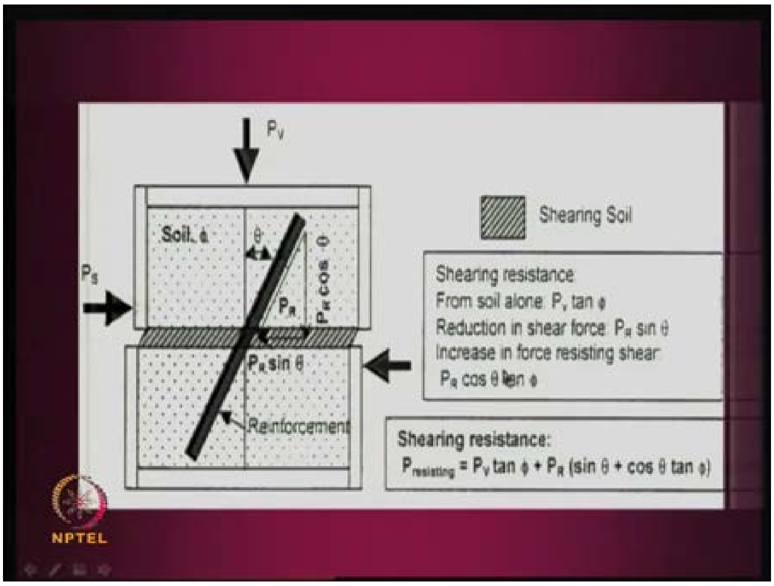

So, we try to put this. Now, what is happening here? If you put reinforcement, what is happening? This is a, see the way that we put was, we are trying to put in a direction of tensile strains little bit, because, you have to; if you want to take advantage of the reinforcement, you should put in the direction of tensile force.

So, I am putting in this direction; then, this is that angle, whatever. Now what I am trying to do is that, this is a shear force acting now because of the reinforcement. So, actually, I have a P R reinforcement force, P R in this; so P R, if you just resolve in two components, P R sin theta P R cos theta, you will get.

So, the shear force, P S, you know there is some opposite direction its acting. So, the way that I do is that, now, shearing resistance for soil alone is P V tan phi; that we have seen earlier. Now, reduction in shear force is P R sin phi, as a sine theta, as I said, you know like this is a. So, you have 2 theta; you have to resolve P R sin theta, P R cos theta you will get.

So, what is a reduction shear force? It is, P S is acting, but this much is reduced now. So, P R sin theta is reduced. So, it is reducing the forces, shear forces causing instability like, whatever is a disturbing force or the shear force, it is reducing by P R sin theta. Then, the other one was, it is a P R cos theta; it increases a shear force like, you know, say, P V is already acting, say for example, there is already a load acting, you cannot remove it, you cannot shear it. Now, with this, what is happening? You have a P R cos theta added extra. So, it definitely cannot remove it; shearing, you know, like, see normal stress is acting; this is a shear stress, if higher is a normal stress, higher is a shear stress. So, if you apply more force, you cannot remove it naturally.

So, you have P R, P R cos theta tan phi; that you have to resolve into that angle. So, this, say this is an angle, right? tan phi in this direction and the increase in force causing shear, right? Increasing. So, total shear resistance is nothing but P V tan phi plus, you know, this an extra component that comes here now, because of this reinforcement action, P R sin theta plus cos theta tan phi. So, you know, tan phi, why is it tan phi? You know this a normal force P R cos theta into...; you are calculating the force, right? So, this a normal force, you have to multiply it by tan phi to get into that shear force, right? So, P V tan phi plus P R . So, this is actually the extra shear resistance you are getting; earlier, it was only P V tan phi; you are getting this much now. You see that, this is a function of theta, which means, the angle and also the friction angle of the soil, right?

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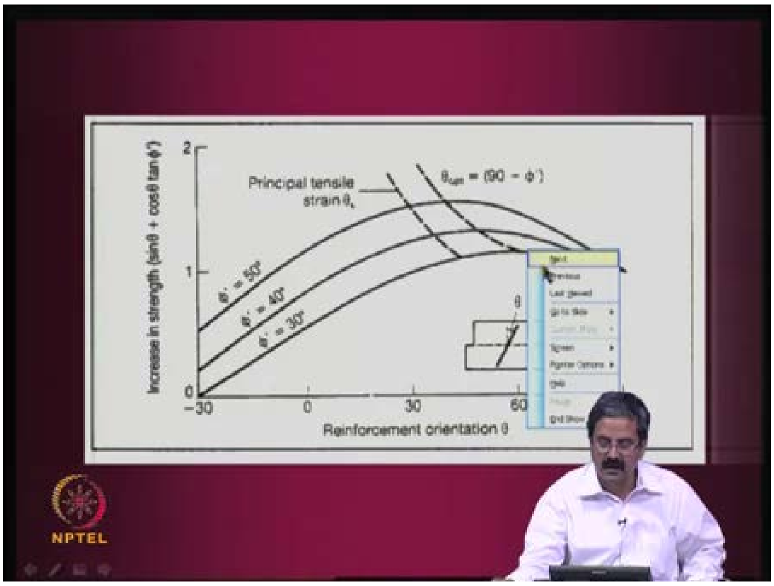

So, we will just write a simple calculation like, increase in shear resistance P sin theta plus cos theta tan phi and reinforcement orientation. So, what is happening here is that, the best orientation is like, you know, you can see you can plot like these diagrams, right? These are all principle strains directions. So, in this angle, you can see that it is maximum, like, you know, it is in the range of say, 1 or, you know, little higher, whatever.

You can just put some numerical values in these numbers like, you know, you can put some numbers here, whatever numbers you want, and then, you know, like P R P V, some reasonable number and see that. So, you will get this sort of diagrams, and it only shows that the between 30 to 60 degrees; the angle of inclination there, is an optimum benefit and it increases as phi of the soil is more that is all it shows like.

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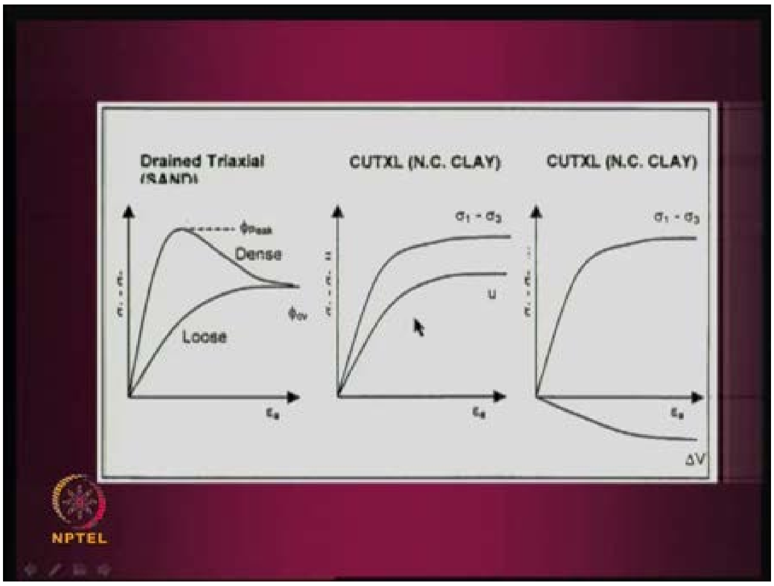

So, that is good. So, this particular thing leads to the conditions that see for example, you it is a very interesting observation that, say, I will take the previous example. You see, this, you know, even you know this particular inclination, whatever. So, it will be in the in the same angle, you know, the way that we try to do in the construction like, you know, you are trying if you place reinforcements while doing construction; they will be at an angle 30 to 60 degrees, the difference is not much; the angle is maybe say, 40 degrees, that angle is always achieved in the case of footing, how? The bearing capacity is there, failure surface is like this, you put reinforcement like this, it intersects a failure surface in the same angle roughly, say 30 to 40 degrees.

So, what it means is that, in many geotechnical operations, it is very easy, very nice to use this technique like, you know, normally what we are doing in geotechnical thing? You just put a layer of soil and then put a reinforce, put again put one more layer, and then compact it put one more layer, compact it. But here, what you are doing? You are doing compaction, then put a layer of geo-grid like, say for example, there is a wheel load coming under the wheel load, the bearing capacity is less because bearing capacity failure surface is log spiral

But, if you put reinforcement there, what happens? The and then it will be actually having the same angle, roughly 30 to 40, 60 degrees, you know, by, because, the failure surface is like this, like a log spiral; and it intersects that reinforcement at that angle, roughly, and you will have a maximum effect. So, for reinforcement applications of bearing capacity or even slope stability and many of these things, it is an excellent technique. Because, number 1, you can do it very easily in the field; number 1, say for example, this is very important, how? The ease with which the technique can be done in the field, because, you do not need to change many of your techniques. See, I have to give another example; people have discovered that a preset concrete is very useful in RCC construction, but the technique itself is so specialized, you will not have many preset concrete structures specialist; and you have an RCC specialist, suddenly you cannot ask him to become a preset concrete expert; here it is not. So, ask him to put a layer of geo-grid extra, and then ask him to compact; he is a very happy, because you can tell him that, yes, you are going to have a significant difference and the project is going to be finished in, you know, a shorter time and also that it can be economical.

So, this is precisely the reason that this technique has been a very, very useful in geotechnical construction; whether it is for the improvements of slope stability by nailing, reinforce soil or improvement of bearing capacity and all that. So, in a simple say, it is yes; it is very useful and one more; so, this is the precisely the reason that, you know, say for example, you can see like between about 40 degrees to about 60 degrees, whatever is that, you have a failure surface; and then, if you put a reinforcement, the angle is not in the same range roughly.

So, that is an advantage. So, you will get a... So, this is precisely the reason why many people have embraced technology without much reservations; and advantage is that, the three people who are very happy; contractor is very happy, because the owner, first of all, owner is very happy, because he has number one cost effective solution; then he also has, as I just mentioned, technical advantage as well as economic advantage. Then, the contractor, first one is owner is very happy, then the designer is also very happy, because he is able to give some design now, using this reinforced soil; you can simply he has to say that, yes, you put a reinforcement like this; you will have a good benefit.

The third one, contractor is also very happy, because he is able to finish the project very fast and it has been very useful. So, these three groups of people, if they agree together and then it is nice, right? So, before we go further, we should be able to understand what is this, you know, you have a now a backfill, right? Soil is there, and soil is to be compacted; because, to have a very good effect, the soil has to be compacted.

So, this is a backfill soil properties like, we know that, if you have a, say, normally we are trying to use sands as backfill materials in many of the fly over projects, and so, loose sand will behave like this; like, it reaches a critical volume, critical state volume at this point. Then, you have peak; in the case of dense, it is like this. This is what I was mentioning as strain softening, right?

So, now, this is in the case of drained, in the case of un-drained test. You see, you will have a pore pressure mobilize; this is the sigma, means, sigma, the geotextiles in the case of, you know, drain test, you will measure volume change also; these are all various types of stress and curves that we see.

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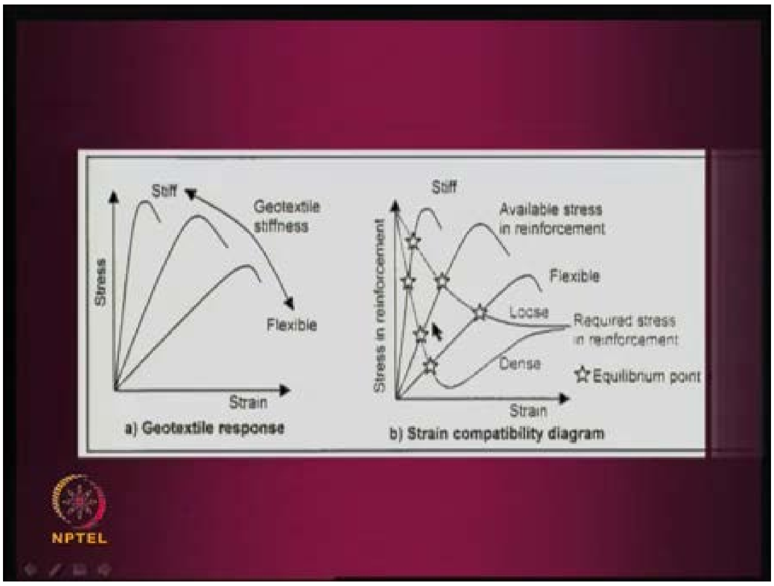

What we need to see, is how both reinforced soil as well as how the reinforced soil behaves; and as I was just mentioned, we have different types of reinforcement elements. One is called, one can be a steel reinforcement; in the case of, like, you know, steel reinforcement, like a geo-grid, like a steel grid, you know; it is very stiff stressing properties are very good, you know; stiffness is there.

Then, you have a geotextile, very flexible; then, geo-grid may be in between like, you know, it is a geo-grid is much better than geotextile in terms of the stiffness; that is the reason why we use it in many of the applications; even the steel also, we use, you know, like, there are companies that only supply steel as a reinforcement, there are some companies which only supply geo-grid as a reinforcement. There also some companies which use a geo-composite, you know; because, sometimes, you want high drainage in some applications, plus reinforcement you have this.

In fact, for one of the projects which I saw, I was mentioning about 42 meter high wall; they used a geo-composite which acts both as a tungsten material as well as geo-grid material, right? So, you have this material and you also have what is called properties of the soils. So, how do they match? This is very important, because, as I just mentioned, the performance of the reinforced soil is a function of the force mobilized in the reinforcement; is it not?

Say for example, you apply some force, you apply some load and you have reinforcement; this thing, the movement there is a force developed in the reinforcement, then it takes care of that load like, you know, there is a one component of that, the tensile force that comes into picture, it starts acting. So, how fast it can act before it takes more deformation is very important. You will see that here, that as I said in the case of loose materials, say for example, so, you can know that, in a, you take a reinforcement in the case of a stiff reinforcement, what happens? This is a stiff reinforcement here; this is a stiff reinforcement available, force available, force in the reinforcement, right?

So, like, you know, in the actually force, the way it force is developed is as higher as the strain; higher is a force in the reinforcement. Like, say for example, a stiff strain in the reinforcement, the stiff; in the case of a stiff reinforcement, you need less strain to go see that the force is mobilized, stress is mobilized in the reinforcement. So, in the case of a stiff material, you have a point here, right, which we will have low strain. Now, you come to a flexible member, you have a higher strain level, so, for example, this could be, say for example, 0.1 percent; this could be 4 percent, right?

So, but then, what is this? This is, you know, like you have seen one more, what is this diagram? It is in the, actually it is a loose; in the case of loose materials, we said that there is a, you know, you have seen in the previous figure, right? Dilation and, you know, the dilation, see if you just compress loose sand, it continuous to compress, right? Like, you know, 0.1 to say may be 10 percent, it continuous to compress.

Whereas, in the case of a dense material, it is like this, you know; the thing is, there is an initial compression, then it starts increasing, right? This is what the... So, this is an important thing. So, because of this, what happens is that, in the case of loose material, the strain, say for example, the, you know, to say, in the case of stiff materials, this is a force, I mean, this actually the combination of this, you know, this point. See, in the case of stiff material, and then this is a loose one; you have one point, this is another point, this is another point.

So, we are trying to calculate the stress, strain in the reinforcement as well as a strain in the soil depending on the type of soil, depending on the state of the soil, whether it is loose or sand. So, this type of diagram is called strain compatibility diagram, and this is very important. Why? Because, see, you have a loose material, the reinforcements, you know, the resistance only comes, the moment there is a contact; and then, the strain gets developed.

So, in this case, you see that, say, you take this case, these two. See, in the case of a dense material, the strain required is marginally lower than this, you know; there are small differences like, if you just draw 2 vertical lines here, this value is somewhat, this is a dense material; this value, say, may be 0.5 percent or may be 0.5 percent, this may be 1 percent. The strain required in the case of a loose sand is little higher compared to that of loose, dense sand; here you can see big difference like strain required in the case of lose sand is much higher compared to that of dense sand. The same is a case, particularly, if it is flexible and if it is lose, you lose a lot of strains; but, whereas here, it is quite less.

So, as well as. So, this is an important advantage that, if you compact it very well, you will have this sort of behavior, you know; do you know a dense a dense materials tend to dilate, right? When they, when there is a tendency to dilate; and then, you do not allow the things to dilate; what happens? The effective stress increases; is it not the effective stress increases because of stopping of the dilation tendency; because, there is no place for dilation in the reinforced soil. So, all are compacted and all that, so that, dilation, it acts on the reinforcement. So, once it starts acting on the reinforcement, the more force is generated. So, you can see that the state of the, you know, loose sand or dense sand, whatever it is, it is quite important, and also the stiffness of the soil is also important. So, this is what is called a strain compatibility diagram and this is very important in the analysis of reinforce soil structures; particularly, you know, a density all specifications come on these lines.

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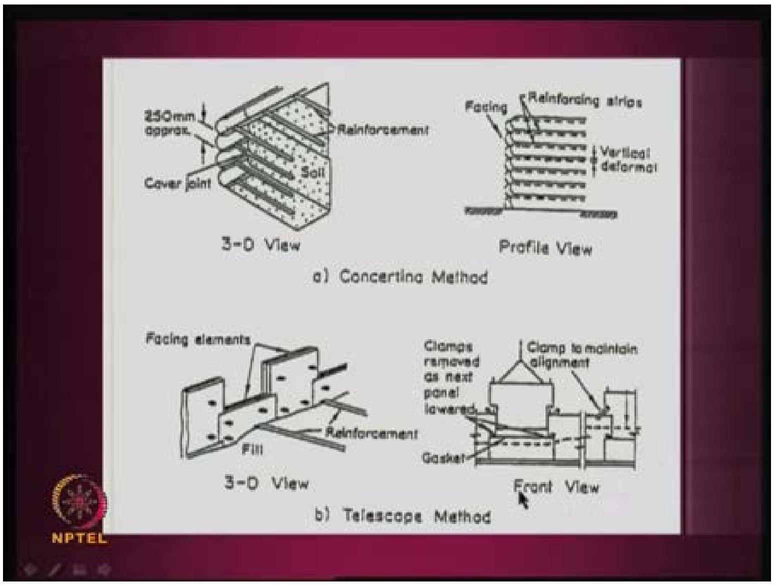

So, there are many techniques that people have been using in the actual construction and I will show you some of them. And, as I said reinforced soil is a construction technique, it is a and then the performance, I mean, the reinforced soil, the way it behaves in the field is a function of how well you construct; if you do a hopeless job, definitely it collapses. May be if the principle is very good, but it fails, because, if you do not implement it properly.

What you should do like, say for example, there are different methods in the olden days, you know, that to when the soil was developed like this is called concerting method. This is one of the methods that is coated in literature. Like, you take some, you know, they were all in a sheets, you know; you can have an aluminum sheets or whatever sheets because, I told you, if you have reinforcement like this, the earth pressure coming on the facing is minimum, but then what happens? You are trying to connect the facing and the reinforcement is it, not you have to connect it. So, because of that, some force gets transferred to the reinforcement also.

So, for which, say for example, they there is so much tensile force; how do you calculate tensile force at any point? It is nothing but, say geotextile, you are using geotextile as more tendency for deformation. So, I use K a K a into sigma v, will be the hard draw force acting. And suppose, I am talking about S v is the vertical spacing and S h is per meter length. So, I am using, say per meter length of the geotextile S K a in to S v into K a in to sigma v into S v will give me the horizontal force acting at any point is it not.

So, you have, you know, the spacing and you know the vertical stress; vertical stress is nothing but gamma into height. So, gamma b, you know, bulk density. So, you will be able to know what a lateral force is, and that much is a lateral force that should be generated by friction, so that, it's opposites acts in the opposite direction. So, that much force you can calculate by this expression; like which I said K a in to sigma v in to S, S v, S v is a vertical spacing. So, that gives a horizontal force at any point and that should be equal to the tensile force in the reinforcement, say per meter length of the… So, I said 10 kilonewton per meter or 15 kilonewton per meter, like what it means that, it needs that reinforce soil wall needs 10 kilonewton in the opposite direction.

So, take a, go to literature, such a material that has a property like, you take any of the geotextile material that you have, it will be say 25 kilonewton per meter or 50 kilonewton per meter, it is fine for us. Because, as I said, if I have a 50 kilonewton per meter, and I only need 10 kilonewton per meter, then the factor of safety is 5, roughly in a working stress method of design. But then, having that 50, you have a damage factor, then you have time factor; for a creep cap factor; for environmental conditions factor; for what I said, life time. All that, there is some 3 or 4 factors that we will discuss in the next class; that once you do all those factors, like, you know, the 50 divided by 1.1 divided by 1.3 into 1.6, like that, you will get some number which could be, say 15. So, that 15 is more than the 10 required. So, it is fine.

So, that is how we have to do the design; and once you are able to design at every step in a some simple sense, then of course, there is lot of sophistication involved; but, in a way, the principle is that, you must be able to design all the spacing and all the reinforcement like this, and I mean spacing of the reinforcement.

The length of the reinforcement is again I, was said, you have a 45 minus 5 by 2 angle here, like a failure plane; that length you have to again, calculate the friction. You have already calculated tensile force there, much that frictional force should be, whatever is a frictional force should be twice of this tensile force mobilized; like as I said, tensile force is k a sigma v, I mean, sigma v into s v, right? So, that is a tensile force.

So, then you have to from where it cuts, you know, that you know the frictional area, the geotextile like, you know, that you have to calculate per meter length. Again, if you are able to calculate a friction force along the geotextile, it if it is more than twice, this it is alright. That is how the simple design is done; and the way that it is practiced in the field is that, you have a concrete panel facing, and you have some sort of this thing here like so; this is in some two spacings of, you know, 250 mm; it is in terms of the compaction lift thicknesses. And these, all they are different methods of doing that, and we will see more of this in the coming classes, because this is one technique that as a, you know, made a very big in impact in infrastructure, you know, construction of fly-overs and all that.

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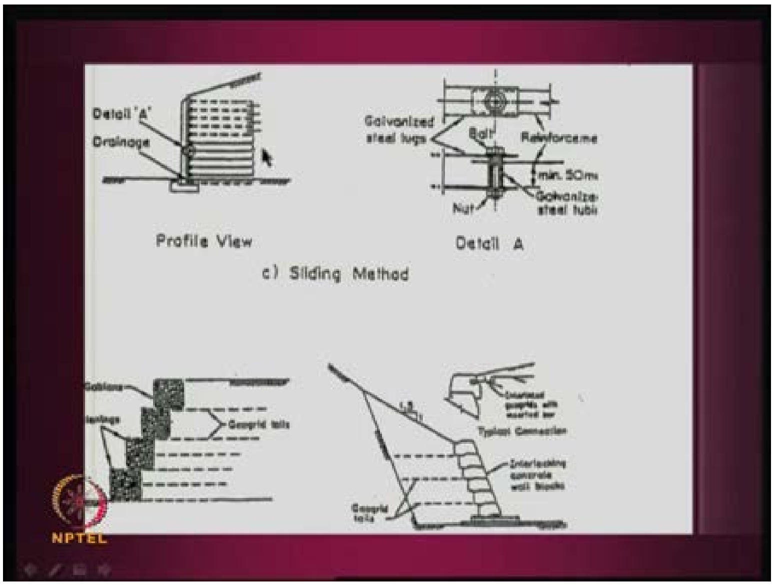

This another one that we would like to show; like, say for example, you also have some drainage elements here, this another method. So, you have, you know, even this can be a gabion type of wall; you can put reinforcement like this geo-grids, like this, so flexible; and in the case of slope also it can be done like this. Actually, you know, you can have different types of facings, you know; this is, we call it full height facing, you know. Like, as I said in one case, the way we have to re-do was that, we made some members, you know, 2 members; we could we put directly concrete into that, put, joined; see the geo-grid was inside. Thus, then, we had a shuttering like this, then put some RCC, you know, just to have a facing, you can do lot of things, and as I just showed the other day, you also have what is a segmental block.

Segmental block means, see this may be a big height panels, may be difficult to handle, but you may have a simple, what is that? A interlocking concrete wall blocks know, they were which can interlock; and, you know, one fellow can lift it and put it, the other fellow will take the reinforcement and stretch it; then, you compact it here. Then again, one fellow will put this and then put this, and like this, you know, they keep on doing it; and then, you do whatever you want; so, that is it.

Say, once this design is complete, essentially, we care looking at these earth pressures, and all that; it is very safe, because, safety is very clear. I showed you that fundamental principle in which I, as long as the forces are within the below the yields of the, whatever that the failure surface, this is going to be safe. So, you have to properly look at some of these fundamentals and you can, one can construct, you know, is it not? So, this is what I meant; say, and I am sure that, you know, this is one technology that has revolutionizes the cost of an infrastructure.

In fact, in ground improvement projects, say for example, you are constructing embankment in a soft soil like, earlier we are using stone columns; stone columns are being used still, but you put a geo-grid at the top or bottom, you know, it helps a lot. Even in a stone column, you can put what is called, a encasement of a, you know; see as I said, we know the failure mechanisms of stone columns in which there is a bulk formation, and all that you put some sort of a confinement, the bulb will not form. The bulb, if it does not form, it is very good, you know; because, bulb formation is because of it is a failure mechanism. If you do not allow the failure mechanism to take place, it is an excellent thing. So, like that, it has even for PVD's and many ground improvement projects; it has taken even geo-cells.

We will discuss it has really impacted in a big way. Thank you.