Ground Improvement
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Lecture No. 24
Deep Replacement (Contd.)

Hello everyone, let me continue on ground improvement and in the previous lecture we had discussed about vibro-compaction and of course vibro-compaction is completed before. But similar to vibro-compaction there is a topic vibro-replacement, which is similar to vibro-compaction mainly because vibro-compaction is when backfill is used it is compacted through vibration and again backfilled.

And deep replacement is almost similar because there are some mechanisms where densification will also happen and the main thing is that everywhere backfilling will be used as in the form of colour. And so, functionally to some extent, construction wise to some extent they are similar.

And because of that, I thought though module 5 is only vibro-compaction I have mentioned, but since it is related to vibro-compaction, I thought of introducing. And so, the differences between vibro-compaction and vibro-deep replacement. One lecture I have shown a different aspect.

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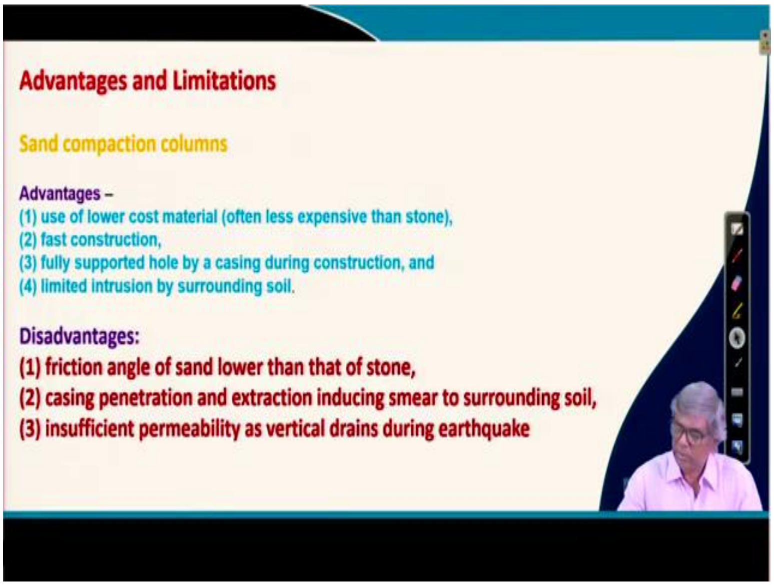

Today I will also continue with that and some more aspect I will try to show. Deep replacement various aspect already mentioned. Now, they have some limited application and also good application in fact and other methods may not work. Deep replacement will be suitably can be worked, can be used. And here if we use then what are the advantages and what is the disadvantage.

There are a number of sand compaction when we are, vibro-compaction we are talking about there is only vibro-compaction only whether backfill, or without backfill with backfill. But when it is a deep replacement, there are a number of them and they are construction wise, the technology wise they are different. Because of that advantage or disadvantage for each of them separately is shown.

First of all, we are taking sand compaction column, you can see use of lower cost material. Because often less expensive than stone and fast construction is possible and fully supported a hole by casing during construction. So, sand compaction we take casing first then only put sand and then limited intrusion by surrounding soil.

When even casing is removed and that whatever backfilling we are giving that one hardly entitled to the surrounding soil. Surrounding soil will be nearly intact and there will be a strong column will be formed. And if a large number of such things are there, ultimately the entire ground will become stronger. And disadvantage will be a friction angle of sand lower than that of stone.

If I use this soft stone if I use then of course stone will be better but sand is used because still it will be cheaper because of that we will use, but if you want more strength and friction, then obviously you have to go for strong stone. Here because of that one of the disadvantages is mentioned, though it is really not disadvantage, some area it is useful, but still with respect to stone, if his hand is used then less friction will be there.

And casing penetration and extraction inducing smear to surrounding soil. As we have mentioned that in this construction casing is used, casing will be forced to penetrate into the soil while doing that, then surrounding soil will be a little disturbed that disturb zone is called smeared zone. That smearing can happen. Casing penetration, an extraction inducing smear to the surrounding soil that is another disadvantage or since we are using casing.

And insufficient permeability as vertical drains during earthquake. Vertical drain during earthquake, it will be, it will may not be serving enough purpose because from a clay soil it has to come to that and then vertically, it will not accelerate that way. Because of that insufficient permeability as vertical drain during earthquake, so that is another disadvantage. Let me take the next slide.

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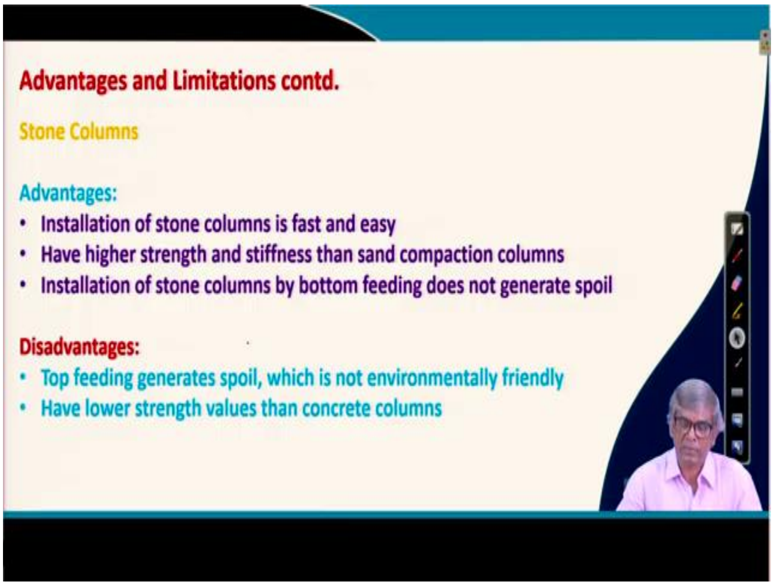

Again, if I take a stone column now, stone column again installation of stone column is fast and easy. And here, higher strength and stiffness than sand compaction. Of course, it is obviously it is an advantage, because it has some large number of application and same time if you compare with the respect to sand, it is much better. Installation of stone columns by bottom feeding does not generate spoil.

Many times, when you make a concrete or stone column or some other material, there are the surface there will be a lot of concrete particularly we use that they will be spoiled in the form of near surface. Here that is not there. And disadvantages will be top feeding generate spoil of course, when you feed from the top, then it will generate, some spoil at the surface which is not environmentally friendly because you have to ultimately clean that otherwise it will not be acceptable.

And have lower strength value than concrete columns. As compared to sand stone is a better again compared to stone only if you make a stone and cement together concrete then that will be much better. That is the strength wise it is lesser than concrete wherever it is required only you can go for otherwise stone column itself the ground improvement technique as deep replacement.

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Then if you talk about controlled modulus or stiffness column that, is you have to make a borehole and then we put grout and that is called, this method is called controlled modulus because that grouting can be designed, what strength stiffness is required accordingly you can put it. Advantages will be can have strength and modulus according to project needs.

That is what the strength and modulus can be adjusted by designing it. And higher strength and modulus that then those are granular columns, granular columns sand and all, if by sand and all, by sand and all you make a column compared to that this method will be stronger and installation is fast, fast with real monitoring and without any vibration and spoil. When we install these types of things, there will be monitoring systems simultaneously agreed in time.

How much is going quantity everything is monitored because then only it is possible to give your desired strength and stability and stiffness. That is another major advantage that we can monitor during construction and then there is a no spoil or no vibration also for other method those things will be there. And no issue of hole collapse. Since we are making hole and then from the bottom we are feeding and coming up. There is no chance of collapse of hole.

And low mobilization costs the equipment is comparatively small and because of that mobilization cost will be comparatively less and the advantage for this is it is more expensive than granular column which is obvious when it will be having better strength, steepness etcetera, and cost obviously will be more it is shown here. That is a disadvantage until unless it is essential, people will not go for it.

And installation may be difficult in soils with rocks and boulders because you have to cut the reverse slide auger through that regard and that cutting by that it will be difficult when there is a rocks and boulders so that of course is a disadvantage, so for this.

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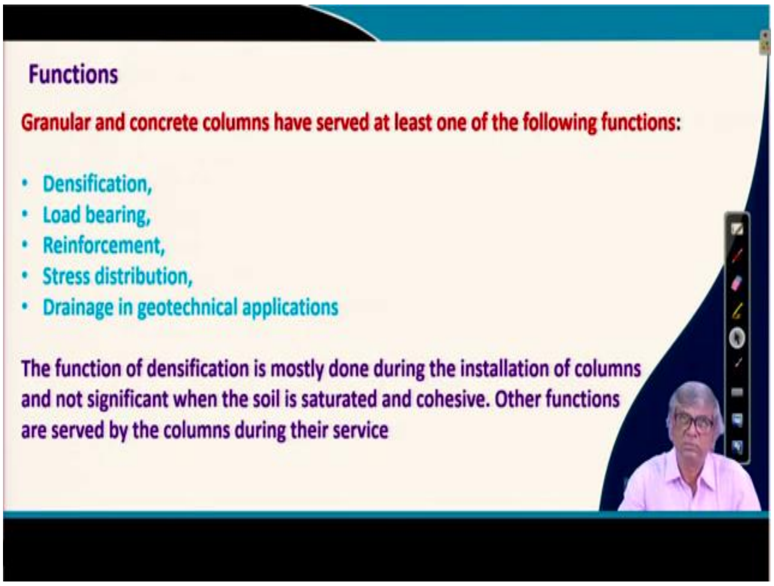

Then these are all advantage or disadvantage, then function how it work that or what are the function it performs when you use deep replacement, that means when you make a hole like thing and then fill it with some material, external material and form a column and then finally use as a foundation soil, then what is the function it performs, it is we have seen that any ground improvement technique, the main function is the densification.

When you make these type of whether it is a granular column or concrete column, they have performed number of them and we have mentioned a list and they at least perform one of them sometimes more than that. Here what are the things, densification, the load bearing.

During compaction it is densifying is happening and the same time that column also can take additional load, or if I silty soil, if I put a load then whatever amount of load it can take, if you have this column then the additional load can be taken. The function, as a function can help to densify, it can help to load additional or it helps to take additional load. The reinforcement, the soil reinforcement type of activity action will be there.

Soil and column together if it will be there, we can assume that is a reinforced soil that reinforcement action will be there sometime. Stress distribution sometime because of this column the stress can be transferred to the bottom, transformer can be side, hat normally if I apply on the soil, different from that. The drainage geotechnical application sometimes this vertical column like particularly granular sand or stone if we use stone column, they also act as a drainage path.

That means, whatever deep replacement we do, they perform at least one of this function, sometimes more than one. For example, if I consider that your deep replacement by sand compaction method, it will be performing as a drainage, also it will perform as a compaction. Both will be densification at the surrounding soil. The function of densification is mostly done during the installation because suppose the sand column construction will be there, when you push the casing that time only side soil will be displaced and densified.

But during service that function will not densification will not happen only additional something else will happen. Function of densification is mostly done during the installation of columns and not significant where the soil is saturated, that to it happens but when it is a saturated soil this densification again will not happen.

And we have also mentioned during our vibro-compaction. And other functions are solved by the column during their service. Like load, reinforcement, stress distribution, drainage these are the four additional function it will be during service time of the column, it will be performing.

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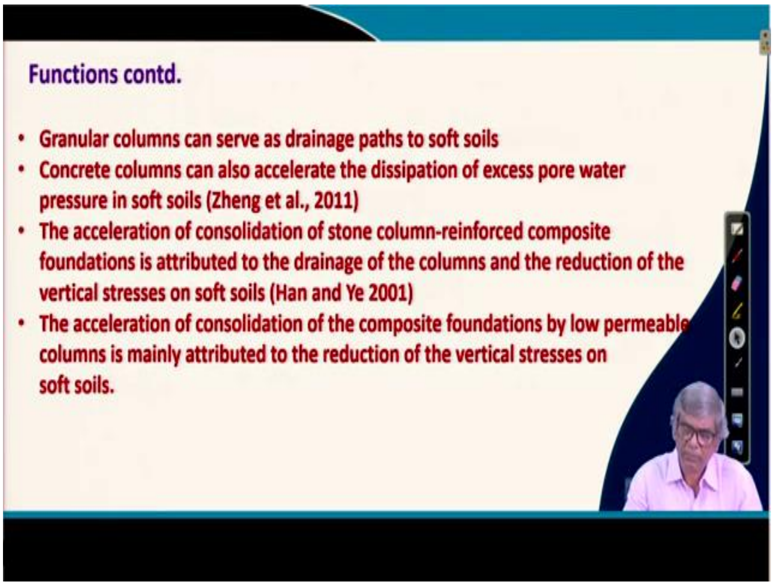

Then granular columns can serve as drainage path also to soft soil, because soft soil permeability will be very low and then if you make number of stone column or sand column, then in a very close interval and put some then because of these extra pore pressure and it will be having tendency to dissipate and it will be entering to the sand layer because the travel distance is quite less and through the sand layer again water can come out and dissipate the poor water pressure.

So, that is why, granular columns serve as drainage path to soft soil. And of course, if it is a granular soil or that obviously they are automatically good drainage, but in the soft soil drainage is not good. When you put column, it helps. Then concrete columns can also accelerate the dissipation of excess poor water pressure in soft soil. And then acceleration of consolidation of stone column reinforced composite foundation is attributed to the drainage of the columns, so same thing.

When the stone column also during the service also it can act as a drainage part and the reduction of the vertical stress on soft soil. That will also happen here. And similarly, acceleration of consolidation of the composite foundation by low permeable columns is mainly attributed to the reduction of the vertical stress on the soil, on the soft soil. These are different function, different deep replacement technology can offer during service or during construction.

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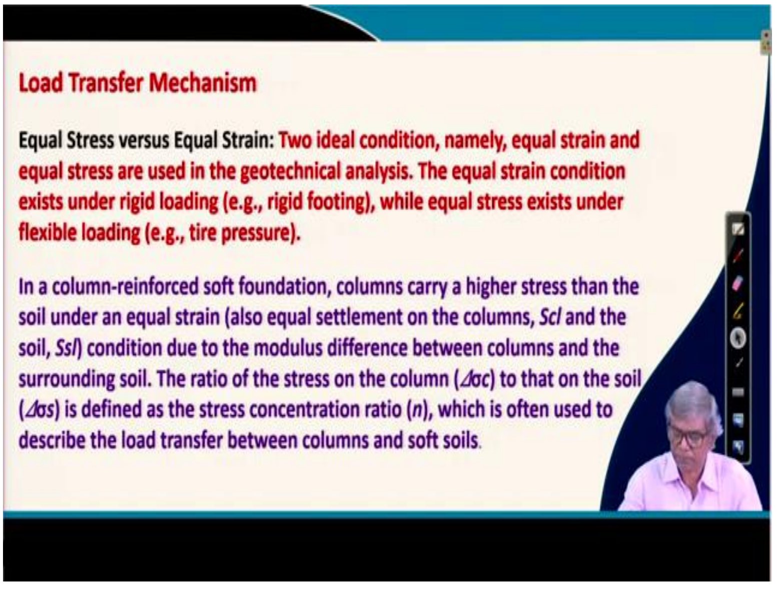

Then load transfer mechanism and when you are talking about load transfer mechanism in the foundation, we have all of you know in either in solid mechanics or foundation engineering that there is an equal strain and equal stress. There are two ways, so two ideals. These are two ideal conditions it can be in between also equal strain and equal stress in geotechnical analysis.

And equal strain condition exists under rigid loading. When there is a rigid putting then they will be settling uniformly and when it is settled uniformly, but if there are different, but settlement will not be equal, whereas, in a flexible footing that it will give you equal stress, but the settlement will be different.

That is a two-load transfer mechanism and before that are two models consider one is equal stress and the other is called equal strain. When it is equal stress the below the foundation your deformation will not be uniform, whereas, equal strain means, it will have equal settlement or strain, but the stress will be a different section will be different. So, that will come on later on in one or two slides will be there.

In a column reinforced soft foundation columns carry higher stress then the soil under equal strain. There will be a sand and suppose column there and that is composite foundation if I consider and under equal strain condition what will happen then the lesser load will be transferred to the soil more load will be there on the column mainly because the both the strain are equal and their modulus is different, the more column modulus is high and if the modulus is high, then more stress is required to produce equal strain.

And whereas soil having lesser modulus. It required less pressure to produce equals strain as it is in the column. That is why, when it will be equals strain condition, and the foundation is column and soft soil composite, then equals strain condition column will be taking higher load than the soft soil. So, that is the point I wanted to mention here. And why it is so, because of their modulus is different, a difference in modulus and because column will have higher modulus and your soil will have lesser modulus.

So, as a result, since higher modulus it will take higher stress, since soil is having lesser modulus, it will take lesser stress. So, that is the point. The ratio of the stress on the column to that on the soil is defined as the stress concentration ratio n, which is often used to describe the load transfer between the columns and soft soil.

This ratio use that is stress concentration ratio. That I will, so we are not going to design but some of the aspects when you use deep replacement method then what are the additional things comes other than vibro-compaction, I am just trying to cover, let me.

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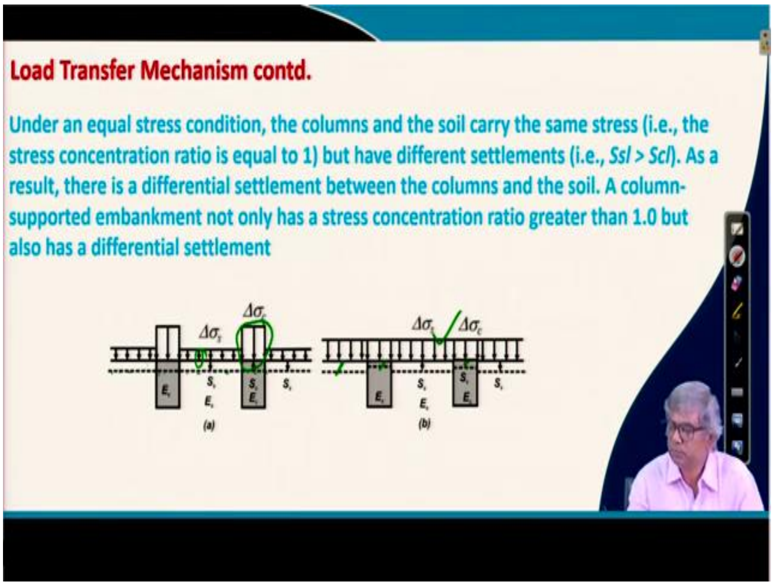

You can see here that this picture is showing that equal strain condition and equal stress condition. You can see here that, here you can see that your stress in the soil, stress is the soil is this much intensity suppose, and whereas, stress in the column, this is the intensity this bigger arrow is showing bigger intensity, smaller arrow integrating lesser intensity.

And you can see though, it has a larger stress and it has smaller stress, but still you can see the ground level was here initially, the ground layer is uniformly going there here, because that means, you will have deformation of sand surrounding soil will be this much and deformation in the column walls will be the same amount, so not much difference.

Whereas, if I take equal stress, you can see here equal stress is throughout because you can see the size of the arrow is equal everywhere. Because of that here, that means, on stress of the column, stress on the soil in both places it is equal. And you can see here that since the modulars in this column is high, the deformation also will be smaller, and you can see this much deformation is taking place, this much deformation is taking place.

Whereas, soil is deformed this much. Because of that, when that equal stress condition, it will be there, then there will be differential settlement between the column and the soil, it will not be uniform. That is what it is indicating here. What note is written here, let me highlight. Under an equal stress condition, the column under soil carry same stress, the equal stress condition the column and the soil carry same stress.

As you can see here, this one, but have different settlements. You can see different settlement that what is mentioned. As a result, there is a differential settlement between the columns and the soil. A column supported embankment not only has a stress concentration ratio greater than one, but also has a differential settlement. If I think of there is a long distance, if there is a soft soil is there, there is one method of ground improvement method is like this, that column that you can make a deep replacement method and we can make a column like thing.

And then this over that if you build embankment, then it will be called as column supported embankment. And when you do this column supported embankment, then we will try to give you equal stress. And if equal stress if you give obviously soil will have more settlement than the column as a result, there will be unequal settlement, so that is what is mentioned in this note, let me go to next slide.

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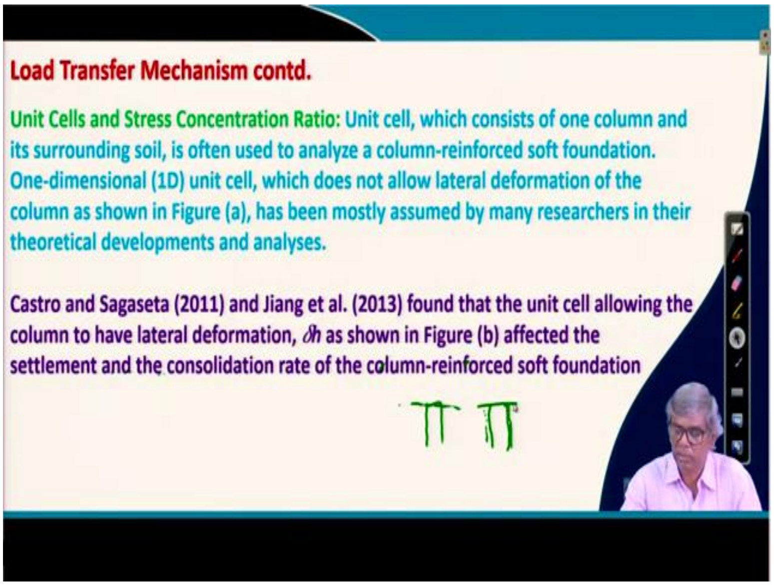

Load transfer mechanism again continued; same we are discussing about load transfer mechanism. Unit cells and stress concentration ratio, unit cell means, if I take one column and surrounding soil that I can be treated as unit cell. And many times, in the analysis, we consider the unit cell and then model it. And once again you can read here one same thing is when a unit cell means which consist of one column and its surrounding soil, as is often used to analyze a column reinforce our foundation.

These two together we will be modeling for the analysis and one-dimensional unit cell, which does not allow lateral deformation of the column, which I will be showing you the figure has been mostly assumed by many researchers in their theoretical development. When you do the analysis, most of the time, we consider that this column and the surrounding soil is only one unit and they consider that there is no lateral movement and that is the assumption is made and based on that people are doing analysis.

But if I do and then later on some people investigated if I have lateral deformation like this, I can show you here the person Castro and Sagaseta that and Jiang also they have observed that unit cell allowing the column to have lateral deformation suppose delta h, I shall show in the next slide. Affect the settlement and the consolidation rate of the column-reinforced soft foundation.

That means, if you have that your assumption is that column and soil there is no lateral deformation, but later on if I consider happens, what, this is the column but it deforms and like this laterally, then obviously, they will be in the result or outcome will be different. So, that what it is observed and pointed out and with that, people may be careful to remodel their analysis and they will not take this model once they are initially assumed as accepted one. So, you can see the slide here, which we have shown.

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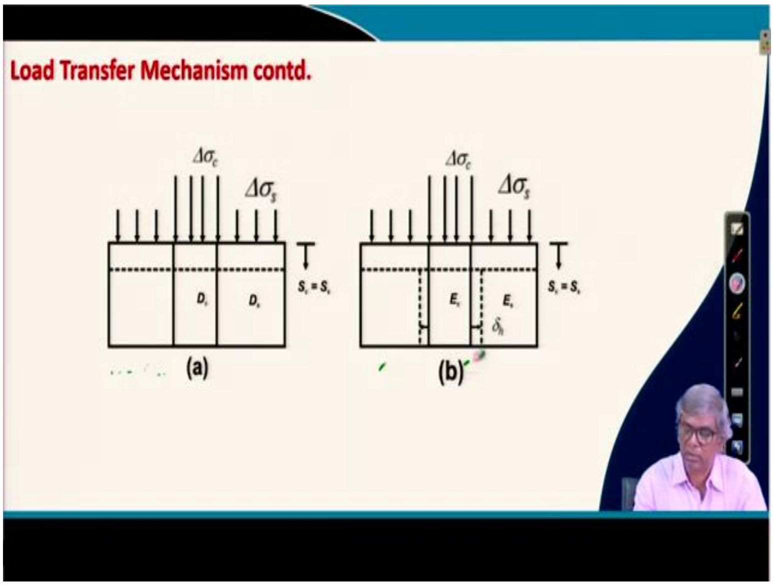

The most time this is the amount, this is the column D_C diameter of the column, and D_S diameter of the soil. And this is the one together, this is the one together the soil and column together people assume that are the single unit, and a single unit and the stress is more here, stress is lead less here and equal deformation, assuming equal deformation that is also may not happen.

But this is the assumption based on that many people started, but here you can see more stress and the less stress here, and as a result, it may have lateral deformation. There will be long general deformation, there will be this was deformation also laterally, it may have deformation. If you allow that, the lateral deformation, then automatically, you will have a lot of difference in the outcome of the analysis. That is what we pointed out by some researcher and has need to be considered in the analysis.

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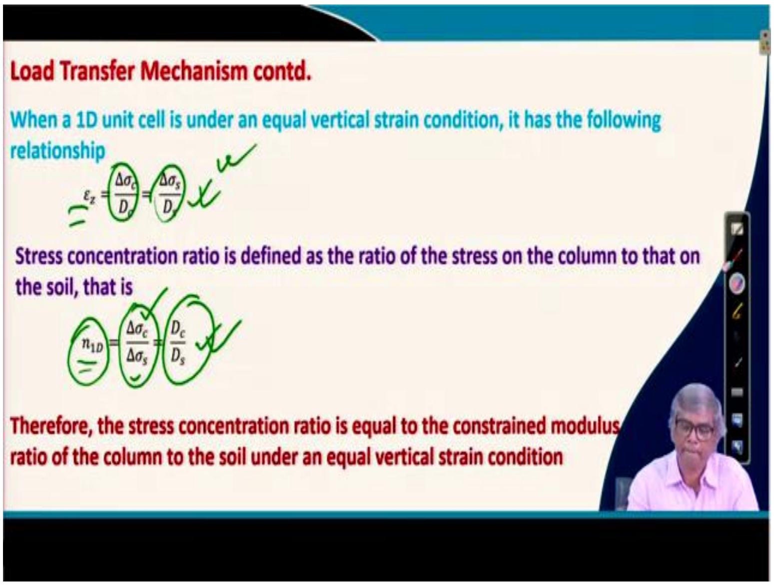

Now, in a 1d analysis, when unit cell is under an equal vertical strain condition, it has the following relationship equal strain means, you can see here epsilon z at any point you can considered strain is epsilon z and then you have column is the stress is del sigma C and D_C is the constant modulus and stress on the soil is delta sigma s and constant modulus suppose D_S.

So, delta sigma c divided by D_C that value and delta sigma s by D_S though D_C and D_S is not equal still the ratio has to be equal when you consider equal strain analysis. And if you equal, if you assume these are equal and then stress concentration ratio is defined as the ratio of the stress on the column to that on that soil. That means, no_{1D} the strain concentration ratio will be stress on the column, stress on the soil.

And if I take this equation again move to this delta sigma c by delta sigma s then you will see D_C by D_S. This equation if this is correct, then this is also correct. Delta concentration ratio, if it is defined by the ratio of stress, but that is also ratio of their constant modulus. That is what I want to mention here.

And that is what is mentioned, there was stress concentration ratio is equal to the constant modulus ratio of the column to the soil under an equal vertical strain condition. The equal vertical strain condition that is the condition I have taken, then only I am defining a stress concentration ratio and then from there I am getting this equal to this. That is why equals strain condition only this is valid, that stress issue will be equal to the constant modulus ratio of the material, sorry. So now, let me take next slide.

$$E_Z = \frac{\Delta\sigma_c}{D_c} = \frac{\Delta\sigma_s}{D_s}$$

$$n_{1D} = \frac{\Delta\sigma_c}{\Delta\sigma_s} = \frac{D_c}{D_s}$$

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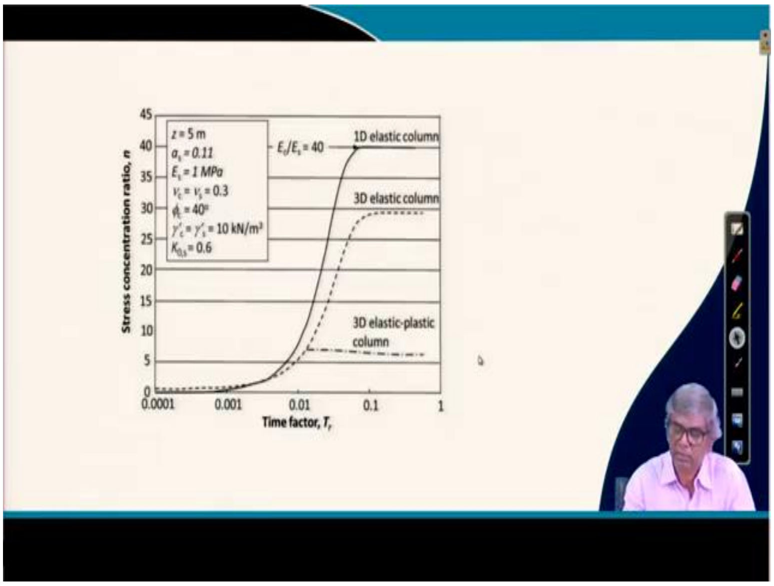

And you can see the stress concentration ratio is considered and then time factor for different values, you can see that E_c by E_s is 40 and 1d elastic column and 3d elastic column and then what is the difference, numerically it is shown that 1d analysis means we are not considering lateral movement. So, that is why that according to that, this is the result and if we consider 3d analysis, that mean general movement also then this is the, this is the difference. Of course, this is the highlight people has to far research. This is of course, for attention for research or not for any examination obviously. This I wanted to highlight here because of that.

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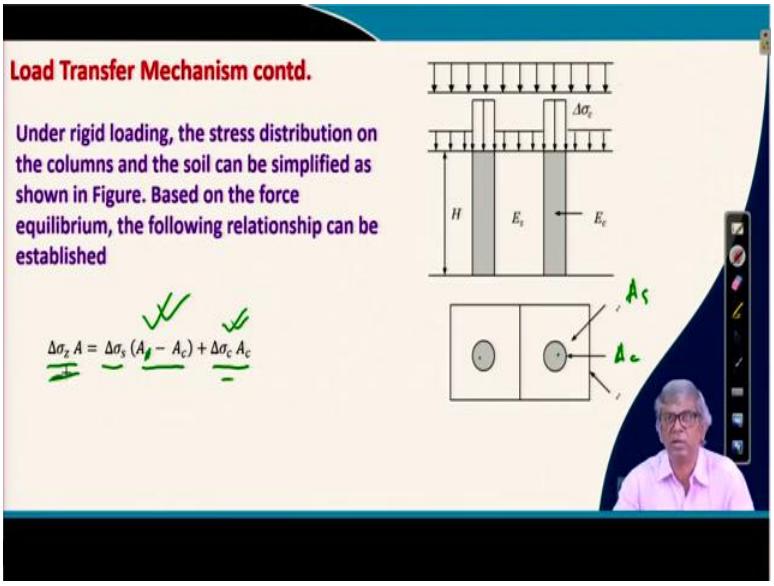

And then load transfer mechanism, again you can see here that under rigid loading if I consider rigid if it is not rigid of course different, it can be that there are different analyses, but if it is a rigid condition, then it is like a reinforced concrete column when you do analysis then As multiplied by Fs and Ac multiplied by sigma c we use to do similar almost here can we shall suppose these two columns are there, this is the stress is applied uniform and this is rigid to be concerned and these two are only equal to this is A column.

Suppose, this is called a column and this is suppose as. So, that is why if you do that, then sigma z, del sigma z multiplied by A, that will be a total load and here are also load taken by your soil and load taken by the column this together also should be equal, so that is why you can see here del sigma s Ae minus Ac.

This is Ae or Ac column minus Ac not the only A, A minus sigma it will be A minus Ac which is that, this is not there, sigma s multiplied by A minus Ac that means, it will be your if I subtract from this, this is total area minus these two areas then it will give you this multiplied by sigma s that is load taken by soil and this is sigma c minus multiplied by Ac, that is load taken by concrete.

$$\Delta\sigma_z A = \Delta\sigma_s \left(A_\varphi - A_c\right) + \Delta\sigma_c A_c$$

These two together will be total load. So, this is the way we have to do analysis. Still many more things are there for analysis of this type of foundation, we are not going in details, only highlighting few points, since it has similarity with vibro-compaction. Then if I look at failure mechanism, how it failed?

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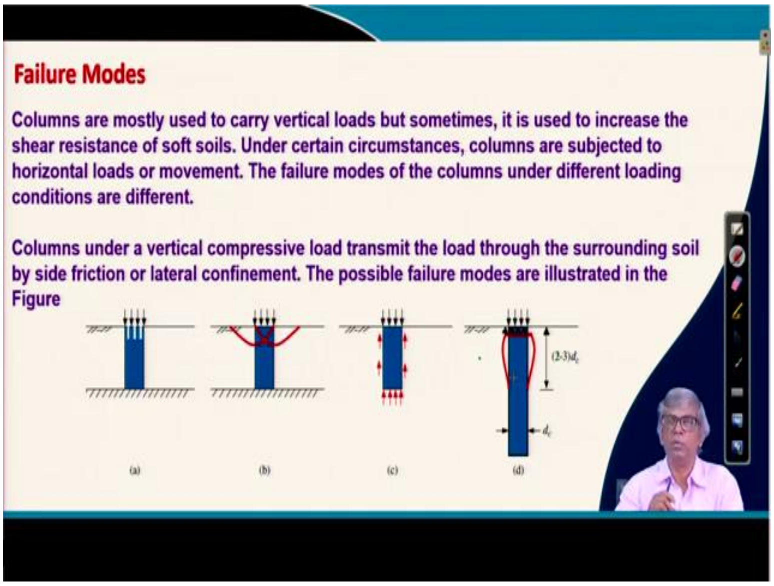

Then, this is the one can see here, the column can fail different ways. When load will be applied there can be crashing, this is crushing. This material just not doing anything, this entire material can crush and load can go inside load point. This is a crushing failure, this is sort of shearing failure, you can see here almost like bearing capacity failure is like shearing.

So, it will be forming like a triangle and then because these are all granular and if I apply load here, so it will have similar, so it can have a similar to be a bearing capacity failure type of things, which is shearing failure it is called. And then this is friction failure, you can have entire friction is not enough then it may sink and this is you can see bulging failure. That is what we can right here.

Columns are mostly used to carry vertical loads, but sometimes it is used to increase the shear resistance of the soil, under certain some circumstances columns are subjected to horizontal load also. And the failure modes of the columns under different loading condition are different obvious and that is of course, we have shown here. Columns under the vertical compressive load transmit the load through the surrounding soil by side friction or lateral confinement, the possible failure modes are illustrated in the figure.

When you apply load of course, the external load will be supported by the compressive load of this, it will take some compressive occurred load and also surrounding friction like this. And so, if that is the mechanism, then sometime because of the heavy load the material can crush, material can shear, and material can inadequate friction, and then maybe a bulging.

Under loading the entire soil and concrete together it will be deforming and it will be that entire column is bulging and is too much is there is not acceptable. These are the different failure modes. Considering all those things, there will be design steps. I am not going to that design aspect because of shortage of time because some more topic I have kept in this topic module only vibro-compaction, but there is some similarity because of that, I have shown what a deep replacement is different from a vibro-compaction.

According to construction, from construction point of view, from mechanism point of view, behaviour point of view, and design of course vibro-compaction I have designed, shown the design but here I am not showing the design. Sample your mechanism, load transfer mechanism some of the things I have shown. Here with this module 5 will be closed. And I will now start with model 6, where I will try to discuss something else. With this, I will stop here. Thank you.