# Ground Improvement

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## Lecture No. # 16

## Heating and Freezing Methods, Blasting Methods-II

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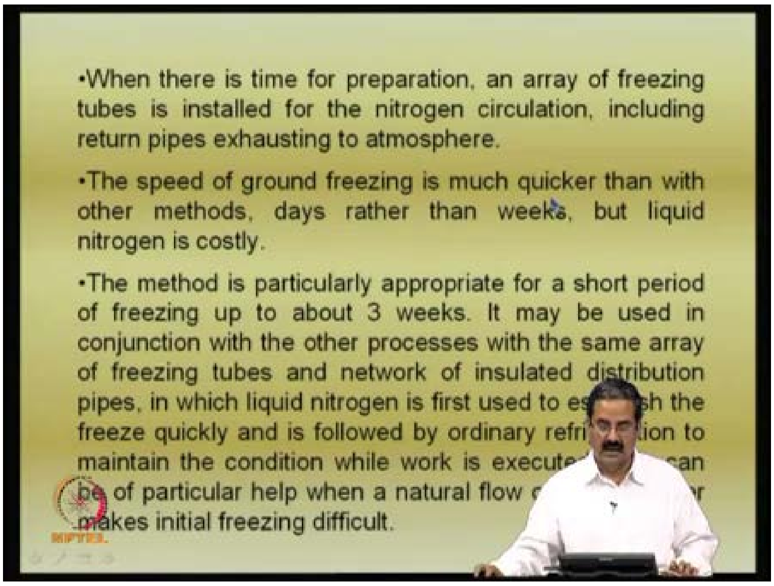

- When there is time for preparation, an array of freezing tubes is installed for the nitrogen circulation, including return pipes exhausting to atmosphere.
- The speed of ground freezing is much quicker than with other methods, days rather than weeks, but liquid nitrogen is costly.
- The method is particularly appropriate for a short period of freezing up to about 3 weeks. It may be used in conjunction with the other processes with the same array of freezing tubes and network of insulated distribution pipes, in which liquid nitrogen is first used to es sh the freeze quickly and is followed by ordinary refri ion to maintain the condition while work is execute can be of particular help when a natural flow c r makes initial freezing difficult.

So, as I just mentioned, the use of this freezing, is some technique, is something very tricky, and one should be able to design the system in such a way, that we have a proper combination of primary cooling and secondary cooling systems, and also see that the circulation of coolant is proper, and also that the frozen barrier, you know, this so-called frozen earth barrier is something that is maintained till it is required.

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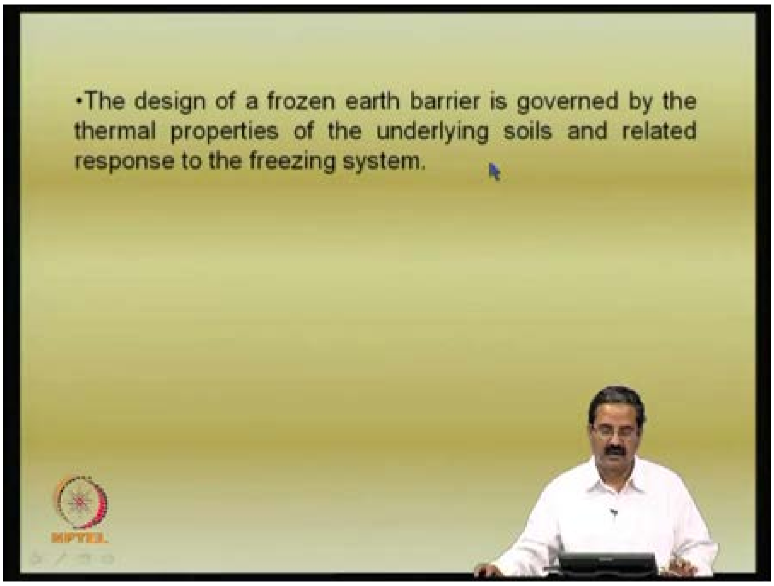

•The design of a frozen earth barrier is governed by the thermal properties of the underlying soils and related response to the freezing system.

Say for example, you need it for a month, it exhaust it exists there, and also works in a proper way, and you have to maintain that. And then, all the design is based on the thermal properties of the soils and also that related response to freezing system; this is very important.

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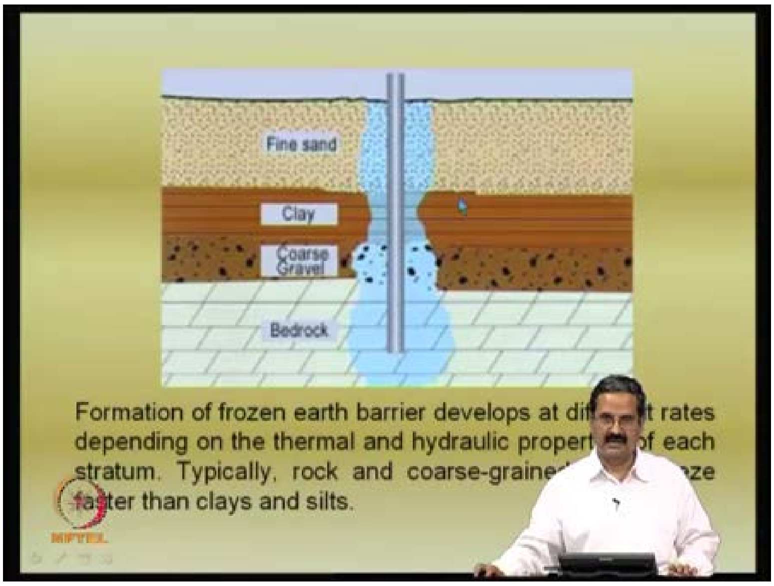

Formation of frozen earth barrier develops at di t rates depending on the thermal and hydraulic propert f each stratum. Typically, rock and coarse-graine ze fa ter than clays and silts.

This is a simple example like, the formation of a frozen earth barrier, develops at different rates depending on the thermal and hydraulic properties of each stratum; like you have say, for example, bedrock; you have the coarse gravel, you have a clay, you have fine sand. So, you have the barrier here that is developed next to the pipe or a shaft or whatever system. So, this is a very important; it should be maintained.

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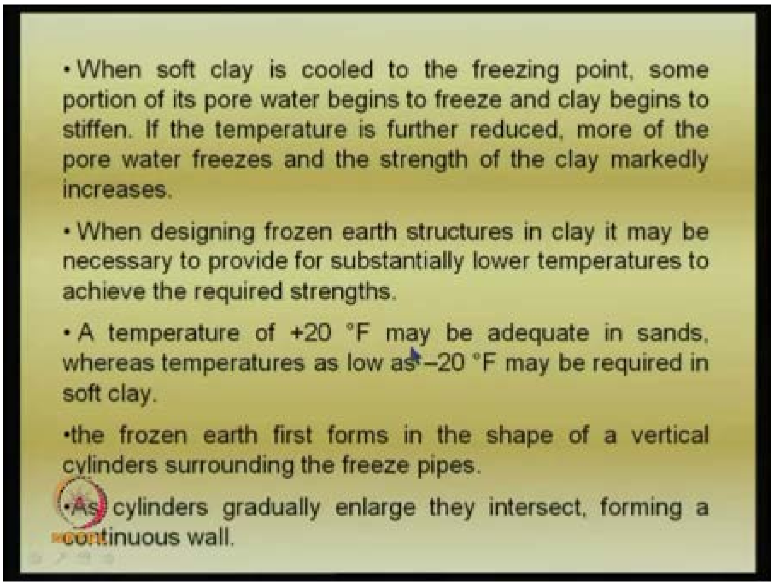

- When soft clay is cooled to the freezing point, some portion of its pore water begins to freeze and clay begins to stiffen. If the temperature is further reduced, more of the pore water freezes and the strength of the clay markedly increases.
- When designing frozen earth structures in clay it may be necessary to provide for substantially lower temperatures to achieve the required strengths.
- A temperature of +20 °F may be adequate in sands, whereas temperatures as low as –20 °F may be required in soft clay.
- the frozen earth first forms in the shape of a vertical cylinders surrounding the freeze pipes.
- As cylinders gradually enlarge they intersect, forming a continuous wall.

When soft clay is cooled to the freezing point, some portion of its pore water begins to freeze and clay begins to stiffen. Why it works is that, say, soft soil has lot of water content and the pore water freezes and clay begins to stiffen. So, if the temperature is further reduced, more of the pore water freezes and the strength of the clay markedly increases. This is actually the mechanism.

And, when designing, frozen earth structures, it may be necessary to provide substantially lower temperatures to achieve the required strength. You know, the thing is that, we know that, with reduce, lower the temperature, the strength is, you know, it is going to be more stiffening, and one should be really careful because, the temperature gradients should have properly understood like, if there is a, you should have an adequate margin of safety; to see that, you get the require strengths.

And then, a temperature of plus 20 Fahrenheit may be adequate in sands, whereas a temperatures as low as minus 20 Fahrenheit may be required in soft clays. The frozen earth must first form the shape of a vertical cylinder surrounding the freeze pipes; as cylinder gradual enlarge, they intersect forming a continuous wall; like, it is like this.

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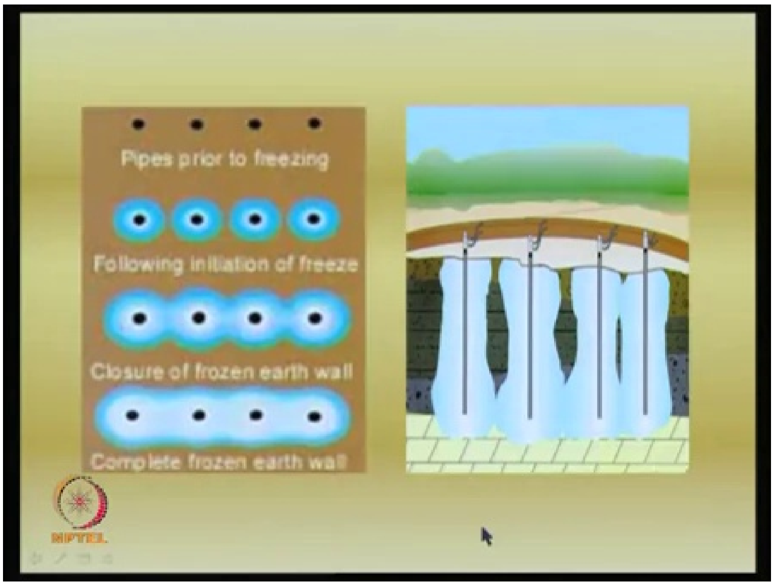

Pipes prior to freezing: you have all these, you know, that frozen is getting developed. And then, initiation of the freeze: once it forms like this, then you can see that, completely it forms like this, so, complete frozen earth wall is formed. So, you can see that, at the top, these are all the bulbs or whatever, is that frozen material is quite useful.

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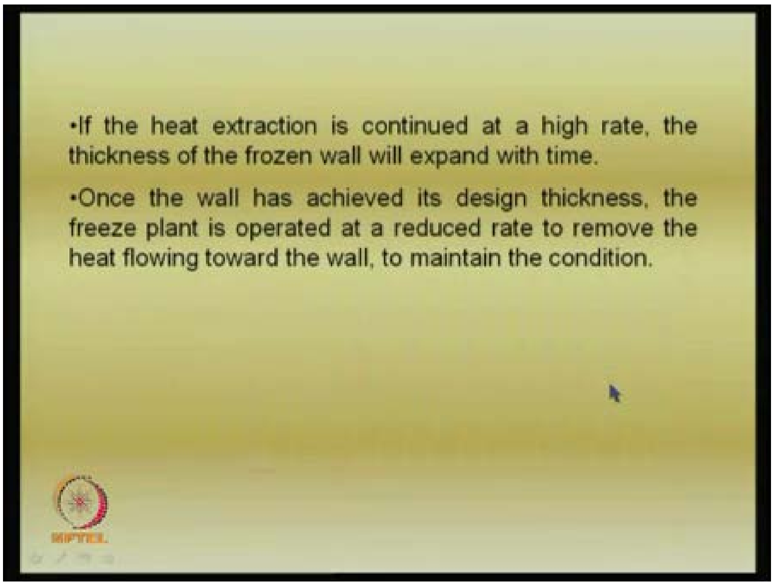

- If the heat extraction is continued at a high rate, the thickness of the frozen wall will expand with time.
- Once the wall has achieved its design thickness, the freeze plant is operated at a reduced rate to remove the heat flowing toward the wall, to maintain the condition.

If the heat extraction is continued at a high rate, the thickness of the frozen wall will get expand with time. Say for example, you are trying to remove the heat from the system, you know, that heat you are trying to recover actually, so, the thickness of the frozen wall will expand with time; higher is a rate, higher is an expansion of the wall.

Once the wall has achieved its design thickness, the frozen plant is operated at a reduced rate to remove the heat flowing towards the wall, to maintain the condition. Once you get the thickness, you know, which is quite sufficient to see that the design is satisfactory, the frozen plant, the plant is operated, reduced rate, to remove the heat flowing toward the wall to maintain the condition.

So, like as I just mentioned, like the similarity of fridge, once you it has actual temperatures that you had wanted, but then subsequently you need only the power to see that the temperature is maintained, the same temperature is maintained.

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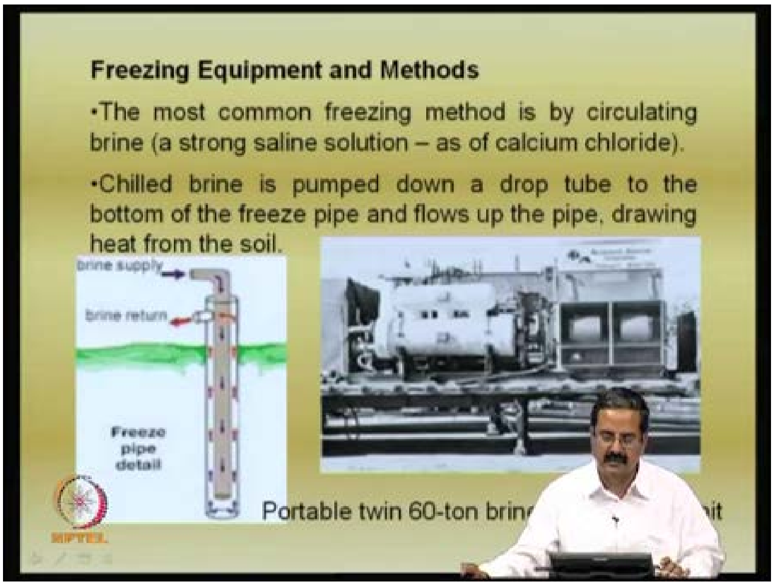

**Freezing Equipment and Methods**

- The most common freezing method is by circulating brine (a strong saline solution – as of calcium chloride).
- Chilled brine is pumped down a drop tube to the bottom of the freeze pipe and flows up the pipe, drawing heat from the soil.

Portable twin 60-ton brin … it

So, I was just mentioned, the most common freezing method is by circulating brine, a strong saline solution like a calcium chloride. Chilled brine is pumped down a drop tube, like this brine supply, and then you have the liquid here, which is there. So, this area, you know, as that creates that particular freezing. So, because of this process, it draws a heat from the soil; this is some sort of refrigeration unit.

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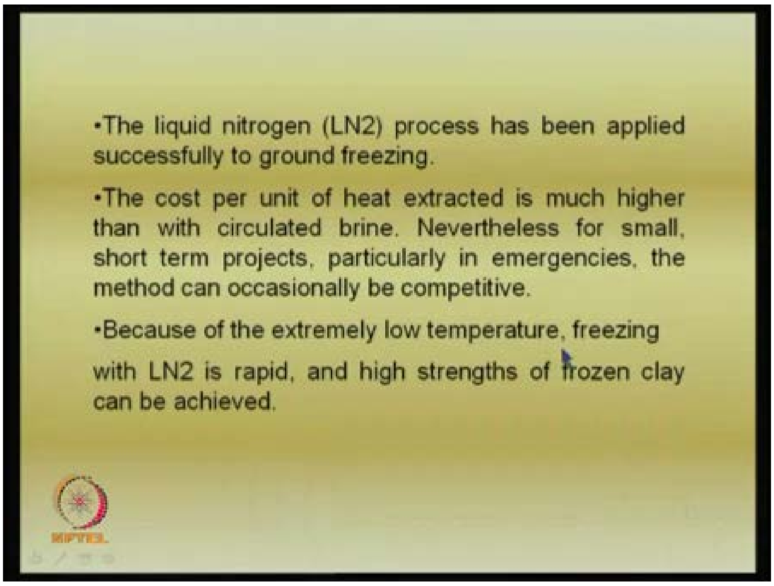

- The liquid nitrogen (LN2) process has been applied successfully to ground freezing.
- The cost per unit of heat extracted is much higher than with circulated brine. Nevertheless for small, short term projects, particularly in emergencies, the method can occasionally be competitive.
- Because of the extremely low temperature, freezing with LN2 is rapid, and high strengths of frozen clay can be achieved.

Liquid nitrogen process has been applied successfully to ground freezing in some places; and the cost per unit of the heat extracted is much higher than with circulated brine; you know, the brine solution is somewhat cheaper compared to liquid nitrogen. Nevertheless, for small, short term projects, particularly in emergencies, the method can be occasionally competitive. Because of the extremely low temperature, freezing with LN2 is rapid, and high strengths of frozen clay can be achieved.

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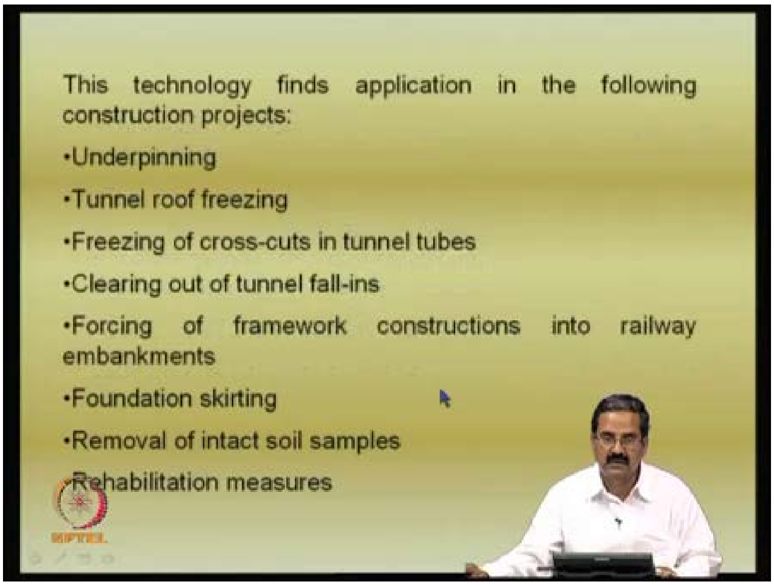

This technology finds application in the following construction projects:

- Underpinning
- Tunnel roof freezing
- Freezing of cross-cuts in tunnel tubes
- Clearing out of tunnel fall-ins
- Forcing of framework constructions into railway embankments
- Foundation skirting
- Removal of intact soil samples
- Rehabilitation measures

This technology finds application in the following construction projects: underpinning, like keeping that in stable condition; a tunnel roof freezing, freezing of the cross-cuts in tunnel tubes; clearing out of the tunnel fall-ins; forcing of the framework constructions into railway embankment; foundation skirting; removal of intact soil samples, even to remove the intact sample also, like, you freeze that area to take the (()) samples in a big, this thing. This is one of the techniques, because you freeze the whole area and take the whole lump into the lab, and then test that, so that, that will preserve the in-situ structure; it has also been used to go for a lot of rehabilitation measures.

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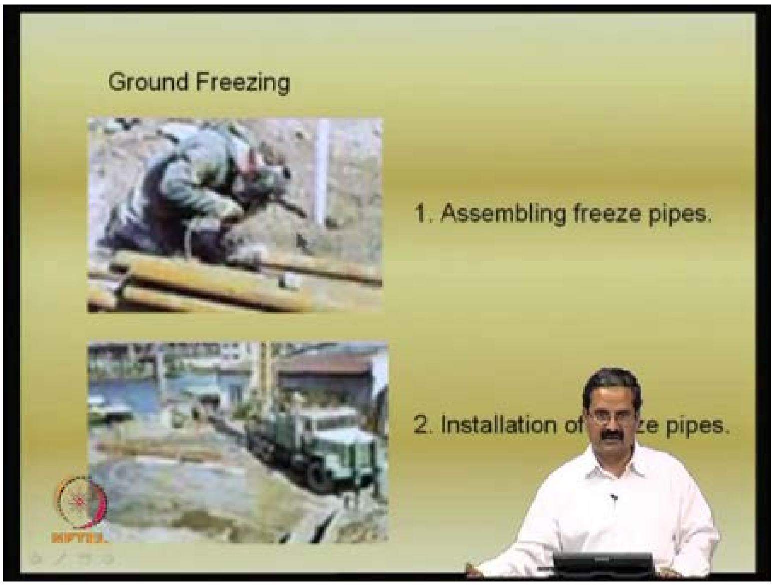

Ground Freezing

1. Assembling freeze pipes.

2. Installation of ze pipes.

You can see that somebody is assembling the frozen pieces here, freeze pieces here; installation, of course, the figure is not very clear; application of the freeze with electronic control refrigeration plant; frost development around the pipes; the movement you know your cool material is inside, you would white things form around the pipes, you know; is it not?

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5. Excavation following completion of freeze wall.

6. Construction of concrete liner. Once completed, refrigeration can be shut down.

Excavation following the completion of the freeze wall: suppose, the area is totally frozen, then you can start excavating, because it will not collapse. So, once, after that, you make the permanent wall, constructed, and the once that permanent thing is constructed, the refrigeration can be shut down; that is it, it is as simple as that. It is a very temporary solution to some of the important issues; this is a very simple technology. But, only thing is that, people have not understood so much in many other developing countries, how effectively one can do? But it has been a good practice in places like west, and even in places like European countries, US and all that.

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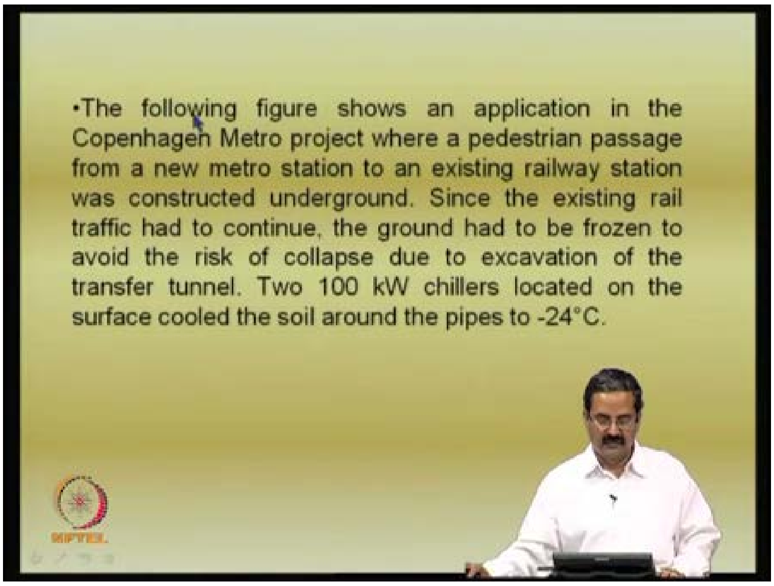

- The following figure shows an application in the Copenhagen Metro project where a pedestrian passage from a new metro station to an existing railway station was constructed underground. Since the existing rail traffic had to continue, the ground had to be frozen to avoid the risk of collapse due to excavation of the transfer tunnel. Two 100 kW chillers located on the surface cooled the soil around the pipes to -24°C.

The following figure shows an application in the Copenhagen Metro Project, where a pedestrian passage from a new metro station to an existing railway station was constructed underground. Here, the question is that, you are trying to have a new metro station, and you would like to have a pedestrian passage; because people have to move from all the sides, since the existing railway traffic had to continue. Because, you cannot disturb the existing railway lines; the ground had to be frozen to avoid the risk of collapse due to excavation of the transfer tunnel. So, two 100 kilowatts chillers, you know, it is cooler, cooling systems, located on the surface, cooled the surface to minus 24 degrees, and then it was effective; like this is how it was done.

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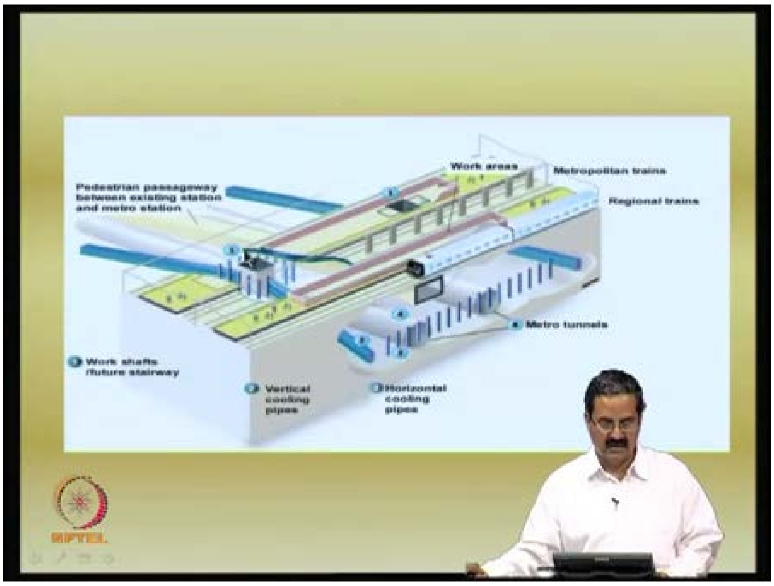

Pedestrian paths were between the existing; this is what they have created, you know; and this is the shaft one, vertical cooling systems, these are vertical systems, horizontal cooling systems. They have a metro tunnels here, like, which are tunnels already working; these are all the systems, then your trains are going, but then, they are able to use a system like this which is quite, which is quite effective in solving their problem; which is, you know, which means, that they have done a solid engineering job in locating all these things; and, you know, they have perfected the system of freezing technology here.

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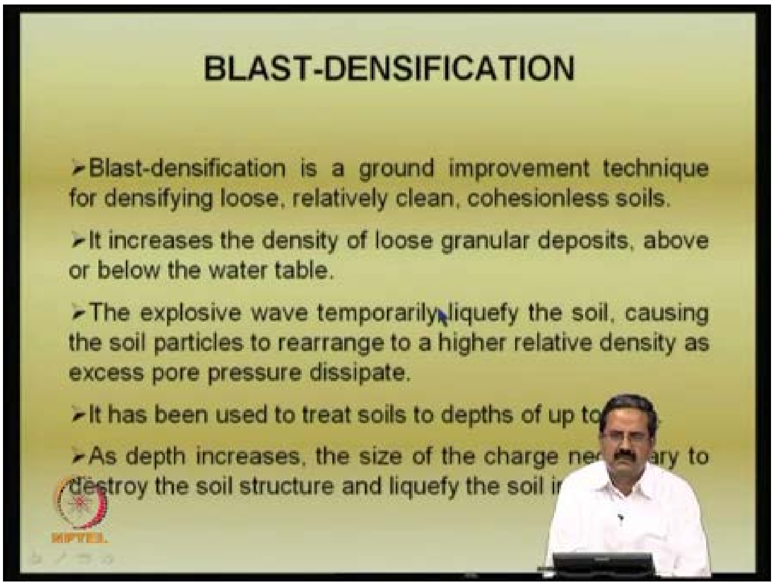

BLAST-DENSIFICATION

- Blast-densification is a ground improvement technique for densifying loose, relatively clean, cohesionless soils.
- It increases the density of loose granular deposits, above or below the water table.
- The explosive wave temporarily liquefy the soil, causing the soil particles to rearrange to a higher relative density as excess pore pressure dissipate.
- It has been used to treat soils to depths of up to
- As depth increases, the size of the charge ne ary to destroy the soil structure and liquefy the soil i

So, now, these two techniques are something very like what we discussed about thermal modification, and all that are quite involved; and I would like to just discuss another ground improvement technique, you know; the thing is that, we have been, there are many techniques that are there like, you know, in the initial stages, we talked about what you called the dynamic compaction. Dynamic compaction, then, even the blast inducing densification is also one technique; like similar to that, normally this goes with that, but then, since coverage is in this form, I just want to complete this as well. And, in the blast densification, it is again like as opposed to... this, also brings out the changes in a soil structure, you know, of course, it is more about removal of water only.

It densifies relatively clean, cohesion-less soils; it increases the density of the loose granular deposits above or below the water table; the technique is quite suitable to both. And, what we do is that, we try to create some explosives; you introduce blast like, there is some 10 meters of area which is there, sand deposit, you put some place in some, in some, 10 meters down, somewhere a blast, then trigger it; then the whole area settles.

So, the consolidation is there in that soft soil area. In the not soft soil sandy area, you are trying to accelerate the, I mean, the thing is, you try to densify the whole area, that is an actual system here, you are essentially trying to densify. In this process, what we do is that, we try to temporarily liquefy the soil, we try to liquefy a soil a bit; and then, you know, what happens? There is a temporary development of pore pressures; these cause particles to arrange to a higher relative density as excess pore pressure dissipate.

You must have seen the case of a sand boil, in which the, you know, the liquefaction occurs, then there is a settlement of the ground and then the pore pressure comes out. So, once the pore pressure comes out, that area is slightly densified, and so, the excess pore pressures will be dissipated; and we all have done this sort of experiments in the lab, where there is a saturated soil mass, and with a loose density, if bit of vibrate, if bit of vibration is there, then there is a settlement, and then the water can, water table is at the top; so, water, you know, you can see that the there is a water table.

Initially, the water table and the ground the ground level are same, but then, once you vibrate it, it goes down; the natural ground, the ground level goes down, and you have, say for example, 1 meter of sand, 1 meter of water lying, which means that the 1 meter of settlement that occurred because of the vibration. So, this vibration, how do you introduce?

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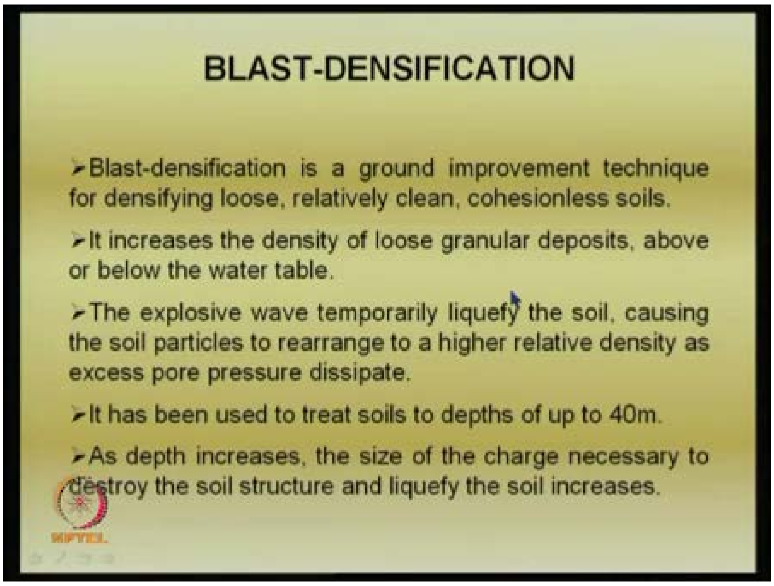

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- It increases the density of loose granular deposits, above or below the water table.
- The explosive wave temporarily liquefy the soil, causing the soil particles to rearrange to a higher relative density as excess pore pressure dissipate.
- It has been used to treat soils to depths of up to 40m.
- As depth increases, the size of the charge necessary to destroy the soil structure and liquefy the soil increases.

This vibration can be introduced using some sort of blast which can be... So, blasts are induced densification, is a very important system, and it has been used to treat soils up to depths of about 40 meters; as the depth increases, the size of the charge necessary to destroy the soil structure, liquefy soil also increases. So, this is a very important concept, people have done lot of experimental work analytical work on this.

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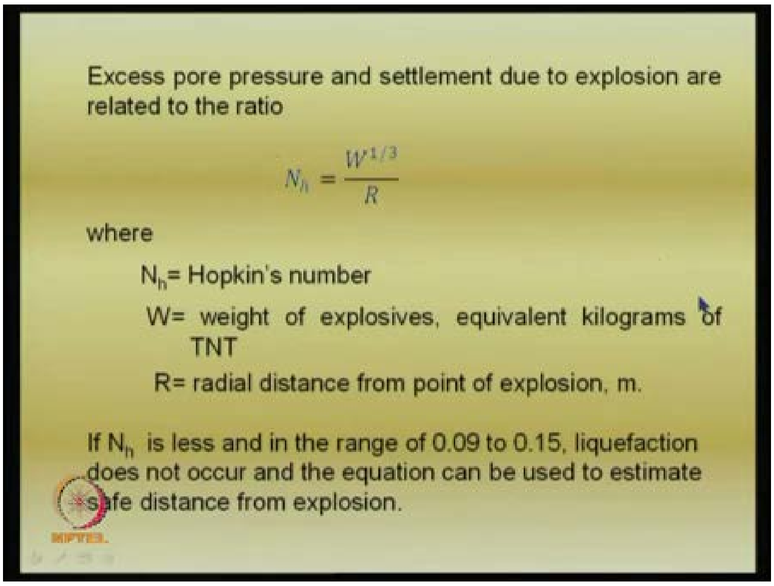

Excess pore pressure and settlement due to explosion are related to the ratio

$$N_h = \frac{W^{1/3}}{R}$$

where

$N_h$= Hopkin's number

W= weight of explosives, equivalent kilograms of TNT

R= radial distance from point of explosion, m.

If $N_h$ is less and in the range of 0.09 to 0.15, liquefaction does not occur and the equation can be used to estimate safe distance from explosion.

And, how do you actually understand? Then, calculate a system as I just mentioned; the excess pore pressure and the settlement due to explosion are related to the ratio, you called N h, which is nothing but the weight of the explosives divide by the radius, radial distance from the point of explosion in meters. So, this is what is called Hopkin's number; and, if you know the weight and the radius, you can get this number.

Actually, studies have shown that, if the N h is less, and then range of 0.09 to 0.15, liquefaction does not occur and the equation can be used to estimate the safe distance from explosion, like, you know, the thing is you would like to densify some 10 meters or 15 meters of area. How do you get it? What is that radial distance? Say for example, if you put a blast at 10 meters level, how much of area could be really densified? So, is that all 10 meters could be densified? How do you do that?

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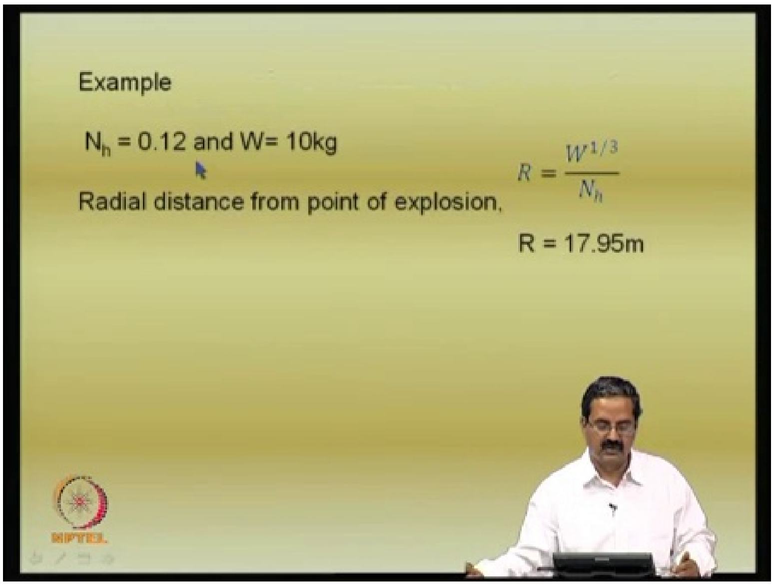

Example

$N_h$ = 0.12 and W= 10kg

Radial distance from point of explosion,

$$R = \frac{W^{1/3}}{N_h}$$

R = 17.95m

So, this can be understood from this point; say for example, I will give a small example. You take N h as 0.12 and weight of the explosive soils as 10 kgs, it can be 1 ton or whatever you know. Radial distance from the point, if you use expression, it could be 20 tons, about 17.0; if you use these numbers, N h and all that numbers, you get R equal to 17.95; this number gives you the safe distance.

So, based on this, this is your fixed, and, you know, the weight how much of weight you can use, so, you can calculate, what is the safe radial distance which can be used, which, which is very useful in design of the blast induced vibration system compactions. Say for example, if you want 10 meters only; now, in this case, you can reduce a weight here, and then you can calculate what is that area to be compacted by this method, is very important point.

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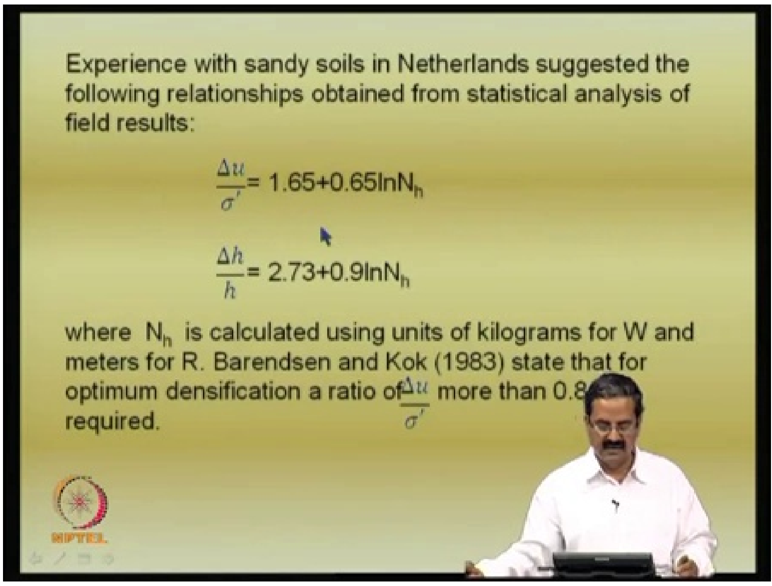

Experience with sandy soils in Netherlands suggested the following relationships obtained from statistical analysis of field results:

$$\frac{\Delta u}{\sigma'} = 1.65+0.65\ln N_h$$

$$\frac{\Delta h}{h} = 2.73+0.9\ln N_h$$

where $N_h$ is calculated using units of kilograms for W and meters for R. Barendsen and Kok (1983) state that for optimum densification a ratio of $\frac{\Delta u}{\sigma'}$ more than 0.8 required.

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So, you have some sort of expressions developed in a Netherlands, which relate the, for example, the pore pressure increase as a function of in-situ, effective stress is given in this form, like, say 1.65 plus 0.65 natural logarithm of N h, these are similar type, where N h, as I just said, we just, we did; and W also, we have the similar thing. So, the thing is that, if you want to have a good densification ratio, like the densification ration, we would like to see that, for good compaction, you know, good, the it should be about 0.8, you know, so, one can keep this, what should be N h value also.

So, if you are looking at, you know, the pore pressure ratio, what it means is that, you are looking at pore pressure ratio of 0.8 divided by the initial effective stress, so, one can really design this N h; and, we also have in the previous equation, some term related to the radius; you can combine some of these numbers and get some estimate, but the important thing is that, now, lot of analysis methods are available. One should use some of these empirical equations with caution; one can do a systematic study on this and then come out with actual guidelines.

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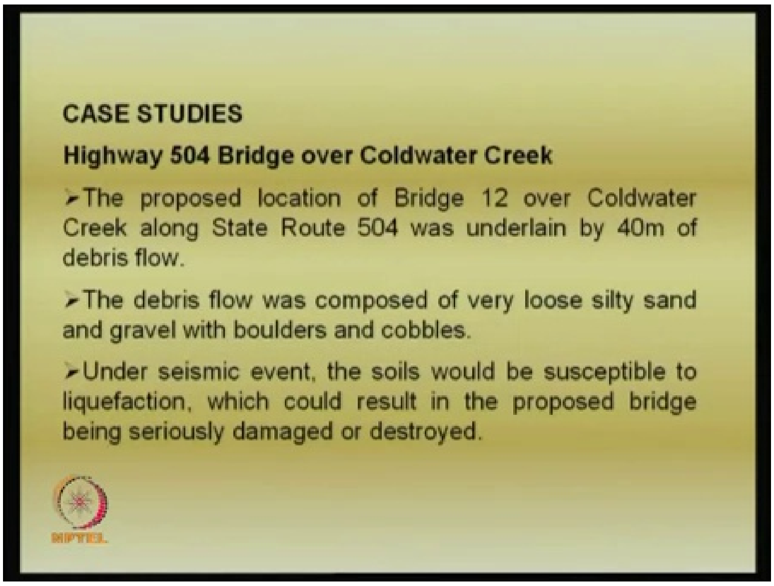

**CASE STUDIES**

**Highway 504 Bridge over Coldwater Creek**

- The proposed location of Bridge 12 over Coldwater Creek along State Route 504 was underlain by 40m of debris flow.
- The debris flow was composed of very loose silty sand and gravel with boulders and cobbles.
- Under seismic event, the soils would be susceptible to liquefaction, which could result in the proposed bridge being seriously damaged or destroyed.

In fact, the best way would be to do a field, case-study; in which, first thing you should do is a trial test. I have done using a charger of 1 ton or, say 504 kgs. What is the distance at which the area gets liquefied? You must be able to roughly calculate depending on the soil type and then use that as a basis for refining your designs. There are some case studies here; one is, a bridge location, and if the soil, in this case, was loose, silty sand with gravel and boulders under in seismic event, the soils would be susceptible to liquefaction, which could result in the proposed bridge seriously being serious damaged or destroyed.

Now, study shows that the soil has a tendency for liquefaction, and then it may give, I mean, lot of difficulties to a proposed bridge. So, which means, that the area should be compacted in the field; of course, we have studied many methods of a, say for example, dynamic compaction, there are stone column, there are... So, many techniques that we did; and underwater, there are some methods and all that. So, in this case, sometimes, you know, (()) we are again looking for a very cost effective technique here; and if you can achieve the cost effective techniques by any of these mines, it is nice.

Say, you can use either, say for example, in a given situation, what you call dynamic compaction method or you can use the densification by blasting. One can, you can just do whichever is cheaper and then go ahead with whichever is convenient and cheaper, right? Because it needs lot of equipment there are many issues involved in both techniques.

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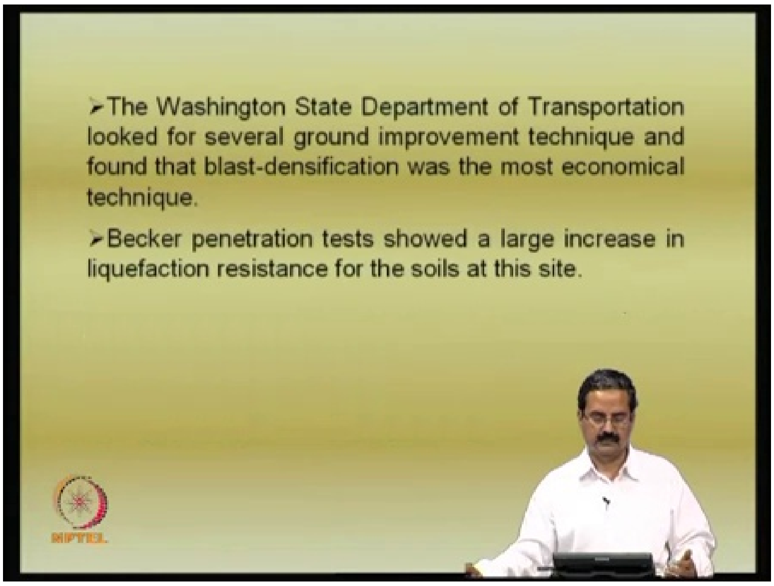

- The Washington State Department of Transportation looked for several ground improvement technique and found that blast-densification was the most economical technique.
- Becker penetration tests showed a large increase in liquefaction resistance for the soils at this site.

So, this Washington State Department of Transportation looked for several ground improvement techniques and found that the blast-densification was the most economical technique. And then, they did a Becker penetration tests, showed a large increase in the liquefaction resistance of soils at this site. So, in fact, they did lot of analysis also, and then cost analysis as well, as the feasibility of doing a work in the site; and then, when they could see that, by blasting this has been effective, they went ahead with blasting.

Then, there is another technique, again another case study in which blast densification was used to densify foundation soils for a large one storey manufacturing facility. Again, here, at the building, has lot of alluvial deposits been, of the, in the foundation area and it is a saturated; very loose to loose, fine to medium fine, grained sands with traces of silt and gravel. So, the soil which is very liquefiable is there.

So, a seismic evaluation indicates that the site would liquefy under the, under the, seismic event, unless the alluvium was densified; if you do not densify the alluvium, the possibility is that, you have liquefaction, and then it could really lead to damages to the manufacturing facility; that is an inference.

So, the seismic analysis was done, and then they got some seismic coefficient or whatever, design earthquake motion was arrived at; and then, when they verified in the design, they found that, that could lead to what is called liquefaction. So, blast-densification was selected over dynamic compaction, vibro-compaction as the best alternative. I just mentioned this was found to be economical.

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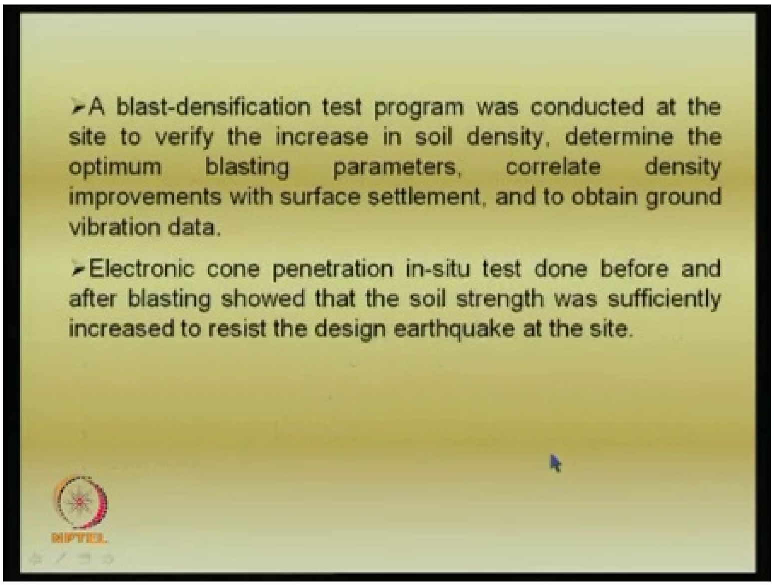

- A blast-densification test program was conducted at the site to verify the increase in soil density, determine the optimum blasting parameters, correlate density improvements with surface settlement, and to obtain ground vibration data.
- Electronic cone penetration in-situ test done before and after blasting showed that the soil strength was sufficiently increased to resist the design earthquake at the site.

So, a blast densification program was conducted at the site to verify the increase in soil density, determine the optimum blasting parameters, correlate density improvements with surface settlement, and obtain ground vibration data. In fact, you have to do particularly, when you do blasting the problem, is that, as I just mentioned the propagation of waves, and it should not cause damage to the nearby buildings, not nearby facilities.

And, blasting may be useful to you, but you should not lead to problems of the neighbors. So, one should really measure, what the vibrations, ground vibration is like. Vibrations at the last point, vibrations of the depth vibration in the lateral extend, and also correlate them with surface settlements, density improvements and parameters like blasting; parameters is nothing, but the charge and the spacing and all that, whatever. So, they did Cone Penetration Test; in this case, Electronic Cone Penetration Test was done before and after, and the result showed that the soils under, subsequently, it is improved, and it increases to resist the earth design earthquake at the site.

What is required was that, essentially, they are looking for a very good ground improvement technique, which is required to match the design earthquake force. So, once you are able to achieve this, then they are all else, able to confirm this with many of these field observations of a CPT test, and they also had enough soil data to confirm that their design is correct; and finally, they have been successful in conducting the blast densification program. And, as I just mentioned, it has been quite cost effective compared to even the standard dynamic compaction methods and other methods of ground improvement.

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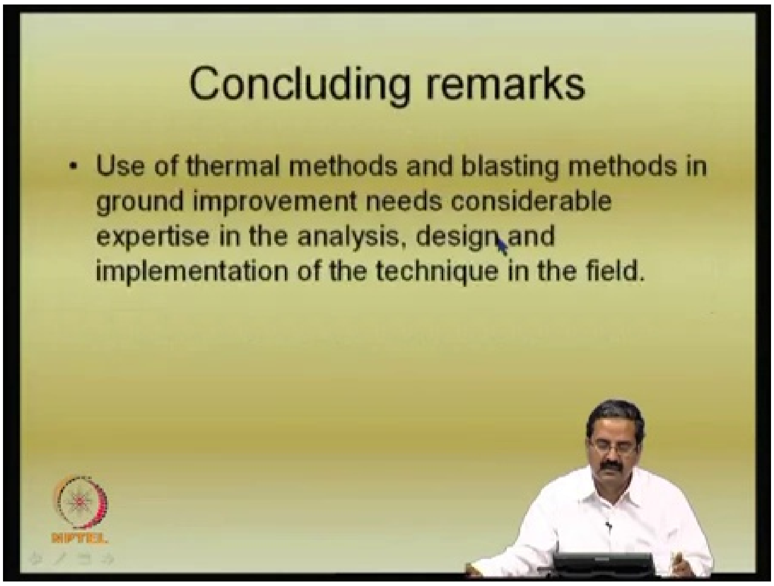

## Concluding remarks

- Use of thermal methods and blasting methods in ground improvement needs considerable expertise in the analysis, design and implementation of the technique in the field.

So, what I would like to highlight to here is that, what we discussed, I mean, in this particular things was that, we are able to use thermal methods and blasting methods, and to improve the considerable, they need considerable expertise; it is not just simple, and you need to do some sort of trial test sections, and design and implementation is also quite involved; it is not easy to do this analysis, because standard, it is not simple to do the analysis, because the methods of analysis numbers are very crude. Design is also not simple; design could be usable, but at the same time, to verify it is something that one needs to worry about it.

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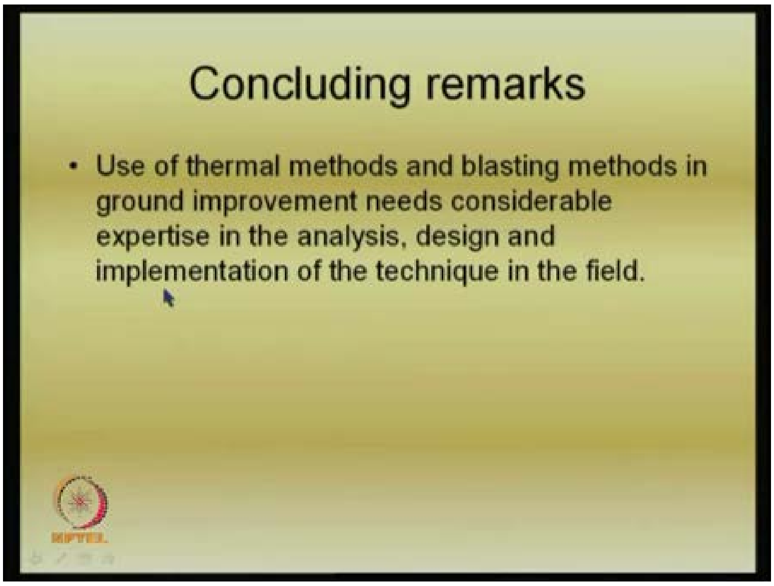

## Concluding remarks

- Use of thermal methods and blasting methods in ground improvement needs considerable expertise in the analysis, design and implementation of the technique in the field.

So, what I just mentioned was that, you should do some trials in their field, and then see if whatever design parameters you are taken are satisfactory or not; then, once you do a trial testing and then back, calculate and check your design, then one can implement in that field and also verify, with many other like, you know, you can use a lot of instrumentations to check if the technique worked in the field.

Thank you.