Ground Improvement
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Module No. # 02

Lecture No. # 07

Dynamic Compaction

In this class, we have a short video of the dynamic compaction process and how it is done in the field.

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You can see that it is being done next to a shopping complex ((noise 00:37 to 02:41)). So, what you have seen is that it is a compaction using dynamic methods, where you try to compact as much as 10 meters of the in-situ soil and improve its performance.

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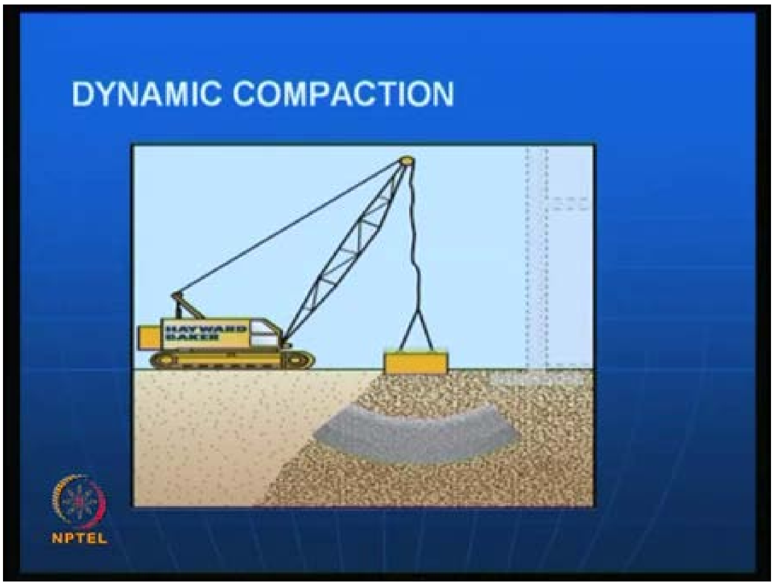

As I just mentioned in my previous class, the way that we do is that we just have a tamper, which will induce energy into the in-situ soil, and this in-situ soil becomes strengthened, because of the energy impact that the material had. The energy whatever we have from the weight into the height, that is, the potential energy that gets transferred to the soil in the form of kinetic in the movement, you know it gets transferred to this soil system. From that potential energy it gets that whatever is the energy that gets transferred to the soil and then there could be some energy losses here because this soil itself is a damping material.

So, with the result that the soil is quite strong, but at the same time it may not have the full energy whatever is transferred, but the energy that is transmitted to the system is good enough to see that it performs as a very good material where in the settlements could be minimum and the bearing capacity is very good.

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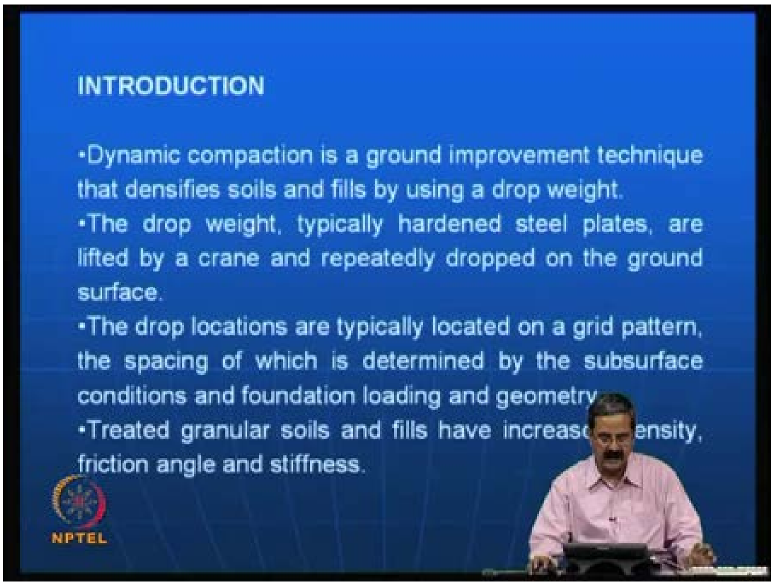

So, as I said this dynamic compaction is a ground improvement technique which can be very useful which densifies the fills by using a drop weight and as you saw just now the drop weight is, it can be hardened steel plate or even it can be a weight; whatever circular or whatever it is lifted by a crane and repeatedly dropped on the ground surface. The drop locations are typically located on a grid pattern like we see that in a design. Now, in a few minutes, the spacing of which is determined by the subsurface conditions and foundation loading and geometry, essentially, we can have most of the time say, grid pattern and the main thing is that the subsoil conditions like the thing is that to what extent is that soil needs to be improved? And then, what is the foundation loading that is coming and the geometry? All that, is very important.

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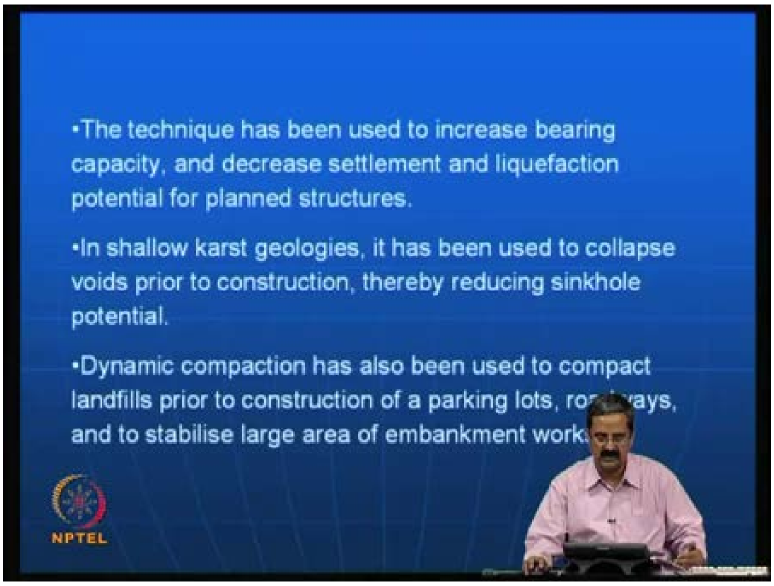

Normally, as treating granular soils and fills have always resulted in increased density friction angles and stiffness we will see this, how it can happen and as I just mentioned, this technique has been used to increase bearing capacity and decrease settlements in liquefaction potential for planned structures. In fact, this is one of the very important applications and in shallow karst geologies where this soil has a tendency to collapse it actually reduces the voids prior to construction.

So that the sinkhole formation are potential is reduced. Then, we also have been using this dynamic compaction for many of the landfill projects because, the landfills in,… the problem with landfills is that they have heterogeneous mixture of waste like papers, food and debris - construction debris and whatever we have waste materials. It is very difficult to (( )) or compact waste materials in a systematic way. But then, the dynamic compaction has been quite useful, why? Because it just directly gives lot of internal energy to the soil by means of this process of dynamic compaction and the behavior or the properties of the municipal waste soil, municipal soil waste are not directly related to the anyway in design. It is just that it inputs lot of energy into the soil system and directly it results in better performance of the structure.

So, it has been used in parking lots; it has been used in highways actually many places in US particularly, even in India it has been done and to stabilize the large area of the embankment works.

Then one of the most important considerations regarding the applicability if there are dynamic compaction, the type of soil being densified as I just mentioned, it is very good for granular materials. And granular materials - they enable excess pore pressures that develop during densification; they dissipate rapidly. In the sense that the dynamic compaction has been very very very much used with considerable effect in coarse grain soils, but then it has been quite effective as well in silts; clay silts and sandy silts as well as in municipal solid waste.

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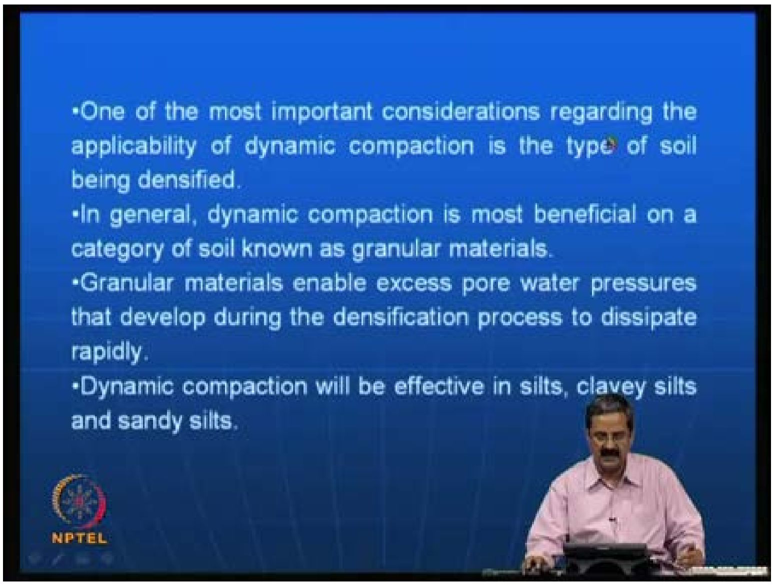

So much so, that it is one of the preferred options particularly, when the little like you know faster it should be you know the rate of the rate of or the you would like to need that area at in a fast manner. You know say for example, if you are trying to for sand drains it could take long time, but then in the case of dynamic compaction it can be required, the area can be required quite fast. Like you must be able to design it properly; that is one thing and then get the weights. Get the tamping, get the proper contractor, then once you have actually the thing is the, in this process what you should do is that you will be compacting up to not less than 10 to 15 meters. You must be able to have the initial soil profile say either using initial profile soil profile as well as a CPT profile and SPT profile and also after compaction you must be able to get the SPT profile or a CPT profile.

We will see how they are useful to us in a minute, but the first important thing is that how do you go about design? The design is something that is very important in this process, but it is a very simple principle that like you know you just compact a soil then it has a shape. You know it has a one the weight densifies a system like this a shape which can be a shape the approximate shape of the area, that is going to be densified could be in this form.

This is a sectional view; this is a top view of that and this thing gives like you have compaction here. You have compaction here; the spacing S g is a spacing and a and b are the parameters say for example, b is the depth of area that you would like to, depth of the soil, that you would like to densify and a is a diameter just we will see some of these parameters.

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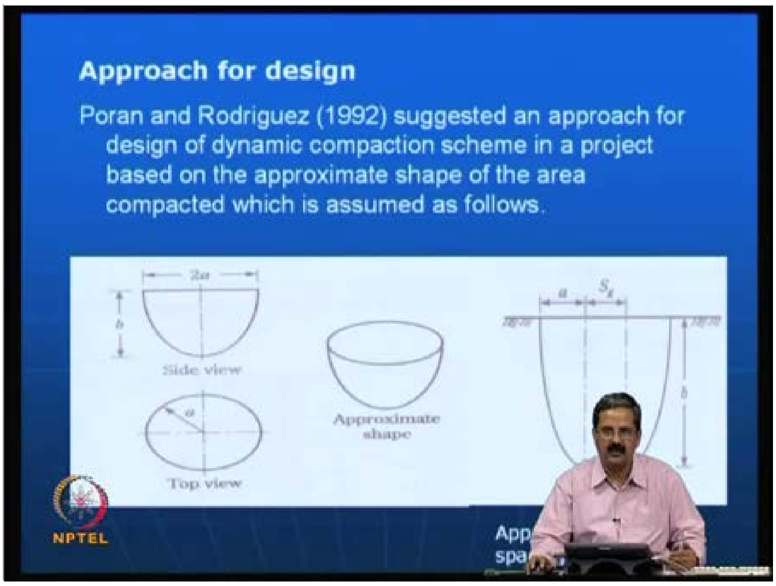

Actually, there is an approach available in literature which can be useful to find out. Actually, in a design we know what is the depth to be improved; so, we should be able to know what is the number of blows required; what is the weight of the hammer required, what is the height of drop, what is the area of the area of the you know cross section. In the sense that if you have a 5 by 5 meter you know 5 meter you know diameter. So, pi by 4 into D square will give you the area of impact then b is the depth.

So, there is some relationship available in literature which has been quite useful to come out with. Once you know this you will be able to know the dimensions a and b. So, that either with this knowledge you will be able to properly get the idea of what should be the in given that you have this weight. Say for example, 10 ton or 15 ton weight and you know this is the height of drop and its area of cross section is known. You must able to design what should be the spacing what should be the spacing and of course, we should also cater to the depth of improvement also.

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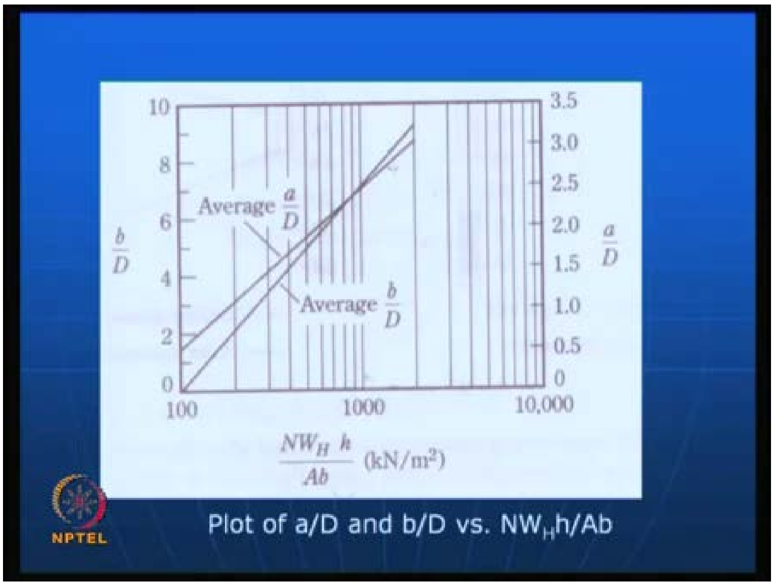

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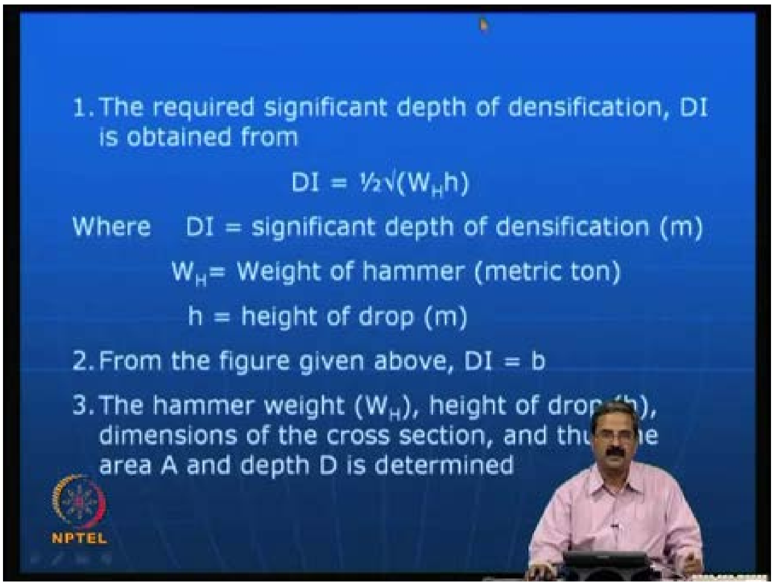

So, we will see that in an example for example, the required significant depth of densification is given by DI is half into square root of W h into H; this is that a simple formula in which earlier also I showed in the previous class about the dynamic compaction methods. The DI is a significant depth of densification, Wh is the weight of hammer, H is the height of drop. Actually, in that previous design diagram that I gave the depth of densification is nothing, but the b if you see the figures they both are same and if you know the hammer weight the height of drop the dimensions of the cross section and thus the area and depth can be obtained.

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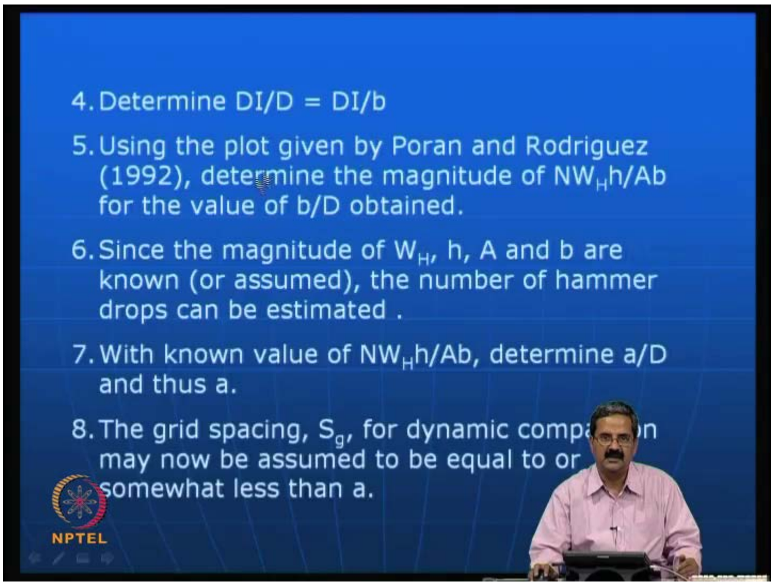

Say for example, this is what we see and this using this plot which is given in an Canadian geotechnical journal paper you need to estimate the magnitude of this particular factor. Actually, and since these are all you have some numbers here say for example, weight and height and all that you have to, you can determine the number of drops in quite comfortable way and you will also cross check what will be the a and D values like what is the. So, A is actually tells you the spacing and b tells you the depth.

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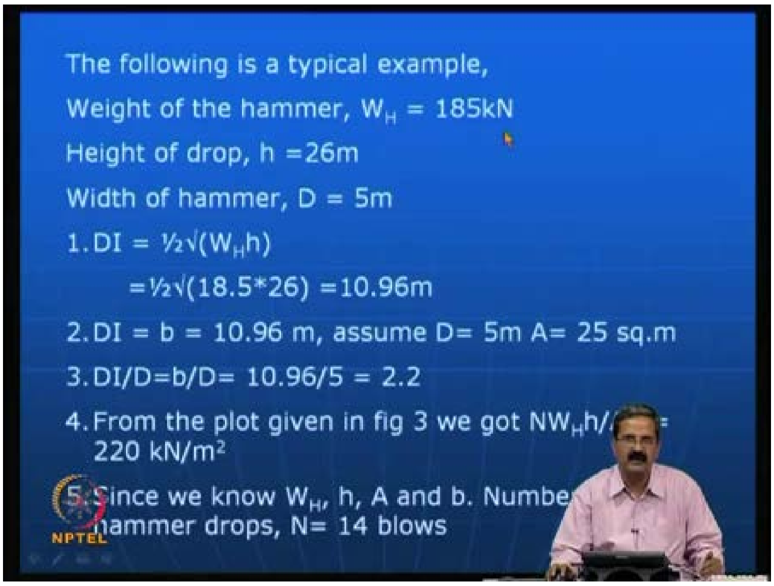

So, for example, in a typical example weight of the hammer is about 18.5 tons or 185 kilo newtons then, the height of drop is about 26 meters and the weight of the width of the hammer say for example, its 5 meters. So, first step is you calculate this depth of significant influence this is given by this expression about 10 meters is what is required about 11 meters now using these values and now, we assume DI have taken it as 5 meters and area of cross section is of 25. I am just assuming it as square for a simplicity and if you just get this b by D you know actually, when I have to refer to the graph where I should go by these numbers its I get a term called to this b by D is like 10.96 divide by the diameter.

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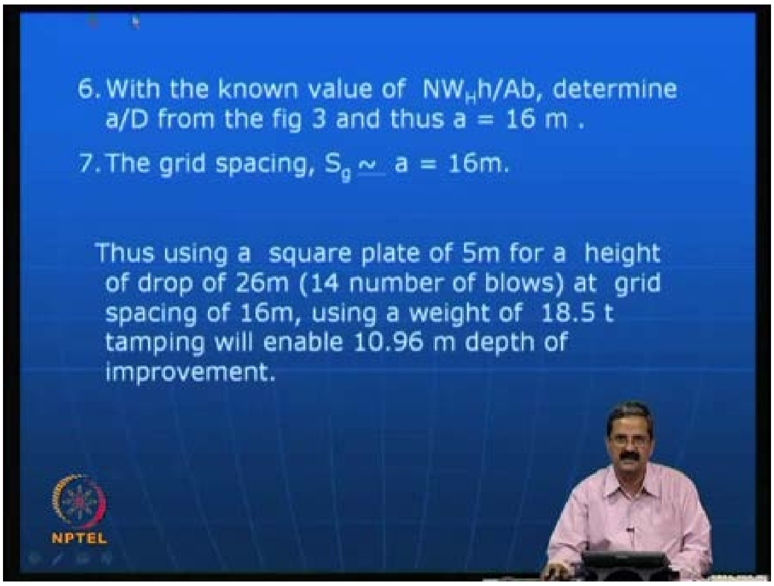

So, 2.2 I will get from the,… for this particular number I get a number Nh is equal to 220 kilo newton per meter square. Now, I know these weights already say for example, I have given as WH as 18.5 height of drop and area of cross section everything is known.

So, what for a corresponding the 220, I should just get back in this particular term the number of drops. So, for example, in this term I know what is 220. So, I am just getting working back what is the number of drops. So, you will get a number 14 and once you know this from the same figure you can also get a by D. So, a by D in the same figure gives you 16 meters is a spacing. So, what it means is that thus using a square plate of about 5 meters for a height of drop of 26 meters with 14 number of blows at a grid spacing of 16 meters using a weight of 18.5 tamping enables 10.96 meters depth of improvement. This is what the statement is like; you are able to now design some in a some sense using these two figures the depth of the,… you are able to understand with a known weight and the height of drop you know what exactly are the variables involved. In fact, if you want to go for higher depth you can increase the depth of height of fall or if you want any other you can always play with some of the variables and come out with whatever is required.

Say for example, if you need only 6 meters you can alter the whole design by using appropriately all the numbers. Essentially, like you know the variables are that you will have, you know height of drop is one variable and the spacing is another variable. So, one can check and then come out with a simple design. Then, once you have to because as I just mentioned here, the design is very like in its simplistic design and best thing is that you have to verify how it is correct to what extent is deep compaction effective.

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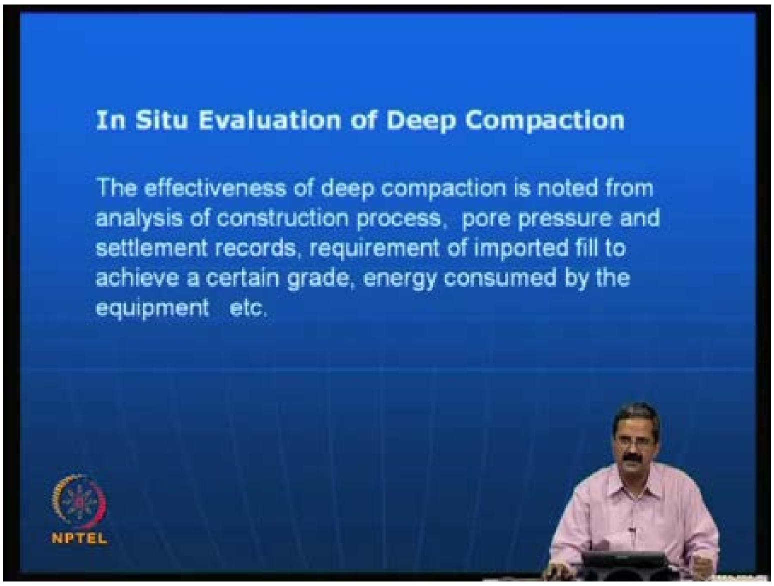

So, what you do is that we go for in-situ evaluation of the deep compaction methods and the way that we do is that you try to analyze the construction process itself like to what, how is the process design like. As I just mentioned, like the calculations procedures we have seen, we can do a parametric study on that and do a proper construction sequence.

Then also, like say for example, if there is a problem of noise also with a,… because of the deep compaction, you can even go for smaller heights and closer spacing; something like that you know one can always work out some sort of processes wherein you can still get the effective improvement.

The other important thing is, pore pressure and settlement records because, the pore pressures and settlements are very important and say for example, finally, you may have initial settlements very high, but the final settlements need to be very low; that is subjective. So, you can only get that from settlement records and pore pressure records. As I just mentioned, many of these materials like particularly, in the process of dynamic compaction the pore pressure is mobilized because the rate of loading is so much that there is lot of pore pressure generated and rate of dissipation of pore pressure gives you what type of soil it is. Like, say for example, in clays you can only say the pore pressure mobilization is very important. So, you have to do the next time lag.

You know you need to really… next type of next tamping when can you do like you know you can done a few tamping's. Now, how do you really release the next time the weight? You know some of these things; you can get an idea from the pore pressures and settlements observations and so that the things are effective. Like, you know say for example, if you keep on tamping it without understanding its pore pressure responses may not be very effective. But, if you really understand all the pore pressures to be dissipated to some extent and then again tamp it like you know your sequence of tamping is something that can be properly optimized. Then what we do is that requirement of the imported fill to achieve a certain grade; sometimes see what happens in a particular place like the whole area is very soft and or some…. So, you are bringing some other soil from nearby island. And then you are trying to require see that it is densified you know because in some places say for example, I just mentioned in Singapore and other places. You will see some more examples here you have to get soil from somewhere and start compacting.

So, in this process what happens? You have to really check if the imported soil has that property like if it has achieved that density or water content and all that. Then another variable is that energy consumed by the equipment itself.

Say for example, the energy that you have put into the soil system is something that has a very good influence. If higher is the energy that is transferred to the in-situ system then, more efficient is the process of compaction. So, you must be able to analyze every bit of this information here and come out with proper understanding and essentially, when if you want to really quantitatively estimate the evaluation the state of the soil because of the deep compaction, you must go ahead with some tests; say for example, you are familiar with SPT test: deep penetration methods, standard penetration resistance. We should get and… the advantage is that you have correlations with the SPT and friction angle and relative density say for example, if the SPT value is 10 or 15.

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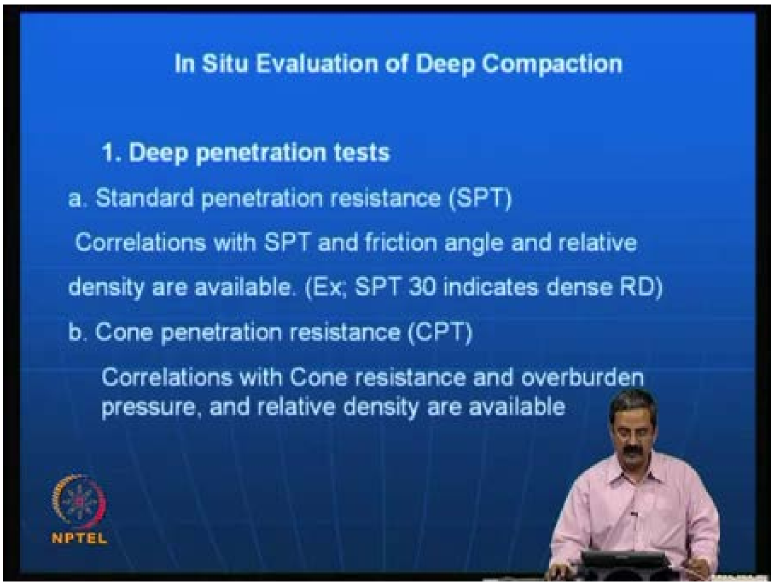

You can say what is the friction angel and then what is its relative density say for example, an SPT of 30 indicates a good relative density. So, like this, like if you have SPT profile much before the compaction process is done you will understand how much is the improved state of the soil.

So, instead of the friction angel say for example, in-situ soil SPT could be 10. Now, it is improved to 30; it is an excellent thing. Now, you also have cone penetration resistance which is we call it CPT test and here again, we have correlations with cone resistance like here the cone continuously drives into the soil and the advantage with cone penetration is that it is a continuous record of the skin friction, shaft friction, pore pressure ratio and many other things. The advantage of the CPT is that it is continuous and it can record many measurements. In fact, it can even measure seismic velocity if you have a proper tip to the attachment to the cone. So, it is. So, much say useful nowadays.

So, here again you have correlations with cone resistance and overburden pressure say. In fact, as higher is overburden higher is its resistance and the higher is the relative density. So, you have some of the literature available which will clearly tell you if the density is very good then the as I just mentioned, compressibility estimates from penetration test say for example, if you as I just mentioned, settlements are very important.

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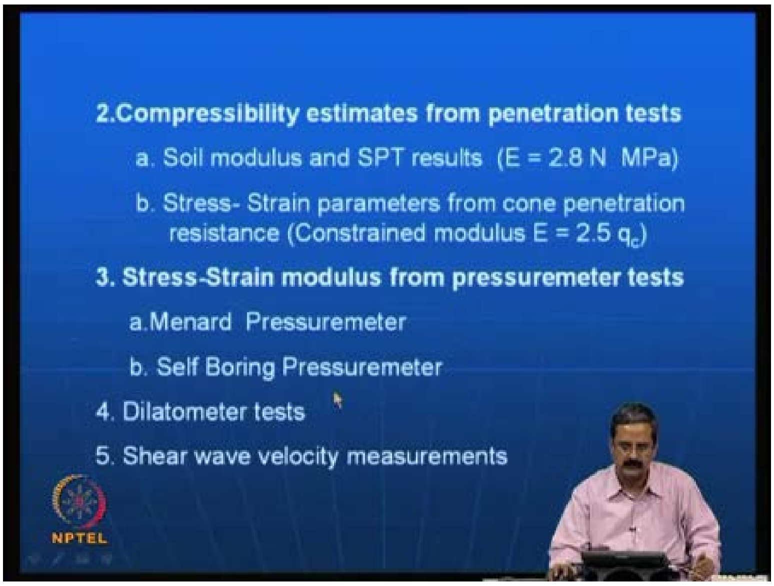

So, if you want to measure settlements, you need to have proper instrumentation and also you need to estimate settlements also. Say for example, you have an SPT value N say 10 it 10. So, if you have, if you want to use a modulus in any of the finite element calculation say what happens is that, you need to have these parameters in once for analysis.

Once you have an SPT test or ACP test - CPT test, how to use that in the the analysis, in design, is very important and suppose you have an SEPT SPT test, you can say that the Young's modulus is related to SPT value. In this form like E equal to 2.8 N M Pa it is a simple expression and say SPT 10 will give you about 28 M Pa you know; which is somewhat poor. But then if you have a 30 number its quite good. So, again stress-strain parameters from cone penetration test is another example constrained modulus is another value that one can get.

We have different types of modulus- in soils like Young's modulus secant modulus and many other parameters like you know 1 dimensional modulus; from the 1 dimensional consolidation test modulus from triaxial test. So, one should understand them properly and you can have even as a simple relationship if you know the cone penetration resistance q c value, it is a 2.5 times, say q c this is another expression.

There is another equipment that we use in a very nice manner which is called pressuremeter test in which you have a small tube which is a, which has a diaphragm and once you insert it expands and then you try to find out the both deformation and the pressure exerted to create that deformation. So, there are two types of equipment here: one is called Menards pressuremeter the other one is self boring pressuremeter actually the Menards's pressuremeter is a very standard one which was developed in France which people have used extensively and it has some parameters you get Young's modulus you get limit pressure limit pressure is related to bearing capacity of soils.

Then we have called,… its actually we have to create a boring when you try to make a when you do a test using Menard's pressuremeter, but later people have done advancement that the pressuremeter itself makes a self bore; you know it is like you know you make a bore and then put the instrument back the problem is that there could be a sampling disturbance and other things. So, they have overcome some of these problems by using what is called self boring pressuremeter which is a very versatile equipment and people have used it.

There is here another equipment called dilatometer test see the pressuremeter test and dilatometer test are very well practiced in like in Europe for example, the pressuremeter test is widely used in France and then dilatometer test is widely used in Italy because they are the countries of origin. But, then they have found their places even in many other other countries like US or even India for example, pressuremeter test are done in NTPC projects and many important projects people have been doing.

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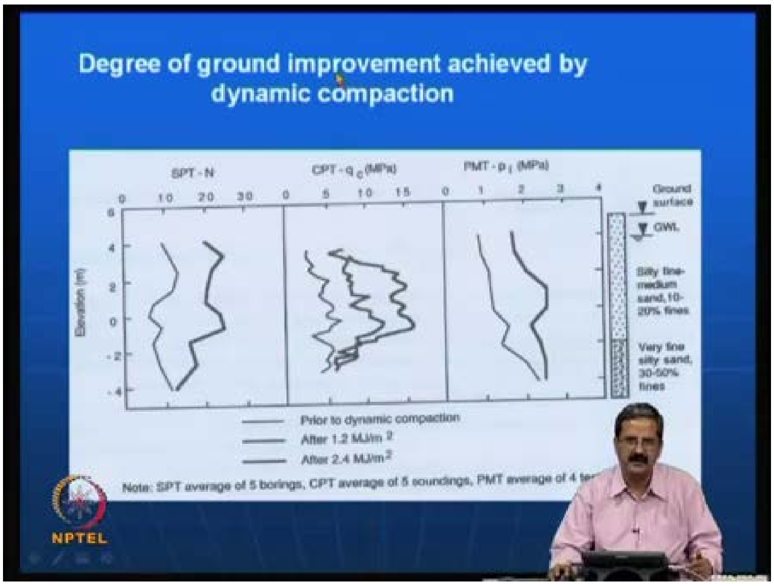

Even say for example, the dilatometer test is it is a simple kit they have a simple kit and one can use that like you know you here again the principle is that you just put that instrument in a particular borehole and then you allow the diaphragm to expand and it resistance to deformation is measured the diaphragm starts expanding because, you will applying some sort of pressure the pressure versus the deformation is recorded and. So, you will get lot of information from both the test because the thing is that advantage is that you do not need to take unlisted samples you are getting the response of the soil from undisturbed state itself.

So, there is some more measurements on shear wave velocities which is very popular we will see some of them now like say for example, this is a typical example you can see that you have a ground surface here and then the water table is here and you have a silty fine medium sand here.

This is about minus, like you know there is a total depth of about 11 to 12 meters. So, the thing is that, you need to really, you know improve this and then the problem is you know you have a ground water table that is very tricky. So, under these conditions it is not its dynamic compaction is quite effective. You can see here that before the dynamic compaction the SPT values are like this; like they are in the range of 10. Once its dynamic compaction is done, you can see that they are in the range of 20.

So, we can see that there is a good difference and you see that in the case of a CPT cone penetration test results is the q c is variable. Here, you can see that the q c is somewhat in the range of 5 kilo 5 MPa, it just increases with depth. But then, we have another, you know q c get's improved with like this. Similarly, in the case of pressuremeter test it is called limit pressure. Limit pressure is another important variable in actually, you will get a result from pressuremeter using it in terms of the limit pressure. You can see that the limit pressure is low when it is not improved and when it is improved it is, there is a good difference.

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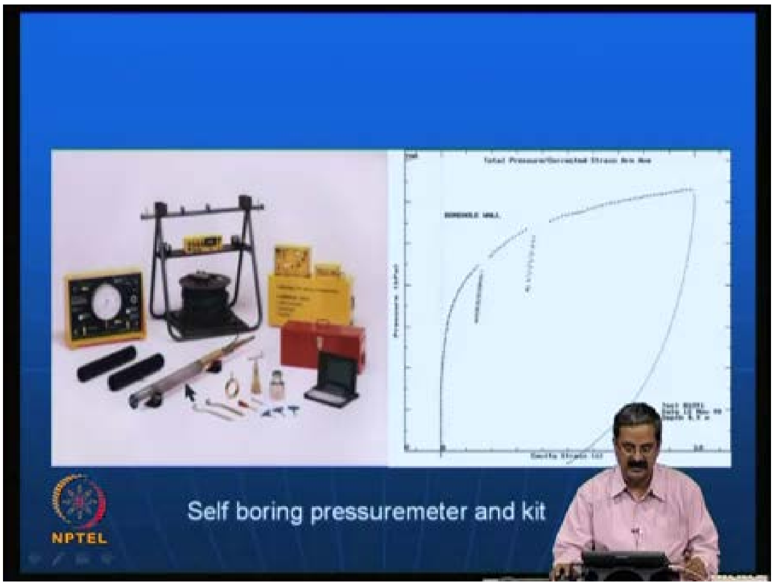

So, that is what I just mentioned the pressuremeter this is a self boring pressuremeter kit like this is that particular material and then this is a gage and this is a system and then all of them you know this these are the extension wires you can go up to 10 to 20 30 meters quite comfortably and you will get a nice profile of its properties. And a typical expansion here you can just see that we call it cavity strain say for example, these things are all based on cavity expansion like you know you add; it is, there will be soil and then you apply some pressure, its cavity expands and then there is a strain here cavity expansion strain you are trying to measure. So, this is how loading portion is there and loading and then this is unloading it comes back. This will be the, in a particular bore hole say for example, this is an old record somewhere which I took from some source. You can see that total pressure versus the cavity strain is given; this can be used to obtain various properties such as Young’s modulus bearing capacity settlements; Poisson’s ratio many things there are lot of information on this.

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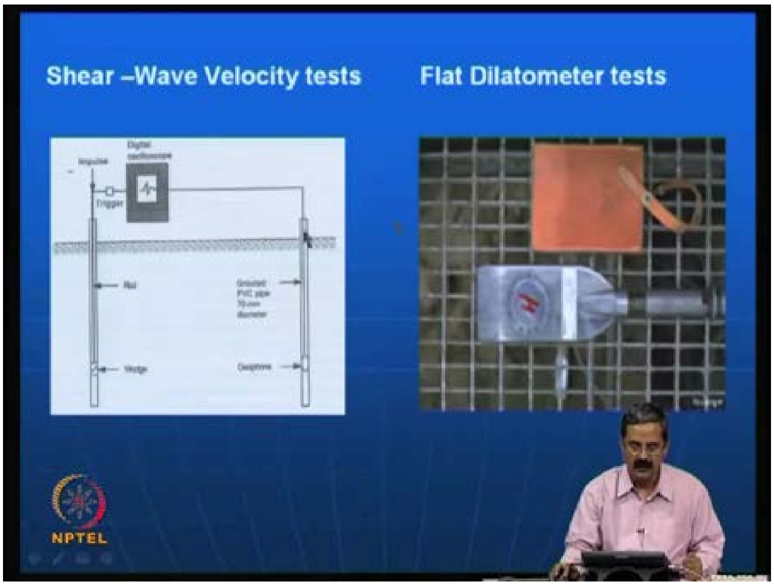

This is a dilatometer; I just mentioned a similar one which in where you have a diaphragm here and then it is a simple kit. Actually, it is a very simple equipment this also has a very versatile application and shear wave velocity measurements. Here again like as I just mentioned whether the dilatometer is also very useful pressuremeter is also very useful and shear wave velocity measurements.

Say for example, in shear wave velocity what do you measure? We measure the shear wave velocity and actually since shear wave velocities are measured from in a,… very using you know you just have a an impulse created and you also have a pick up. Say for example, here in this case like you have an impulse here then you have a rod here you a wedge; then it is picked up by a geophone and then based on this you have shear modulus measurements, Young’s modulus measurements and all that.

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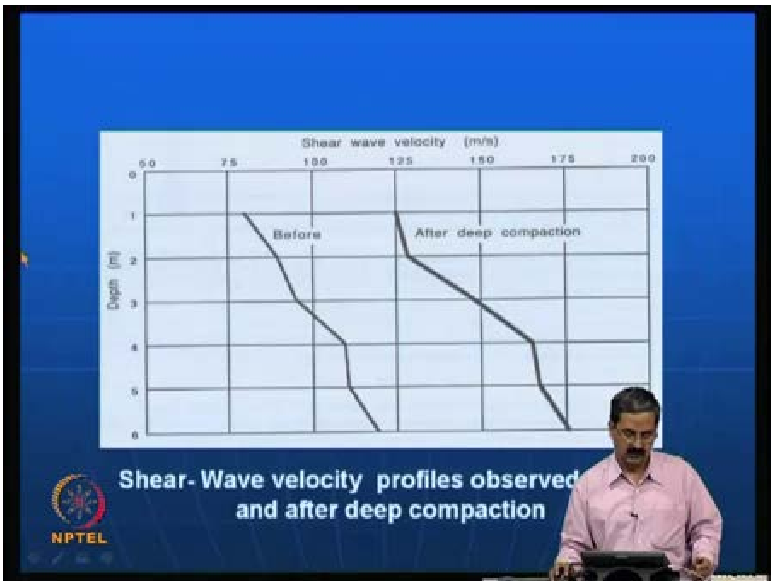

So, you can see the difference here like before dynamic compaction the E value the shear wave velocity values are like this whereas, after deep compaction it can be like this. What I mean is that some of these in-situ techniques are very essential particularly, right from SPT value cone penetration pressuremeter, then flat dilatometer and shear wave velocity measurements have been very effective in improving the in assessing the improved state of the ground.

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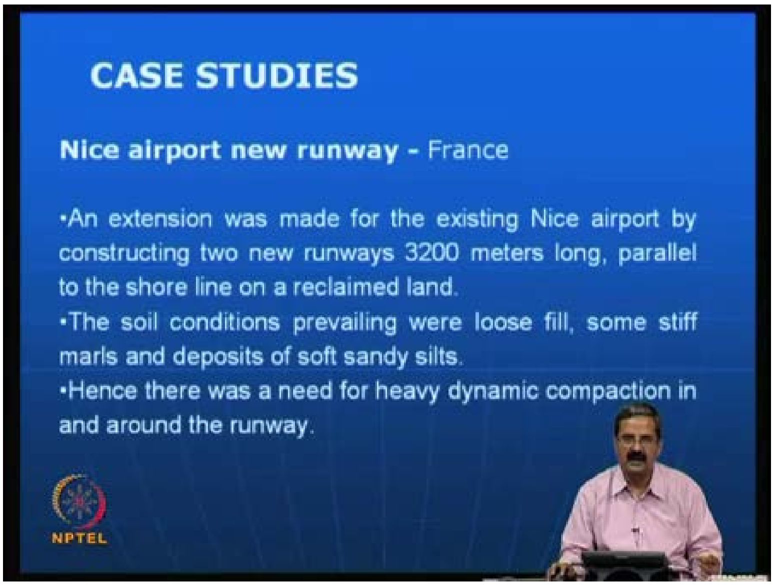

So, what I will do is that I will just take you to a few case studies because the this is say we have some case studies which are well documented we can see that this is a nice airport runway new runway in this case an extension was made for the existing nice airport by constructing 2 new runways the runway length is about 3.2 kilometers long parallel to the shore line on a reclaimed land.

Actually, the reclaimed land is something that has a very low properties low like you know the soil conditions were loose fill, some stiff malls and deposits of soft sandy soils and hence there was a need for heavy dynamic compaction in and around the I mean close to the runway this is the problem.

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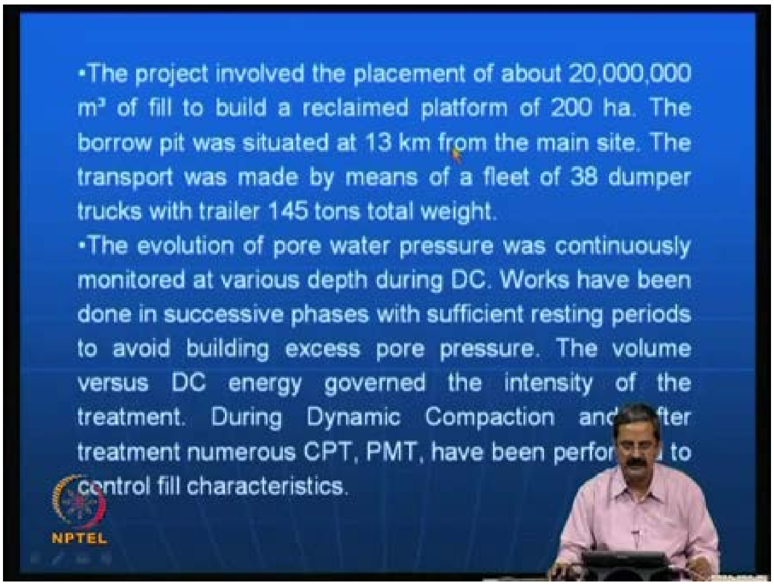

So, what they did was that they had to place about 20 million meter cube quantity is. So, high 20 million meter cube of fill to build a reclaimed platform of 200 hectares area; you can see imagine that area 200 hectares is quite high. The borrow pit was situated at a distance of 13 kilometers from the main site; the transport was made by means of a fleet of about 38 dumper trucks, you know, the number of trucks that are going from the over the distance of 13 kilometers or about 38 and they have a trailer weight of 145 tons; you know the weight that they can carry.

You know you must be able to design your, even your transportation system also very well in a ground improvement project because you cannot there is no you have to get as much as material as possible. So, that you can start reclaiming and then doing a compaction and then recover the soil faster.

So, this is a big process involved in this process, in this planning of operation for a dynamic compaction. So, in this case the evolution of pore pressure was continuously monitored at various depths during the dynamic compaction. As I just mentioned, the pore pressure variations during dynamic compaction have a very significant role on trying to decide about the construction; you know the tamping operations the release of load and all that.

So, the work in this case was done in phases with sufficient resting period to avoid building up of excess pore pressure; the volume versus DC or the dynamic compaction energy governed the intensity of the treatment. Say for example, how much is the volume that has been compacted and the energy input into the system in something that is very important. And, they are able to understand this process and during the dynamic compaction after the treatment they have done number of CPT test pressuremeter test to control the fill characteristics. You can see that this is a process of compacting like you can just see that they have a specific sequence here.

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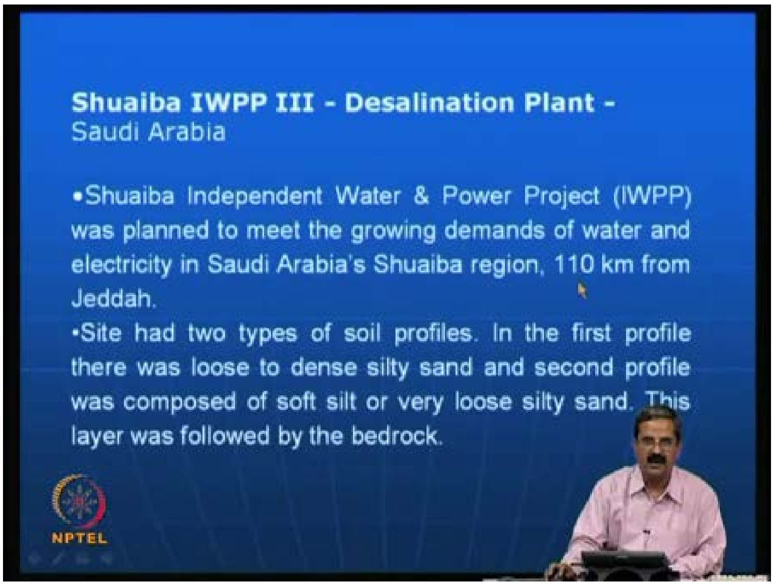

So, there is another example here where for a desalination plant in Saudi Arabia. Actually, if this is one of the plants which required which was required to be constructed to meet the growing demands of the water and electricity in Saudi Arabia in somewhere close to about 110 kilometers from Jeddah and soil has two types of profiles on this. First one was the loose material; loose to dense sand and second profile was composed of soft or a very loose silty sand; this was followed by bedrock.

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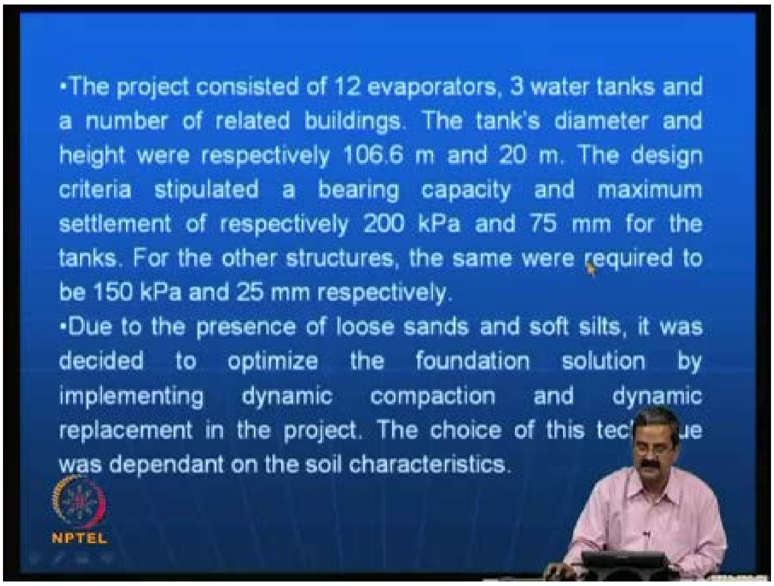

So, we can see that it is quite complex and so, what they did? Like, it has the projects also had its quite huge like since it is more of a water supply project. It had 12 evaporators, 3 tanks and number of related buildings; the tanker's diameter and height were about 106 meters and 20 meters high.

The design criteria stipulated a bearing capacity and maximum settlement of about 200 k Pa and settlement of 75 mm for the tanks. See this is even we have you know for example, in very soft soils on soft soils you must be able to construct water tanks in villages. So, for example, in many of the coastal areas in India, the bearing capacity requirement could be like this and the settlements could be even the 75 mm is valid there also. So, you need to really improve a particular thing using particular some sort of ground improvement technique.

So, that way one can see that this is very stringent requirement you can see that for the water tanks they had a 200 k Pa as the bearing capacity and 75 mm is the settlement

For other structures the same was required to be 150 k Pa and 25 mm set, respectively like you know 70 mm is a (( )) of structures say for example, the water tanks it could be little higher in may be in a raft type foundation, at that they had, but in this case of isolated footings you should have a settlement of 125 mm or something.

So, it is very important that the whole area needs to be stabilized. So, because there was a presence of loose sands and soft silts it was decided to optimize the foundation solution by implementing dynamic compaction and dynamic replacement in the project. So, the choice of this technique was dependent on the soil characteristics.

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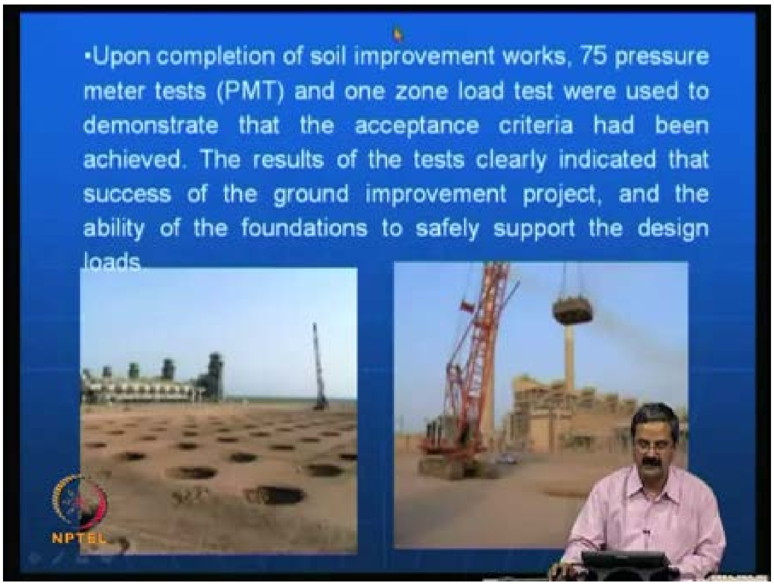

You can see that upon completion of the soil improvement this is a type of work that they have undertaken this from the particular company. They have done 75 pressuremeter tests and load test to demonstrate that the acceptant criteria had been achieved say for example, the acceptance criteria is what the bearing pressure and settlement.

So, you can calculate the bearing pressure settlement using limit; you get a parameter called limit pressure. Limit pressure is related to bearing capacity from pressuremeter test and also settlements could also be calculated. So, the acceptance criteria of settlements and bearing capacity is met using this. So, the results clearly showed that the success of the ground project and the ability of the foundation safely support the design loads. So, essentially you must be able to give guaranty for whatever you do. Say for example, the soil is so soft you must be able to improve to the required capacity whatever the client asks. So, that is a very important thing here and you can see that it is a square - one square plate that what we use in our design, roughly square. There is another one which is an airport that is close to a road. Actually, its widened up to 200 meters by reclamation of about it is about 0.9 million square meters. Actually, it is using dredged sand for a depth varying from 4 to 12 meters like you know the road widening project.

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You know it has to, it has, a lot of filling is involved. So, they removed, they got the sand from some places and then they filled up to 4 to 12 meters and the length of the structure is about 4.75 kilometers and actually, it was, it should have been anchored with sheet pile walls. But, it could not be embedded into hard rock and it was necessary to be equilibrated by well compacted submarine backfill to generate necessary horizontal reaction.

Actually, you know in the sheet pile wall construction the thing is that we also need if you have a well compacted back fill as in the behind sheet piles, the head pressures coming on to the retaining wall or much less like you know the you can optimize the design in a proper way.

Say for example, you have a sheet pile wall, you have a less good backfill that is next to the sheet pile wall definitely the load that the,… that comes on the sheet pile wall will be much lesser compared to what it can be in the case of a poor soil.

So, what that it was that they used dynamic compaction with 15 ton pounder and a high energy dynamic compaction you know you have two types was done for the main part of the fill with special emphasis on areas with sockets.

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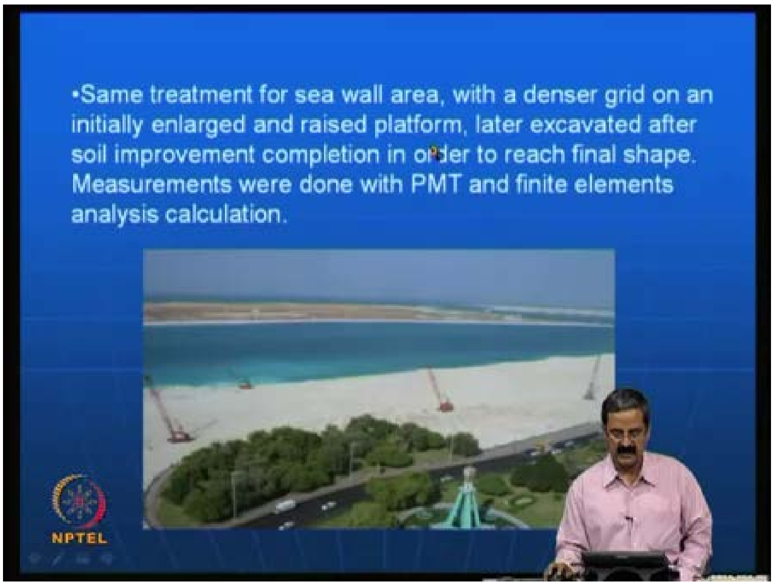

So, we can see that next to the sea beach these all done and the near the sea beach like with a denser grid on an initially enlarge area and a platform was constructed, later excavated after soil improvement, completion was done to achieve the final shape. So, measurements were done with pressuremeter test and finite element calculations. In fact, one should verify some of these calculations and prove that and because you need parameters like Young's modulus and other Poisson's ratio and other model parameters for finite elements. One should use sophisticated testing that is the reason in fact, pressuremeter test was used.

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So, what I would like to say is that of course, I must thank some of the sources from which I got this particular equipment like particular Hayward Baker and Menards and Haussmann is a book I followed. What I want to say is that we are able to, in this particular section we are able to understand what exactly are the issues that are involved with dynamic compaction. And we have seen how what are the different types of dynamic compaction involved say for example, dynamic consolidation is one variable we have seen actually whole of the Changi airport was constructed because of that and there are some more case studies that we have seen.

So, this technique we are able to see the design like you know we have used a simple method in which you can design based on the weight of the weight available you can design the height of drop and the spacing and for the required depth of improvement. Actually, the depth of requirement required depends on say for example, you say that 2 b is a significant zone say for example, you have a footing b 2 b is a significant the depth of pressure ball. So, one must be able to calculate the significant zone say for example, using even finite element calculations.

You can simulate the whole structure at the top of the soil and then understand where the stresses are coming. Say for example, if the stresses are going to reach to a very soft area then the problem is that it could lead to lot of settlements and one should really optimize and then see that those settlements are not there.

And then So, these are all some of the issues that one can need to understand and see that dynamic compaction is done in a proper way and there have been many case studies even. In India also, where particularly in many of the coastal areas the dynamic compaction was done in flash ponds it was done.

So, it has been quite effective because the method itself is quite simple like it only involves the weight to be dropped for a everything is pre-designed and say for example, the height and the spacing and all and only problem is to what extent you are correct. You know is a improved ground. So, that can be only ensured by proper you know in-situ testing using SPT or a cone penetration or pressuremeter test once it is done it is ready for further construction.

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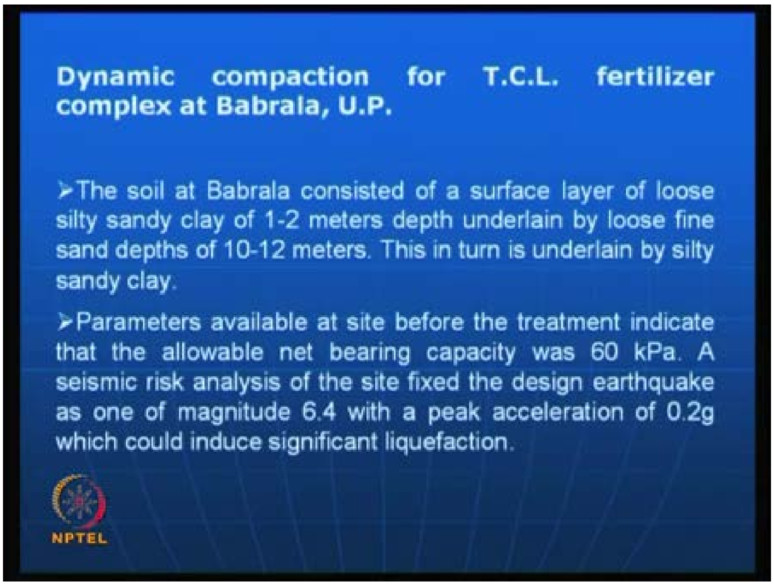

We will take up one more case study on dynamic compaction. This is a case study from India where it is for a fertilizer plant at Babrala, UP. The ground improvement technique using dynamic compaction was required in this area; you have a surface layer of silty sandy clay of about 1 to 2 meters and beneath that you have a loose fine sand of about 10 to 12 meters. Again, a silty clay - the parameters available at the site before treatment indicate that the allowable net bearing capacity was about 60 K Pa whatever is the allowable bearing pressure is about 60 K Pa and other design requirement was that. For this fertilizer plant people have done seismic risk analysis and they find that the risk the design earthquake coefficient should be corresponding to an earthquake of magnitude of

6.4 which is corresponding to peak acceleration of about 0.2g. So, what they observed was that if you have this sort of acceleration that is coming in the site then, since a material is of loose sandy type, there is a possibility of significant liquefaction and they do not want that.

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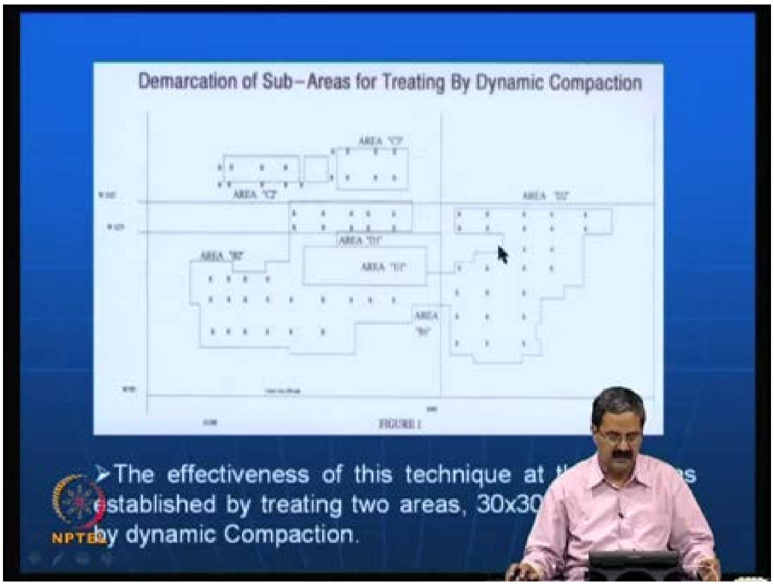

So, they wanted to essentially go for a ground improvement technique which has been essentially using dynamic compaction these are all the areas that they have identified in the site it has a big area which has been marked here A B C E D all that. And first thing what they did was that trial was done in areas of 30 by 30 meters using dynamic compaction because, it is very important to just do a trial test in dynamic, I mean, in dynamic compaction or even for that matter in any ground improvement technique. Because, you will exactly understand how is it working in the field and you can find it here it also like, if you are not really doing well or if the assumptions whatever you made are not appropriated then, you can really make some corrections in the design.

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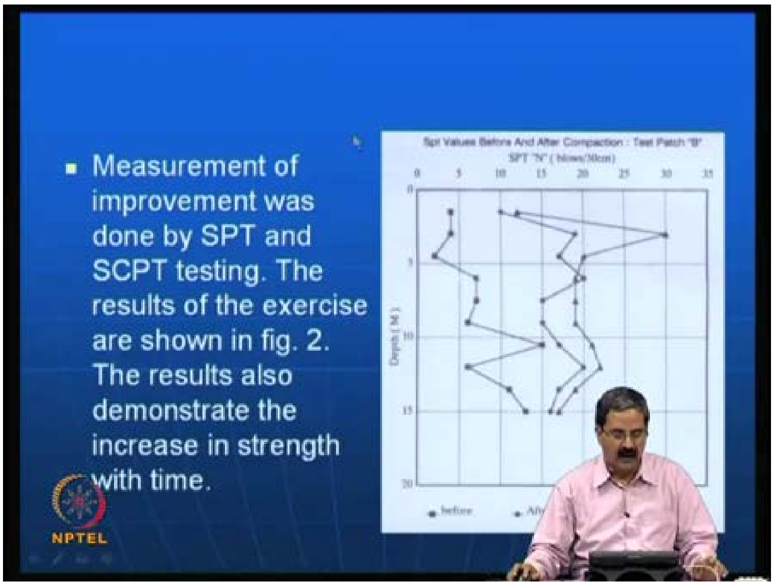

You can see that this is the experiment that was done on the field you know trial site where they did static cone penetration both SPT as well as standard penetration as well as static cone penetration test and this is the figure that shows the profiles. We can see that the SPT profile is very clear like you know the SPT value is very low like 5 blows and then whereas, it increases about 15 which is not really good number I mean. So, of course, we know the trend that the strength increases with depth, but even the value of 5 to 10 is quite low.

Now, after the improvement they just see that they made it; they did some sort of testing it is a tile section you can see that the SPT improved to some extent and it was good everywhere. This point was away from this point and there is a good difference and one can also see that there is another line that if you take SPT values after 1 month there is another some more increase. What it means is that normally, you know like the time dependent behavior is there if you allow things to happen like you know say for example, consolidation is a time dependent of phenomenon in clays. Even in sands also like you know because of the pore pressure dissipation in about 15 days to 1 month time there is an increase in strength which was observed which is good.

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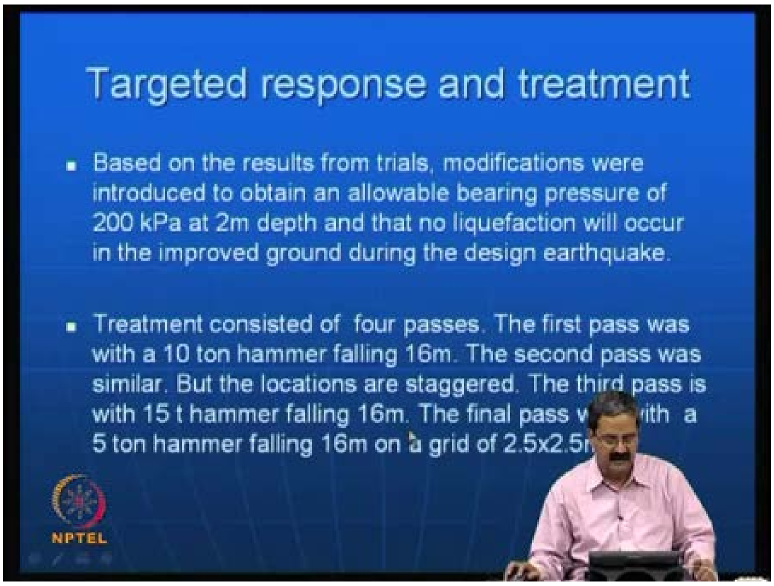

So, based on the results from the trials modifications were introduced to obtain the allowable bearing pressure of 200 K Pa at 2 meters depth this is what they wanted. Say for example, this is allowable bearing pressure 200 K Pa, 2 meters depth and other thing was that no liquefaction should occur in the improved ground during the earthquake; actually the requirement is that. In fact, there is a standard tool like if the SPT value is about 25 you know then the liquefaction will not occur which means that there is a very good density.

There are some criteria one needs to fix up in the particular site and so, say for example, we know that we know how to conduct an SPT test we know how to correct all they have. So, many corrections in the SPT test. So, one should get the correct number like a design SPT value and then correct it using the energy you know energy like 0.65 or the 65 percent efficiency and all that. And there is a criteria that whatever like you know you should be able to get the number you know what should be the actual field number that should be there that you should achieve with your equipment one should be able to get say for example, if it is 25 as SPT value then everywhere all along the profile the SPT value should be more than 25 or 20 whatever.

So, in this case once they really figured out that these are the requirements in the particular site they went ahead with the treatment and its very interesting that they had four passes it is not number of passes like 4 tampings the first pass was with a 10 ton hammer falling 15 meters the second pass was second pass was similar, but the locations was staggered like you know, they just put a little bit of staggering there and then third pass is with a 15 ton hammer falling 16 meters. Now, the weight of the tons is like you know it is a little higher like 15 tons. In the previous case, it was 10 tons and finally, in the last one it was made with a 5 ton hammer falling; on falling 16 meters on a grid of 2.5 into 2.5. Actually, in the beginning itself I just said you know if we just make it you know closer then you know you have shallow depths densified. If you take little deeper the possibility is that the deeper materials get strengthened. So, these concepts one can use and then come out with some good improvement. You can see that the treated soil was you know as assessed in terms of the SPT values because that is a assurance you know like if the contractor does that work you have to see that you get this number.

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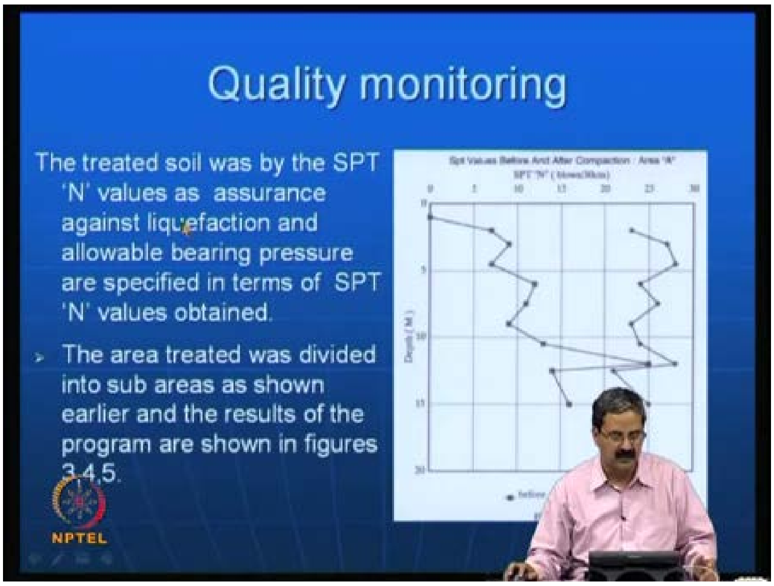

So, the quality assurance program consisted of having SPT values more than what is required. So, for example, you can see that this is the before it was like this, but whereas, it was consistently above 20 say for example, its 20 which is reasonable. So, this is in a particular location area A then in the other location area B you can see that it is always more than 20 everywhere. You can just say that one point its touching here you can say that the area C like there is some one point which is somewhat less than 20, but all other points are ok.

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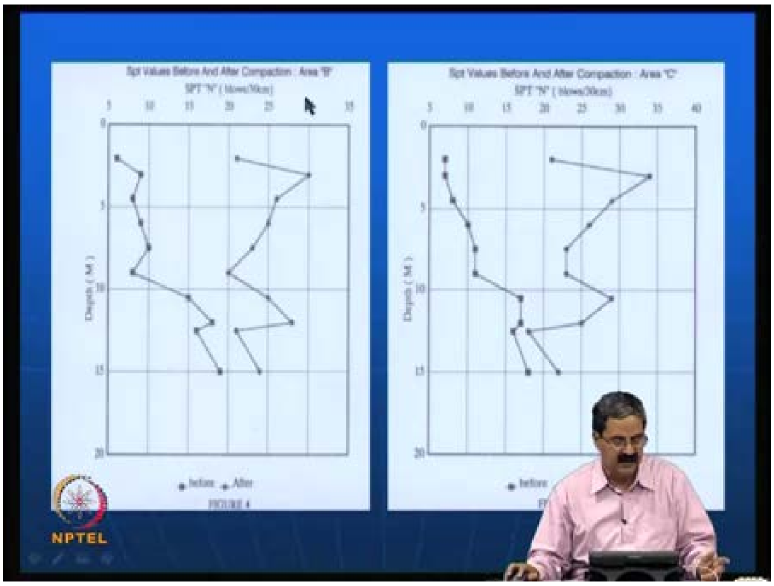

Actually, sometimes you know this also like you know the earlier the specification was that at the top 2 meters they should be a good bearing capacity this could be an abbreviation actually because the possibility is that this you know when there is a good value here there is a good value here possibly this number could be wrong. So, one should really take like that and then come out to say that yes, this SPT value criteria is satisfactory.

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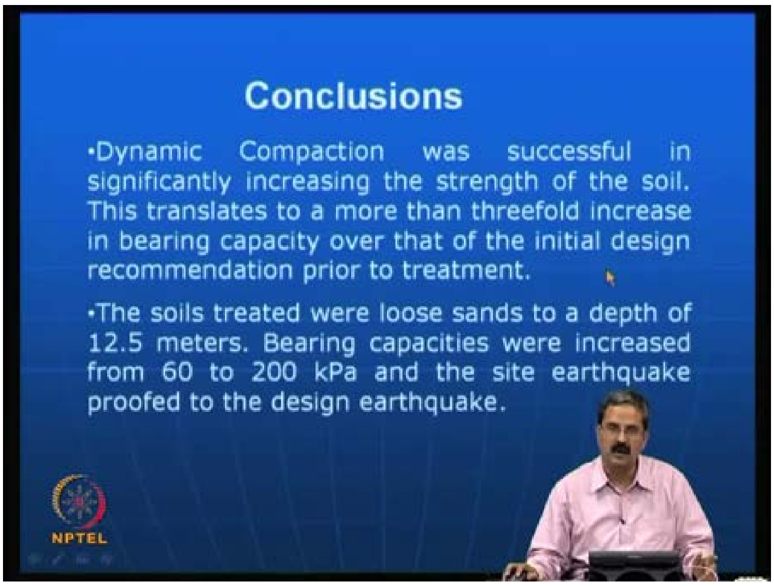

So, this was what the people normally say and in this case definitely the dynamic compaction was very successful in significantly increasing the strength of the soil and this translates to a more than threefold increase in bearing capacity. Like, you know what we thought was 60 K Pa, now we got 200 K Pa. So, that was quite good. Then the soils were treated to loose sands; they were up to depth of about 20.5 meters and bearing capacities increased to whatever we wanted. And also the earthquake resistant design was possible that was what I meant. And particularly, these people have explored lot of other options in the site like any other similar treatments like removing the whole soil trying to back fill and some of them.

You know, like trying to do the piling you know say for example, if you want to increase the bearing capacity of the foundation area like you know why do not you go for piles. Why do you go for this simply compaction which we do not know much? So, some people like you know it depends on the consultant that the project has. If somebody is a geotechnical consultant, he will be able to give geo technical alternatives; but, if there is a structural consultant may be he may recommend piles because he has lot of confidence. So, in this case the technique was very effective and you know cost effective. In fact, the its very may be 40 percent cheaper or even 50 60 percent because piles are expensive.

Definitely, when you do the, compared to just a tamping that you are trying to use and do SPT tests and all that definitely, what we are trying to do is that we are trying to improve this soil as it is rather than trying to remove the soil and then put with an RCC and you know put some piles and all that which is a not, which is efficient in terms of the efficiency. Definitely, we should improve whatever is existing; then, that may be always cheaper than trying to replace the whole material. Try to ignore that material like soil strength. You ignore the soil strength. Actually, in many of these cases you do not particularly, when you design the pile foundation you do not consider the soil between the two piles, pile groups or you know, what is the role. May be, you can consider the skin friction and something like that in a sandy material, but its contribution largely is ignored.

But then here in the ground improvement techniques, what we do is that we just compact the material to what we want, like then some performance you specify. Say for example, SPT 20, you will get it. You have to you have do till you get it. So, particularly this is very useful one you are trying to handle large foundation areas. Say for example, you know coastal areas they result in cost effective solutions depending on the size of the project the type of soil conditions. Say for example, as I just mentioned the techniques of dynamic compaction it can the range is quite big like right from municipal soiled waste to sands it can take care. And, the cost of suitable free material is also important like in some places we have to borrow some material like say for example, we just now you know in the previous case studies we saw that in some places to construct the airport you should bring soil from nearby islands.

So, possible possibility is that they could be expensive. So, one should really weigh against many alternatives and decide about which is the best. So, in this lecture I would like to thank many of these people Sarfraz Ali, professor Gandhi and then some material I have taken from this and Haussmann book. So, I am sure that with this you have a good understanding of the ground improvement technique using dynamic compaction.