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

Module No. # 02
Lecture No. # 06
Deep Compaction

In the last few classes, we discussed various points related to mechanical modification of soils involving compaction, in which I said that compaction is possible by using shallow compaction methods and also deep compaction methods. In the shallow compaction methods, we discussed various points related to the quality of control, using various types of equipment for compaction of soils, behind retaining walls for back fills and many other applications.

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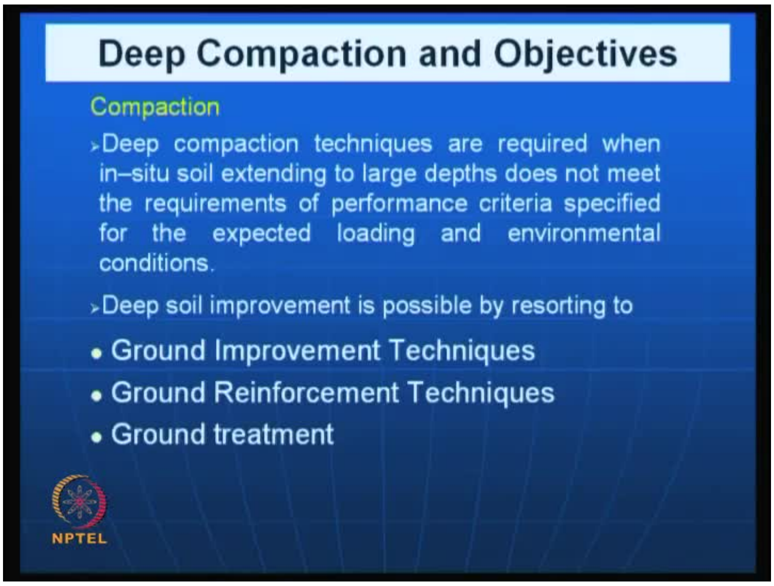

Today, we will discuss some points related to deep compaction. Deep compaction techniques are required when the in-situ soil extending to large depths does not meet the requirements of performance criteria. For example, the places like Kerala and east coast, west coast, some areas the soil is very soft, and if you want to construct some infrastructure on them, the settlements are going to be huge, and they do not have then adequate bearing capacity. So, what we do is that by using some deep compaction techniques, which we would be discussing, we try to stabilize the in-situ soil, for example, maybe 10 to 20 meters below the ground level as opposed to the shallow compaction, where you just compact the soil to about half a meter to 30 centimeters in different layers. Here we need to understand what is the performance criteria expected from the ground improvement technique and we should also see to what extent one can design it.

In this, the deep soil improvement is possible by a couple of techniques; in fact, we can classify them into three categories. We can say that ground improvement techniques can be used like say for example, the deep soil improvement techniques one can use by many methods like stone columns, jet grouting, deep mixing; many other methods that we would be discussing. Then, ground reinforcement techniques are also possible where you have micropiles, use of geosynthetics, stone columns; many things that used reinforcement function as a main criteria for improvement of deep compaction, we try to classify them under ground reinforcement techniques.

Then, one can also treat the ground using varieties of treatment methods say for example, they can range from lime treatment. Any of the modifiers one can use. So, we will just see all of these techniques one by one. What I would be doing is that each of these techniques I would be presenting in detail in the coming classes. If possible, we will try to look at how the technique is developed, what are the principles of the technique, how it can be done in the field. If you want to do in the field, what are the precautions one should take, what are the design criteria, what are the case studies wherein these techniques were demonstrated – we will examine all that. Wherever possible, I will also show some video clips of these installation techniques.

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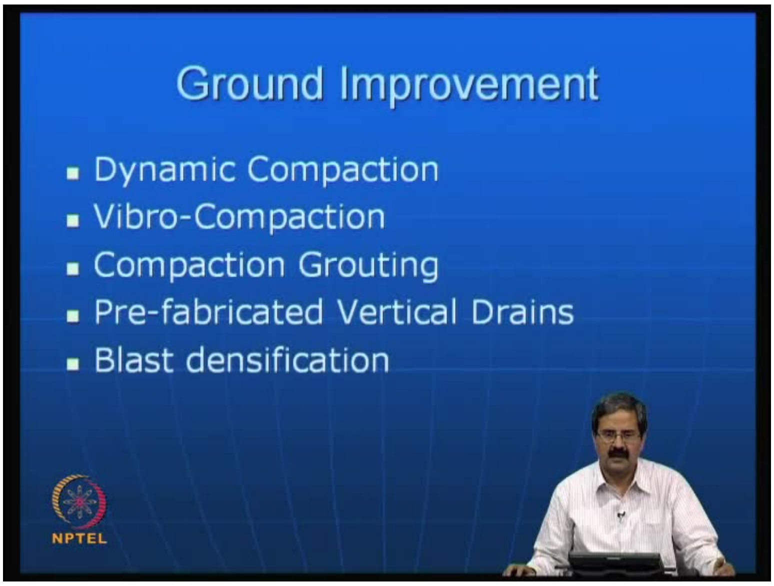

Again one can classify this ground improvement. The following methods like dynamic compaction – is one of the ground improvement techniques; one can use vibro-compaction; one can use compaction grouting; one can use pre-fabricated vertical drains; one can use blast densification. We will see some of these techniques in detail in the coming lectures.

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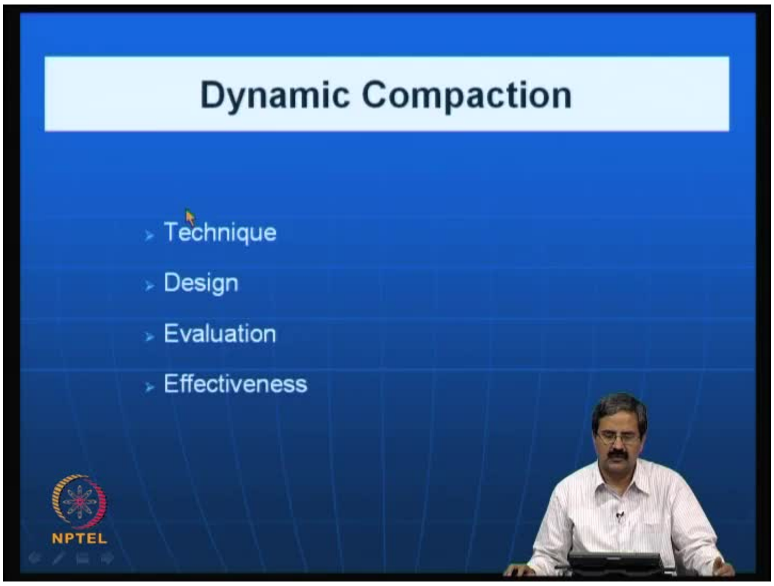

In this dynamic compaction, I would like to describe what is this dynamic compaction and how does it help. So, we will discuss the technique, we will see how the design could be done, we will see how the evaluation could be done, and what is its effectiveness.

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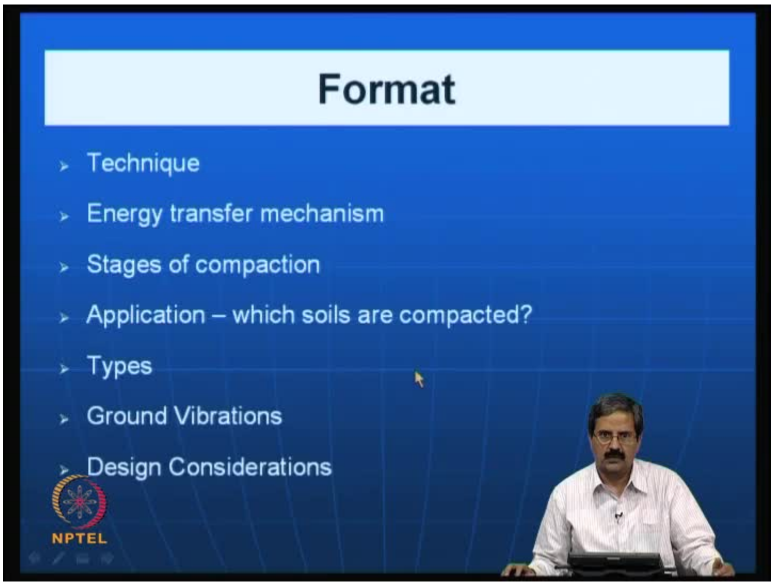

We will see these techniques – What is the energy transfer mechanism? What are the stages of compaction? What type of soils can be compacted? What are the types of dynamic compaction that we have? Once you do this sort of dynamic compaction, which involves huge weights being dropped on to the ground, there could be ground vibrations generated. So, how do you handle them and what are the design issues? We will be seeing one by one some of these points here.

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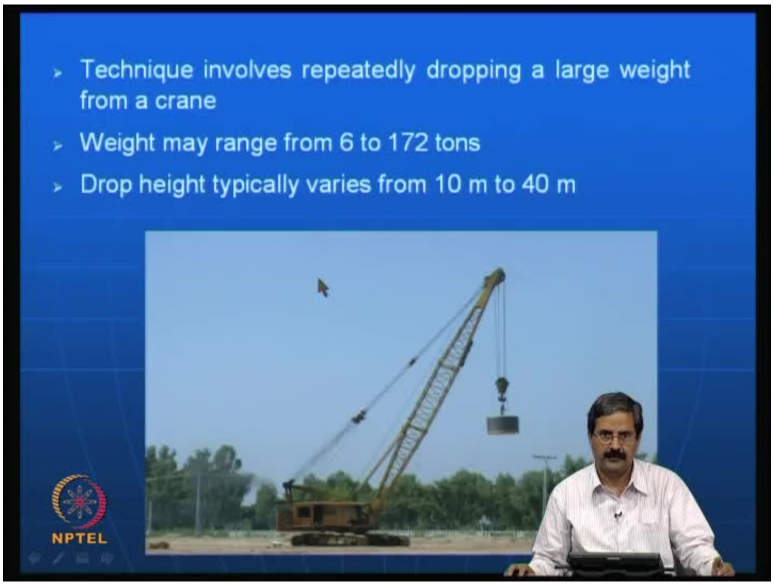

The technique will be essentially that it involves repeated dropping of a large weight from a crane. For example, you see a crane here and you can see a weight here. You can design what weight you want. Weight ranges from 6 to 170 tons. Drop height varies typically from 10 to 40 meters.

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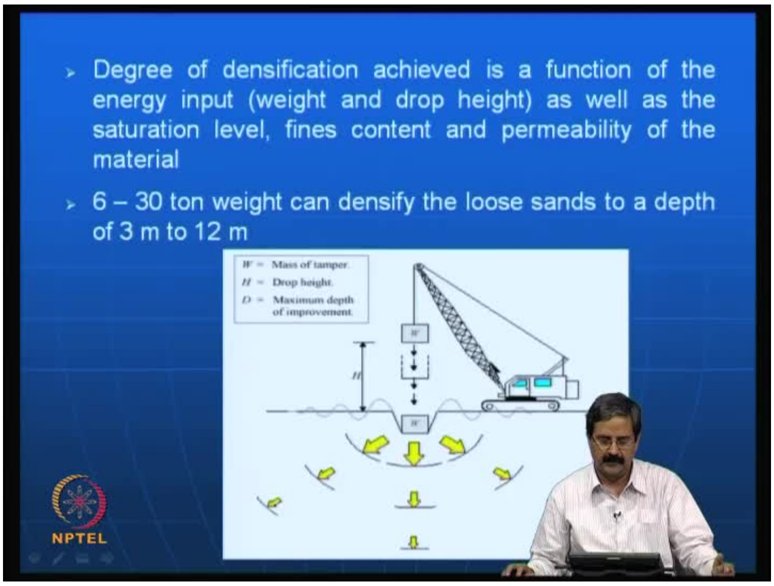

The degree of densification achieved is a function of energy input like the weight and height of drop. We know that the energy can be calculated in terms of the weight and height of drop as well as the saturation level of the soil, fines content and permeability of the soil. These are all some of the important points one should remember; that the degree of densification from the dynamic compaction test is the function of some of these variables like energy input, the saturation level, the fines content and the permeability of the material. Then, these weights of 6 to 30 tons can density the loose sands up to a depth of about 3 to 12 meters. For example, if the depth of compaction that we need is about 12 meters, then one can use this technique.

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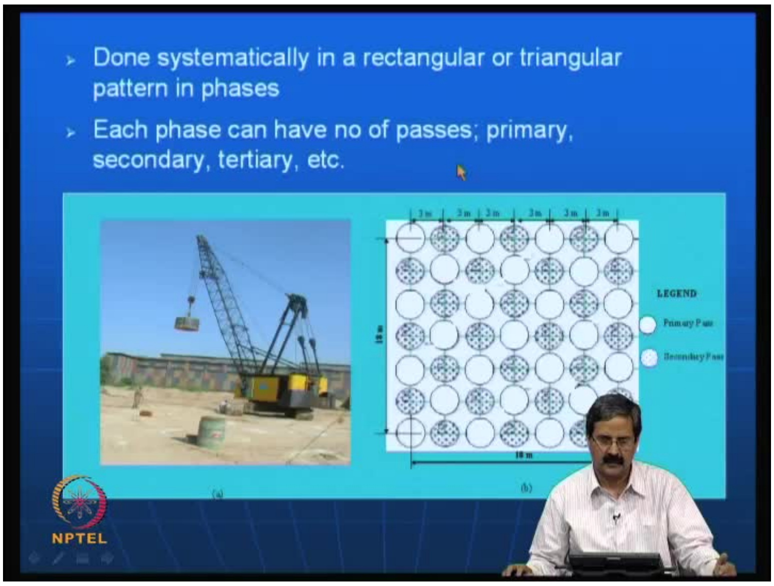

You can see here that this is done in a systematic manner. For example, these are all the tampings that you have; there is a drop. This is systematically done in a rectangular or triangular pattern. For example, the patterns could be triangle or square. Then, each phase can have a number of passes and it can be primary, secondary, tertiary. Primary means first of all, you just compact in a particular place; you compact like this (Refer Slide Time: 07:28). This is a triangular pattern of 3 meter spacing. Next, in between one, you need to compact. Because these three are already compacted, you would like to compact this; you call it secondary pass. So, this is the primary pass like 1 2 3. For example, this is a rectangular; this is a square pattern; this is a primary pass – we call it like 1 2 3 4; you can give. The central one is the secondary pass. So, you compact them in this manner (Refer Slide Time: 07:56). You can just see a circular weight about whatever it depends on the project. So, based on this, one can compact a ground to about…; whatever is the depth like may be 10 to 15 meters, one can definitely compact using these techniques.

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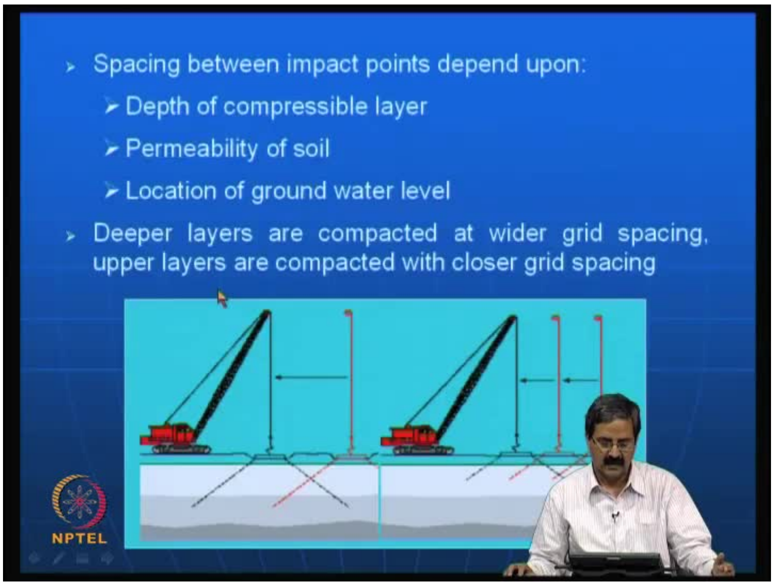

The spacing is an important variable here. The spacing influences a number of variables like say for example, if you want to go for large depths, you need to have wider spacing. So, the spacing between the impact points, we call them – they are the points of impact. It depends on the depth of compressible layer, permeability of the soil, location of the ground water level. Deeper layers are compacted at wider grid spacing; upper layers are compacted with closer grid spacing. You can see the difference here. For example, here you have deeper layers to be compacted; you can see that you have a wider spacing here; has maybe 5 to 10 meters; then, you have these lines of influence going like this (Refer Slide Time: 09:13). Whereas, one can go for shorter spacing if you want to; the procedure that we do is that we first compact the deeper layers; then, we come up and see that the same level of compaction is reasonably achieved at top layers as well.

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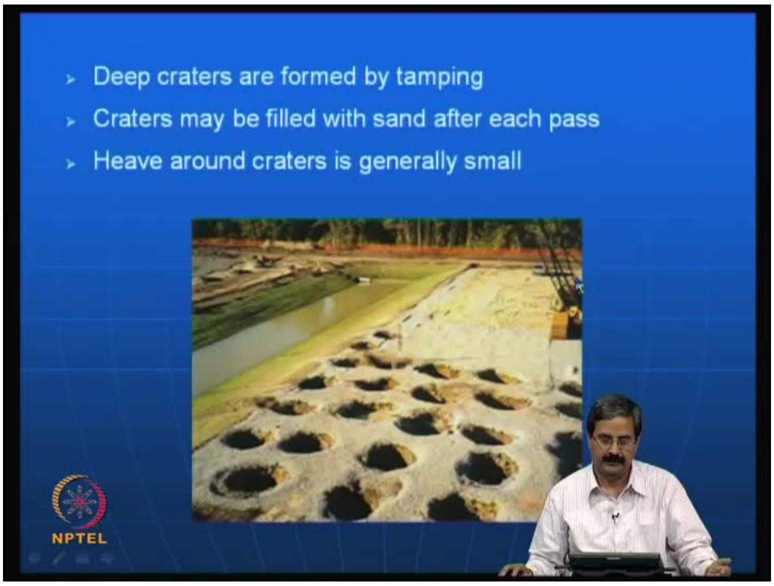

What we do here is that because of this compaction, deep craters are formed, because of the tamping. These craters may be filled up with sand after each pass. Then, there is a possibility that heaving occurs like a small amount of soil comes out around these craters, which is normally small.

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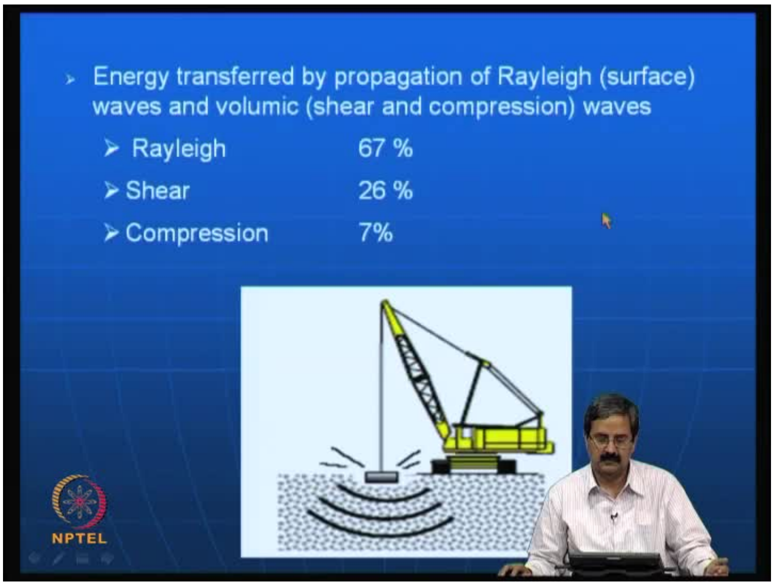

What is energy transfer mechanism? The energy is transferred by the propagation of Rayleigh waves and the volumetric and shear waves. We know that when you do the impact test, there are three types of waves: shear, compression and Rayleigh waves; only three waves are present. Most of the time, it is a Rayleigh wave that becomes very significant here – the energy transfer. The important thing that we should understand here is that you are trying to transfer some amount of high energy like the kinetic energy is converted into a potential energy, which means that the kinetic energy, which you can calculate upon tamping gets introduced into the soil system. Since this energy is important to the soil, it becomes more dense; it becomes more stronger; that is what it means. So, this is the relative contribution of different types of waves here.

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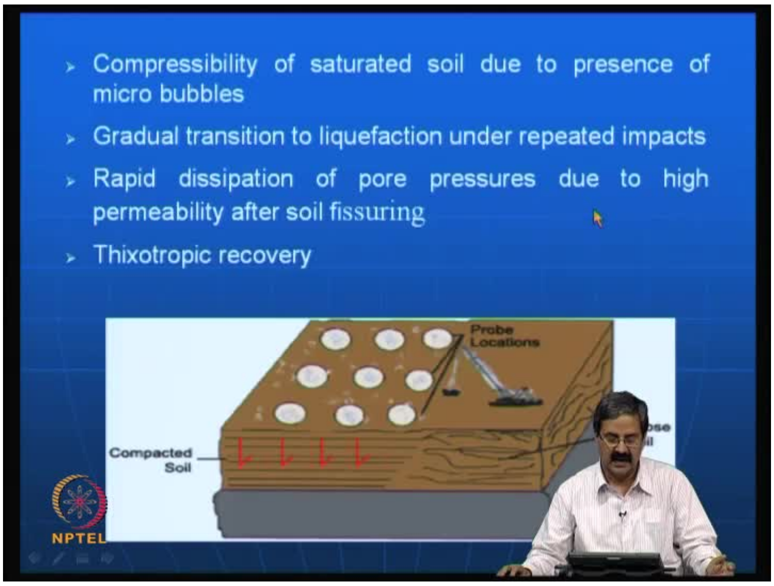

The process of densification is like how does it get compressed? For example, this is a big point because the thing is people were under the impression that how is that you can compact or consolidate a saturated soil? Which is already a saturated soil, if you compact, what is going to happen? Then the mechanism of improvement of the dynamic compaction needs to be understood. For example, the soil is essentially saturated and when you compact it, there is no more… What is going to happen? What is going to happen is that the compressibility of the saturated soil is there and then that takes place, because of the presence of micro bubbles.

Bubbles are there at micro level; small bubbles that can get removed. Then, in the process, the saturated soil gets consolidated. Then, there is a gradual transition to liquefaction under repeated impacts. In fact, there is a tendency of high pore pressure mobilization because of repeated impacts. If you allow that repeated pore pressures developed because of the repeated loads, then the process of consolidation is OK. So, what we do here is that you can see that the rapid dissipation of pore pressures due to high permeability after soil fissuring. Sometimes there is another mechanism that is always presented. There could be some small fissures in soils that leads to higher permeability and that higher permeability leads to rapid dissipation of pore pressures.

Then, there is what is called a thixotropic recovery. The thing is that actually there is so much energy important to the system and with time also, there is mobilization of strength, because of all these other three effects. So, what is going to happen is that in this case, you can see that these are essentially loose soil and you have a probing locations in this manner; (Refer Slide Time: 13:31) you compact the sample as I just mentioned that if you want larger depths, you have wider spacing; if you want shallow depths, you want a closer spacing of the tampings. So, the mechanisms of dynamic compaction are that the compressibility of the saturated soil due to the presence of micro bubbles is helpful; gradual transition to liquefaction under repeated loadings also helps. Because this is also accompanied by some pore pressure dissipation later, this is also aided by… For example, in some cases, there could be soil fissuring because of the impact loads and permeability gets increased. So, these are all some factors that could lead to better improved performance from the dynamic compaction.

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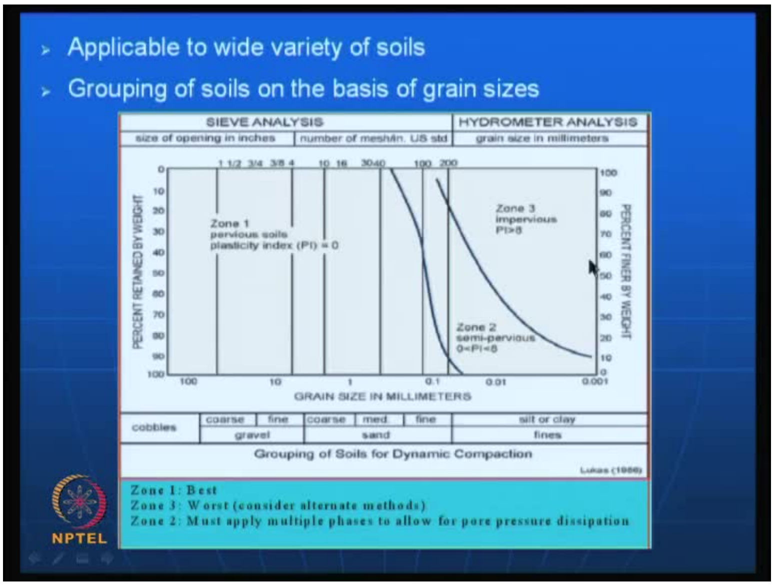

Is it applicable to all ranges of soils? Actually, many of these ground improvement techniques are all specific to soil. As I just mentioned, you cannot use one technique for all soils; like there is no one medicine for all diseases. The good thing is it is applicable to wide variety of soils and then the grouping is done on the basis of grain size characteristics. For example, here you see that there is zone 1; then, the soils are supposed to be pervious here and plasticity index is 0 like non-cohesive soils; then, the grain size distribution is reasonably bigger. We think that the materials that are there in this are best suited for ground improvement by dynamic compaction.

Then, the zone 3 like impervious materials, where the plasticity index is more than 8; say for example, clays. Clays are not very effective; they all come on under this region, (Refer Slide Time: 15:40) where the grain size distribution is quite…; like it is less than 0.1 mm; it is in this range like essentially clay material. In between, like say for example, zone 2 what we call, we can say that it is semi-pervious and then the plasticity index is in the range of 0 to 8; here one should be little more careful in applying these dynamic compaction techniques; it cannot be rapid in the sense that in the case of sands, it can be little rapid because you are depending on pore pressure dissipation because of the grain size. However, here the grain size being little smaller, you need to look for delayed time intervals; or, if there is another way of improvement of pore pressure dissipation it is OK.

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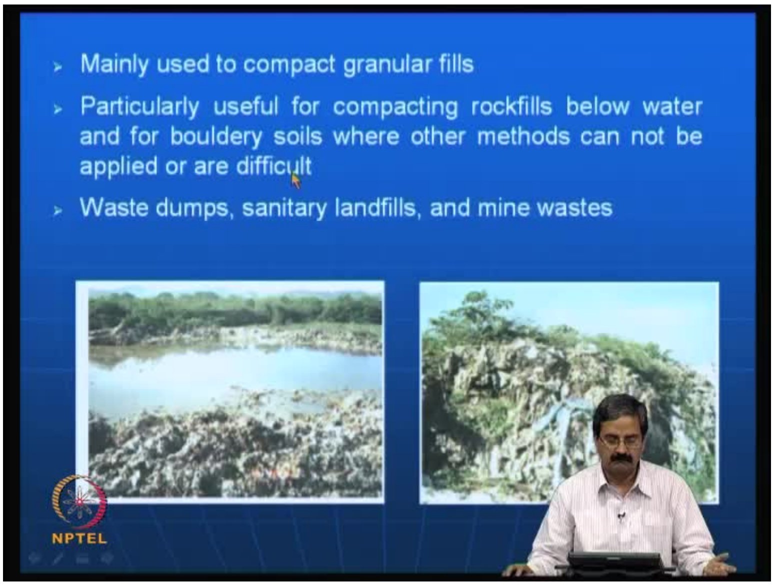

Essentially, one can improve these many types of soils using the dynamic compaction, but then people generally used to compact granular fills. They are very much useful for compacting rockfills below water table and for bouldery soils, where the other methods cannot be applied are very difficult; like other methods are not easy. For example, as I just said, there are different methods like prefabricated vertical drains cannot be used for gravelly soils; it is an extreme example. Like clays are low – the permeability of the clays is so low that dynamic compaction cannot be used. So, in such a case, you go for a prefabricated vertical drain to increase the rate of consolidation, because the clays are very slow in consolidation. One of the best applications of the dynamic compaction is in the case of waste dumps or sanitary landfills and mine wastes.

Suppose you want to recover some areas for rehabilitation. For example, construction of multi-storeyed buildings in the outskirts of a city; in the outskirts of the city, you have always waste dumps and sanitary landfills. What is happening is that waste dumps are quite common like if they understand that the waste dump is going to be very dangerous, then they convert into a sanitary landfill. In either case, the waste dumps and sanitary landfills are very good candidates for dynamic compaction, because the waste dumps are highly erotic in the sense that all the materials that are considered as waste are dumped. In the sanitary landfills, you cover the dumps. You have a proper lining system both at the top and bottom and in all the sides as well. You try to have these sanitary landfills, but once the sanitary landfill is closed, after all the biodegradation activity in the landfill is complete, one can use a landfill space. For example, the top of the landfill space for construction of a mall; that is the simple example; like if you want to construct big mall on the top of a landfill, it can be done.

Then mine waste; mine waste is something that you have in huge quantities in India or in many places. How do you stabilize the mine waste? In many of the box-side mines, the zinc mines, you have lot of waste material. You need to handle them in a proper way, so that the… For example, there is slurry of mine waste; there are so many issues there and one should stabilize the area. For example, NTPC is National Thermal Power Corporation; it is a classical example. They generate lot of thermal power. They also generate lot of flyash; how do you really stabilize the flash and how do you make it useful? They cannot dump flyash wherever they want; they must construct some means of storing them properly; also, if at all they dump, sometimes they must be able to reuse the same space; all that.

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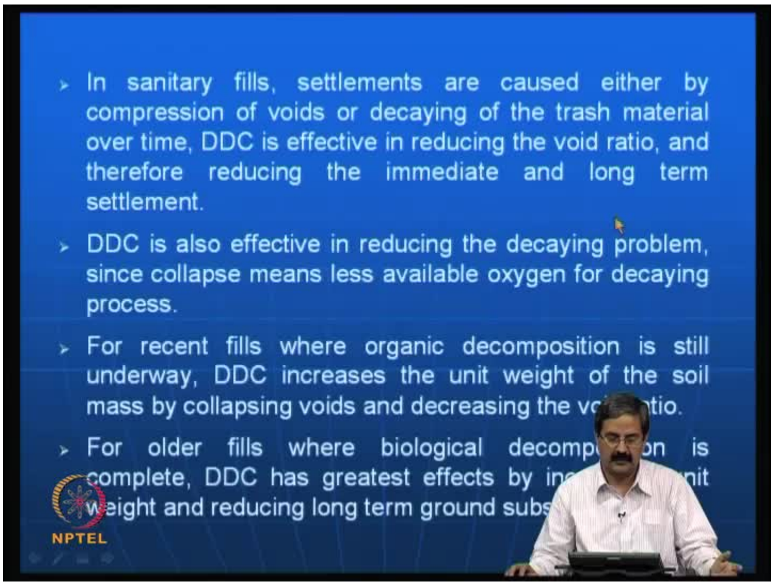

In sanitary landfills or waste dumps, the settlements are caused either by compression of voids or decaying of the trash material over time. In fact, as I just mentioned, the landfills have biodegradable, degradable, all sorts of materials. Essentially, we try to say that for example, if you are using plastic and papers, they are not biodegradable, but there could be a green waste, which are biodegradable. So, all these materials are there. In such a case, it is not easy; I may say some void ratio is there, but what is this void ratio? The definition of void ratio is somewhat tricky when you have biodegradable matter present.

You may calculate some void ratio now, but after the biodegradation is complete, there could be something. The void ratio is because of the two components here: one is voids present in the non-biodegradable portion and voids present in the biodegradable portion. So, it is very important that one should understand some of these things properly. The dynamic compaction is very effective in reducing the void ratio, and it is very useful in reducing the immediate and long term settlement. In fact, the problem is when there are so many materials present there, different materials have different decaying; rate of biodegradation for each material is different. For example, in the case of pep, the food waste is very fast, but in some other type of organic waste, it could be different. So, this rate of biodegradation is something very tricky. As long as the materials are biodegradable, we have volume change. That volume change needs to be preempted; in the sense, if you are able to compact it, the post settlements will be much less. So, that is what is meant here that the dynamic compaction is very effective in reducing the void ratio both in the immediate and long term settlement. If I have a waste dump in somewhere, if I use dynamic compaction, both immediate settlements are mobilized and long term settlements will also be less. Very important point is that since… The dynamic compaction is also effective in reducing the decaying problem. Why the decay occurs, biodegradation activity occurs is because of the availability of the oxygen. So, it is better that there is sometimes the collapse in the case of this materials; it makes availability of the oxygen less. In fact, as long as the oxygen is available and the biodegradation is complete only, you can be very sure that the consolidation is complete.

Then, for some recent fills, where organic decomposition is still underway – still it is going on; the dynamic compaction increases the unit weight of the soil mass by collapsing voids and decreasing the void ratio. Actually, it accelerates many things. What it is trying to do is that so much of settlement it accelerates. For example, if the biodegradation takes five years and if I just do the dynamic compaction, what is going to happen is that all the voids are reduced and the settlements are preempted. These settlements; for example, you may be expecting about 3 meters; you can expect settlements of the order of 3 to 4 meters. For example, I will tell you a simple example; the landfill is about 30 meters height; a typical case. Normally, the settlements you will be expecting about say for example, 5 percent. In 30 meters, about 1 percent is quite less. For example, you will have about how much? About 300 mm. So, the settlements could be little. For example, you have seen this sort of heights of landfills, where the settlements are going to be very huge. Say for example, if I say the possibility of the landfill settlements could be as high as 30 percent. Can you imagine? It is very difficult. 3 meters could be the total settlements that one expect in some landfills because the settlements in landfills is composed of three components: one is the immediate settlement under load; then, the second one is the secondary compression that we call in geo technical engineering; third one is called settlement due to all these material like biodegradation and all that. In fact, people have measured that the settlements can be as high as 20 to 30 percent. It is too big a quantity. So, it is not like 5 percent or 10 percent like what you expect in a typical case; in the case of even 0.1 percent, we expect in the case of well-compacted materials. In the case of compacted samples, if you have embankment, you have to expect some sort of settlements. That could be of the order of 0.1 percent of the total height. Here the settlements could be very high, 10 percent because of the biodegradable matter being present.

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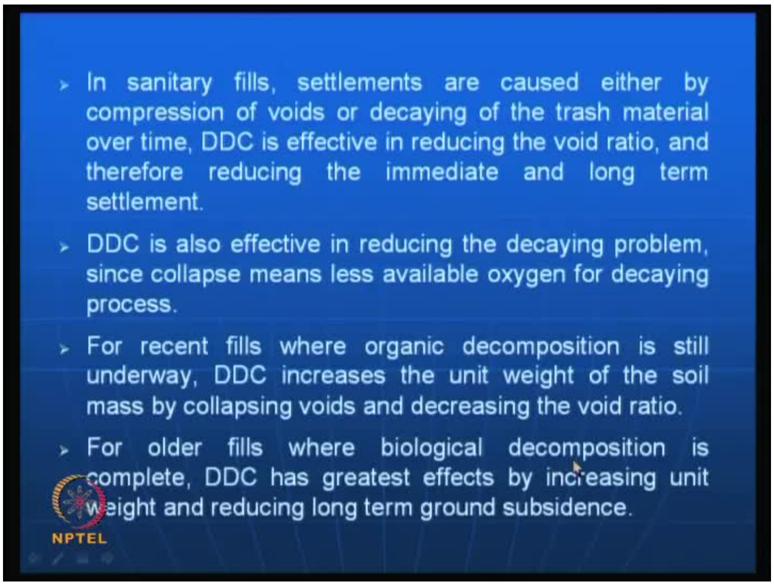

Definitely, this dynamic compaction is very helpful in reducing the settlements. In some places where these fills are old, biological decompression is complete, dynamic compaction is very useful in increasing the unit rate and in reducing the long term substance. This is another important point.

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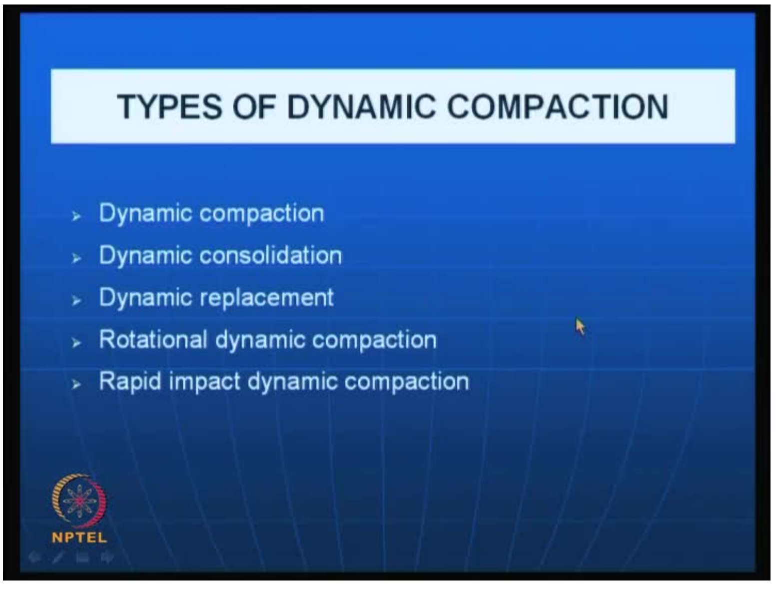

I will just mention about the types of compaction here because the dynamic compaction is the term that is normally mentioned. However, it can be classified into different categories here: one is called dynamic compaction; dynamic consolidation, dynamic replacement, rotational dynamic compaction, rapid impact dynamic compaction. Actually, it is just based on the method that we do, nothing else, but all are effective.

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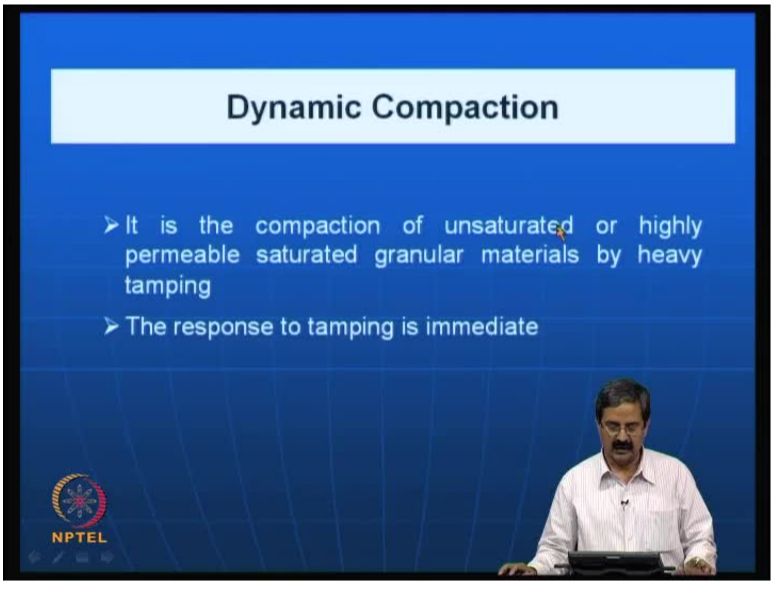

What is this dynamic compaction? It is essentially the process of compaction of unsaturated or highly permeable saturated granular materials by heavy tamping. Assume that you have a sandy layer; maybe some areas in Chennai or someplace in west coast or east coast, you are trying to come up with big infrastructure there. This soil in some places is unsaturated or it is saturated granular material. One can really use this dynamic compaction using this tampers; the response to tamping is immediate, which is very good.

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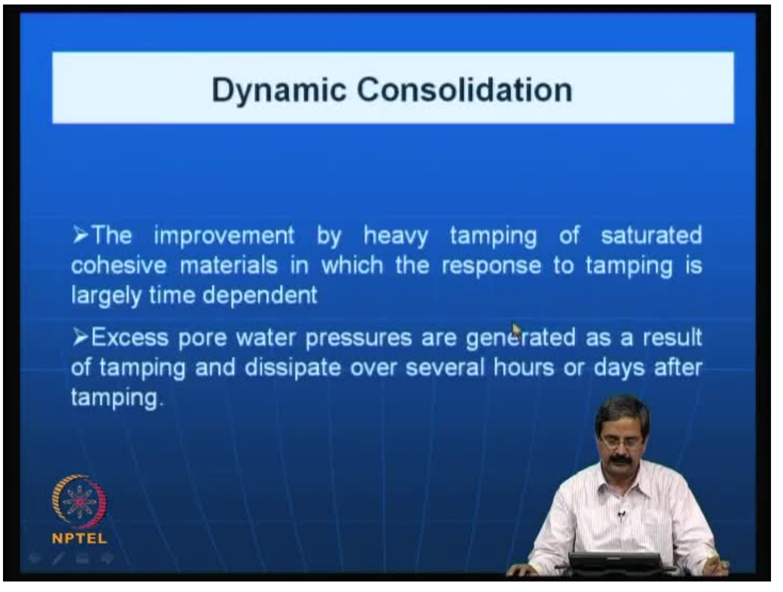

What is dynamic consolidation? This dynamic consolidation is nothing but again a heavy tamping of the saturated cohesive soils. In the previous case, we studied about what the candidate versus cohesive less soil; there is no cohesion there. The permeability was very high; response is very fast. Here since it is a clay, the response to tamping is largely time dependent. We know that the clays have a tendency for consolidation, which is a time dependent phenomenon. We have excess pore pressures generated as a result of tamping and dissipation takes place several hours to days after tamping. So, this is the difference.

In fact, I must tell you the example that the whole Singapore airport; we call it Changi airport; whole thing was reclaimed from the sea. For example, there is a soil; if you want to extend land area, you try to bring lot of soft soil and dump into the coastal areas, and then it gets deposited. They constructed that whole thing. Then, the soil is fully saturated and clay. Even in some places in islands; if you are living in island, whether it is a soil, clay or sand, it is very expensive. You may get any other thing cheaper, but not clay and sand. However, you need to really a very good engineering method. Say for example, between a couple of islands, if you want to transfer some clay or a sandy material from one place to another place, it is very expensive. So, people have been using reclaiming. Once you get that material, you must be able to construct the infrastructure very fast using proper ground improvement technique. If you have sandy soil, which is very loose, you want to construct something on it, you should go for dynamic compaction; whereas, if you have clay, you should go for dynamic consolidation.

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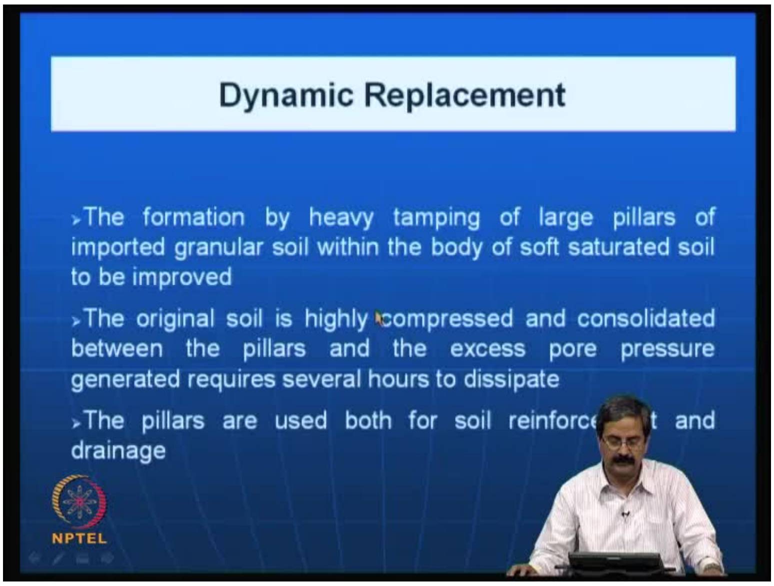

There is another one, which is called dynamic replacement in which you have a heavy tamping of the large pillars of the imported granular soil within the body of the saturated soil. The original soil is highly compressed and consolidated between the pillars, and the excess pore pressures generated requires several hours to dissipate.

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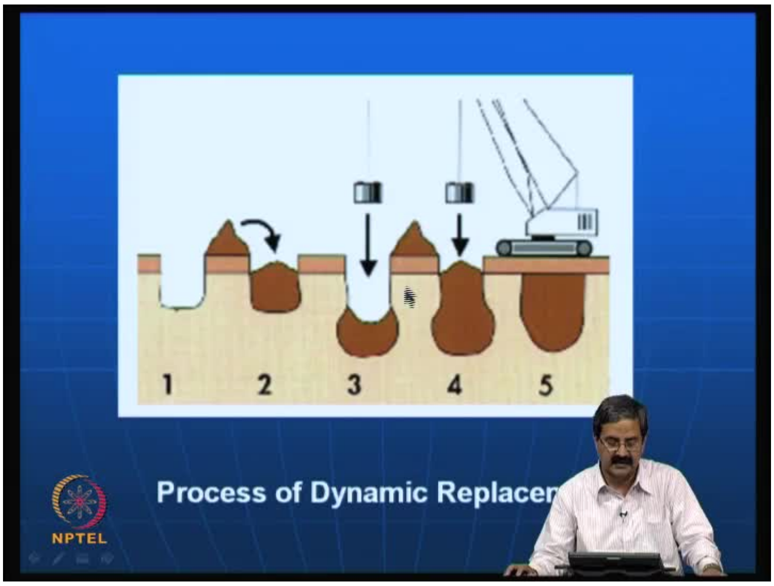

Pillars are used both for soil reinforcement and drainage like this here. It is actually dynamic replacement – we call it. The term is something; these are all very lot of terminology is there. However, the principle is very simple that you have clay, then you have this material, then again compact it and push it like you have this material. So, you are trying to replace say for example, this material in this manner. Then, you are trying to introduce a good material in the place of weaker place. So, that is what we call it replacement. So, that is also possible.

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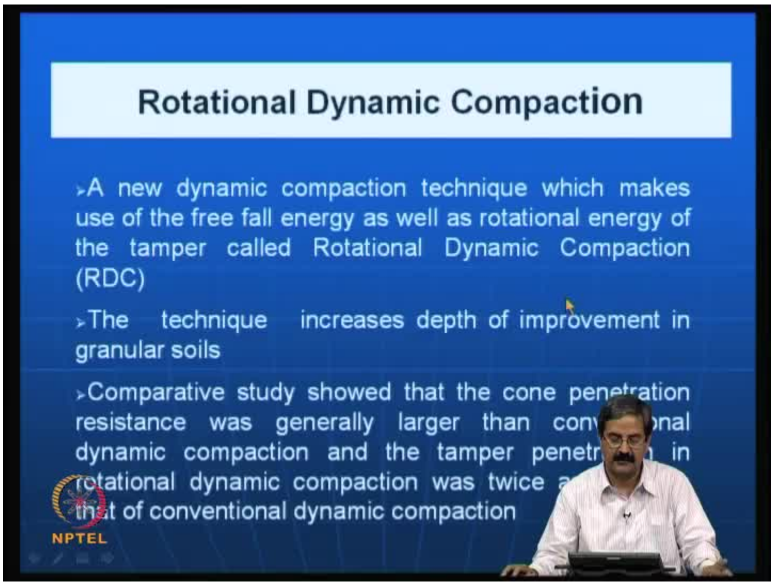

Then, what is known as rotational dynamic compaction is also possible, because people have done some studies where it is a new method in which you have the use of free fall energy. We know that you just drop a weight, then there is a free fall energy, then you rotate it also; like the same place, there is a rotational energy also. So, it is called rotational dynamic compaction. The technique increases the depth of improvement in… While doing it, it has removal as well as compaction; both are there. So, what people have observed is that in the case of a rotational dynamic compaction and the dynamic compaction, there are some small differences, which showed that cone penetration resistance was generally larger than that observed in the case of conventional dynamic compaction and the tamper penetration in the rotational dynamic compaction was twice as large as that of conventional dynamic compaction.

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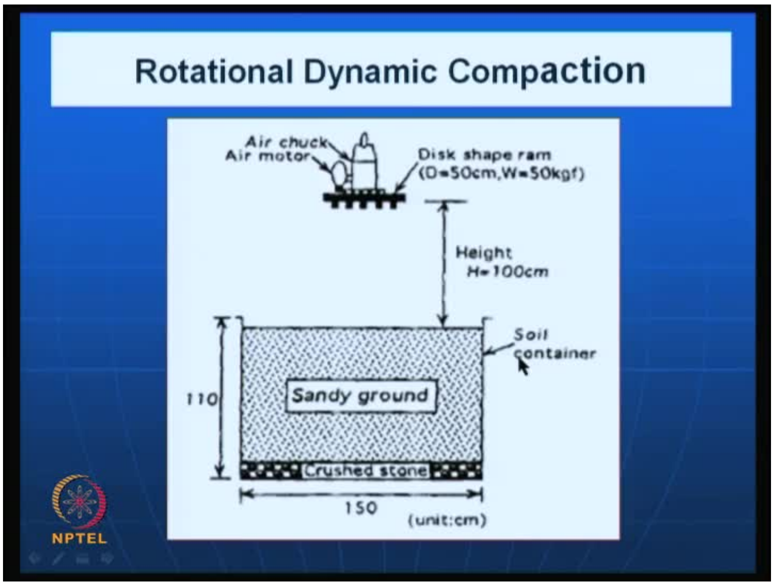

Actually what we are doing here is that you just have a sort of a material here. You rotate and then do that. It has both… Its impact is much here. You can see that you have some sort of rotational tampings; both are there. This is some sort of laboratory study like you can do simple thing, but people have seen that with some rotation as well as direct tamping, it can improve better.

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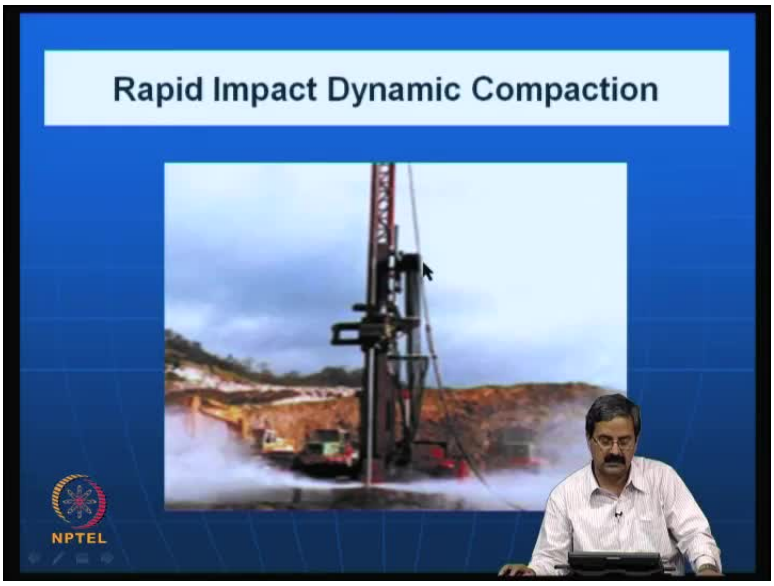

Like this example, you need to have some sort of equipment for that. Actually in many of these cases, the equipment is a very important thing. You must be able to mobilize lot of equipments, which can do the job very effectively; otherwise, it is very difficult. The job should also be very big so that you can justify the equipment, you can justify the posting of personal and there should be an office, and all that. For small jobs they are all going to be very expensive and no contractor will come for this.

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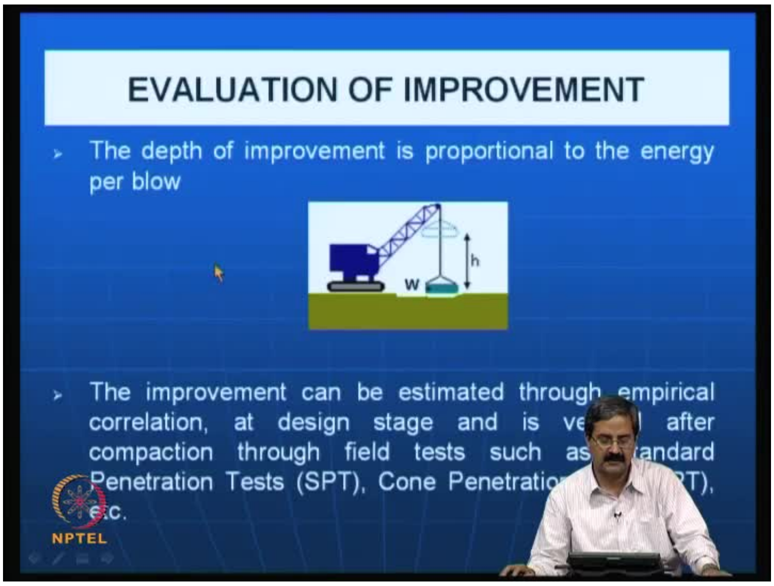

Then, how do you evaluate the performance of these materials, which are improved using dynamic compaction? We will see that. As I just mentioned, the depth of improvement is proportional to energy per blow like, you have some weight, you have some energy; then, that much of energy is important to the system. How do you assess whether it is improved or not? Best way is that as geotechnical engineers, we know – before construction, we take SPT values with depth. For example, 20 meters is the depth of improvement required; you take SPT values or cone penetration values up to 20 meters. Then, measure them after improvement. So, that is the only way of improvement that one can see correctly; otherwise, it becomes very difficult.

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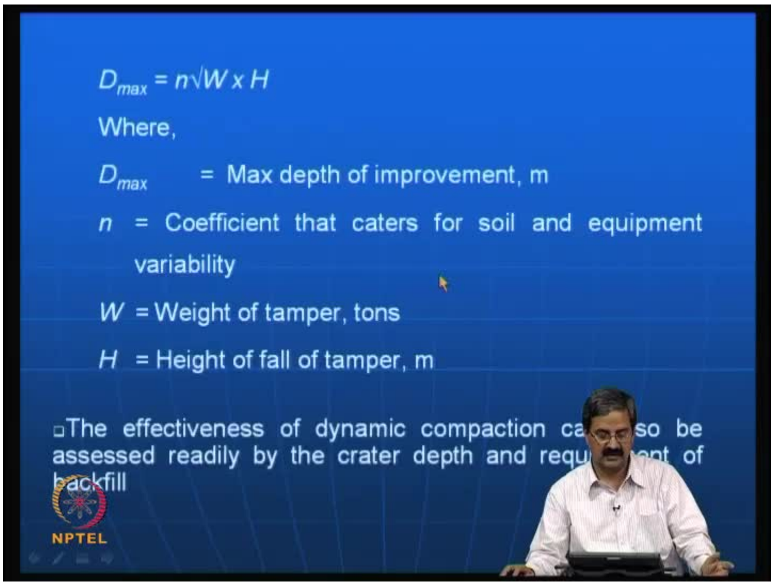

The dynamic compaction maximum depth; There is an expression that is given in terms of n into square root of W into H. This is the standard expression that is available in many of the textbooks available on dynamic compaction; where, maximum depth is the depth of improvement in meters; n is the coefficient that caters for soil and equipment variability; n is a term like… We say that WH is the energy, but there is a small correlation; n into square root of W, which is related to this depth; W is the weight of tamper in tons and the height is height of fall in meters. So, the effectiveness of dynamic compaction can also be assessed readily by crater depth and requirement of backfill.

Another point that I would like to say is that if you want to compare the effectiveness of the dynamic compaction, we use this particular terminology (Refer Slide Time: 35:04). For example, it has gone by about half a meter; yes; in other case, it would be only 25 centimeters. So, you can say that looking at the depth of the crater, one can say that which method is better.

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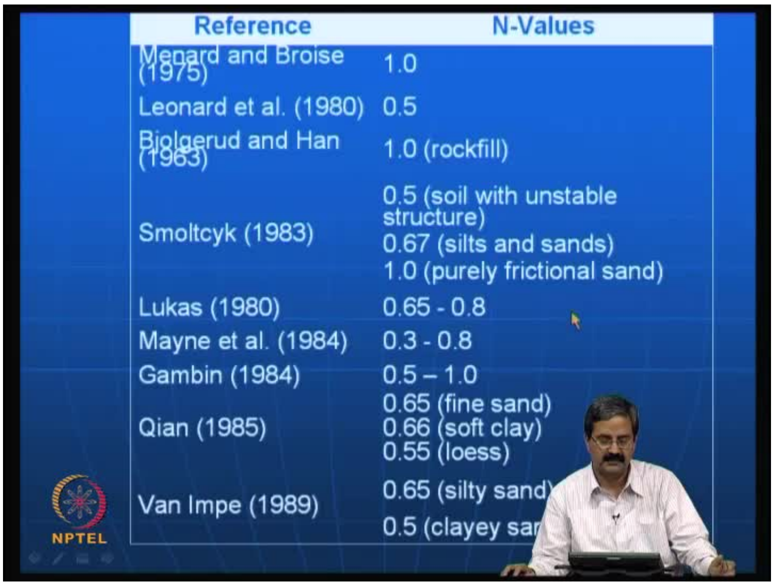

This is a small N-value. Actually, there are different coefficients to be used in the formula; that is, depending on the soil type, there are values given by different investigators. These are all from field.

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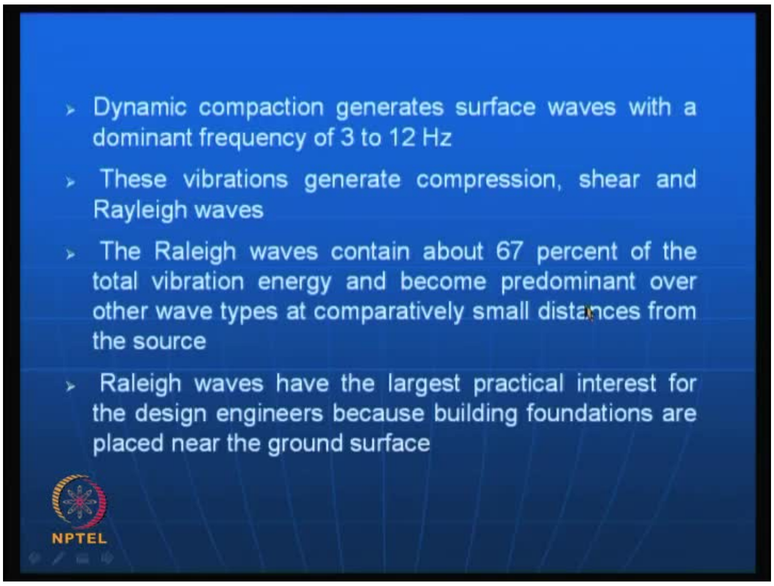

As I just mentioned, the dynamic compaction generates surface waves with dominant frequency of 3 to 12 hertz. If you are doing dynamic compaction – as I will be showing in the video later that it generates lot of sounds. The frequency is going to be quite high and it is very difficult for the person working; or, if it is next to parking, residential area, it is difficult. These vibrations generate compression, shear and Raleigh waves. As we know, any vibration induces these waves: p waves, s waves and r waves. As I just mentioned, Raleigh waves contain 67 percent of the total vibration energy and become predominant over other type waves when compared to small distances from the source. Raleigh waves have the largest practical interest for design engineers because building foundations are placed near the ground surface. So, particularly the Raleigh waves should not hit the foundations that are there next to the source. Here the source means compaction.

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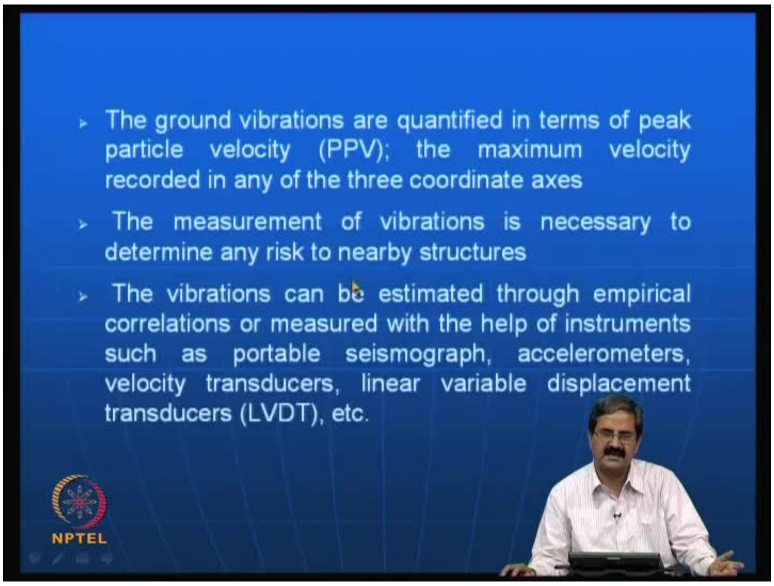

How do you assess this effectiveness or the problem with these vibrations? This is assessed in terms of the peak particle velocity. In fact, once there is a tamping made, the particles will travel in the form of waves and it has certain velocity; like, you can pick up; you can use some pickups here and there, and then pick up the velocity. What is the velocity of the particle that is travelling? The maximum velocity is recorded; if you put accelerometers, from accelerometers, you can get velocities and displacements also. It will have three components: x, y, z.

Sometimes measurements of vibrations is necessary to determine any risk to structures. For example, if you are doing a dynamic compaction in a particular project, the next building person should not say that because of your dynamic compaction project, all the glasses in my house broke; this is a software office and all the glasses have broken, and your ground vibrations because of the dynamic compaction, has given so many problems to my staff, and I lost lot of money because of your project. So, people should not say that. So, what should be done? Measurement of vibrations is the only way.

As I just mentioned, in fact, I did a case – there is a big IBM office here; next to that, there is some big opening in which rock is being blasted out. They wanted to construct again an apartment. It is a fractured rock, small rock; lot of rock is existing. They want to make foundations. Again, one more multi-storeyed building next to IBM office; then, the IBM office said that no, we should not allow this fellow to construct the house. Whatever structure he is getting, they got a stay. However, how was it resolved? The thing is that there is a court order that this fellow should not construct, but this fellow is in a hurry to construct the apartments, because he took lot of money from all the people, who are already interested in that. It is actually a big business. so

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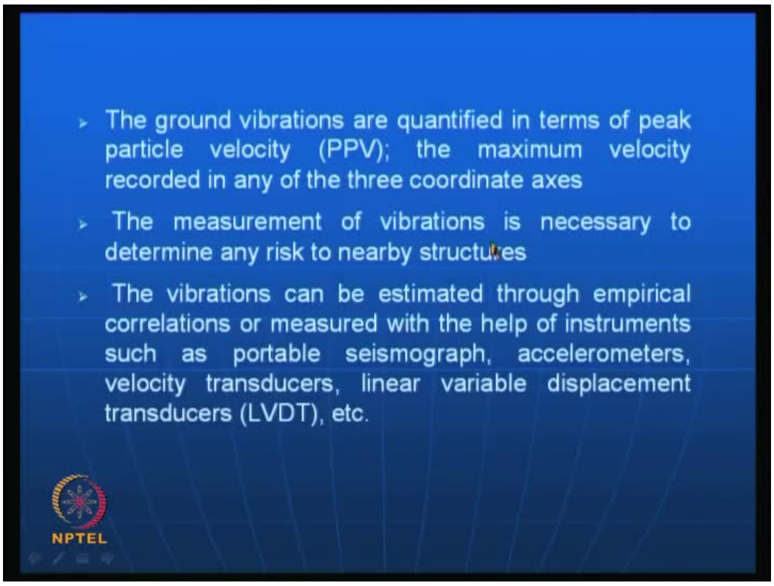

So, finally, to see that it is resolved, we have to measure the vibrations. Also, that fellow should not use vibration techniques; there are different types of like if you just… Rock blasting cannot be used. You should not use rock blasting, which is very unscientific and it should not… So, there are different ways of blasting again. It is called putting a liquid; if you put a liquid, what happens? It enters the fractured rock, then it expands, then the whole rock gets broken. Then, you can remove the rock pieces. That is an easier way of doing. So, this is one of the important ways in which one can measure the vibrations.

Without vibrations measurements, it is very risky. In fact, we get lot of cases where because of the traffic, I have lot of problems. So, you have to measure the vibrations before taking it up.

Even if you are trying to construct a road or a big project, first take the velocity measurements, then construct it like what I said peak particular velocity. If you measure it, then if it is within acceptable limits, then you can say that my structure did not cause any difficulty to you. So, the vibrations can be estimated through empirical correlation or measured with the help of instruments such as portable seismograph, accelerometers, velocity transducers, linear variable displacements, etcetera. So, you have a number of equipments like this.

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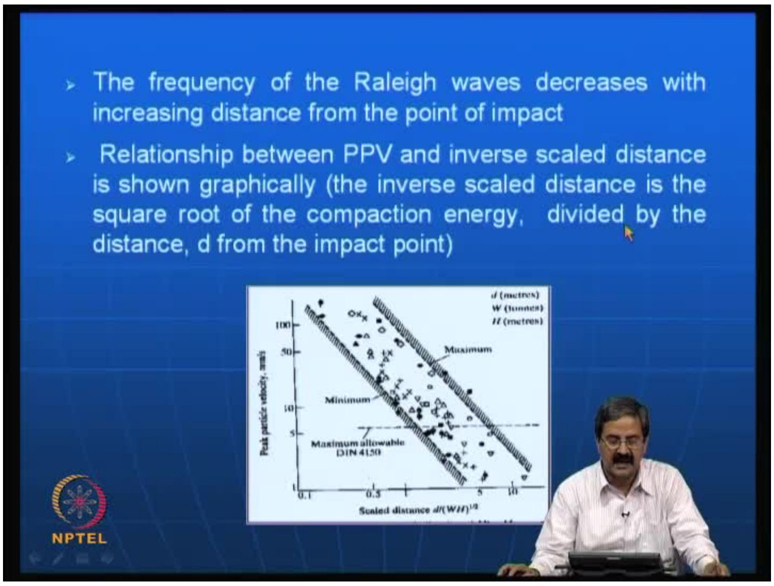

The relation between the peak particle wave velocity and the distance is like this. Say for example, you have a peak particle wave velocity and then distance. Depending on the distance, different parameters are given here – distance in meters, weight in tons and height. So, all the parameters plotted. Then, the maximum allowable range as per the German standard; actually, these are as per the German standard; maximum allowable DIN standard 4150. If the material falls in this range, it is acceptable; that is what they say. If it is very close, you should be able to really reduce a weight and height and something like that. So, you must come out and see that this is practiced in some sense; otherwise, that leads to lot of litigations. That is what according to German standards.

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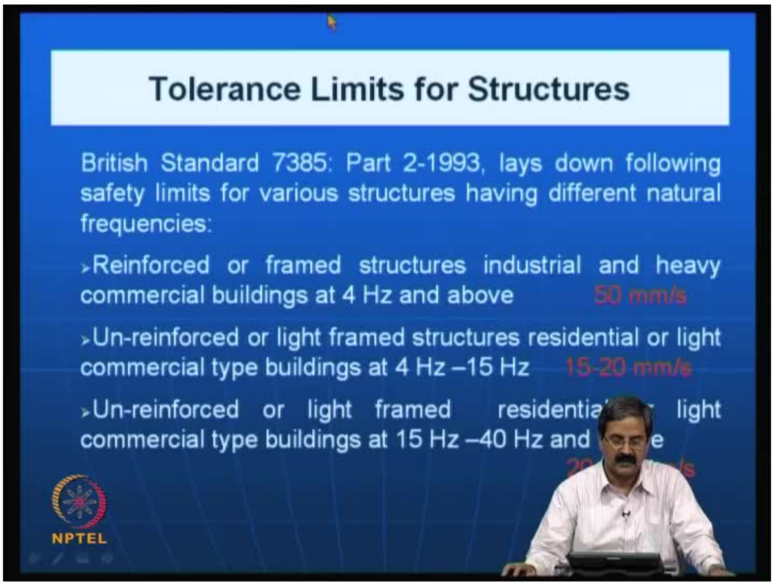

Even in British standards, they have some limits. Say for example, you have a reinforced structure, RCC structure, industrial structure; what should be the peak particle velocity? About 50 mm per second; or light, un-reinforced building or something like that, 15 to 20 millimeter per second. Then, the other one like small residential buildings, 20 to 50 millimeter per second. So, these are all some limits.

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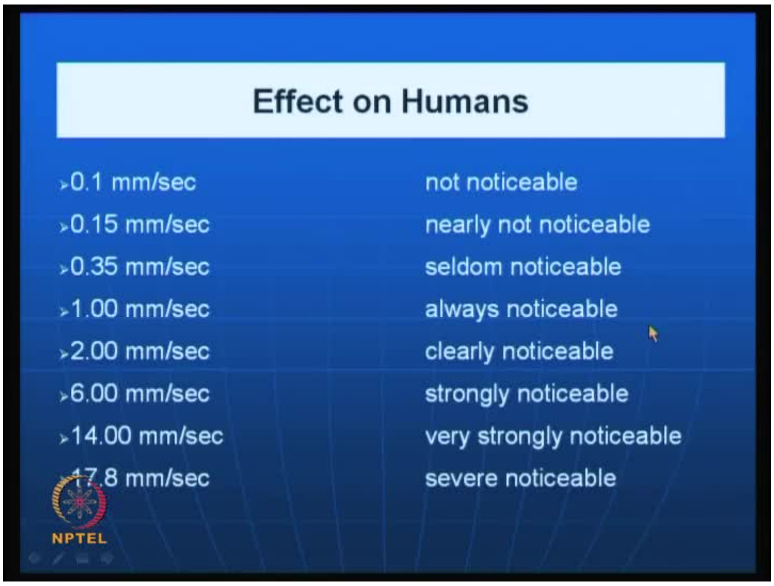

In fact, there is also the effect of these vibrations on humans. You do not want to tolerate these vibrations; you do not like. Even the earthquake; I think earthquake came and nobody must have slept in Delhi or somewhere. So, you see that if these velocities are so less, 0.1 mm per second is not noticeable. You have a scale here right from being noticeable, not noticeable to highly noticeable; you have a classification here. One should really measure this peak particle velocity. Say for example, the metro is coming up; one can say that because of the metro, there could be velocities, vibrations induced into the next structures. So, in fact, not only from health point of view, it is even from the health point of view of the structures that are there. If too many vibrations of small vibrations are there, there could be fractures developed in the systems. Small vibrations lead to lot of problems. So, small is not that easy; actually it is a small sound, very low level, can make big problems. People have understood that to some extent and then they have been taking measurements. This is a very serious problem like it can affect health of persons, health of the structures and all that.

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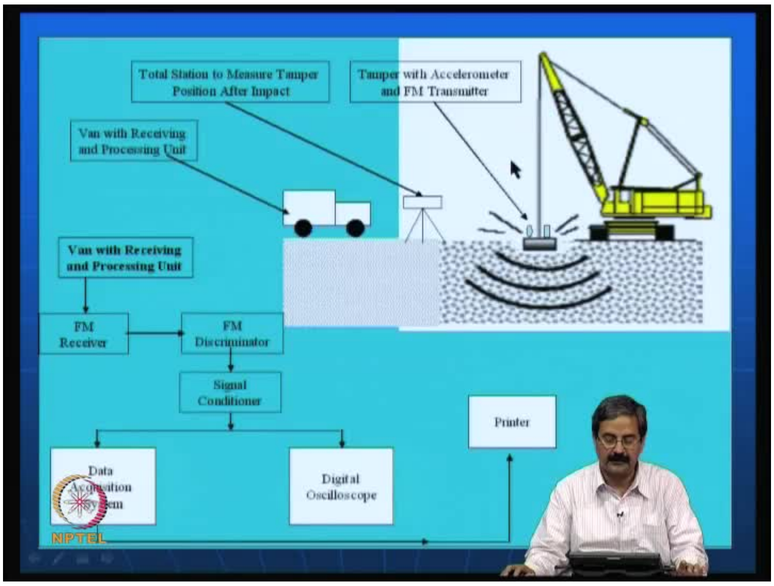

Monitoring and control is another important point in the dynamic compaction. What we do here is that – you can see that this is the machine that can do that dynamic compaction. It has a tamper with accelerometer and FM transmitter. This is one thing. Then, you have total station to measure tamper position after impact. There is some surveying equipment, which is sophisticated, which can measure the tamper position. You would be interested in the depth and what is the impression it has caused and all that. Van with receiving and processing unit – it is another one. Then, you have a van with receiving and processing unit, you have all that data acquisitioned and all that. What it gives is that what is that is going on.

We had some discussion earlier where you are trying to get the information about; it is called the chart for this particular location. You have a chart for telling what the initial health of this location is. Say for example, 10 meters in terms of the SPT values, in terms of the cone penetration values, water content, all that. What is the health of the particular soil up to depth say for example, 10 meters after dynamic compaction? These are all that will give the signature of the ground. The signature of the ground you are able to capture very well with instrumentation; that is very important.

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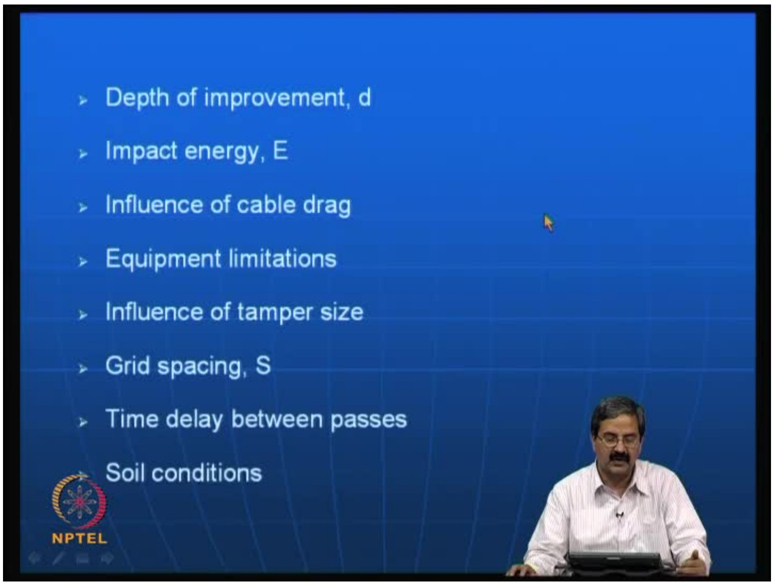

Then, how do you go about design? Actually, one should understand that this is a technique that has been very effective. People have used it some in some places and they have understood that compaction helps or dynamic compaction helps. They are trying to analyze because the advantage of analysis is that you can design properly. So, what is that we do in the design is that you can get the depth of improvement, you can know what type of energy you can give as an impact, then influence of cable drag, equipment limitations. We should understand the equipments that are there because we are planning for some energy level and that is in fact related to the equipment.

Then, influence of the tamper size, grid spacing, time delay between passes because how much delay… As I just said, there is a difference between the dynamic compaction and dynamic consolidation. Because you need consolidation, you need to give some time there; that is a simple difference. Then, soil conditions. So, the design must be able to address some of these issues, so that you come out with some rational design approach.

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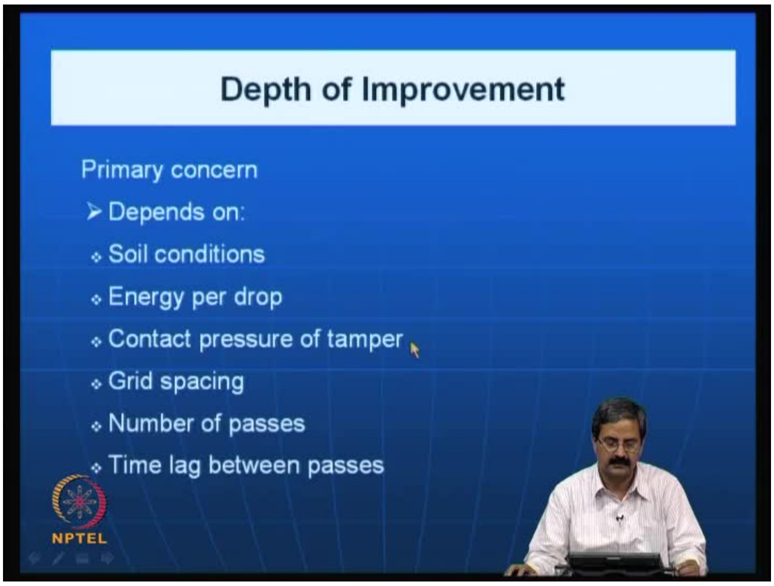

What is the primary concern in the dynamic compaction is the depth of improvement, which depends on the type of soil, the energy per drop, the contact pressure of the tamper, then grid spacing, number of passes, time lag between passes. These are all some of the important variables.

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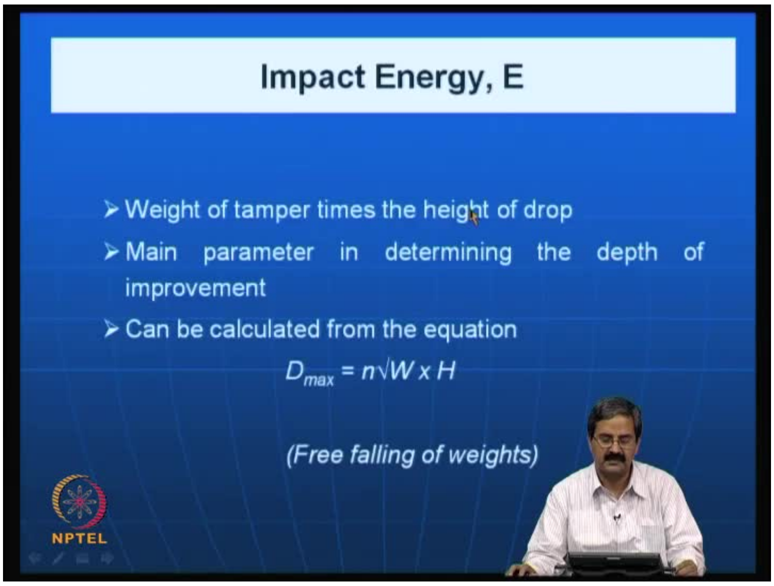

As I just mentioned, weight of the tamper times the height of drop is energy. Main parameter in determining the depth of improvement is from this expression, which is from the free fall of the tamper. D max is equal to n into square root of W into H; this is an expression.

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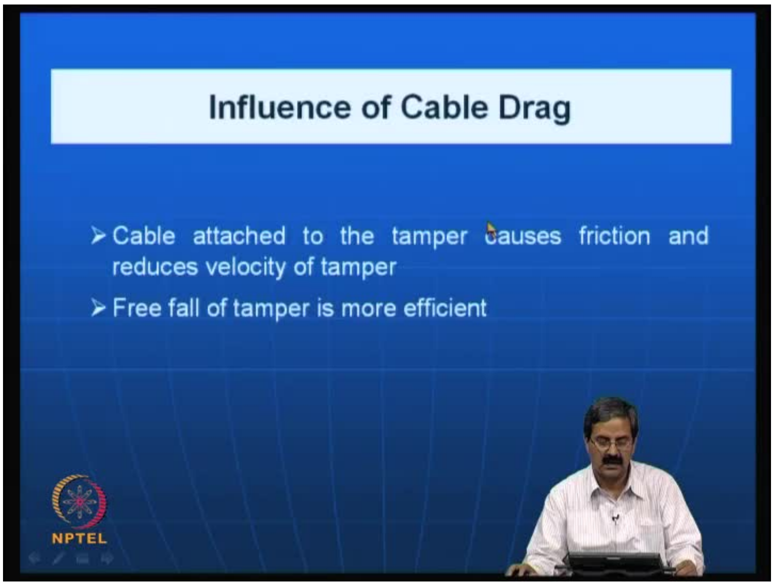

What is influence of cable drag? The cable attached to the tamper. You have seen in the photos that you have a cable attached to the tamper and it causes friction, reduces the velocity of the tamper. It is supposed to be freely… We said free fall similar to an SPT test. If it is not falling freely, then the total energy into the system may not be fully realized. Free fall of the tamper is more efficient. That is what we want because all the energy that you are trying to give should be totally into the system; there should not be any loss. In the case of SPT test and all that, we have losses in the transfer of energy. That is why in fact, the energy transfer in the case of SPT is about 50 to 60 percent; it is not much.

What are the equipment limitations? Why these things we should understand is that all people cannot do this; people should understand that dynamic compaction is a technique. People should understand that the technique has to be followed properly. The technique you can only follow if you have the knowledge of what goes into this method itself.

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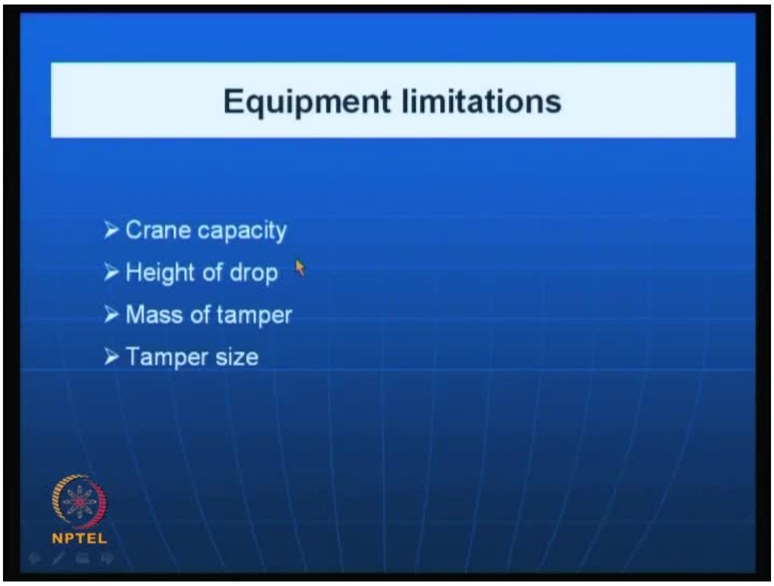

For example, crane capacity, the height of drop, the mass of the tamper, the tamper size – these are all based on the equipment.

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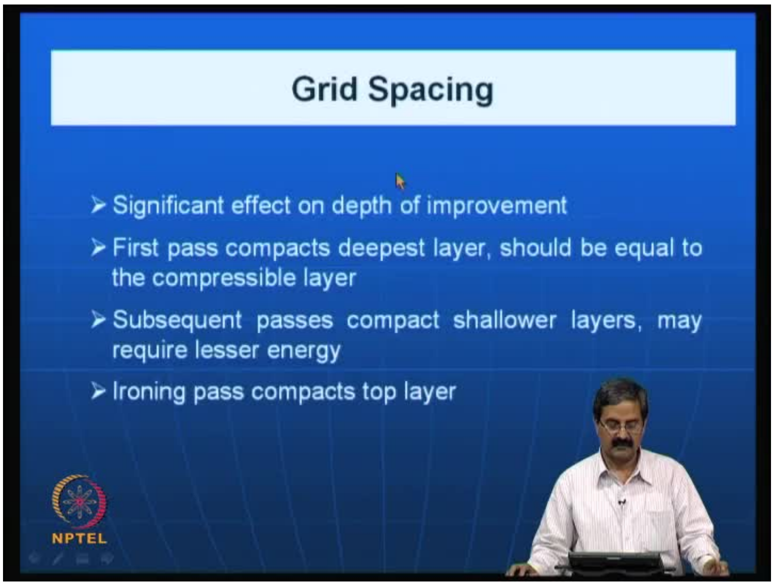

Grid spacing is an important variable here. As I just mentioned in the previous slides about a few minutes back, depth of improvement depends on the grid spacing. If you have wider grid spacing initially, it means that you are trying to compact larger depths. As you just go up, you try to reduce the spacing, so that you have a good improvement even at the top layers as well.

First pass compacts deepest layer. That is what one should understand. The first one should be equal to the compressible layer. Actually in some places there are two ways. Compressible layer – it can be 10 to 20 meters; like you need to have a criteria how much I would like to compact – is it 2 b or 1.5 b, 3 b? For example, 100 meters is the width of the area; you cannot go 100 meters. You should be able to do some sort of analysis. You have a soft soil area and I did construct all the buildings there, then what is the load it is getting transferred, to what point? Suppose I assume that the soil is soft; up to which point the stresses are going? Suppose I compact very well and then make all these very strong; this stresses will not go deep. So, you must be able to compare… Actually, stress gets mobilized; when you apply load what happens? Shear strains get mobilized in the soil system. So, you must be able to do a numerical analysis, finite element analysis or some sort of detailed analysis, where you just impose a load and calculate the strains; say strains of the order of 0.1 percent or 1 percent; some sort of limitation one should have similar to the depth of pressure bulb concept. So, one should look at it.

If the material is going very deep, definitely you cannot do a stone column or any of the ground improvement technique up to that. The objective is to restrict it to about some depth, which can be cost effective for you; very safe and cost effective. There are two issues here. In ground improvement techniques, number one is the safety of the operations. Next is the economy. It is not without safety; there is no economy – meaning. So, generally what we do is that shallow subsequent passes compact shallow layers may require lesser energy. Then, ironing pass compacts top layer.

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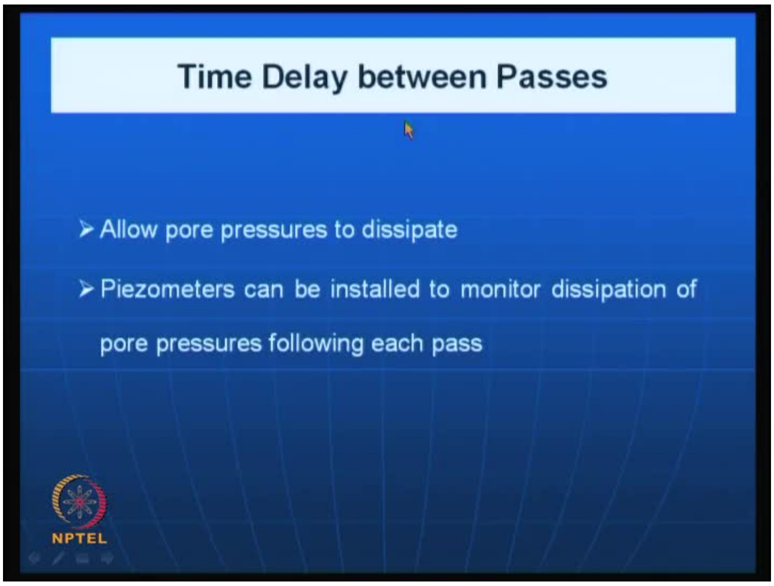

The time delay between passes is another important variable. As I just mentioned, it allows the dissipation of pore pressures. How do you assess this? In case of clays, you can put piezometers. Piezometers measure pore pressures and they help you to monitor the dissipation of pore pressure in each pass. One can do a lot of experimentation there; trial and error and then do that; this is going to be very effective.

What I will do is that in the next class, I will show you some videos of how this process could be done, dynamic compaction could be done and some case studies. What I feel is that this dynamic compaction is somewhat empirical, but it has been very effective particularly in US, on landfills, they use it to a large extent. As I just mentioned, even the whole of Singapore Changi airport is reclaimed from the sea and compacted using this method. I must tell you that one professor S. D. Ramaswamy, who did masters here in (( )) of science; when he went later and settled in some places and then finally, in Singapore at the time, he was wholly responsible for doing that reclamation. It is called land reclamation of the Changi airport. It is a very marvelous achievement; it is not easy. It is published in American Society of Civil Engineers journal also. There are many case studies in this line. The advantages of these techniques are that its effectiveness can be seen by doing it and theory is simple.

Theories are simple, but the practical advantage is very high, because as I just mentioned, it is applicable to wide varieties of soils particularly municipal solid waste or waste dumps or even sandy soils, where there is more permeability, clays – it was done. The effectiveness is essentially because of the… Here the principle is simple that you are trying to tamp, which is layman's way of doing things. If you know that the distant is not there, you try to put lot of energy into the system and then it becomes stronger. So, with that background, it has been proven technique in many projects.

I am sure that we will have some more discussion on this in the next class.

Thank you.