Ground Improvement
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Lecture 13
Deep Dynamic Compaction (contd.)

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Hello everyone. We are module 3, lecture 3. In this I will try to discuss on design steps. Of course, some of the design aspects already I have discussed in the previous lecture. And now, some of the things to be discussed some quantity to be estimated before and after compaction and some weight and height to be adjusted. All those things the energy requirement depending upon type of soil, all those things we will be trying to discuss in this lecture. Let me see the first slide.

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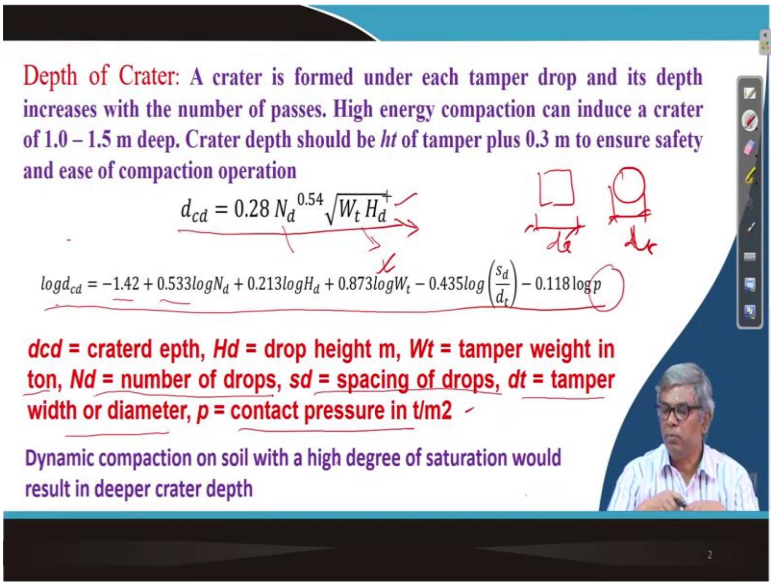

First of all, this is the one depth of crater that means when you, the crater means actually is, a crater is form under each tamper drop. That means, when the weight actually maybe as I have mentioned that weight will be lifted 10 to 40 meter and again the weight of the tamper weight is between 5 to 40, when it falls let us say 25 meters and they suppose 20-ton weight, then it will be some penetration will happen or subsidence will happen below the tamper. So, that one is called crater and that depth increases with the number of passes.

$$\log d_{cd} = 1.42 + 0.533 \log N_d + 0.213 \log H_d + 0.873 \log W_t - 0.43 \log\left(\frac{s_d}{d_t}\right) - 0.118 \log p$$

$d_{cd} = craterd\ depth$

$H_d = drop\ height\ m$

$W_t = tamper\ weight\ in\ ton$

$N_d = number\ of\ drops$

$s_d = spacing\ of\ drops$

$d_t = tamper\ width\ or\ diameter$

$p = contact\ pressure\ in\ \mathrm{t/m^2}$

In the first phase, or phase one or drop one, then whatever you will see in if you repeated second drop it will be further deeper. If you use third drop it will be further deeper like that, it will continue and high energy compaction can induce a crater of 1 to 1.5 meters. So, that means it can be 1 meter, between 1 meter to 1.5 meter deep. And crater depth should be height of tamper plus point three meter to ensure safety and ease of compaction operation.

Height of tamper, the tamper that will be definite height will be there and with that 0.3 meter that should be the value, expected value close to that and that will help to have the compaction smoothly. Otherwise, there may be some difficulty in between because that safety issues and all will be there related to that and finally there is an equation given to estimate the crater depth and in fact two equations one is a comparatively simpler. Both are empirical obviously and these are developed based on the lot of field experience.

And, and you can see here that this is the comparatively simpler equation where dcd equals to 0.28 N_d to the power of 0.54 under root, W_t, H_d and see this terminology already perhaps I have mentioned before the N_d is the number of drops and of course it is written here and W_t is the weight of tamper and H_d is the height of drop.

And this another empirical equation is given it is more accurate, but it is not as but, in the field, when you do, the work will not be so much under control. So, little error actually does not matter most of the time particularly in civil engineering and particularly in the ground improvement activities.

It is not very essential that it has to be accurate and since it is based on data and it is nothing is accurate, but compared to this it is more accurate. But the equation is something is given logs dcd minus 1.42 0.533 log N_d plus 0.213 log H_d plus 0.873 log W_t minus 0.435 log S_d by dt minus 0.118 log p. So, these are the different, p is the pressure in the when it drops and S_d is the, you can see S_d is the spacing of drops and dt is the tamper width or diameter.

If the tamper is squared, this one will be d_t, tamper width. And other things dcd is the crater depth, Hd is the drop height in meter and W_t is the tamper weight in ton. Again, it has to be taken the same unit. N_d is the number of drops, S_d is the spacing of drop, d_t is the tamper width or diameter. It can be, if it is circular, then diameter is the dt and so and p is the contract pressure in ton per meter square.

These exactly to be used in this equation to get the value. Dynamic compaction on soil with a high degree of saturation would result in deeper crater depth. This is obvious that if it is a saturated soil degree of saturation is very high, then it will have easy to resistance will be less under that heavy energy. Obviously, the crater depth will be more. This is quite obvious.

This is one thing to be sometime calculated because there is a regulation that if it is more than that or less than that, that is not suitable or they are not recommended. You have to calculate this and you have to see that because safety is also related with this based on crater depth. So, let me go to the next slide.

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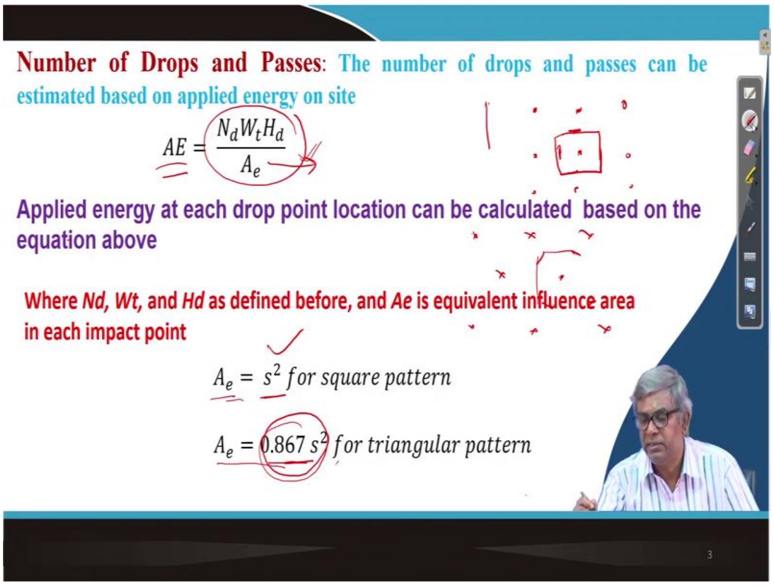

As I was talking about the design, now exactly I have come to the point of the design point, so, number of drops and number of passes. That is a thing to be designed. That is most important height, weight, etc. That the number of drops and passes can be estimated based on applied energy on the site. And this applied energy how to calculate, this applied energy can be calculated by this equation, this is the one and, in this equation, you can see a number of parameters are involved. There is N_d, there is W_t, there is H_d, there is A_e.

$$AE = \frac{N_d W_t H_d}{A_e}$$

$$A_e = s^2 \text{ for square pattern}$$
$$A_e = 0.867s^2 \text{ for triangular pattern}$$

And this N_d is the number of drops already we know and W_t is the weight, and H_d is the height and A_e is the new term, which is the area is equivalent influence area in each impact point. what is the meaning of it if this one is there and this is the way suppose you do and this is the way if we do then if this is the suppose this is the one, then influence area will be half this side, half this side, half this side, half this side.

This is the influence area of this drop. That is why the Ae if the square pattern is a square and if it is an equal to 0.867 a square that can be proved I can take this one later on, not today. If it is a triangular pattern, suppose if there is a drop here, there is a drop here, there is a drop here, there is a drop here, there is a drop here, there is a drop here then ultimately and then another row supposes drop here and then drop here, then drop here.

Then if I want to find out the influence area, half like that it will be hexagonal area will come and that hexagonal area equivalent area if you convert then ultimately it comes A_e equal to point that hexagonal area if I find out area that comes equal to 0.867S square if it is a triangular pattern.

These things actually known then I will be able to find out applied energy. Then, if you want to, if you get the applied energy, the best if you get the applied energy and then I can find out how much, how many drops, how many passes that can be designed easily. If I use a particular tamper weight and if I take a particular height and then energy requirement in the field and based on whatever I am getting and by one drop and then how many drops is required, how much that can be estimated. Let me see the next slide.

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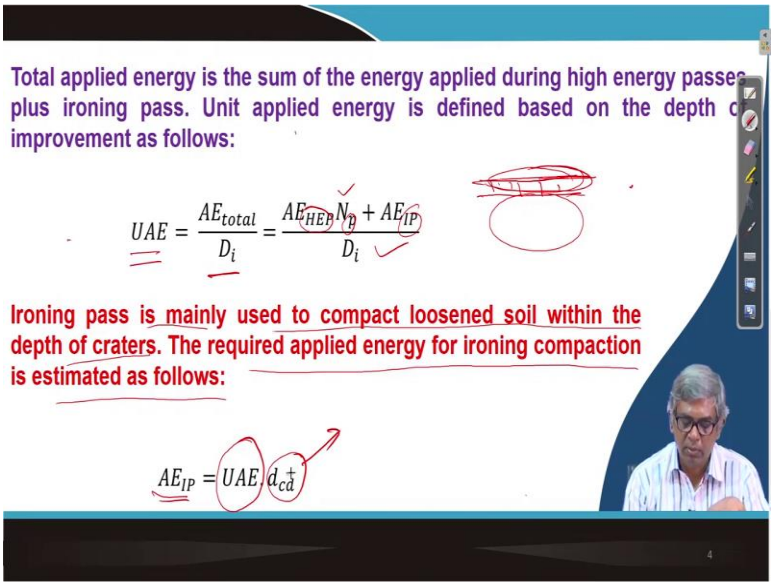

So, this is the one. You can see the total applied energy is the sum of the energy applied during high energy pass plus ironing pass. As I have told you that when there is a deep, dynamic compaction, so if there is a little surface area maybe approximately half a meter, it will be disturbed.

$$UAE = \frac{AE_{total}}{D_i} = \frac{AE_{HEP} N_p + AE_{ip}}{D_i}$$

$$AE_{ip} = UAE d_{cd}$$

So, this one is actually compacted by normal or regular shallow densification method that we rule out unless something can we use this one. There that stage actually some amount of energy will be used and deep dynamic compaction there will be an amount of. So, these two together is the total energy, applied energy and unit applied energy is defined based on the depth of improvement.

So, this is Unit Applied Energy. Unit applied energy again defined like this, A_e total by Di and Ae total can be Ae heavy energy pass multiplied by p. This is not p, it should be D. Of course, it will be D number of drops and plus A that is ironing pass and divided by D_i. So, ironing pass is mainly used to compact loosen soil within the depth of craters.

The required applied energy for ironing compaction is estimated. Again, an energy in ironing pass is estimated by unit applied energy multiplied by d_{cd}. So, this is a depth of crater whatever I have shown in the last previous lecture, that depth of crater there is an equation. So, from there you can estimate and unit applied energy if you know and that actually ironing pass, that pass energy is required.

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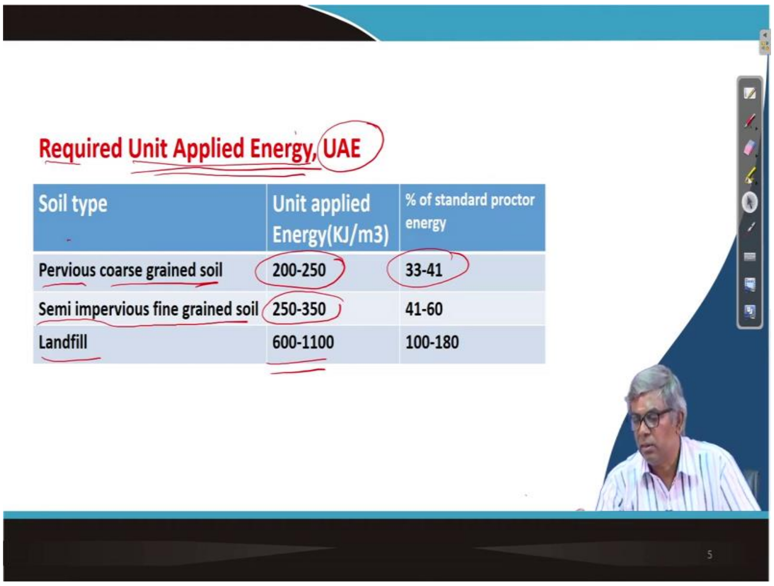

And you can see that unit, required unit applied UAE for different soil is there actually. It is known. It is given or it can be assumed. So, these are while you are designing these are the chart or recommendation to be used. If it is a pervious coarse-grained soil, then you need Applied Energy kilojoules per meter cube range between 200 to 250 and it is percent of standard proper energy 30 to 41 percent.

And if it is semi-impervious fine-grained soil, then unit applied energy actually 250 to 350 kilo joule per meter cube and if the landfill then the unit applied energy will be quite high. It is 600 to 1100 kilojoules per meter cubed.

This is the requirement for a different site, this is the requirement. If this is the requirement and if we will choose a particular tamper width and height and then based on that you can find out the unit applied energy and from there actually subtract ironing pass energy and then we can find out how much, how many drops required to satisfy this much energy or to achieve this much energy. Let me go to the next slide.

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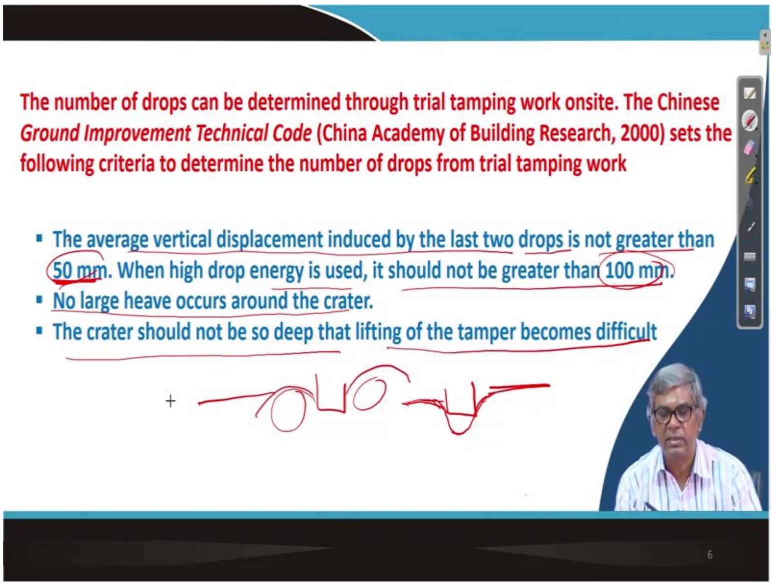

So, number of drops can be determined through trial tamping work. Of course, that is calculation can give you some value, but if I can do a trial, you can see physically what is happening and the Chinese Ground Improvement Technical Code actually that given some criteria to determine the number of drops from the trial tamping work and what are the guidelines actually given.

The guidelines are the average vertical displacement induced with the last two drop is not greater than 50millimeter. This is the one. The trial one, last two drops it should not have more than 50millimeter settlement.

When the high drop energy is used it should not be greater than 100 meters. When high drop energy is used settlement should be more so that is why it has a different guideline. High drop energy is used then 100millimeter. If it is low, then it is the 50 millimeter, last two drops.

And no large heave occurs around the crater. When the tamper is falling here and soil is here, soil is supposed to look like this, supposed to, sorry, if the surface and then it is supposed to be like that instead of that if this is the crater and the soil is like this happening, is happening like this ground surface then, there is heaving around, that is also not expected. That should be checked and the crater should not be so deep, the lifting of the tamper becomes difficult.

That is what when the crater depth actually we can calculate, but here also physically by trial, you can see how much it is and once it is too deep, then the lifting of that one will require a lot of energy and some time may be difficult. So, these three aspects we seen on the trial to find out number of drops in a particular soil at a particular site. Now, let me see the next slide.

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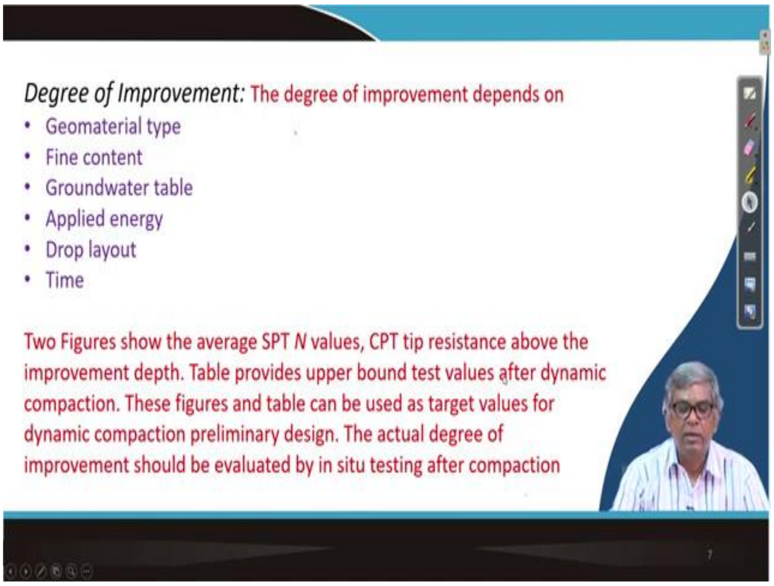

And Degree of Improvement. Again, this degree of improvement depends on actually different things. Actually, what material is at the site, what is the fine content, what is the groundwater table location, applied energy, how much energy you are applying, how we are dropping, drop layout and time, and I will show two figures.

They are actually the average SPT N value, CPT tip resistance above improvement depth. Table provides upper bound test values after dynamic compaction and these figures and table can be used as target values for dynamic compactions in the preliminary design.

The actual degree of improvement should be evaluated by in situ testing after compaction. That means, and I will show there are two things actually different country, different site. They have after compaction they have conducted CPT tests; they have conducted SPT test, the energy applied and the SPT value. The plot is given for two tests and from there again different types of soils are there and they have average line is drawn from their average guideline can be determined and that can be used for guideline in this particular site.

But if you want to find out the exact or to evaluate how a particular site to be used, then you have to carry out certain trial test as I have mentioned before. So, let me see those two figures what I have shown.

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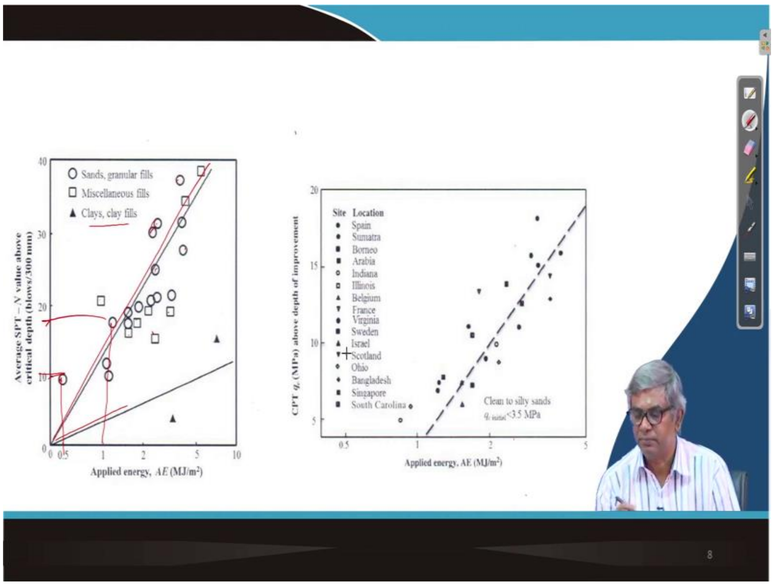

You can see here this figure actually you can see sand granular for round marks. These are actually sand and granular fills test results. And the square blocks actually miscellaneous fill square blocks, miscellaneous fills and triangles solid triangle is clay and clay fill and on that actually applied energy is a mega joule per meter square that is 1, 2, 3, 4, 5 like that different side, different amount of energy is applied and then average SPT N value you can see here this one is there actually energy is this much and after SPT value is this. For this one, this is the energy, this is the SPT value. For this one like that it is given.

Now, you can see for sand and miscellaneous fill, the data is scattering in a particular zone and for that we can draw an average line. That means from this line I can by and large approximate the energy versus SPT, average SPT value, I can try to apply in the particular site.

And if it is a clay only two data is there and you, can one be here one is here. One can imagine the average line between that and that can be also sometimes used to find out preliminary design value.

Similarly, here you can see a different site actually around the globe actually. You can see data and the plotted here applied energy versus CPT value, and you can see here whatever maybe the country location and all, the CPT value is scattering in a particular zone and you can imagine a line actually and that line can be considered as a trade line for any compaction, any dynamic compaction and if you have the energy level here and accordingly what should be the CPT value expected for your site that also you can find out from this figure. This is of course can be used as a guideline. This is available in the literature one can use. Let me see the next slide.

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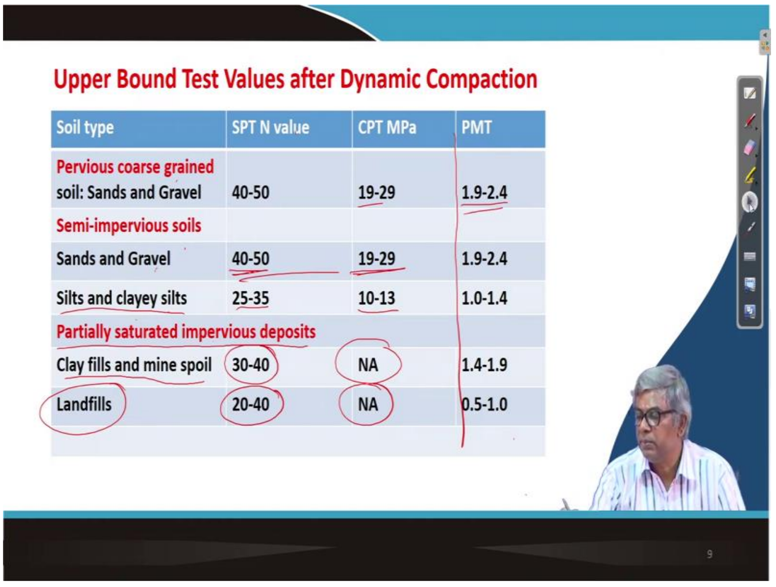

This is upper bound test values for dynamic compaction. You can see here what are those things that are given, that soil type if it is a pervious course grained soil, sand and gravel, then SPT N value should be 40 to 50. That is upper bound test values for dynamic compaction 40 to 50 and CPT should be 19 to 29 and PMT pressure meter value should be 1 percent.

This I have not discussed yet. That can be of course, if you do not like, do not want you can skip this one. Only these two can be seen. If it is semi-impervious soil, sand and gravel again, again the SPT value range should be between 40 to 50 and CPT value should be between 19 to 29 and if it is silt and clay so of course semi-impervious sand and gravel this is the value, and if it is silt and clay, then it will be SPT value between 25 to 35 and CPT values between 10 to 13 and partially saturated impervious deposit if it is then again it can be of clay fields and mine spoil, then your SPT value should be after dynamic compaction should be between 30 and 40 and CPT value under this condition not available.

If it is a landfill, then after dynamic compaction, you should have SPT value between 20 and 40. And under this type of site condition, no CPT information is available. So, only it is based on SPT one can judge or of course CPT one can carry out if there is the requirement is known. Until and unless the requirement is fulfilled, then one can do the compaction. So, now, let me go to the next slide.

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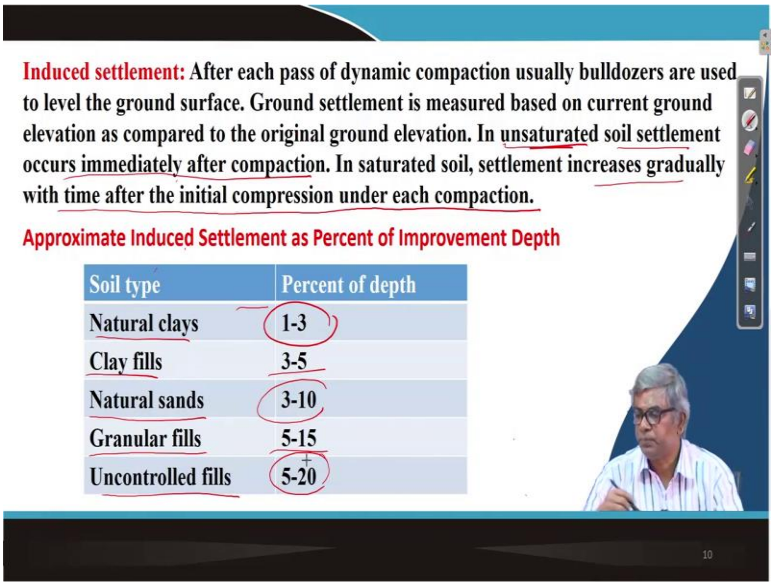

The induced settlement how much that because when you are dropping weight on the ground, then the soil will be subside and that amount would be what is the limit. So, dynamic compaction usually for each pass bulldozers are used to level and then from the comparing with the original ground elevation and present ground elevation, we can find out the subsidence amount.

In unsaturated soil, typically unsaturated soil settlement occurs immediately after compaction because immediately after compaction then weight immediately it happens, but if saturated soil settlement increases gradually with time after initial compaction under each compaction. That is what is obvious of course, already saturated because that excess pore pressure is developed and that will dissipate and that helps to consolidate and settlement.

That is why, so, how to find out this induced compaction induced settlement that after compaction, number of passes, number of drops, then use bulldozer and level it, then find out present elevation compare it with the original elevation then that is the settlement and we know that since settlement, unsaturated soil happens immediately you can do that on immediately.

But if it is unsaturated soil, it gradually increases with time. Because of that you can allow some time and then only you can measure the elevation and then we can find out and approximate induced settlement as percent of improvement depth can also give, that should be there.

These are actually you can see if they are natural clay then 1 to 3 percent of depth. If it is a 10meter depth of improvement, 1 to 3 percent of 10 meter should be the settlement. Clay fills actually 3 to 5 percent can be settled. Natural sand, it will be 3 to 10 percent. Granular fills, it can be up to 5 to 15 and uncontrolled fills it will be 5 to 1. Uncontrolled fills induced settlement can be as high as 5 to 20 percent and if it is a granular fill, it will be 5 to 15 percent. So, these are all guidelines actually to be used while designing your dynamic compaction for a particular site.

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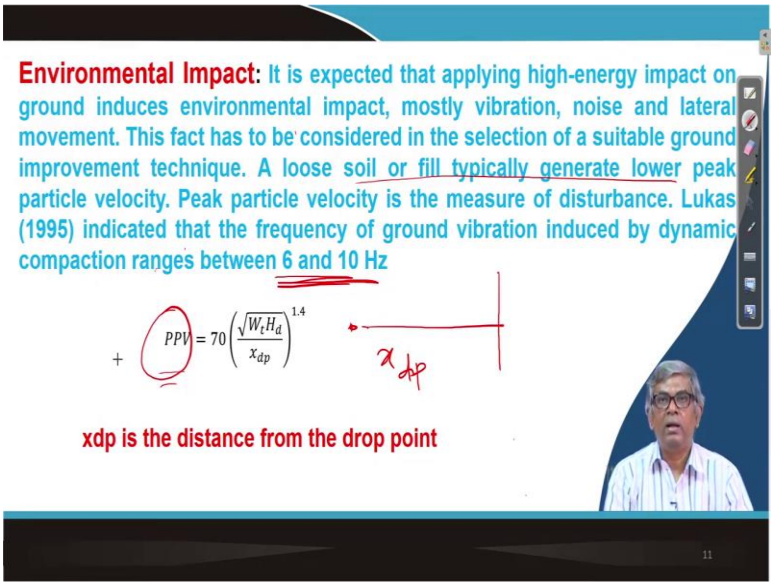

So, there is as I mentioned the environmental impact that because of these falling weight suddenly in a particular site, there will be heavy vibration happens and then noise also will be there and all those things and these are all quantified by big particle velocities. And this big particle, it is expected that applying high energy impact on ground induced an environmental impact mostly vibration noise and lateral movement. And this fact has to be considered in the selection of suitable ground improvement techniques.

$$PPV = 70\left(\frac{\sqrt{W_t H_d}}{x_{dp}}\right)^{1.4}$$

x_{dp} is the distance from the drop point

If it is close to the locality that deep dynamic compaction is a wrong selection because this will not, people will not allow actually. A loose soil or a fill typically generate a lower peak particle velocity and so lose soil or fill typically generate lower peak particle velocity and peak particle velocity is the measure of disturbance.

And Lukas indicated that the frequency of ground vibration induced by dynamic compaction ranges between 6 hertz to 10 hertz. This is the one that the vibration frequency will be this and typically lose soil or field typically having low self-peak particle velocity and if it is a strong fill, if you try to still make more compact then obviously the vibration and all will be more.

So, that time you have to be careful and peak particle velocity actually can be calculated by some empirical equation, which is given PPV and which is actually given by 70 multiplied by under root H_t H_d by x_{dp} whole to the power of 1.4 and all those terms are known all except one term which is x_{dp}.

X_{dp} actually is the distance from which the deep dynamic compaction activities in the progress. Suppose you are the building is here or locality is here, this distance is x_{dp}. So, this peak particle velocity again different tolerance will be there for different soil and different activities. That value, recommended value is also given, which can be seen in the next table and you have to satisfy that while designing the deep dynamic compaction.

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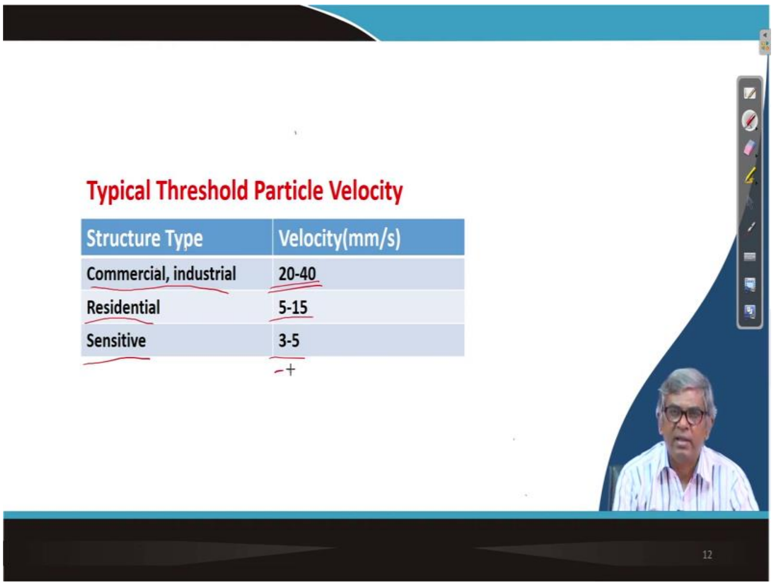

You can see here typical threshold particle velocities depending upon the type of locality available actually. If it is a commercial and industrial, then peak particle velocity tolerable is 20 to 40 millimeter per second. You can the previous slide whatever equation I have used given in that equation, you know the weight of tamper and height of drop and HDP based on that you can calculate the peak particle velocity and that value should be compared with this value and if it is a commercial industrial area if the value falls between 20 and 40 or even less, then it will be acceptable or if the value become more than that it is unacceptable.

If it is a residential building, then the value should be between 5 and 15. If it is more than that of course not acceptable. And if it is a sensitive area maybe hospital or similar type of things are there or many other nuclear facilities, there actually again, peak particle velocity should be further requirement would be less and that is actually between 3 and 5. If it is more than that sometimes it will be discouraged.

These are the different requirements and some of the calculation I have shown over the three lectures in a good number of slides and each slides I have tried to keep as much information as possible mainly because by seeing these of course once if anyone go through those slides itself, one can get the entire document and at the same time whatever I am saying some of the important things to highlight those, these two together one can get the design philosophy of deep dynamic compaction and whatever the information is there all form of information cannot be kept in your head.

Actually, these things will be available as a reference. When you design that can be referred and can be compared or can be used for your design. Next class actually, next two lectures actually, I will try to illustrate whatever we have discussed so far in the three lectures, how to design a particular site deep dynamic compaction facility technique can be designed. I will try to illustrate by using one or two actual examples. So, with this today, I will close here. Thank you.