Soil Dynamics
Prof. Deepankar Choudhury
Department of Civil Engineering
Indian Institute of Technology, Bombay

Module - 6
Soil Improvement Techniques
Lecture - 35
Soil Improvement Methods
Dynamic Compaction Reinforcement Techniques

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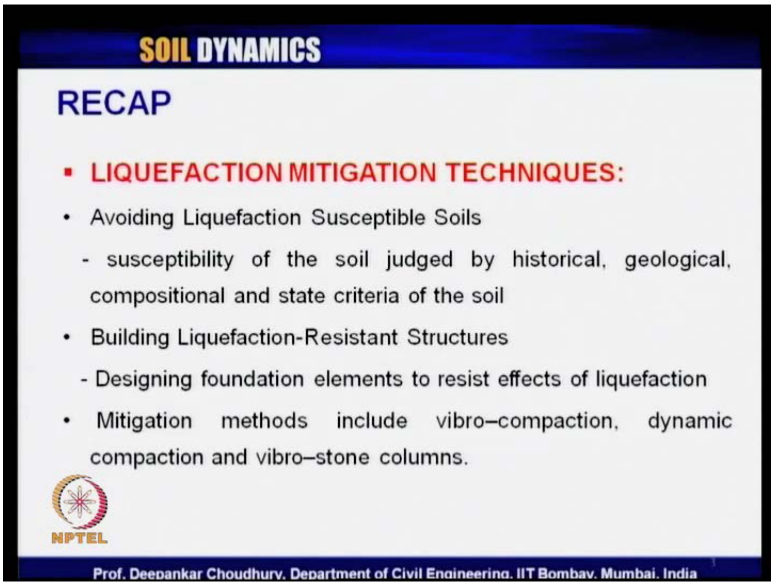

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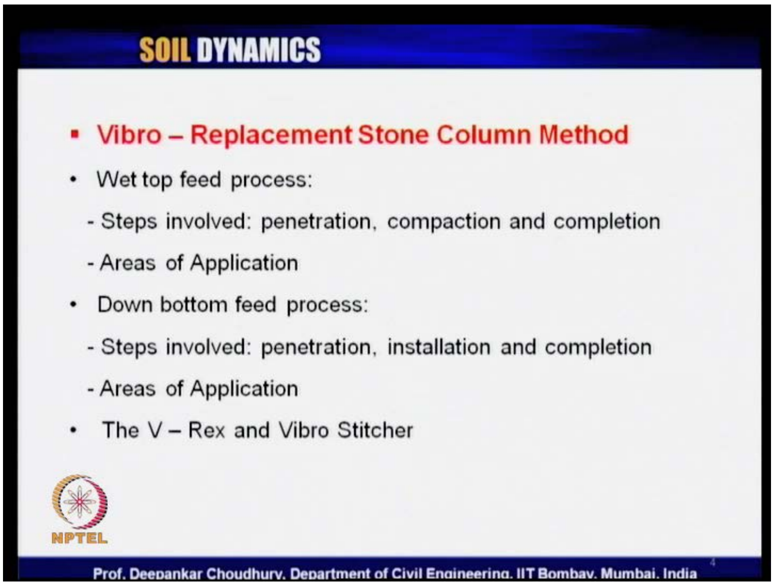

Let us discuss today's lecture on soil dynamics. So, we were discussing on module 6 of this course soil dynamics, which is on soil improvement techniques. In our previous lecture on this module 6 that is on soil improvement techniques, we have discussed about. Let us do a quick recap liquefaction mitigation techniques that is to avoid liquefaction susceptibility in a soil, susceptibility of the soil is judged by its historical geological compositional and state criteria of the soil. Now, building liquefaction resistance structures is one of the major important goal for geotechnical engineers or geotechnical earthquake engineers; designing foundation elements to resist effects of liquefaction is the primary goal. So, we have to find out the mitigation methods, which include vibro-compaction dynamic compaction and vibro-stone columns.

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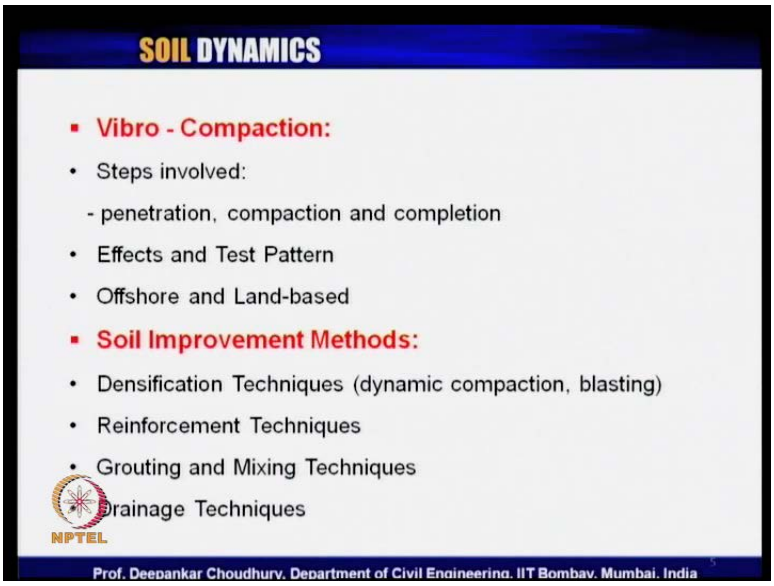

Now, we have seen in the previous lecture in vibro- replacement stone column method there are two major methods which we have described as (( )) of fit process were the steps involved at penetration compaction and completion and areas of application also, we have discussed and the second major category is down bottom feed process. We have discussed about the steps involved which are again penetration installation and completion and we have discussed about the areas of application for that case as well also, we have seen some special cases like v-rex and vibrostitcher in the case of vibro–compaction. We have discussed in the previous lecture like steps involved in the process of vibro–compaction like penetration compaction and completion effects and test patterns typically used for vibro–compaction and what are the basic two major categories of vibro – compaction one can be offshore and another land-based. So, among the soil improvement methods we started discussing the densification techniques. We have discussed already, about dynamic compaction and blasting then other techniques are like reinforcement techniques grouting and mixing techniques and drainage techniques so, let us go through this process once again today.

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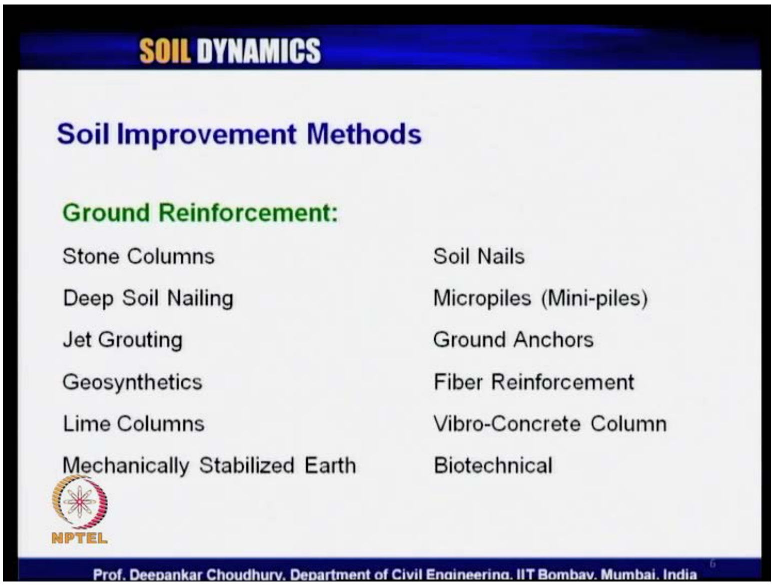

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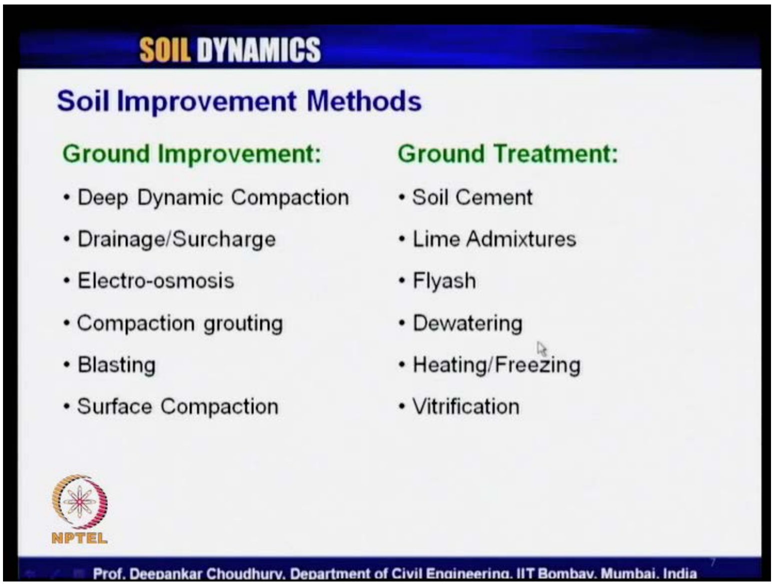

So, when we are discussing the soil improvement methods through ground reinforcement we typically use stone columns deep soil nailing jet grouting geo synthetics line columns mechanically stabilized earth soil nails, micro piles or mini-piles ground anchors fiber reinforcement. Vibro-concrete column and biotechnical issues and in this ground improvement method we consider the ground treatment like deep dynamic compaction drainage surcharge electro-osmosis compaction grouting blasting surface compaction. These are various ground improvement methods and the ground treatments typically adopted at sight a soil cement lime admixtures flyash dewatering heating or freezing vitrification.

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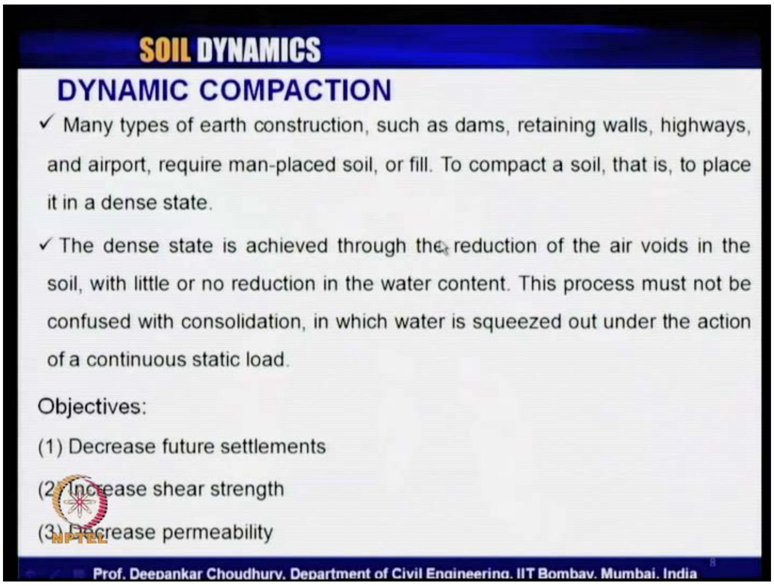

Now, let us see the dynamic compaction many types of earth construction like dams, retaining walls, highways and airports require man placed soil or the filling material. What we called typically now, to compact that filling material or that soil to place it in a denser state why because when a soil is in a loose state we known it is prone to more liquefaction during an earthquake or any kind of dynamic load due to the generation of excess pole water pressure.

So, to mitigate that we first need to achieve the goal of identifying the soil by doing some ground improvement technique so, dynamic compaction is one of that let, us look here. So, the dense state is achieved through the reduction of the air voids in the soil with little or no reduction in the water content. So, in this process of compaction as we know in this case we are hardly getting read of the water content of the soil but, we are getting the read of the air voice this process must not be confused with consolidation because, we know in the consolidation water is squeezed out under the action of a continuous static load which is not the case for the compaction and similarly, for the dynamic compaction.

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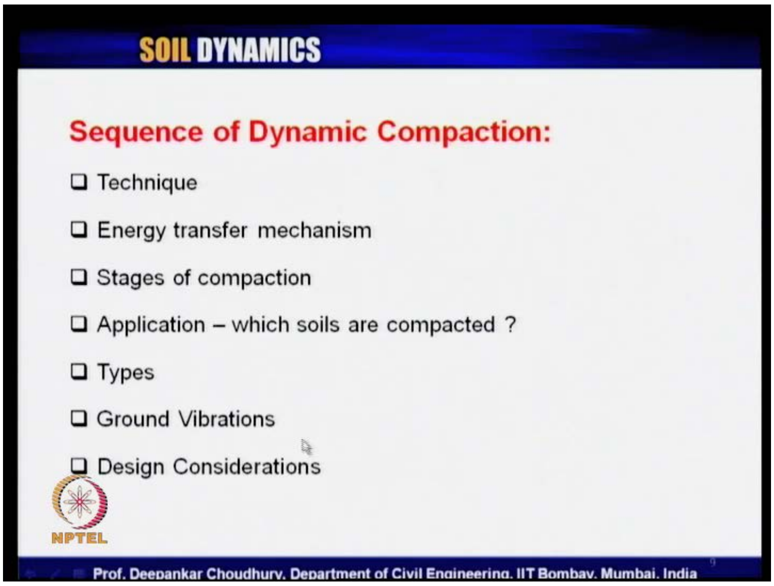

So, what are the various objectives of dynamic compaction to decrease the future settlement in that area increase in shear strength properties of the soil and decrease in permeability. So, the various sequences of this dynamic compaction are like first which technique we are planning to adopt we have to finalize that then, what is the energy transfer mechanism in the dynamic compaction which is not the case, in case of the static compaction. So, this is an additional part we have to take care for the dynamic compaction stages of compaction adopted in the dynamic compaction application that is for which type of soil this dynamic compaction can be adopted it is not that for all soils it can be suitable. So, we have to check which kind of soil it will be most effective or most useful.

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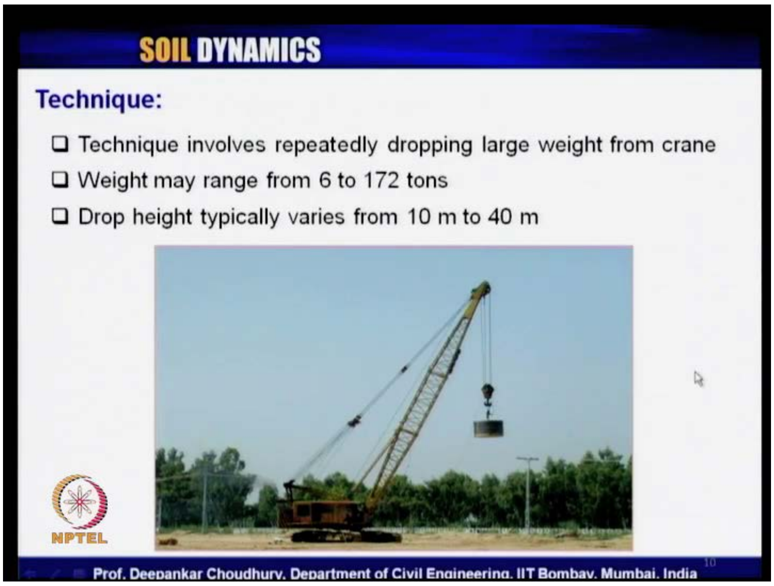

Now, types of dynamic compaction ground vibrations and various designs considerations. So, if we talk about the technique of dynamic compaction this technique involves repeatedly dropping a large weight from the crane. We can see in this picture from this crane this large weight is dropped repeatedly on the ground this weight may vary from 6 tons to 172 tones. So, that is the range of the variation of this weight that is the dropping weight which is dropped through a typical height of from 10 meter to 40 meter. So, depending on amount of the dynamic compaction require at a sight and the energy require to be transferred this weight and height of all is calculated are used accordingly.

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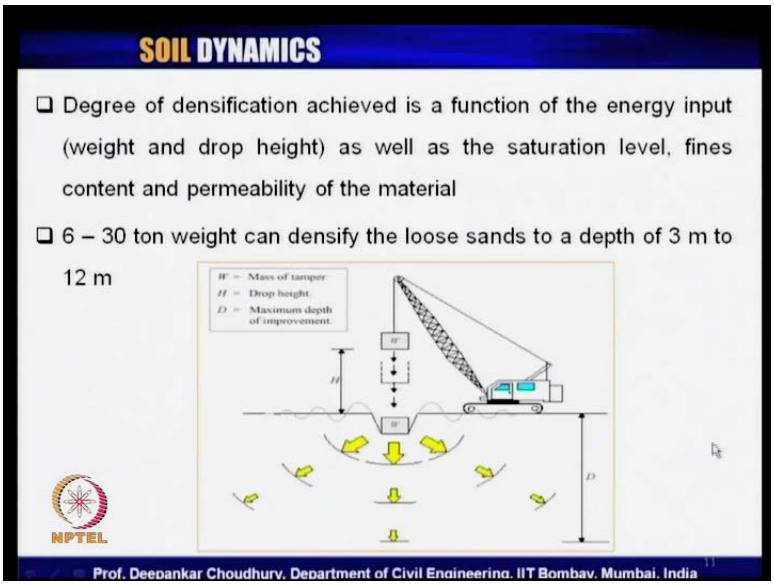

So, degree of densification is achieved which is the function of the energy input now, what is the energy input this is a function of the weight of that drop hammer and the drop height through which it is following as well as what is saturation level of the soil.

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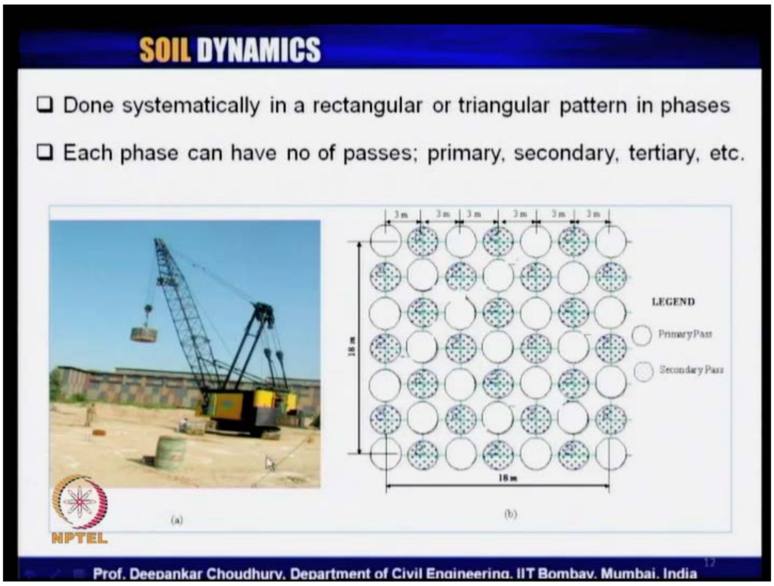

What is the fines content and what is permeability of that material which is getting densified through this dynamic compaction. So, 6 to 30 ton weight can densify the loose and to a depth of about 3 meter to 12 meter. So, if we see this arrangement again this is the crane this is the dropping weight w so, w is the mass of this hammer h is the drop height this is the drop height and d is maximum depth of improvement this d is maximum depth of the improvement this depth as it is mentioned over here. If we use this hammer weight 6 to 30 ton in case of a loose sand strata typically about 3 meter to 12 meter depth. We can densify by this dynamic compaction process this process is done systematically in a rectangular or in a triangular pattern in various phases. So, we can see in this picture here the rectangular pattern is shown it can be adopted as triangular pattern also, I will explain it within few minutes and each phase can have no number of passes like primary secondary tertiary etcetera.

So, this arrangement this weight is falling from this crane from a particular height and that can be mod in the form of you can see over here mod with this white chalk or the chalk powder that these are the portions were the weight will be dropped from a certain height to compact this ground and that arrangement one can make through this triangular arrangement. You can see the legend here the open circles indicates the primary pass the first one and the circles with dots are showing the secondary pass similarly, one can use the tertiary pass also, and in the greed pattern form so, you can put say about 3 meter distance it also depends up to which depth somebody wants the dynamic compaction to be effective. So, this primary passes are in triangular fashion and secondary passes are selected in such a way that is also in triangular fashion. But, the final number of passes or the arrangement of improvement after primary and secondary pass comes in a rectangular fashion and this is the greed pattern which can be typically followed at a sight for improvement of the ground?

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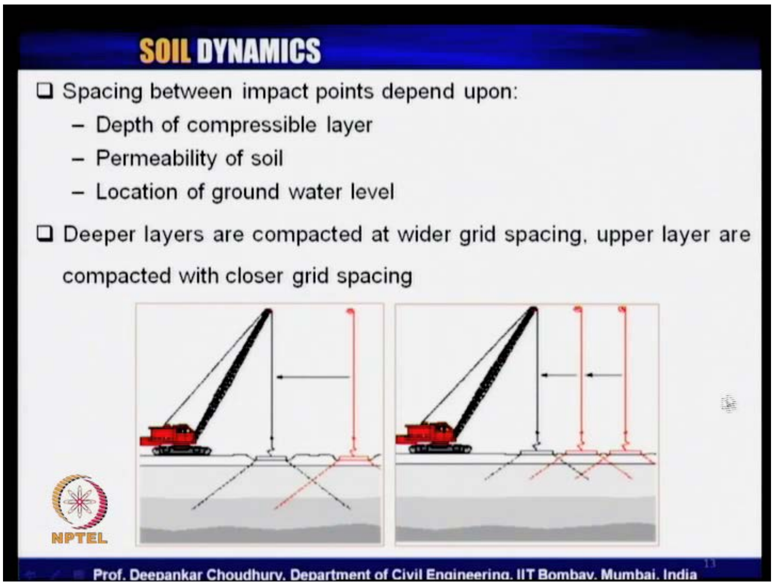

Now, as I was mentioning how to decide about the spacing between that impact points it depends on depth of the compressible layer. That is the layer which we want to compact the permeability of the soil and location of ground water table. Deeper layers are compacted at wider grid spacing whereas, upper layers are compacted with closer grid spacing so, what is mentioned here we can see through this typical picture if somebody wants to compact a deeper layer of the soil then the spacing of this arrangement of grid that is dropping the weight should be wide enough. So, that its influence zone as can be seen from this picture can improve the larger depth of the compressible layer whereas, if somebody wants to compact the shallower depth of the compressible layer then the spacing of this grid should be close enough.

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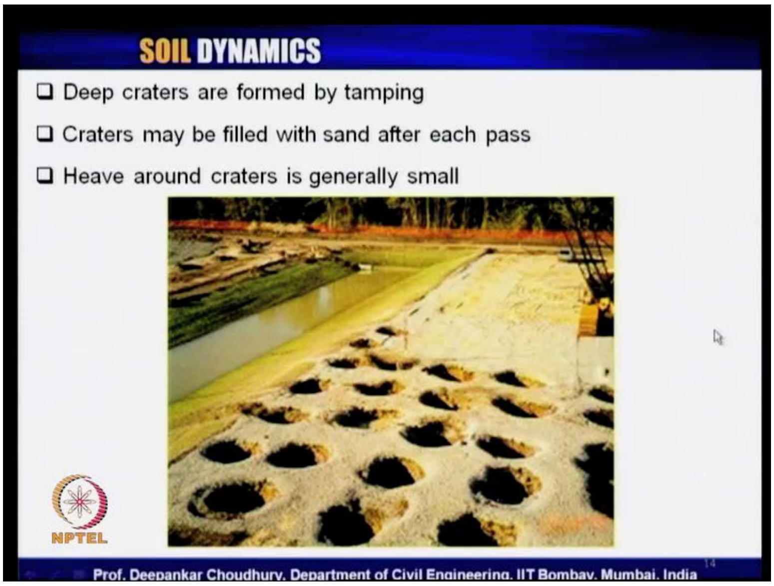

So, that the influence zone can compact the shallower depth like this as shown in this figure so, deep craters are formed by tamping as one can see a very big craters have been formed through this process of dropping of wet through this tamping process and craters may be filled with sand after each pass. So, once this dynamic compaction is over through this drop height process one can fill this craters with good quality sand and then make a roller pass through this to make it a level ground and heave around this craters is generally, small has can be easily seen because obviously, it is already a soft soil. So, which is getting compacted by expulsion of the air so, that is why chances of getting heaving near to the compacted area is very very small because it is a already, a compressible soil and we are trying to improvise or make it more densify if we look here that is why hardly any heaving can be seen around this craters.

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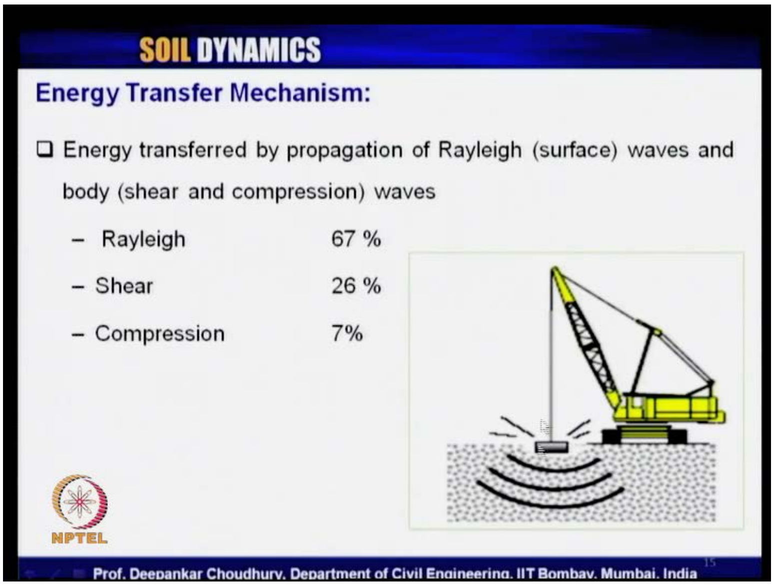

Now, if we talk about the energy transfer mechanism energy transfer by the propagation Rayleigh wave which is a kind of surface wave as we have already discussed in detailed. In this, module were we talked about the wave propagation and the body waves that is shear and compression waves. Now, these when the weight is dropping from a particular height then through the impact it creates the waves in the soil and that passes through as Rayleigh wave that is surface wave close to the ground surface and the body waves through this soil media in form of shear and compressional waves. Now much percentage of typical energy is getting transferred through this transfer mechanism. We can see that Rayleigh wave transfers about 67 percent of the total energy through this process whereas shear wave is carrying about 26 percent typically, of the total energy and compressional or p waves carriers about only 7 percent of the total energy getting transferred through this dynamic compaction process.

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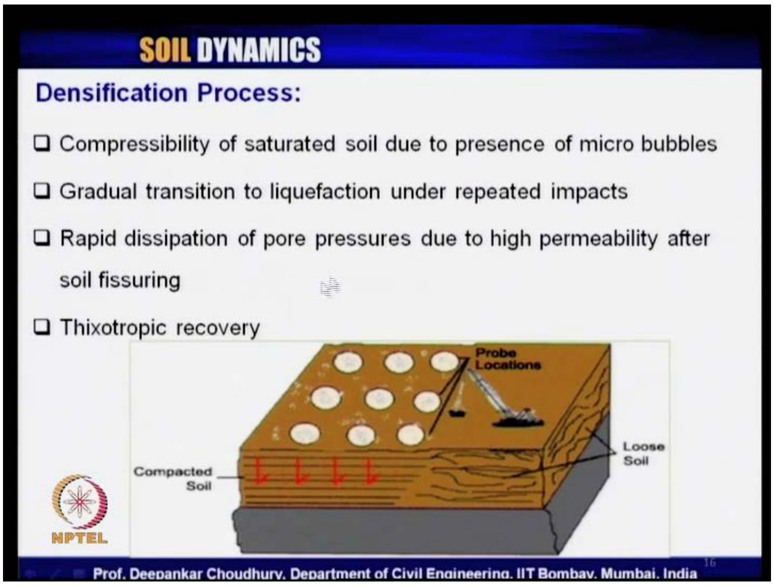

So, the densification process in this compressibility of saturated soil due to presence of micro bubbles occurs gradual transition to liquefaction under repeated impacts because this also, we have to keep in mind that whenever we are applying the dynamic compaction it is not necessary that too much of compaction is good for a soil. We have to determine that how compactive effort or energy is required to compact or densify how much thick layer of a compressible soil or a soft soil it is not that if we compact again and again that layer it will be more resistance to the liquefaction in other words it can go in the reverse direction. That is with the process of more dynamic compaction the soils sometimes may get more susceptible for liquefaction due to continuous impact because that also ,creates a kind of a dynamic load on that soil. So, obviously after a certain number dynamic compaction are passes or dropping hide it may lead to a liquefied state to much of compaction is continued for that

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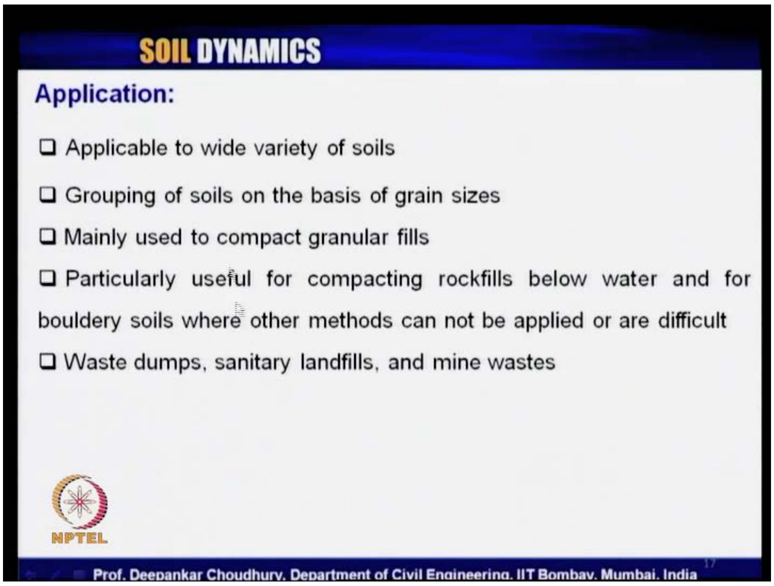

So, that is why it says gradual transition to liquefaction under repeated impact loads. So, this repeated is very important here rapid dissipation of pore pressures due to high permeability after soil fissuring can be seen thixotropic recovery. That is with time it recovers the properties of the soil so, what are the applications of this dynamic compaction it is applicable to wide variety of soils grouping of soils on the basis of grain sizes mainly used to compact granular fills particularly, useful for compacting rock fills below water and for boulder soils where other methods cannot be applied or difficult to apply and waste dumps sanitary landfills and mine wastes can also get compacted through this dynamic compaction.

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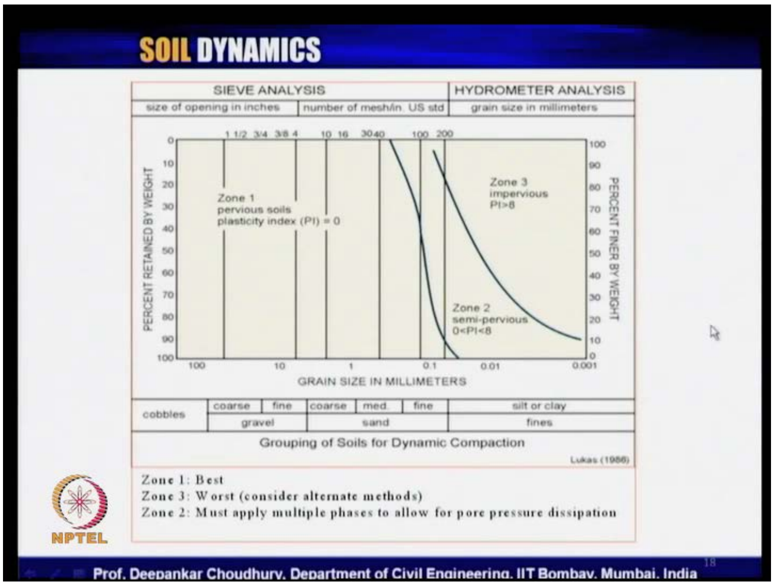

So, as we mention just now that it can be applied for various types of soil but, it should be damp through the its grain size. So, if we see a typical grain size distribution curve for sieve analysis and hydrometer analysis combinely based on the grain sizes in millimeters in z axis and the percentage retain by weight or the person fine is what we say we will see. It has been divided into 3 typical zone for finding out the application of this dynamic compaction as proposed by Lukas in 1986 this 3 groupings of soils are zone one where it is pervious soil with plasticity index of 0 this is zone 2 semi pervious with plasticity index between 0 to 8 and this is zone 3 soil which is pervious with plasticity index more than 8. So, what it says that for zone one this dynamic compaction is best that is if we apply the dynamic compaction process for this zone of soil that is best suited or best applied.

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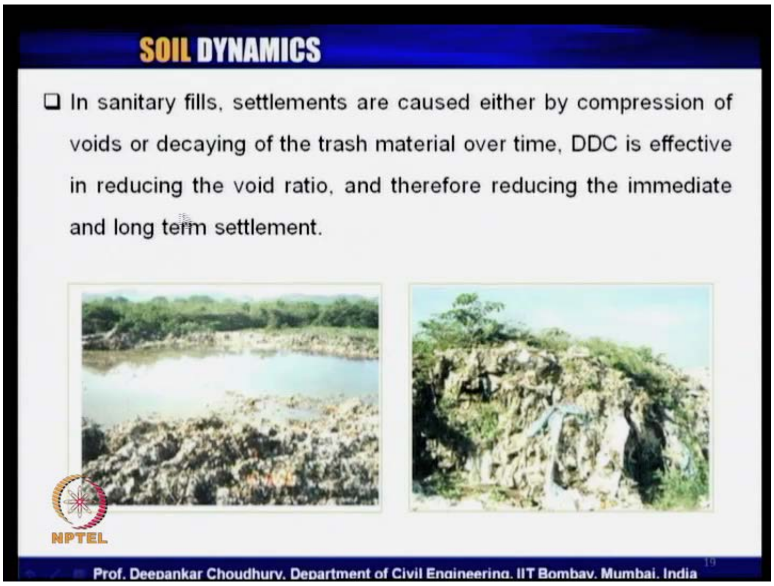

Whereas, on other extreme if we apply dynamic compaction for zone 3 that is this soil it is worst that is for that we should consider some alternate method not the dynamic compaction and for zone 2 it must apply multiple phases to allow for pore pressure dissipation if we apply for this zone 2. So, in zone 2 it can be applied but, with a particular caution or requirement or precaution during the process of dynamic compaction in case of sanitary fills settlements are caused either by compression or voids or decaying of the trash material over time. So, dynamic compaction is effective in reducing the void ratio and thereby it reduces the immediate and long term settlement because if void ratio is reduced obviously, the amount of settlement gets reduced in longer term.

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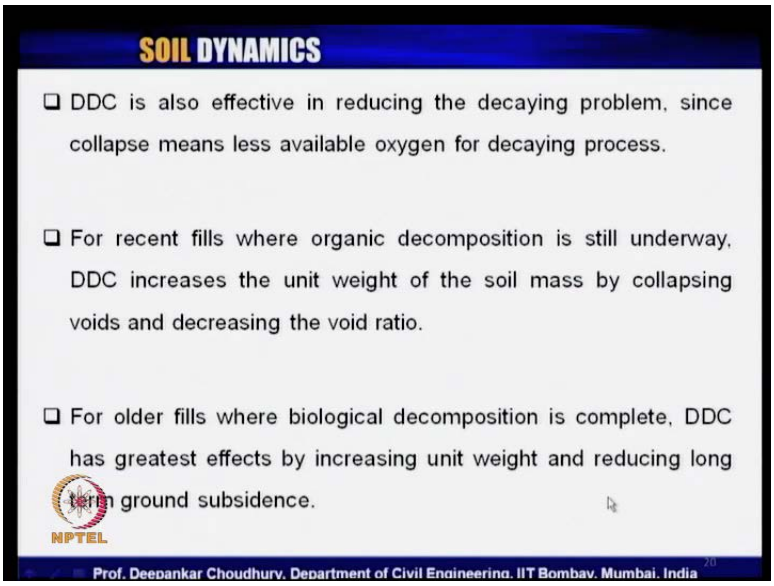

Coming to the dynamic compaction which is also effective in reducing the decaying problems since collapse means less available of oxygen for decaying process for the sanitary landfills for recent fill that is younger fields what we called or fresh damping fill, where organic decomposition is still on going in that case this dynamic compaction increases the unit weight of the soil mass by collapsing all the voids and it decreases the void ratio which is helpful in long run for the use of the fill material for the construction purpose or the liquefaction mitigation purpose. Whereas, for older fills where biological decomposition is complete in that case dynamic compaction has greatest effects by increasing the unit weight and by reducing the long term ground subsidence. So, in all the cases or all the phases of this sanitary land fill we can see that dynamic compaction is very suitable whether it is a younger fill or it is old fill.

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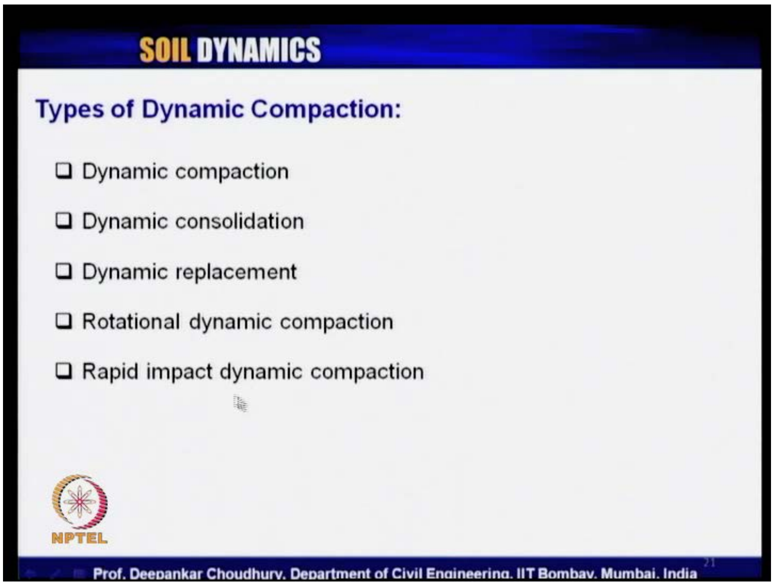

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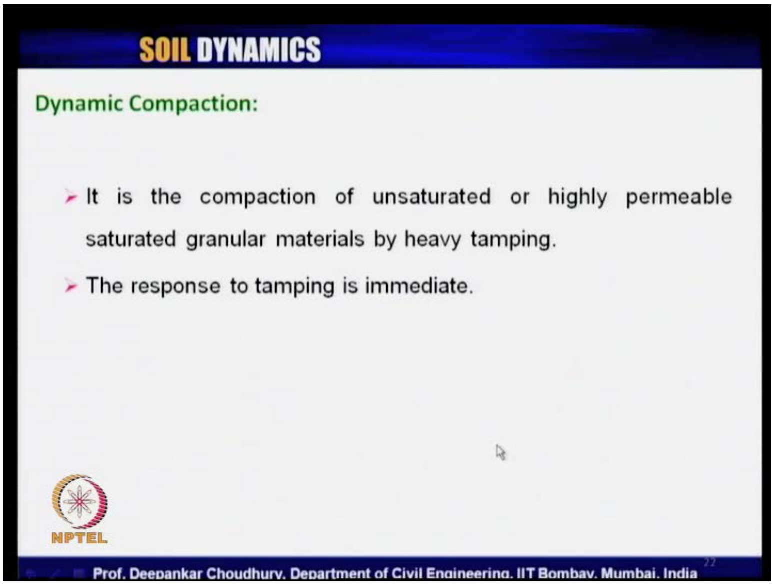

What are various types of dynamic compaction like dynamic compaction, dynamic consolidation, dynamic replacement, rotational dynamics, compaction and rapid impact dynamic compaction. Let us see all of them dynamic compaction as we have understood it is the compaction of unsaturated or highly permeable saturated granular materials by heavy tamping which we have seen through pictures and the response of this tamping is immediate that is we get the advantage of the densified soil with immediate effect.

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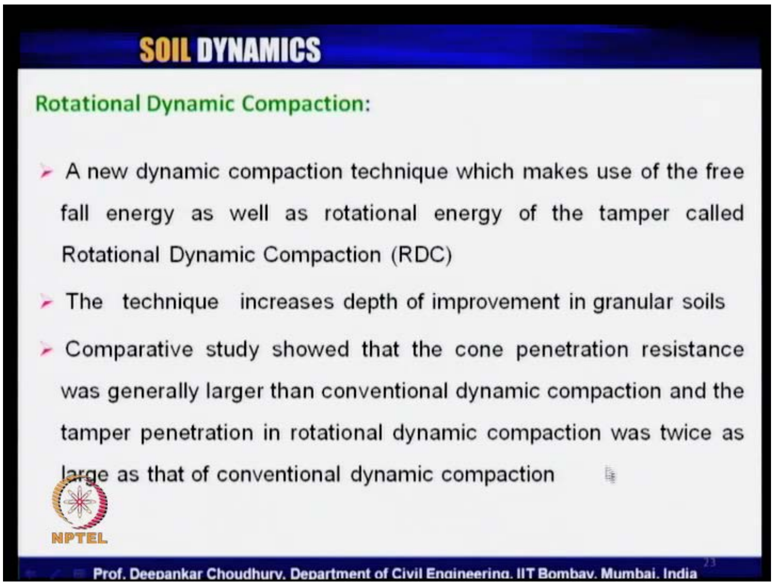

Coming to the next one that is rotational dynamic compaction a new dynamic compaction technique which makes use of the free fall energy as well as the rotational energy of the tamper is called the rotational dynamic compaction or r d c the technique increases depth of improvement in the case of granular soils and compactive. Comparative study showed that the c 1 penetration resistance was generally larger than conventional dynamic compaction and the tamper penetration in rotational dynamic compaction was twice as large as large as the convectional dynamic compaction.

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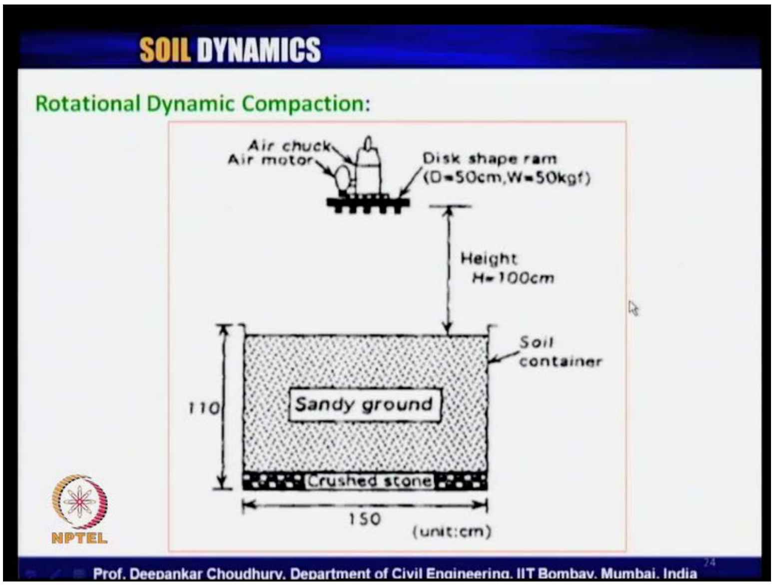

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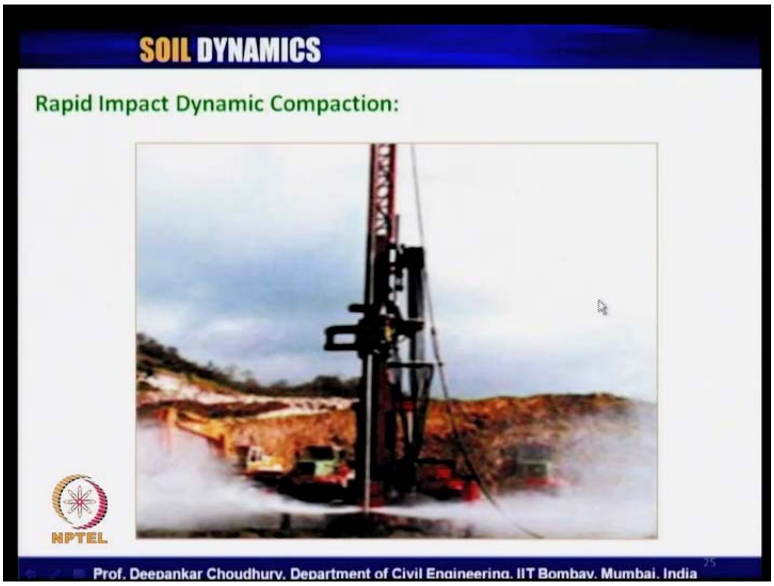

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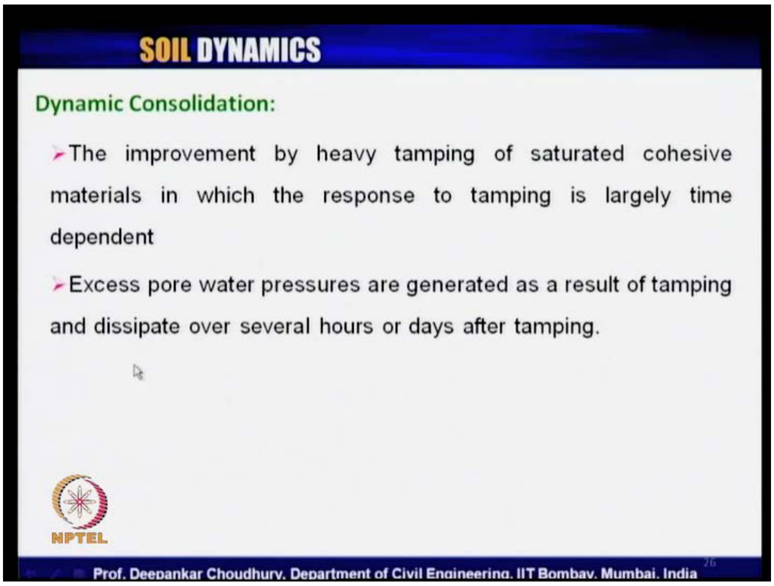

So, if we see a picture of this typical rotational dynamic compaction this is the sandy ground this is height of fall and sand container in which this sandy ground has to be improvised through this rotational dynamic compaction. There is a air motor disk shape there is a free fall and it rotates after getting compacted. So, this is the process of rapid impact dynamic compaction at sight whereas, the dynamic consolidation in this process the improvement by heavy tamping of saturated cohesive materials in which the response of tamping is largely time dependence. So, you can see in this case we are proposing this method for cohesive material whereas, the compaction we have proposed mostly for the granular or cohesive less material excess pore water pressures are generated as a result of tamping and dissipate over several hours or days after the tamping.

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In case of dynamic replacement the formation by heavy tamping of large pillars of imported granular soil with in the body of soft saturated soil to be improved and the original soil is highly compressed and consolidated between the pillars and excess pore pressure generated require several hours to dissipated the pillars are used both for soil reinforcement and drainage. So, it serves the dual purpose it improves the soil by providing the soil reinforcement also, through the process of drainage it reduce the chances of getting generated excess pore pressure.

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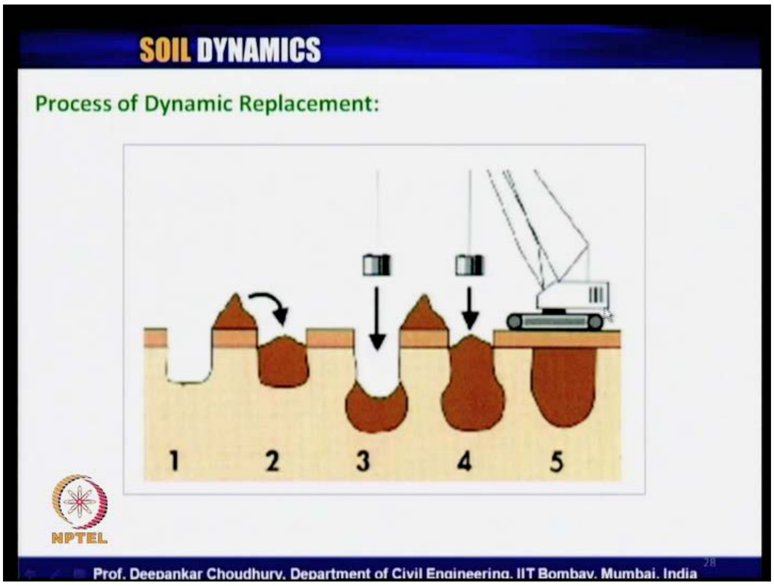

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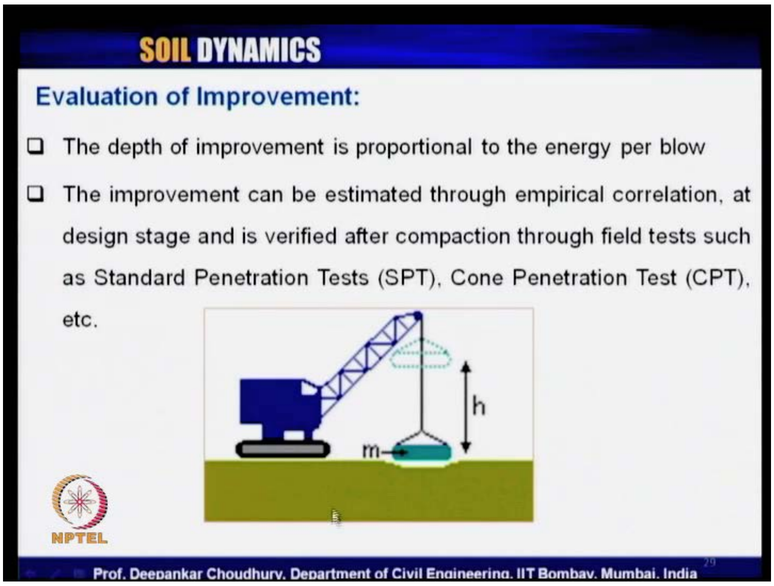

So, this the picture of the dynamic replacement process this is the first step second step you put the soil then, tamp it in the third step come to a certain height and after that you refill it back and make it a level ground in the free step. So, how to evaluate how much improvement has occurred so, evaluation of the improvement suggest the depth of improvement is proportional to the energy per blow that is in one blow how much energy is getting transferred that value is proportional to how much depth it gets influenced and the improvement can be estimated through a empirical correlations there are few empirical correlations available through each one can estimate it at design stage and it is verified after compaction through field tests such as standard penetration tests or cone penetration test etcetera, that is once you compact the ground then through some s p t s p t or c p t 1 can find out how much improvement of the ground in that particular compressible or formal compressible layer has been achieved.

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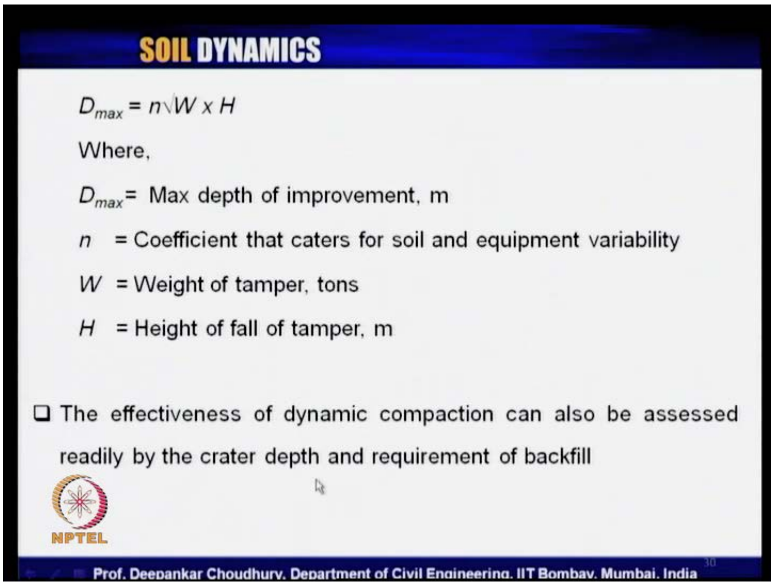

So, this is the amount of improvement of depth that is d max is maximum depth of a improvement in the unit meter n is coefficient that caters for soil and equipment variability root of w. Where w is weight of the tampers in tons and h is the height of fall of tamper in meter unit. So, this is the empirical relation which can be used to find out how much depth the soil is getting improved through that process of dynamic compaction the effectiveness of dynamic compaction can also be accessed readily by the crated depth and the requirement of the back fill to fill up that crater. So, that also give an indirect estimation that is once the dynamic compaction is done there is a crater formed so, those craters needs to be fill back with the soil or back fill material r good soil. So, how much soil is require to fill those crater or the volume of that crater created also provides some kind of guideline or estimate that how much improvement of the soil has be done.

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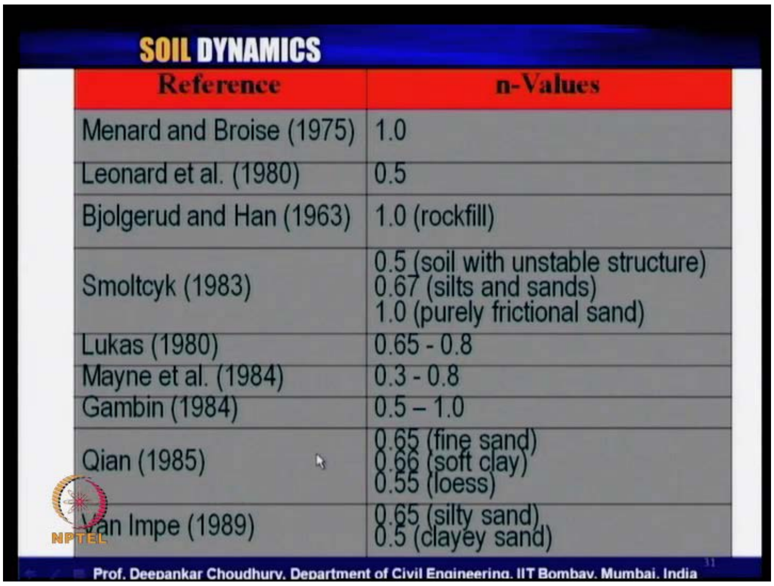

Reference	n-Values
Menard and Broise (1975)	1.0
Leonard et al. (1980)	0.5
Bjolgerud and Han (1963)	1.0 (rockfill)
Smoltcyk (1983)	0.5 (soil with unstable structure) 0.67 (silts and sands) 1.0 (purely frictional sand)
Lukas (1980)	0.65 - 0.8
Mayne et al. (1984)	0.3 - 0.8
Gambin (1984)	0.5 – 1.0
Qian (1985)	0.65 (fine sand) 0.66 (soft clay) 0.55 (loess)
Van Impe (1989)	0.65 (silty sand) 0.5 (clayey sand)

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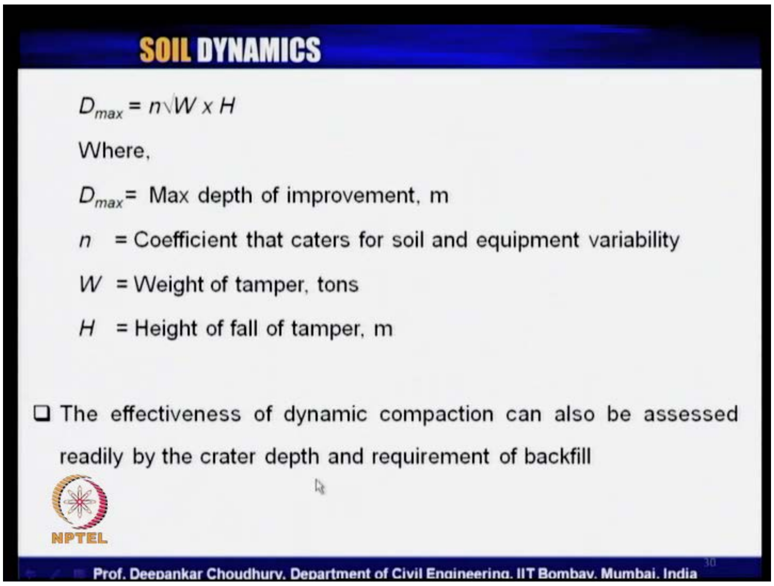

So, if we see the values of n proposed by various researches this table shows a typical values of n for different types of soils and conditions as proposed by various research is over the years as can be seen from this table. So, in the previous equation this n value can be used using this known design chartered table as proposed by various researches for different patterns are types of soil and other parameters are known at the sight that is how much weight of tamper is used and how much height of fall is used.

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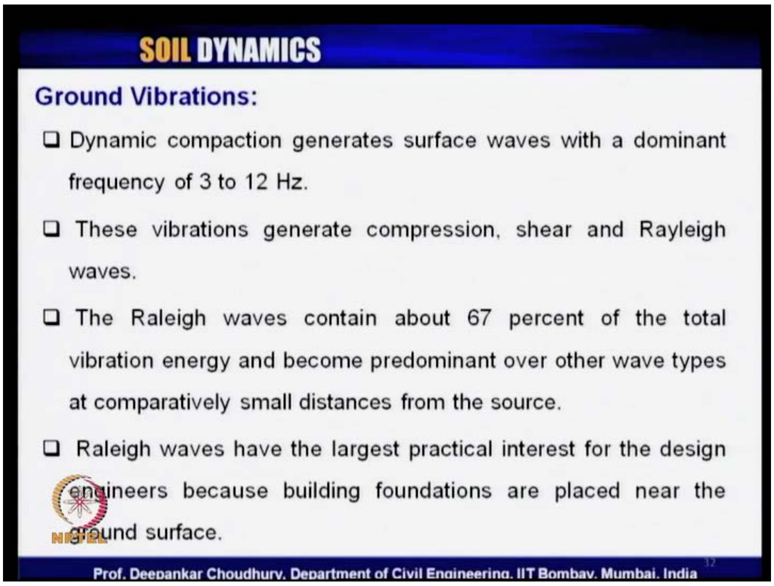

So, using this relationship one can easily calculate, how much depth of the soil is getting improve through the dynamic compaction process in case of ground vibrations the dynamic compactions generates the surface wave with dominant frequency of a about ranges between 3 to 12 hertz's and this vibration generate as we have mention just now all 3 types of waves that is p wave or compressional wave shear, wave or Rayleigh type surface wave.

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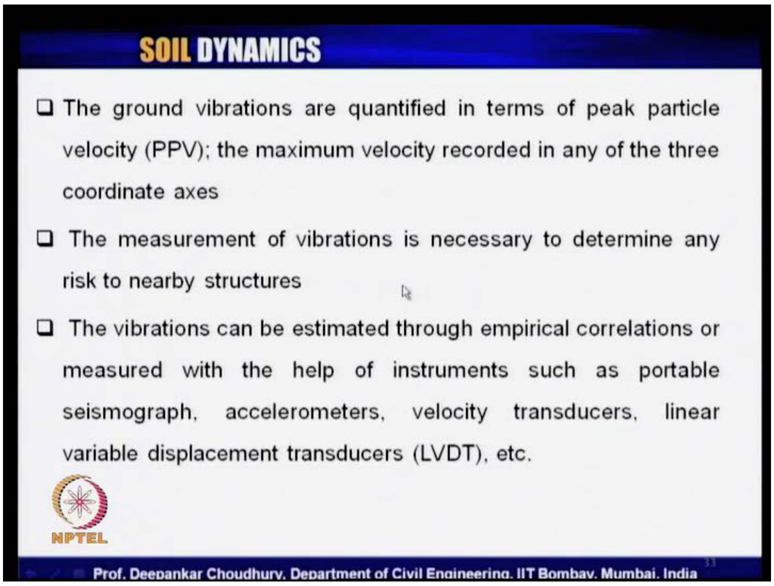

The Rayleigh waves contain about 67 percent of the total vibration energy and hence it is the predominant over the all types of waves at comparatively small distances from the sources. Rayleigh waves have the largest part practically interest for the design engineers because building foundations are placed near the ground surface. So, that is why obviously, the Rayleigh wave criteria is more important for the structural engineers are the building foundations when we are talking about the ground vibrations are quantified in terms of peak particle velocity. So, this is the one of the most important estimation for knowing the ground vibration due to the blasting etcetera which is called peak particle velocity during a vibrational blasting process. The maximum velocity recorded in any of the 3 orthogonal coordinate directions the measurement of the vibrations is necessary to determine any risk to the nearby structure which is very important because in open area using dynamic compaction is perfectly fine. But, if we want to use the dynamic compaction in a congested area or in an urban area where nearby surrounding buildings are existent habitants are they are we should be very careful that what is the zone of influence and what are the disturbances it creates to the adjoining structures and the people are working in that environment.

So, that is why that measurement of that vibration is very necessary to find out the risk on this nearby structures the vibrations can estimated through empirical correlations or can be measured with the help of instruments such as portable seismograph accelerometers velocity transducers linear variable displacement transducers or which it called as l v d t etcetera.

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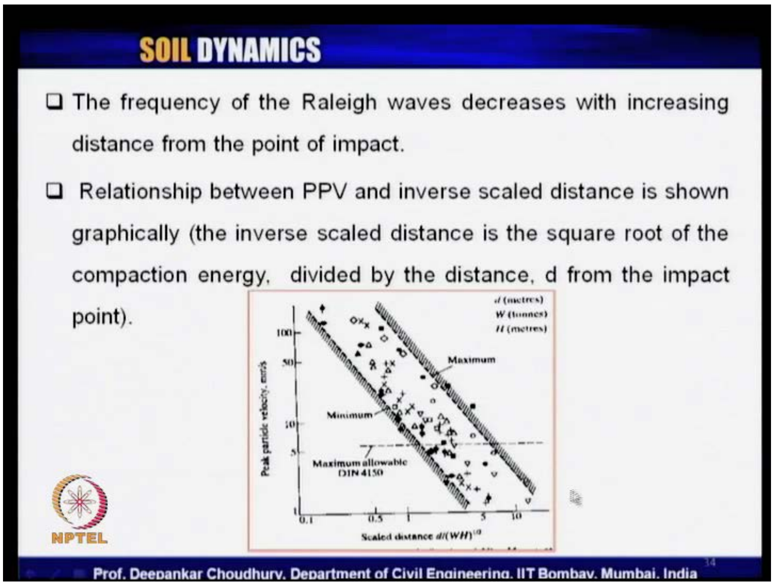

So, these like accelerators etcetera can easily quantify that when we are using the dynamic compaction at a sight if there is a nearby building. If we put accelerometers in those locations or at a certain distance from the dynamic compaction sight we can measure with distance how, much degree of vibration or the disturbances is causing because of the dynamic compaction at a particular sight and if it goes beyond at tolerable limit then we cannot adopt that process of dynamic compaction or, we have to minimize the amount of energy which is getting transferred through that dynamic compaction process the frequency of the Rayleigh waves decreases with increase in the distance from the point of impact because, as we go further away from the point of impact the frequency of Raleigh wave will decrease and the relationship between the pick particle velocity p p v and the inverse scaled distance is shown in this graph the inverse scale distance is the square root of the compaction energy divided by the distance d from the impact point. So, as we see the peak particle velocity in millimeter per second that is keep on decreasing as we go far away from the impact point.

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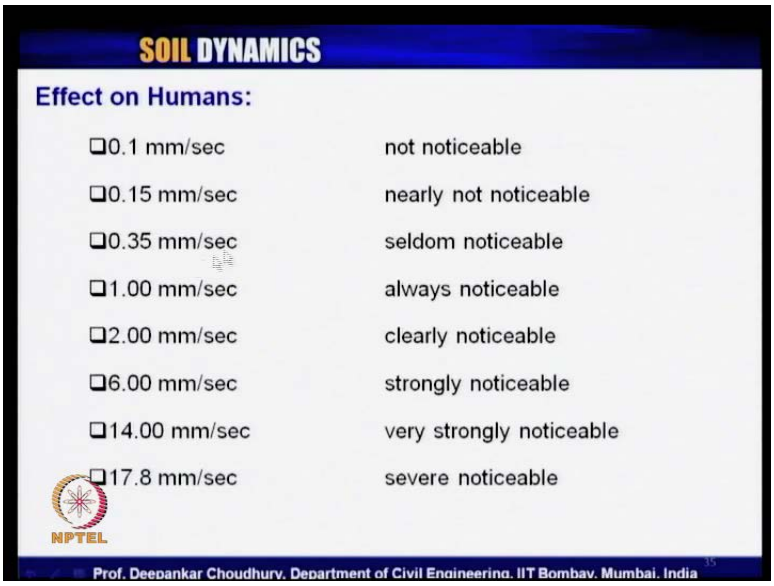

Now, what are those typical ranges of the values of this peak particle velocity on human being like if it is point 1 millimeter per second all less than that it is not noticeable to human being? So, if the at a sight if we measure the pick particle velocity is of that order we need not to worry at all if it is about point 1 5 millimeter per second nearly, not noticeable if it is point 3 5 millimeter per second seldom noticeable if it is 1 millimeter per second always noticeable if it is 2 millimeter per second clearly noticeable if it is 6 millimeter per second strongly noticeable is p p v is 14 millimeter per second. It is very strongly noticeable and if the peak particle velocity is 17 point 8 millimeter per second then, it is severely noticeable now we have to decide at a site that at which level of comfort for the human being can be applied. So, may be either nearly not noticeable or seldom noticeable will be preferred so, may be about point 3 5 millimeter per second or may we can go in between this 2 cases may be point five millimeter per second p p v will be desired at a particular sight.

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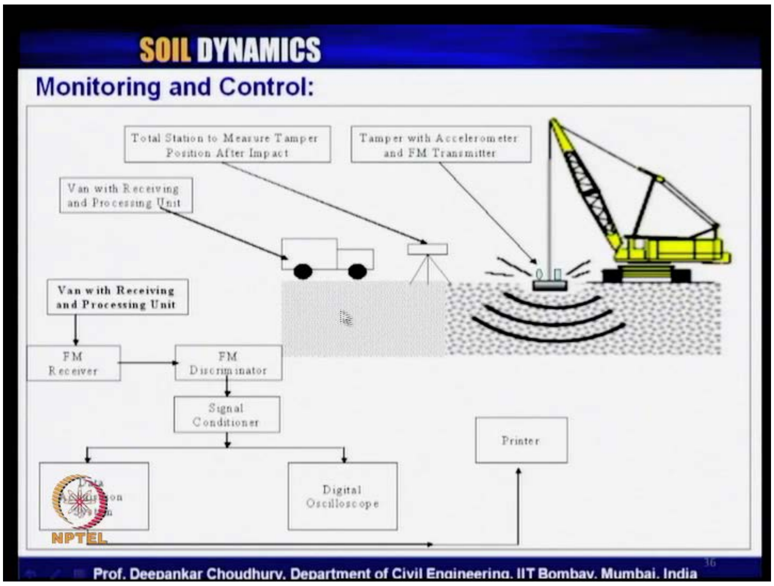

Now for monitoring and control of this we can see the process tamper with accelerometer and f m transmitter. Then total station to measure the tamper position after the impact van with receiving and processing unit then van with receiving and processing unit transfer the data through f m receiver then f m discriminator signal coordinator which goes to data acquisition system and digital oscilloscope and through data liquidation system. Finally, we get the print out of the data and we get the information that how much p p v is getting generated and how much controlled is required in the surrounding region and so on many other data.

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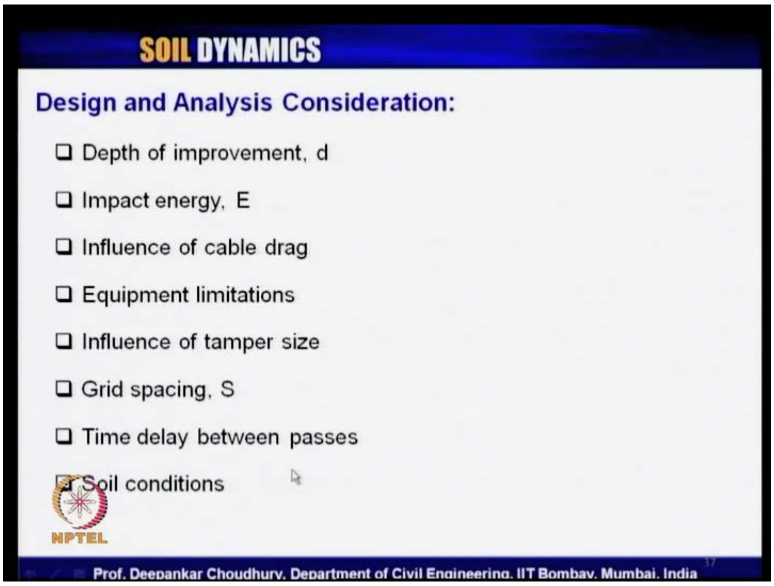

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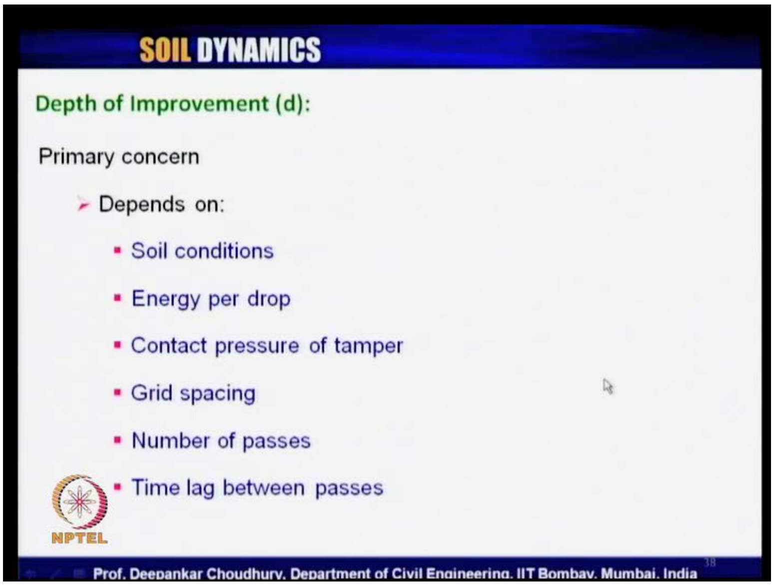

Coming to the design and analysis consideration for this dynamic compaction depth of improvement impact energy influence of cable drag equipment limitations influence of tamper size grid spacing time delay between, passes and soil condition this can be considered for the design and analysis among this the depth of improvement d the primary concern it depends on the soil conditions energy per drop contact pressure of tamper grid spacing number of passes time lag between the passes.

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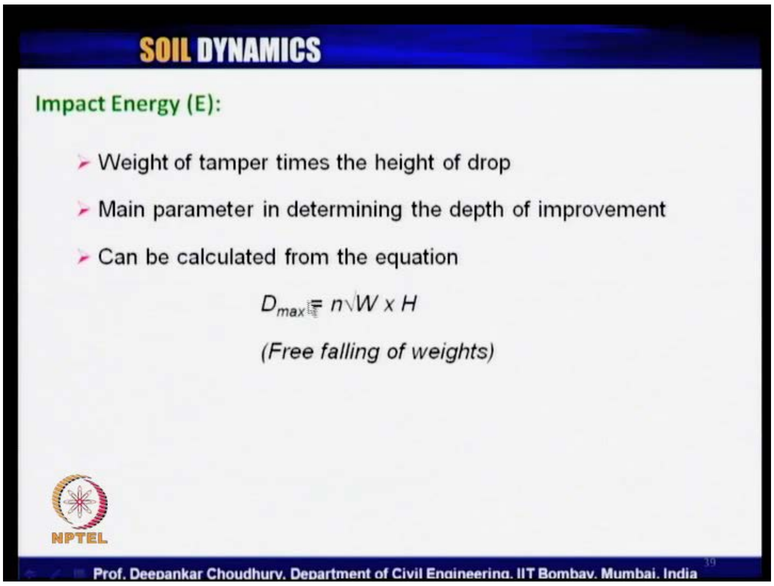

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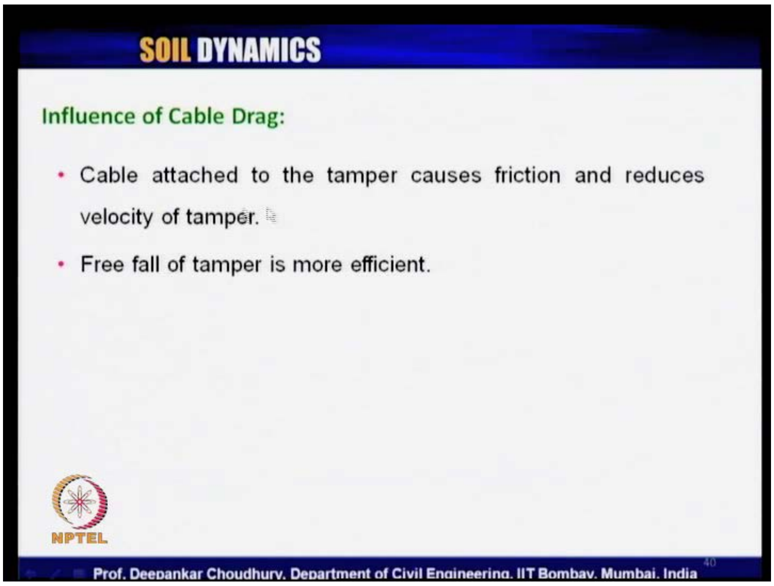

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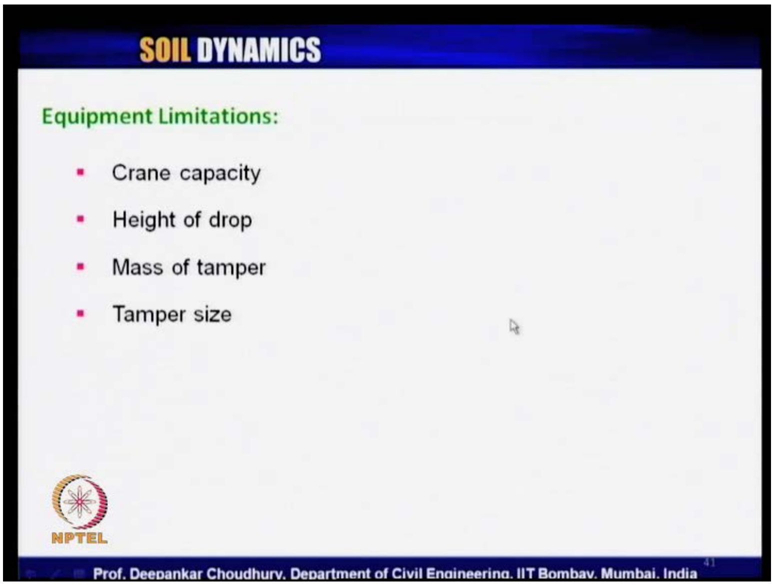

Impact energy how much it is getting transferred as we have discussed. We can calculate through this empirical relation influence of cable drag cable attach to the tamper causes the friction and reduces velocity of the tamper. So, it will be best if it is a friction less theoretically but, that can never be achieved obviously, in practice so, we have to reduce that friction in that cable as maximum is possible and free fall of the tamper is most efficient then we get maximum energy out of it. Equipment limitations like crane capacity, how much load it can carry and how much drop with hence can be correlated to it, height of the drop mass of tamper and tamper size how much it can take.

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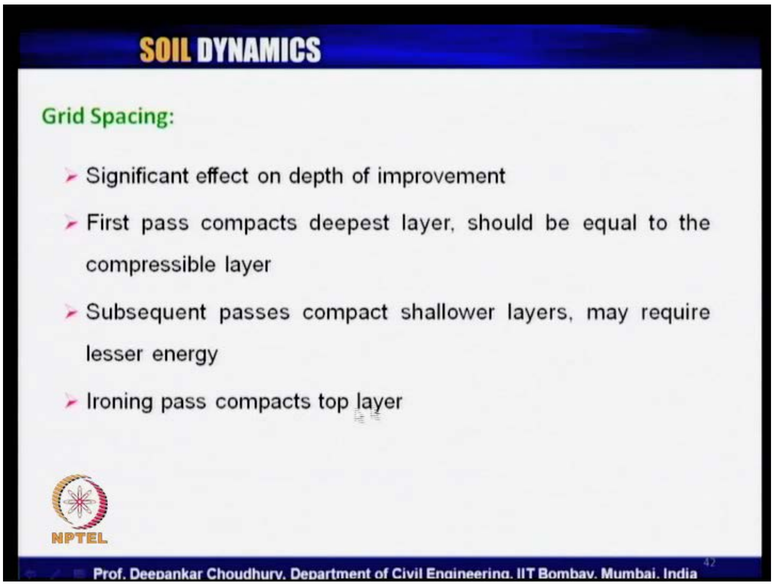

The grid spacing as we have already discussed, how much grid spacing is required, it depends on significant effect on the depth of improvement of the ground, first pass compacts the deepest layer and should be equal to the compressible layer. Subsequent process compact the shallower layers and may require lesser energy. And ironing pass compacts the top most layer.

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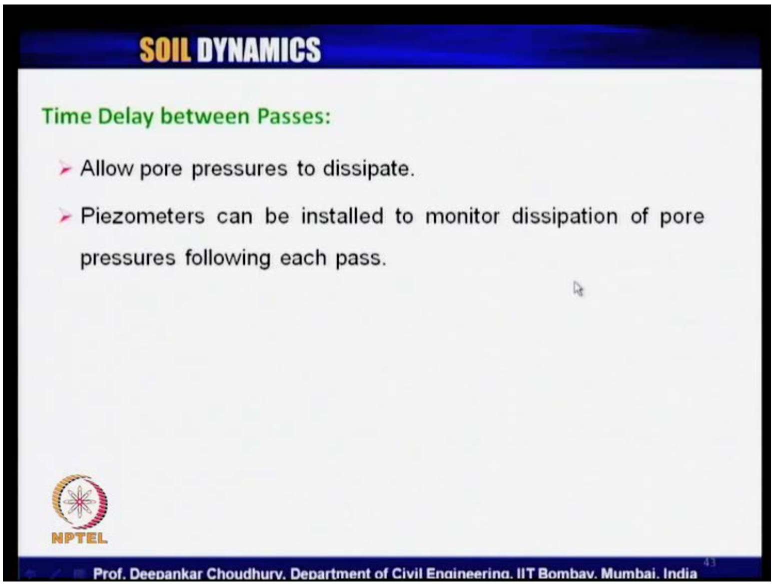

Time delay between passes that allows the pore pressure to dissipate, which is one way good, because it helps also the soil to gets densified if we allow the time between 2 passes, which helps to dissipate the pore water pressure. Piezometers can be installed to monitor that how much dissipation of that pore pressure is getting done after a particular pass.

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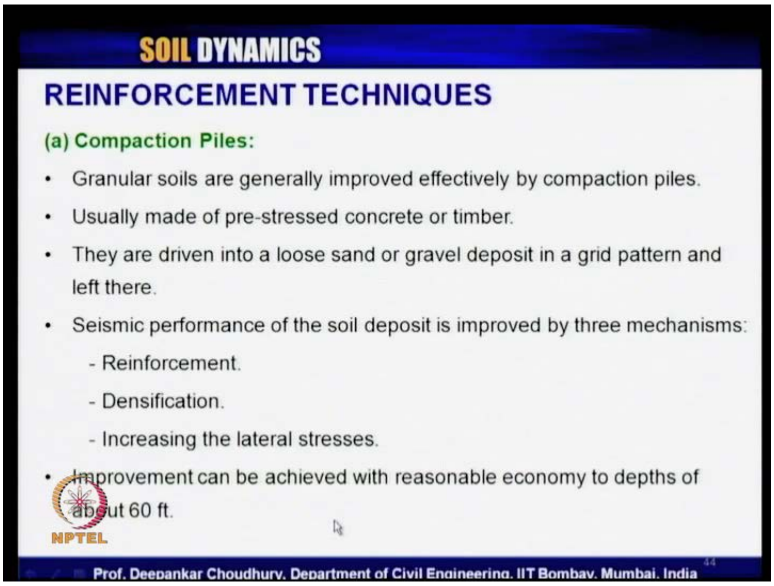

Now, coming to the reinforcement technique we use the compaction piles granular soils are generally improved effectively by compaction piles usually made of pre-stressed concrete or timber they are driven into loose sand or gravel deposit in to a grid patterned seismic performance of the soil deposit is improved by 3 mechanism through reinforcement through densification and increasing the lateral stresses are the confinement stresses that confinement also helps in the soil to get improvise in terms of the liquefaction susceptibility.

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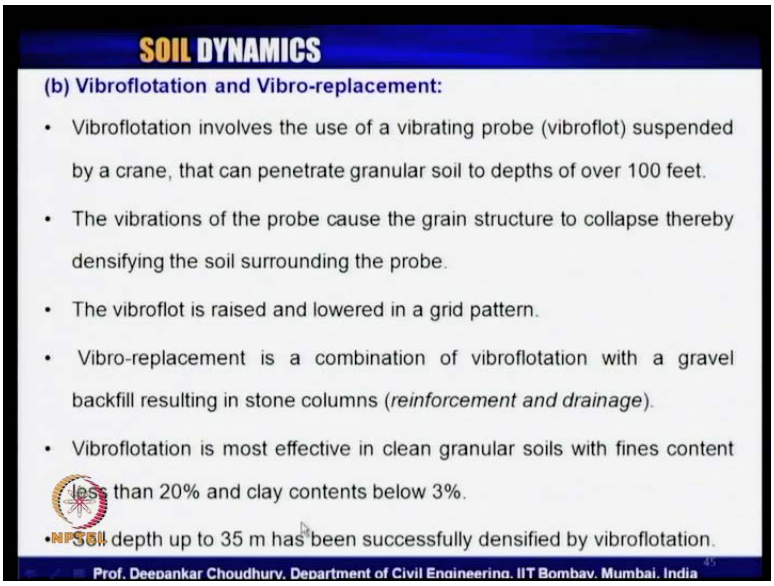

Improvement can be achieved with reasonable economy up to a depth of about 60 feet. In case of this compaction piles vibroflotation and vibro-replacement vibroflotation informs the use of the vibrating probe which we have discussed in the previous lecture and suspended through a crane and penetrate up to a depth of over 100 feet the vibrations of probe cause the grain structure to collapse there by densifying the soil surrounding the probe. The vibroflot is raised and then lowered in to a grid pattern and it vibro replacement is a combination of this vibroflotation with a gravel back filling resulting in a construction of stone columns which provides the the reinforcement as well as it provides the drainage purpose as we have discussed in our previous lecture.

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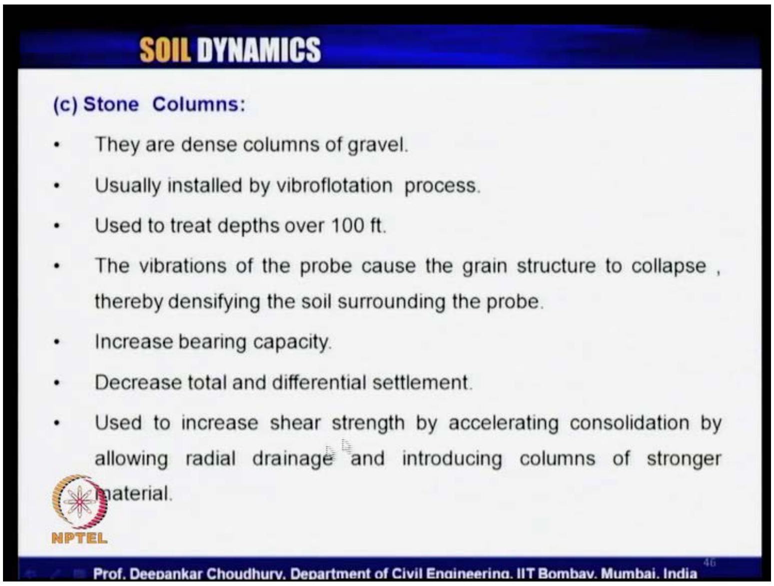

Vibroflotation is most effective in clean granular soil with fines content less than twenty percent and clay contents below three percent and soil depth up to about thirty five meter can be successfully densified through this vibro flotation process where as stone columns which also we have discussed in the previous lecture these are dense columns of gravel usually installed by vibroflotation process used to treat over hundred feet of depths of compressible soil layer the vibrations of the probe cause the grain structure to collapse there by densifying the soil surrounding the probe it of course, increases the bearing capacity of the soil and decrease the total and differential settlement use to increase shear strain by accelerating the consolidation by allowing the redial drainage also and introducing the columns of the stronger material in the soil.

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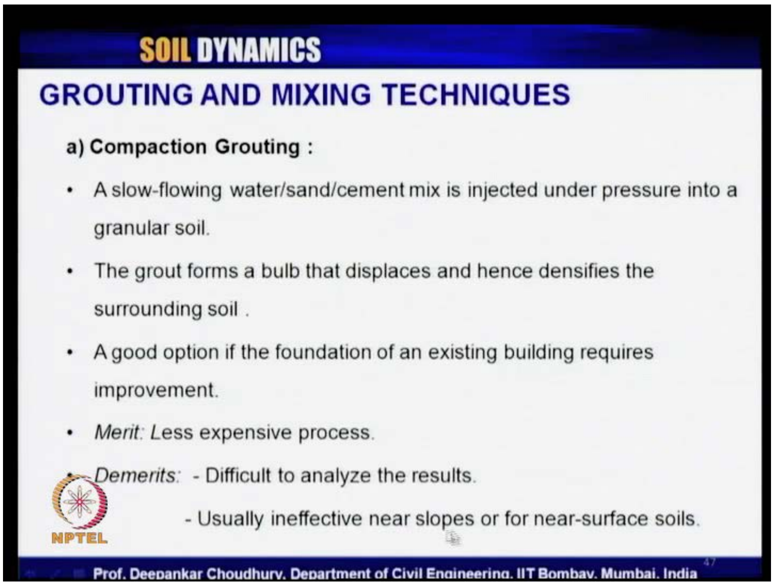

Coming to next method that is grouting and mixing techniques compaction grouting it is the slow flowing water sand cement mixture in injected under pressure in to the granular soil that is called grouting and grout forms a bulb slowly that displaces the soft soil and hence, it densifies the surrounding soil a good option if the foundation of existing building requires the improvement then, this compaction grouting can be used its merit of this method is it is less expensive process and what are the demerits it is difficult to analyze the result that is how much improvement has been done.

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Finally, it is difficult to analyze and usually it is in effective near a slope or for near surface soils the second method is jet grouting the soil is mixed with cement grout injected horizontally under high pressure in a previously, drilled bore hole jet grouting begins at bottom of the bore hole and proceeds to the top leaves behind a relatively uniform column of mixed soil cement the diameters of jet grouted columns are generally greater in coarse grain soils than in fine grain soil.

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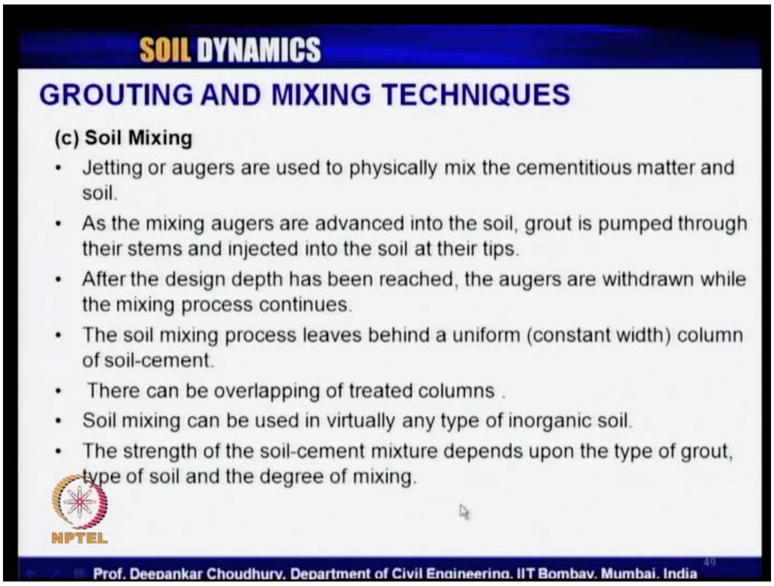

Jet grouting can be performed in any type of inorganic soils to depth limited only by the range of the drilling equipment. The third category of grouting and mixing technique is soil mixing in this process jetting or augers are used to physically mix the cementitious matter with that soil which needs to be improved as the mixing augers are advanced in to the soil, grout is pumped through their stems and injected in to the soil at their tips after the design depth has been reached, augers are withdrawn while the mixing process continues the soil mixing process leaves behind a uniform constant width column of the soil cement. There can be over lapping of treated columns soil mixing can be used in virtually any type of inorganic soil and the strength of the soil cement mixture depends up on the type of grout type of soil and the degree of mixing.

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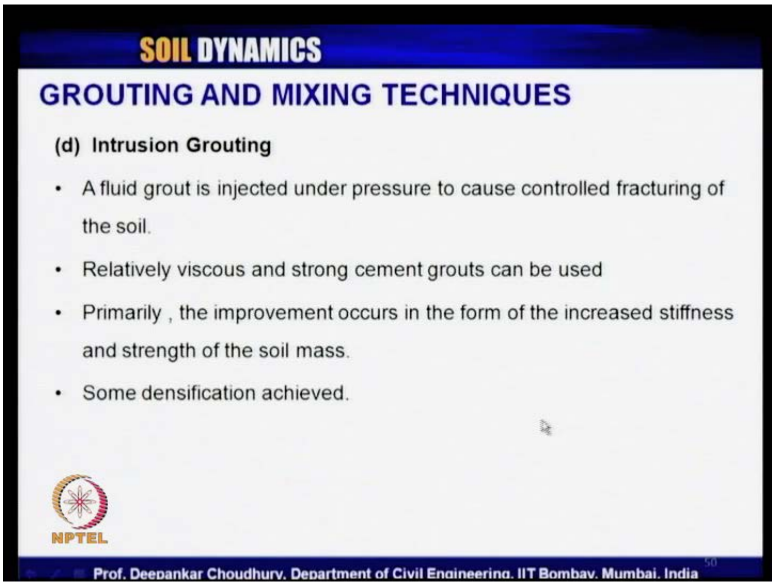

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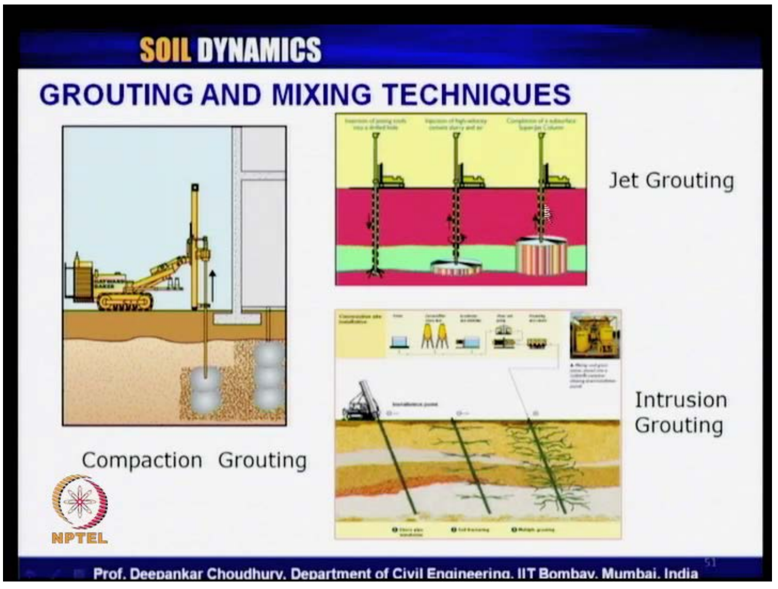

Next category is intrusion grouting a fluid grout is injected under high pressure to cause controlled fracturing in the soil and relatively, viscous and strong cement grouts can be used in this process of grouting primarily the improvement occurs in the form of increased stiffness and the strength of the soil mass and some densification can be achieved through this intrusion grouting.

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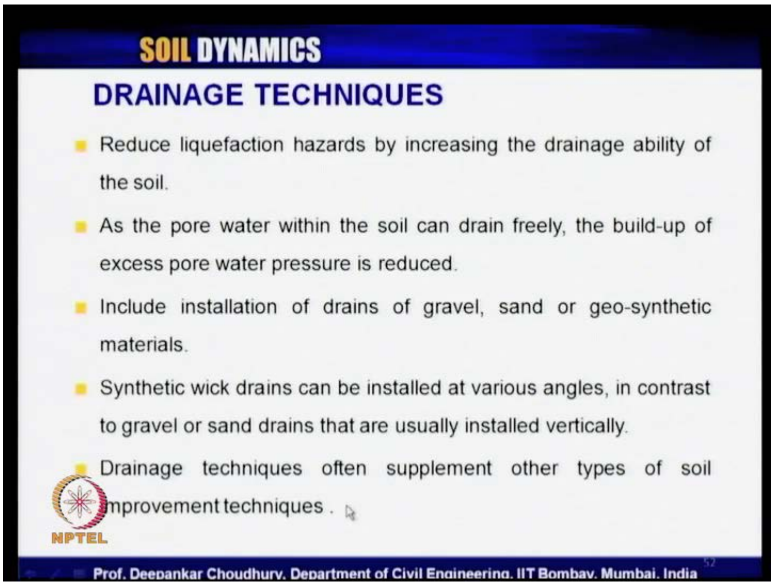

So, these are the some of the pictures various methods grouting as we can see this is the compaction grouting. This is the process of jet grouting, this is the process of intrusion grouting coming to another method of ground improvement or soil improvement in drainage techniques which reduce the liquefaction hazards by increasing the drainage ability of the soil. That is if it can drain out the pore water pressure which is getting generated during and liquefaction process during an earth quake then obviously, it is better?

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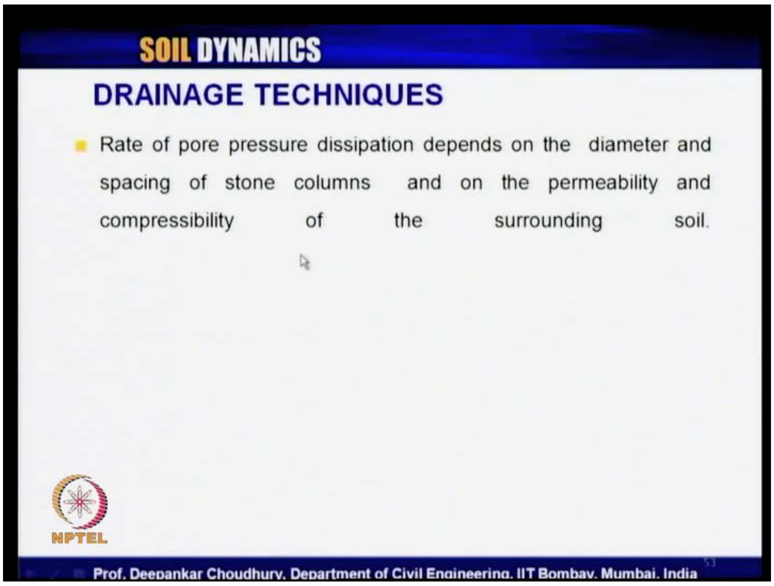

So, in these process of drainage technique it eases out the soil to drain out the water more effectively or in a better way. So, that is why it reduces liquefaction by increasing its drainage capacity or drainage ability as the pore water with in the soil can drain freely the buildup of the excess pore pressure is reduced include the installation of drains of gravel sand, or geo synthetic material and synthetic wick drains can be installed at various angles in contrast to gravel or sand that are usually installed vertically drainage techniques often supplement other types of soil improvement techniques rate of the pore pressure dissipation depends on the diameter and spacing of the stone columns and on the permeability and compressibility of the surroundings soil.

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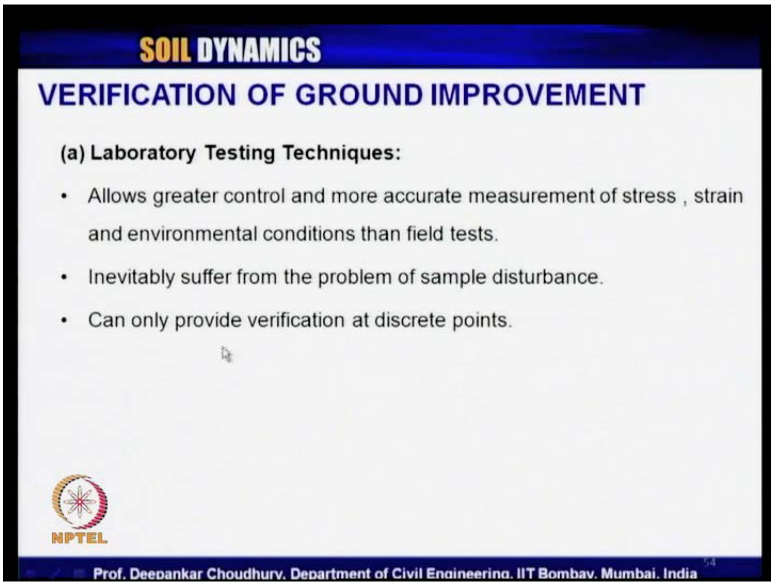

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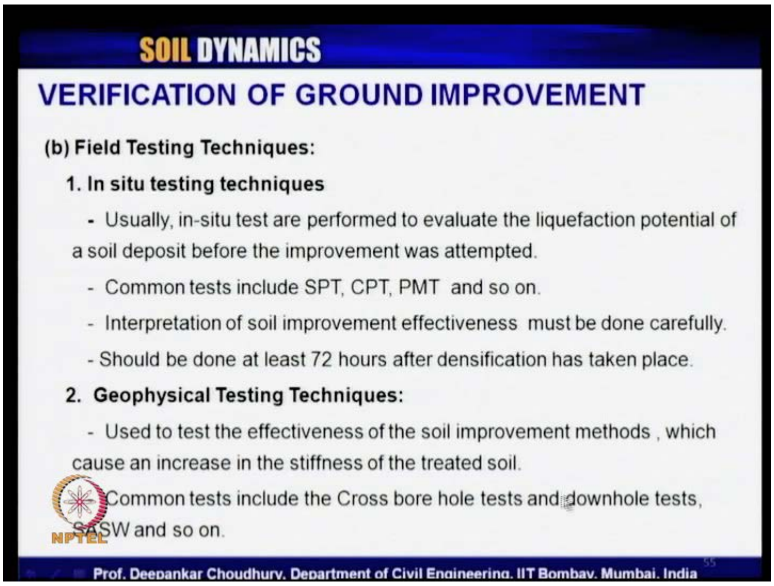

Now, how to verify the ground improvement that is whether the improvement what is desired is achieved or not how to verify that ground improvement. So, laboratory testing techniques are it allows greater control and more accurate measurement of stress strain and environmental conditions then, field test inevitably suffer from problem of sample disturbance can only provide verification at discrete points whereas field techniques. There can be in situ testing technique like usually in situ test are performed to evaluate the liquefaction potential of a soil deposit before the improvement was attempted and common test used are standard penetration test cone penetration test p m t and so on pressure meter test ultimate set it is excetra. Interpretation of soil improvement effectiveness must be done carefully and should be done at least 72 hours after the densification text place at a sight. So, this check of improvement should be done minimum 72 hours after the densification has been carried out at a sight.

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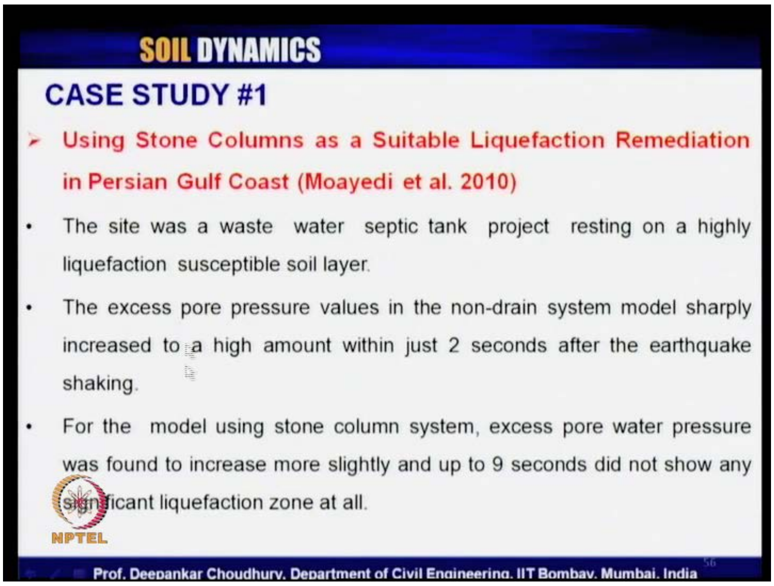

Again indirect testing techniques are filled using geo physical testing can be used to identify the amount of the ground improvement used to take the effectiveness of the improve soil improvement method which cause an increasing the stiffness of treated soil common tests include the cross borehole test down hole. Test s s w m s w test and so on now, let us look at one case study where this ground improvement has been actually, practiced for the liquefaction mitigation at a sight. So, let us look at this case study number 1 using stone columns as a suitable liquefaction remediation in Persian gulf coast this work is published and proposed by moayedi et al in 2010 they discuss that in this the sight was a waste water septic tank project sight resting on a highly liquefaction susceptible soil layer. So, they have to improvise this soil to construct this waste water septic tank the excess port pressure values in the non-drain system model sharply increased to a high amount with in just 2 seconds after the earthquake shaking.

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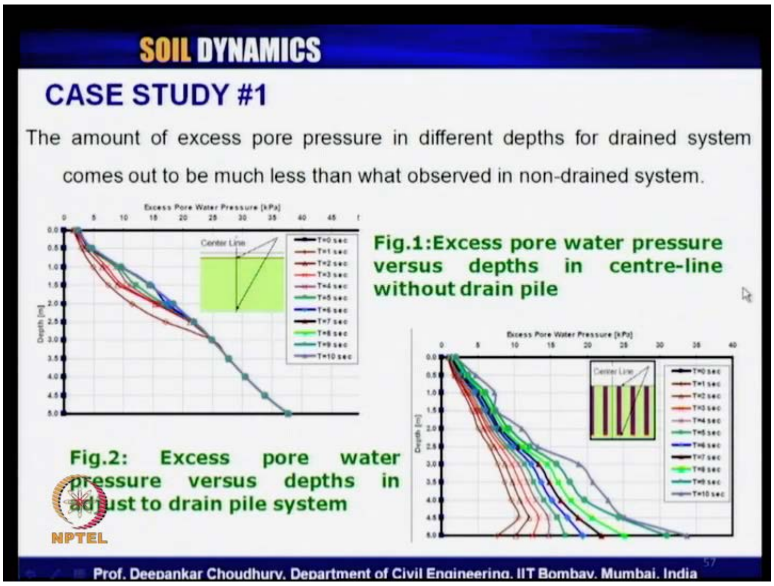

So, that is what it is it is showing that soil was very susceptible or highly susceptible to this liquefaction that within 2 seconds excess pore pressure values is increases very high amount for the model using the stone column system. They adopted the ground improvement technique using stone column excess pore water pressure was found to increase more slightly up to 9 seconds and did not show any significant liquefaction zone at all that is from 2 seconds to that excess pore pressure generation is delayed up to 9 seconds and then there was no much effect of liquefaction in that zone by using that stone columns. So this is these are few results as proposed by them the amount of excess pore pressure in different depths for drain system comes out to be much less than what observed in non-drain system like excess pore water pressure verses depth. You can see the picture excess pore water pressure in excess verses depth. How much values at different times it is showing in the central line without the drain pile so, and this is with drain pile. So, excess pore water pressure verses depth in adjust to drain pile system so, you can see with respect to time how much pore pressure is getting generated.

So, if you take any particular time so, let us take 5 seconds. Here in the green color 5 second at a depth of say 1 meter it developed about this much excess pore pressure about 9 or so, where as in these case but, the 5 second at 1 meter it has reduced to about 6 or so, the similarly, further improvement can be observed at different time intervals and which is shown through results nicely.

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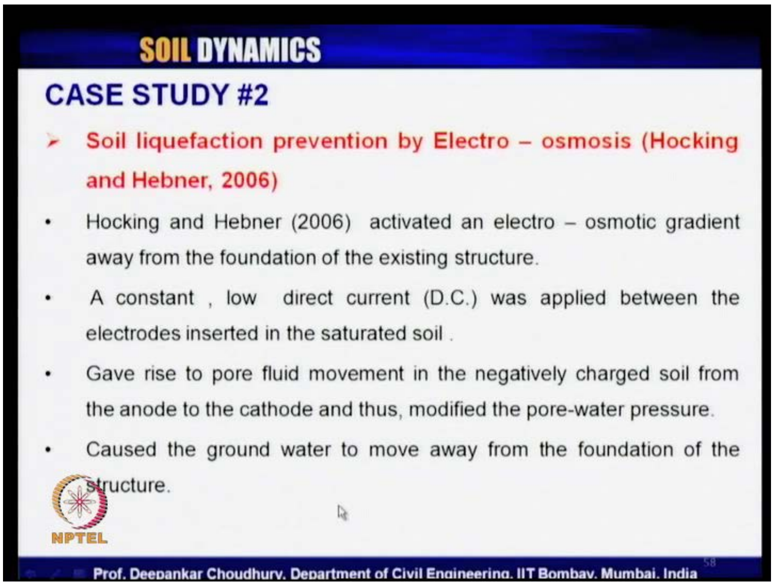

Let us discuss another case study case study 2 where the soil liquefaction prevention by the electro osmosis process was shown by hocking and Hebner in 2006. In this case hocking and Hebner they activated and electro osmotic gradient away from the foundation of the existing structure to reduce the liquefaction potential of a soil so, a constant low direct current was applied between the electrodes inserted in the saturated soil, that gave rise to pore fluid movement in the negatively charged soil from the anode to the cathode and thus it modified the pore water pressure it caused the ground water to move away from the foundation of the structure.

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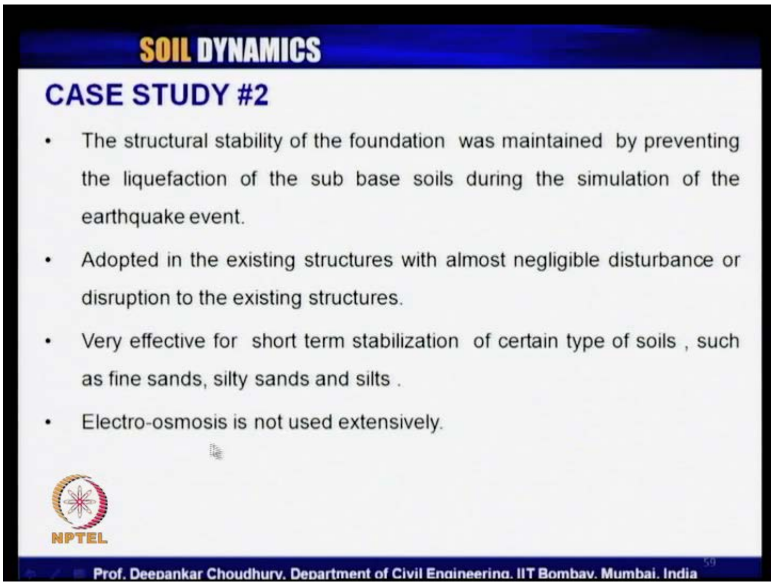

And the structural stability of the foundation was maintained by preventing the liquefaction of the subway soils. During the simulation of earthquake event and adopted in the existing structures with almost negligible disturbance or disruption to the existing structures. So, this is the very good proposed method electro osmosis method by which this liquefaction can be minimized for an already, established structure in a soil without much of a disturbance to the structure very effective for short term stabilization of certain types of soils such as fine sand silty sands and slits and electro osmosis is not used very extensively but, should be used or can be used.

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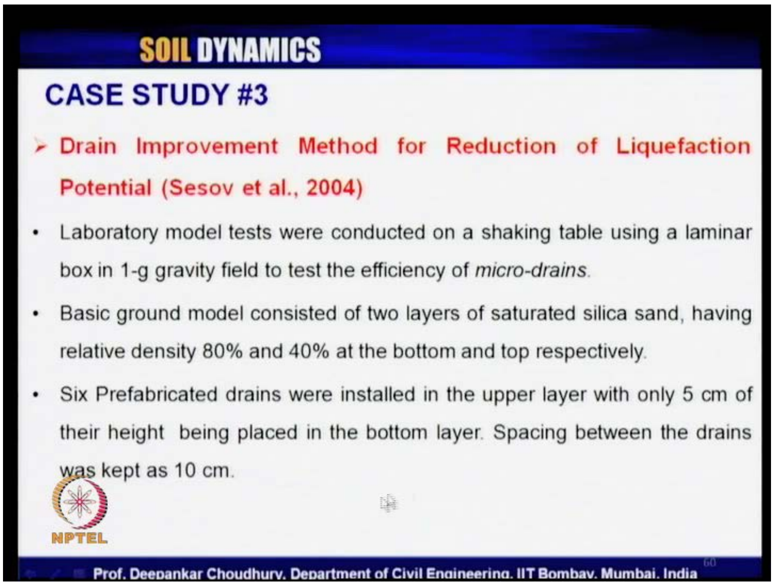

Let, us talk about the third case study in this case drain involvement method for reduction of liquefaction potential, which is practiced and described by Sesov et al in 2004 there they mentioned laboratory conduct test. Where conducted in a shaking table using a laminar box in 1 g 1 gravity field 2 test the efficiency of the micro drains or small drains in a soft soil basic ground model consisted of 2 layers of saturated silica sand having relative density of 80 percent and forty percent at the bottom and at the top respectively.

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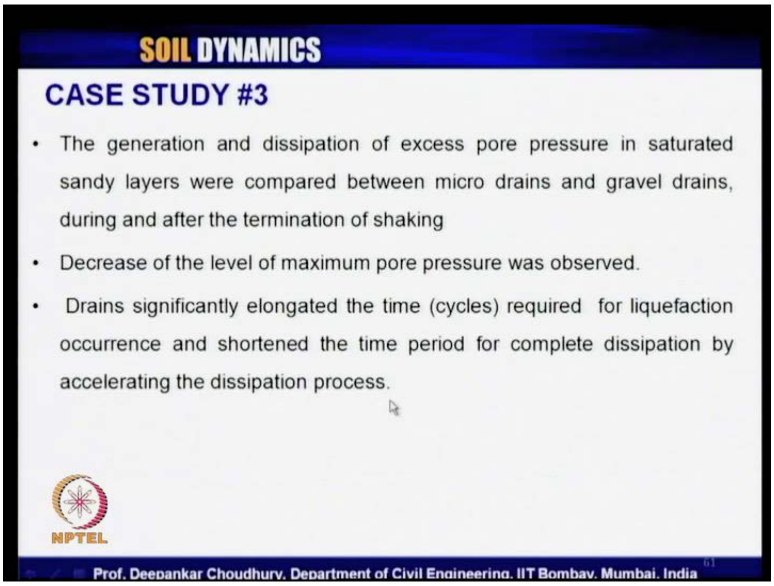

So, 6 prefabricated drains were installed in upper layer with only 5 centimeter of their height being placed in the bottom layer. Spacing between the drains was kept as 10 centimeter in that a study and the generation and dissipation of excess pore pressure in saturated sandy layers were compared between the micro grains and gravel drains during as well as after the termination of the shaking.

There is a decrease of the level of maximum pore pressure which was observed through this process of using micro piles drains significantly elongated the time that is the cycle which is required for a liquefaction to occur co and shortened the time period for complete dissipation by accelerating the dissipation process so, we can see through this process of using micro piles also, at a sight it delays the process of liquefaction or it requires more number of cycles to the soil gets liquefied that is way this is also an advantage that can be achieved for the liquefaction resistance or to stop the liquefaction susceptibility of a soil at reduce it at a particular sight.

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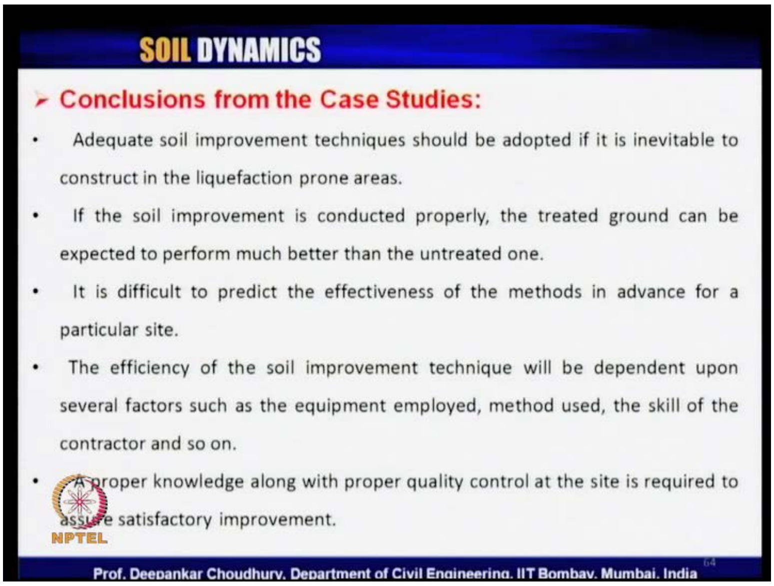

So, what are the conclusions from this case study we can see from these case studies that adequate soil improvement techniques should be adopted? If it is inevitable to construct in the liquefaction prone areas because, we generally propose for a big and important construction avoid he liquefied prone sight but, if it is not possible to avoid that sight because of space crunch or some other reason than it must be improved before the construction takes place.

If the soil improvement is conducted properly the treated ground can be expected to perform much better than the untreated one. So, that automatically takes care of this liquefaction process it is difficult to predict the effectiveness of the methods in advance for a particular sight. But, it is needs to be checked always after the soil improvement technique through both laboratory test as well as field test the efficiency of the soil improvement technique will be dependent on various factors, like equipment employed method used the skill of the contractor and so on and a proper knowledge along with proper quality control at the sight is essential to assure the satisfactory improvement of the soil against this liquefaction susceptibility of a soil. So, that only can bring him liquefaction mitigation. So, with this we have come to the end of this present module 6 that is soil improvement techniques for liquefaction mitigation.