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Lecture No. 09
Module – 1
Soil Compaction – 2

So welcome to lecture number 9 of module 1. In the previous lecture we have introduced our self to soil compaction. And then we discussed about the principle of compaction, factors affecting compacting, and methods for determining compaction characteristics of soils in the laboratory. In this lecture we will be discussing about continuing or discussion about factors affecting compaction. And field assessment of compaction and some field compaction methods.

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So this lecture title is soil compaction 2. As we discuss in the previous lecture the, especially for fine grain soils compaction, it depends upon the particularly the soil structure which actually changes from dry set of optimum to wet set of optimum.

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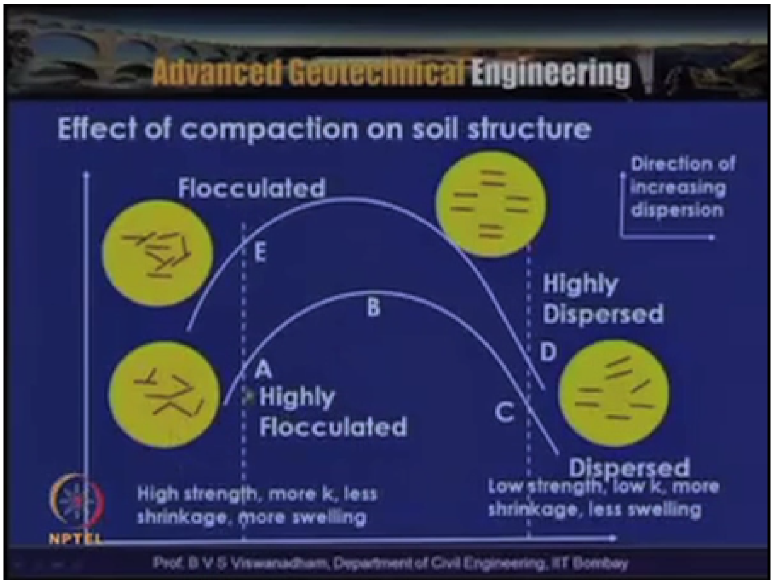

If you can see from this slide here, this is for a light compaction, and this is for modified compaction. So for at point A the soil structure are fabric or soil fabric is highly flocculated in nature. And it poses, it has high strength and higher permeability and less shrinkage and more swelling. And as we transverse from A to B, it actually, the particles undergo rotation and then at point C the soil is now soil solids actually has been replaced by more water.

So hence the low strength, and low permeability and more shrinkage and less swelling. So this is adopted whether to compact dry set of optimum or wet set of optimum, depending upon the type of application. Suppose if you want to compact the soil for a sub grade, then it is preferable to compact it on the dry set of optimum, so that high load or high strength can be achieved. In case if you are constructing a barrier to prevent angles of any per meant, then it is advisable to compact on the wet set of optimum so that the low permeability's can be achieved.

So the scenario of in case of modified compaction also you have the similar status, so this is actually the direction of increasing dispersion somewhere in this direction, this actually happens.

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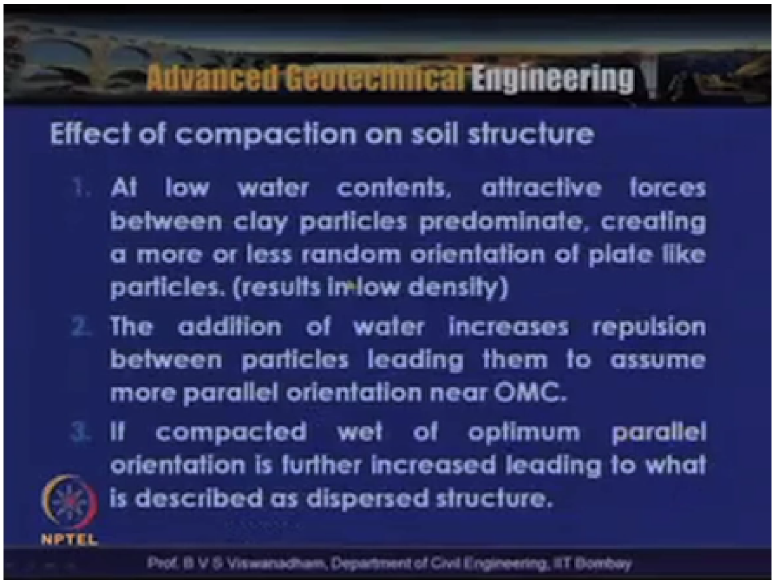

So what we discussed in the previous slide is that at low water contents attractive forces between the clay particles predominate. So creating more or less orientation of plate like particles are trust like orientations. So at low water contents the attractive forces are actually dominating, because of that more or less the orientation of plate like particle results in low density. And the addition of water increases the repulsion between the particles leading them to assume more parallel orientations.

So once water is added the particles are actually deprived from coming closer and so, hence the repulsion of the particles takes place. If compacted wet of optimum parallel orientations further increases leading to what is described as a dispose structure. So that is what actually we have seen, so these soil structure has got a significant effect on the compaction. So if you wanted to test or exchange this compaction in the field, then we need to have different compaction equipments.

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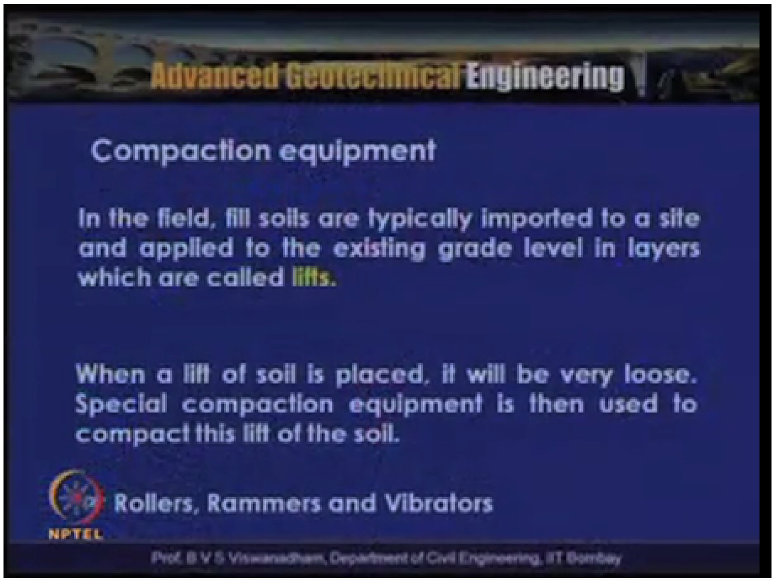

In the field basically field soils are typically imported from a borrow site and apply to the existing grade leveling layers which are called as lifts. So if you wanted to construct the amendment above the existing ground level, the soil is, lose soil is placed at certain water content. And based on the characteristics which are actually required the soil is compacted. So these compacted layers are called as lifts.

When a lift of soil is placed it will be very lose as I said, and special compaction equipment is then used to compact this lift of the soil. So we have different types of soils, and for these different types of equipments are required.

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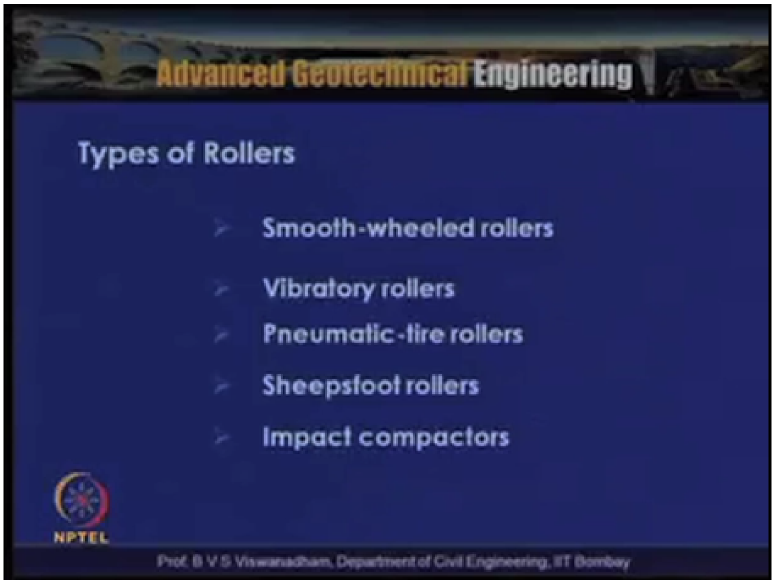

These are rollers, basically types of rollers where we have a smooth-wheeled rollers, vibratory roller s, pneumatic-tire rollers, sheepsfoot rollers, and very recently impact compactors.

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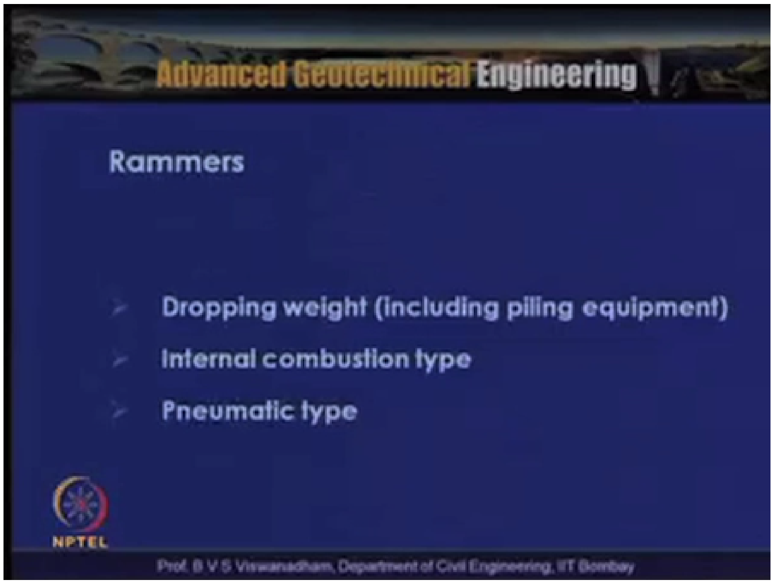

Rammers these are also types for inducing dropping weight, this including pilling equipment, and internal combustion type rammer are pneumatic type rammer.

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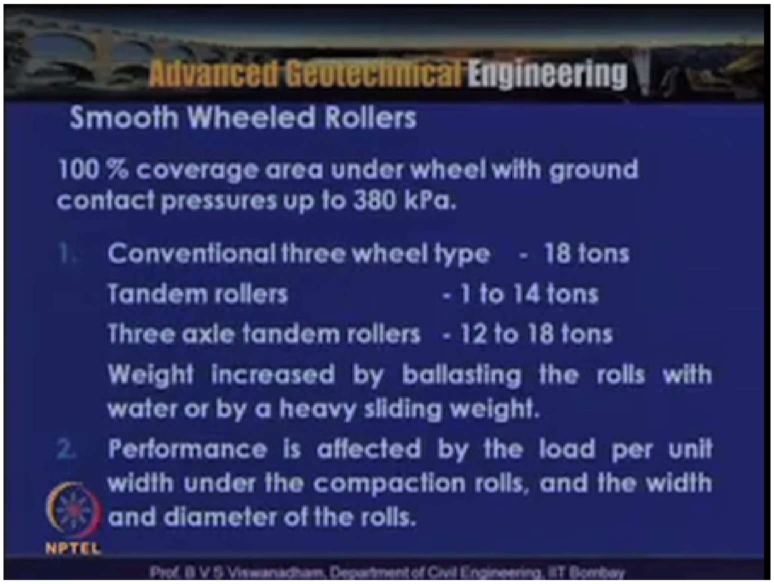

So these smooth-wheeled rollers basically they posses a 100% coverage area under the wheel load with ground contact pressures up to 380 kilo pascals. So smooth-wheeled rollers have 100% coverage area, and they have a ground contact pressures up to 380 kilo pascals. So they will be able to induce a pressure of 380 kilo pascals on the surface on the ground, so that the soil can be compacted.

So in the conventional three way type, the weight will be around 18 tons, random rollers will be about 1 to 14 tons, three axle random rollers about 12 to 18 tons. So weight can be increased by ballasting the rolls with water or by a heavy sliding weight, or it can be ballasted with sand. So performance sis affected by the load per unit width under the compaction of rolls and the width and diameter of the rolls.

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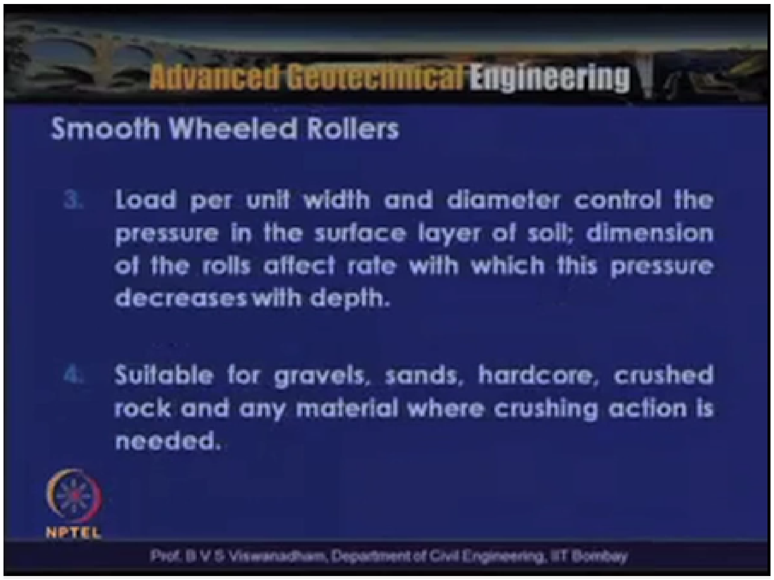

So load per unit width and diameter control the pressure in the surface layer of the soil and dimension of the rolls affect the rate with which the pressure decreases with the depth. So these smooth-wheeled rollers are basically suitable for gravels, sands, hardcore and hardcore type soil and crushed rock and any material where crushing action is needed. So any material where the crushing action is needed or crushed rock, or hardcore, sands are gravels.

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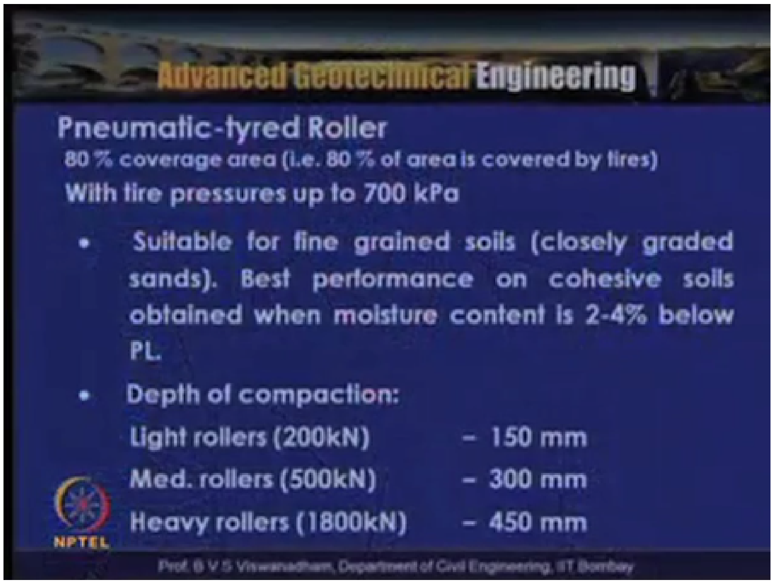

Pneumatic-tyred rollers basically they have 80% coverage area. So 80% of area is covered by tyres, with tyre pressures up to 700 kilo pascals. So suitable basically for fine grain soils closely in graded sands or silty sands, and best performance on cohesive soils can be obtained when moisture content is maintained 2-4% below the plastic limit. So the depth of compaction with the pneumatic-tyred rollers can b e like the rollers with 200 kilometer weight up to 150mm.

Medium rollers with 50 tons or 500 kilo Newton up to 300 mm. And heavy rollers with 800 kilo Newtons the depth of compaction can be ensured up to 450 mm.

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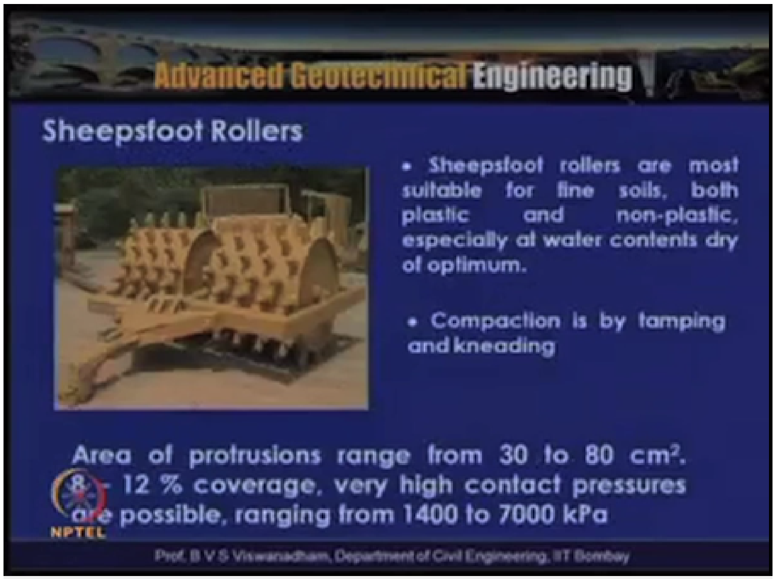

So these rollers which are actually shown in this slide, they are basically sheepsfoot rollers, and we have used it basically for compacting fine grain soils. The protrusions what we see here, they are very effective in inducing very high pressures to the soil, so hence the needing of the soil takes place, damping and needing of the soil takes place, when the roller rolls of the soil.

So sheepsfoot rollers are most suitable for fine grain soils, both plastic and nonplastic, especially at water contents dry up to. So area of protrusions range from 30 to 80 cm^2, and 8 – 12% coverage and very high contact pressures are possible, ranging up to 1400 to 7000 kilo pascals. So because of this protrusions the area, it can be induce a pressure up to 1400 to 7000 kilo pascals.

As we have discussed in previous lectures in order to compact the fine grain soil is a higher amount of static pressures are required to push the clay particles closer. So the sheepsfoot rollers are used basically the protrusions significance is that to induce high contact pressures.

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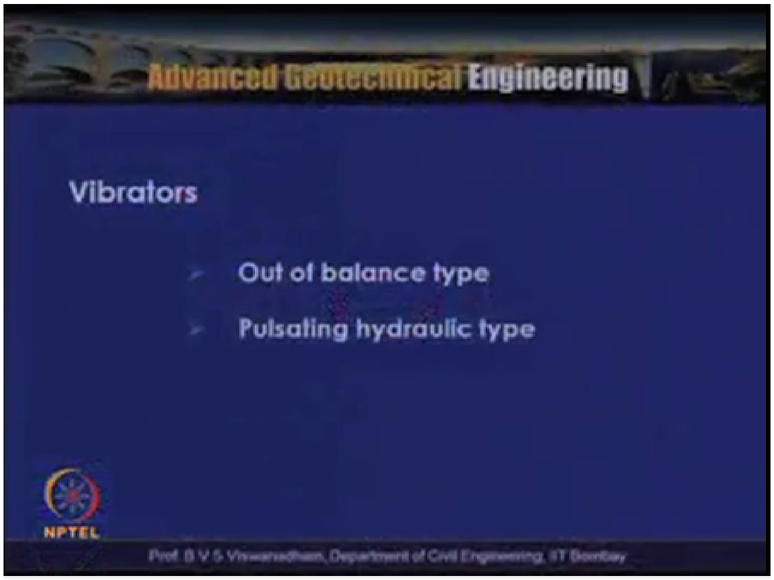

Now coming to vibrators which are basically used for sandy or gravely soils there are two types of vibrators will be there out of balance type or pulsating hydraulic type.

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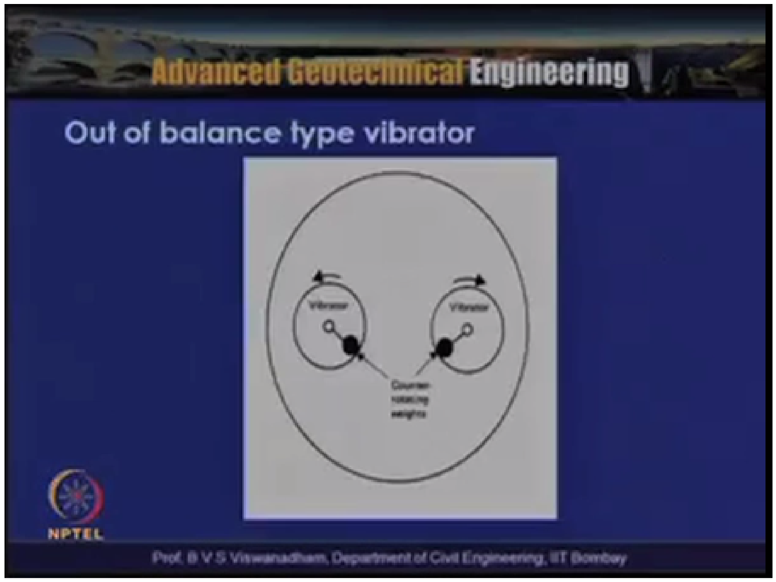

The out of balance type vibrator we have two eccentric masses which are actually rotated in a opposite direction which indices vibration and because of this damping above the eccentric height is created. So this makes the particles to rearrange into the denser configuration.

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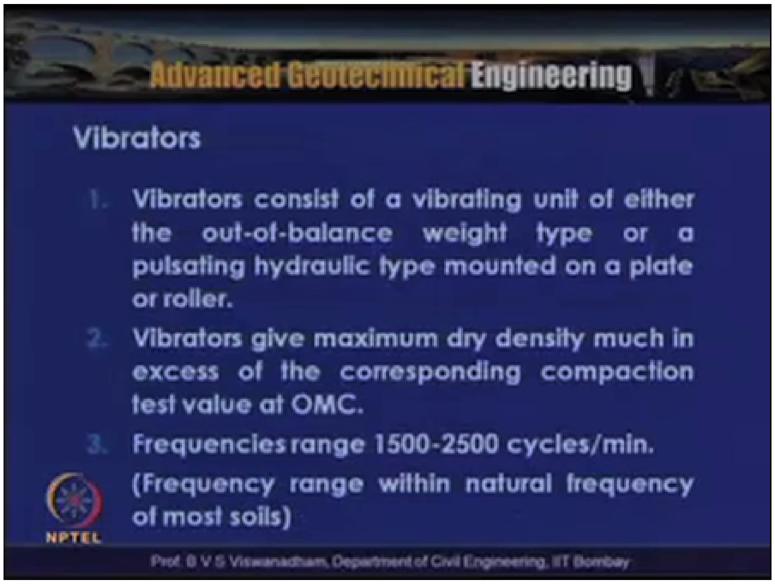

So the vibrators consist of a vibrating unit of either the out of balance weight type or a pulsating hydraulic type mounted on a plate or roller. So the vibrators consist of a vibrating unit either the out of balance weight type, what it was shown in the previous slide or a pulsating hydraulic type mounted on a plate or a roller. So vibrators give maximum dry density much in excess of corresponding compaction test value at OMC.

And frequencies of these rollers range from 1500 – 2500 cycles/min. Frequency range within the natural frequency of the most of the soils. So the frequencies have to be in the range of the most of the natural frequencies of the soils.

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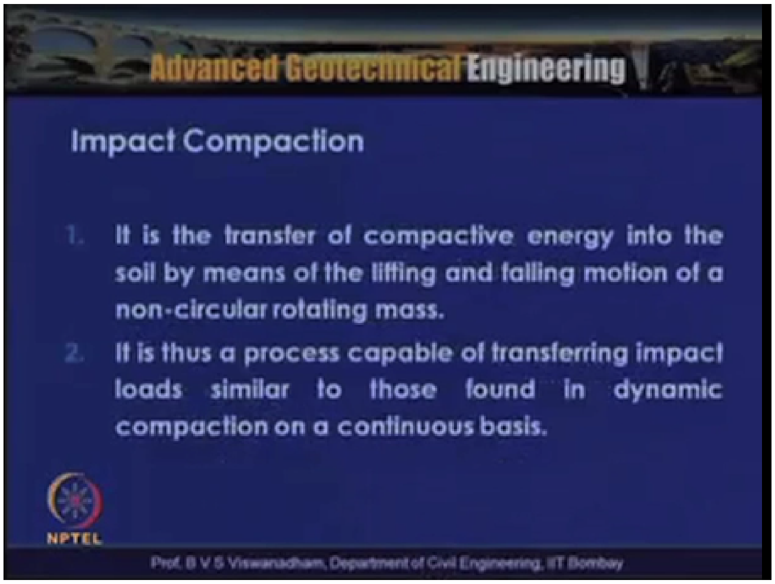

The another type of compaction which is known in nature is impacted compaction. And it is the transfer of compactive energy into the soil by means of lifting and falling motion of a non-circular rotating mass. So in this case we have a non-circular rotating mass, this actually induces and impact type of compaction energy. So it is the transfer of compaction energy into the soil by means of lifting and falling motion of a non-circular rotating mass.

It has been observed that this depth of influence of compaction can be larger in case of impact compaction. So it is thus a process of capable of transferring impact loads similar to those found in dynamic compaction on a continuous basis. So this is somewhat very close to be the so called dynamic compaction. So the impact compaction is the transfer of compactive energy in to the soil by means of lifting and falling action of a non-circular rotating mass.

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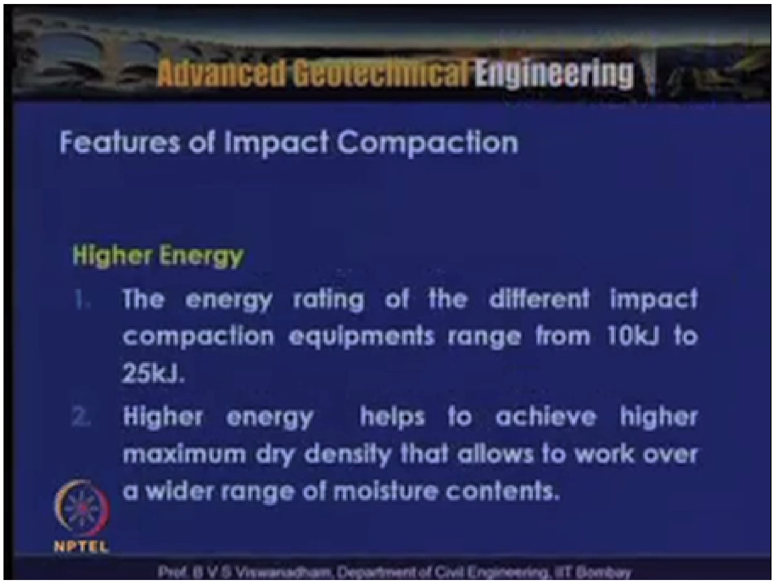

So as I said that the features in clued the energy rating of the different impact compaction equipments range from 10KJ to 25KJ. So the energy rating ranges from 10KJ to 25KJ, and higher energy helps to achieve higher maximum dry density that allows to work over a wide range of moisture contents.

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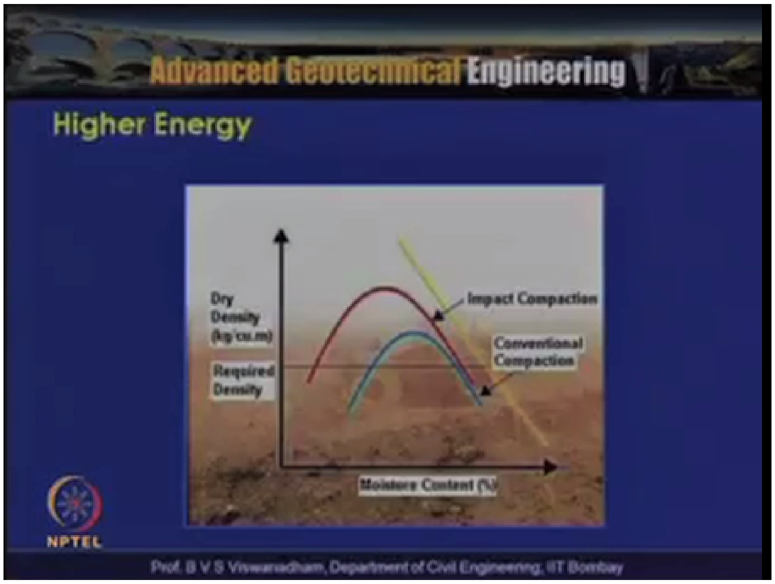

So here it is shown here in this slide, this is with conventional compaction, and this is with impact compaction. So what it can be seen is that impact compaction induces higher amount of compaction. The density structures are high, especially this is mount to be very significant when, you know when we compact it on the dry set of optimum.

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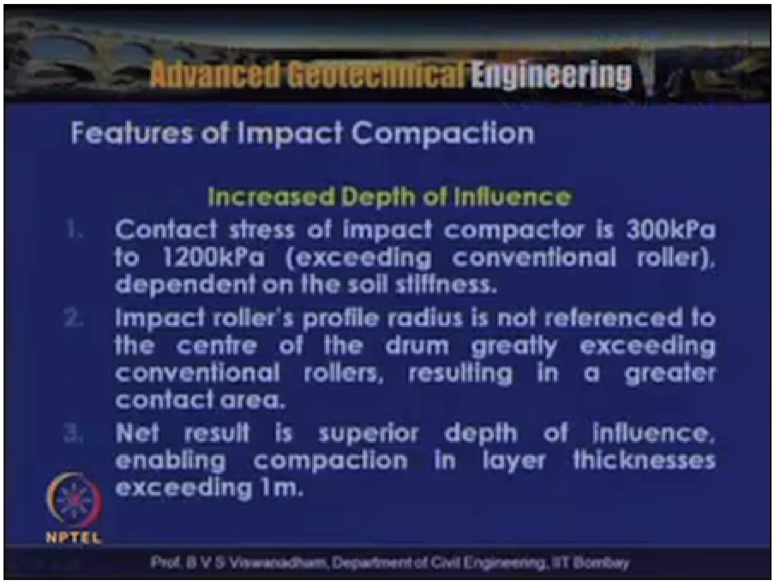

As it has been mentioned the other feature is that increased depth of influence. The contact stress of impact compactor is about 300 kilo pascals to 1200 kilo pascals. This is exceeding the conventional rollers depending upon the soil stiffness. And impact rollers profile radius is not reference to the center of the drum greatly exceeding the conventional rollers resulting in a greater contact area.

So the impact rollers profile radius is not reference to the center of the drum which is exceeding, which actually exceeds the conventional rollers, and results in a greater contact area. Net result in superior depth of influence, enabling the compaction in layer thicknesses exceeding more than 1m. So this is exceeding 1m, so net result is that the superior depth of influence of ensuring adequate compaction up to layer depths of 1m.

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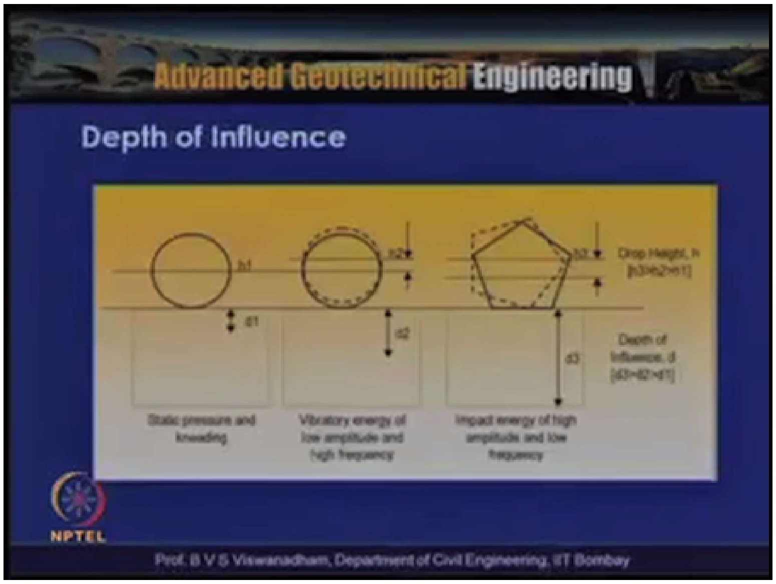

So this is stone pictorially here, here a conventional static pressure roller is shown here, so the depth of influence if it is D1 and with a vibratory roller if the depth of influence say D2, so D2 is greater than D1, but when you have impact energy with the impactor which is actually have non-circular compactor, and because of this the dropping height which is actually here for this H3 will be greater than H2, greater than H1.

So this means that, this induces very high energy and because of this it ensures depth of influence significantly high. So impact energy of high amplitude with low frequency and because of this reason the impact compaction ensures higher depth of influences.

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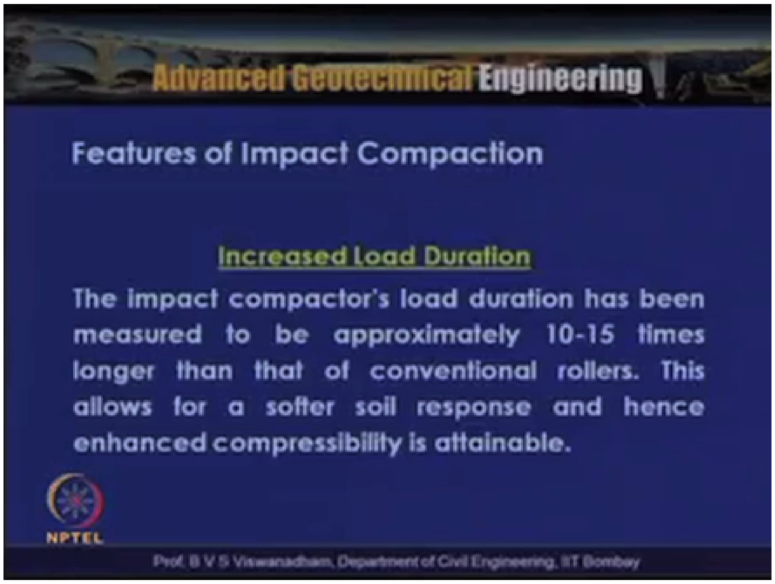

Other feature is that increased load duration. The impact compactors load duration has been measured to be approximately 10 to 15 times longer than that of conventional rollers. So this is good for some fine grain soils to arrange into the denser configuration. So because of this, it enhances the soil to arrange into the denser configuration.

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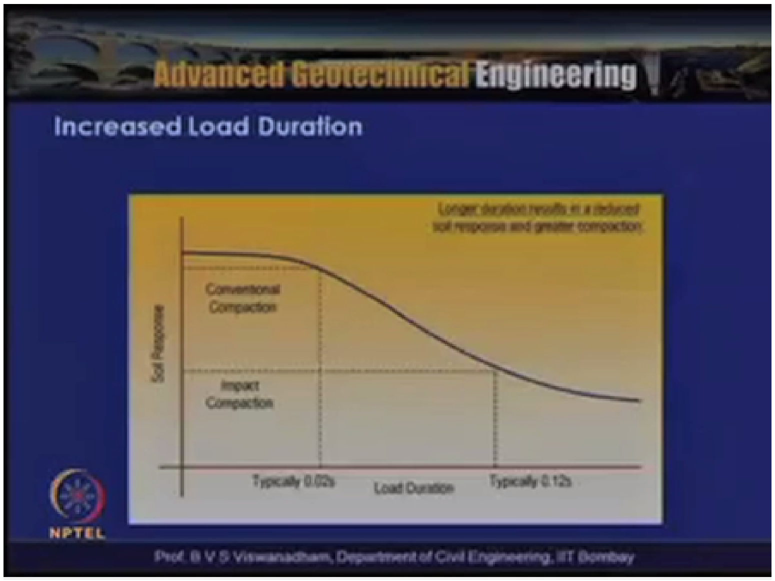

So here it is shown here increased load duration or a conventional compaction if it 0.02 seconds or a impact compaction it is about 0.12 seconds. So longer duration results in reduced soil response and greater compaction. So this is one of the other merits of impact compaction.

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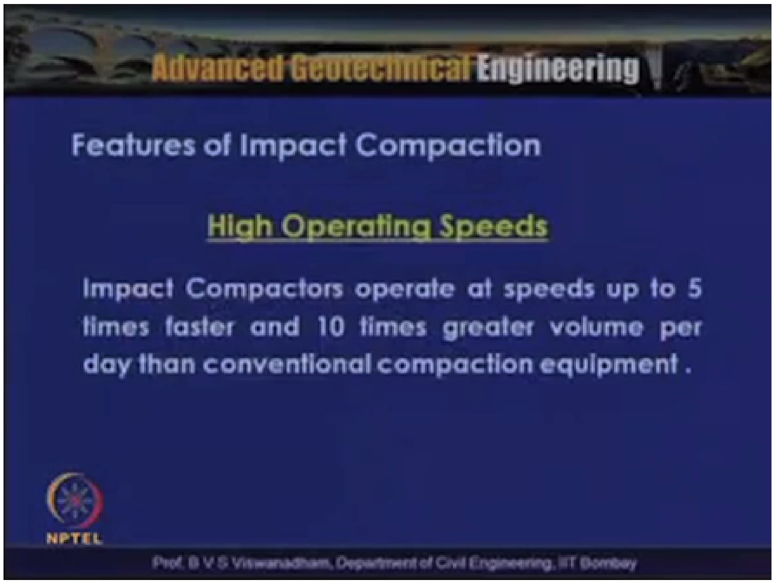

And another feature is that high operating speeds, impact compactors operate at speeds up to 5 times faster and 10 times greater volume per day than the conventional compaction equipment.

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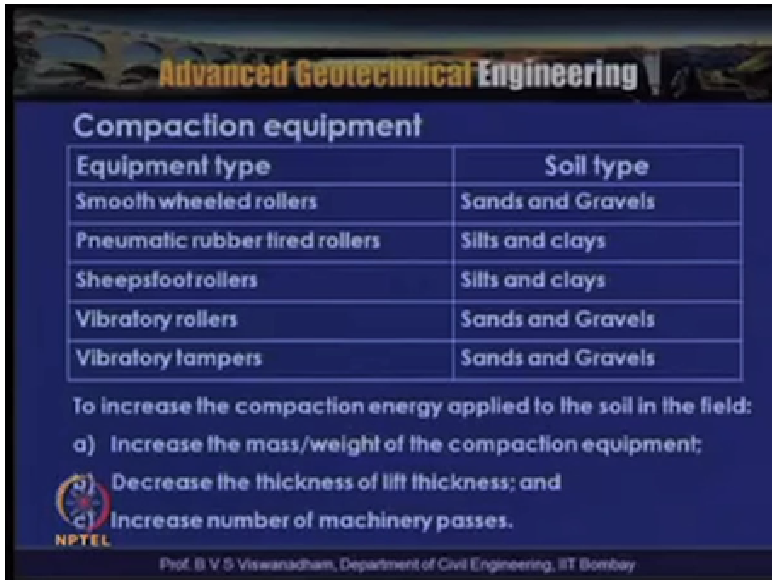

So in the summary here smooth-wheeled rollers what we have seen here they are actually used basically for sands and gravels, and pneumatic rubber tired rollers slits and clays, sheepsfoot rollers basically for slits and clays and fine grain soils. And vibratory rollers especially used for sandy and gravel soils, and vibratory tampers also used for sands and gravels, these basically to increase the compaction energy applied to the soil in the field increase the mass or weight of the compaction equipment are decrease.

The lift thickness that is mean if your able to decrease the lift thickness there is a possible to that good adequate compaction can be ensured in the field and increased number of machinery passes so these we have also have discussed with that the increasing the number of machinery passes also. Sometimes will be wasted because further increase with you know increase in number of passes does not completely ensure compaction energy there should be a optimal number passes so in the field compaction as we are actually trying to simulate.

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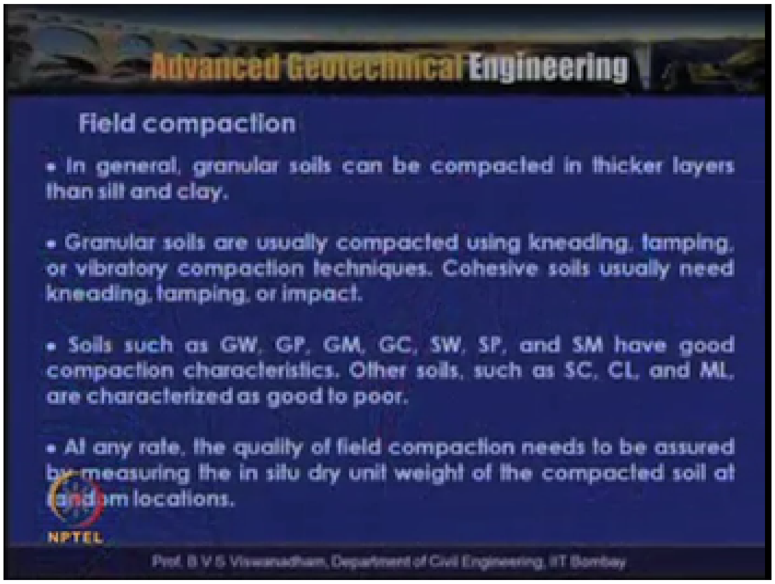

In general granular soils can be compacted in thinker layers than silt and clay so granular layers can be compacted in thinker layers than slit and clay slit and clay or if you have got a fine grain soils or now a day's materials like coal ash they are required be compacted in thin layers and granular layers are usually compacted using kneading tamping or vibratory compaction techniques and cohesive soils usually need kneading, tamping and impact type of compaction.

So this cohesive soils require kneading and tamping are impact type of compaction so as a, per our pervious discussion in the lectures we have actually classified the soils and soils such GW. GP that is well gradated gravels and poorly and grated gravels and well grated silty gravel and gravelly clay and sand with well grated stand and poorly grated sand and silty sand have good compaction characteristic so if you look into this soil such as GW, GP and GM and GC, SW, SP, SM have good compaction characteristics.

And other soil such as SC, SL and ML they characteristics does the good to poor characteristics as far as the compaction point of view at any rate the quality of the field compaction needs to be assure by measuring the in situ dry unit of the compacted soil at random locations so whenever we are actually doing a compaction of a particular soil the density as to be ensured because the inadequate compaction of a soil can lead to the distance in the structure once it is released for usage so the felid compaction and specifications.

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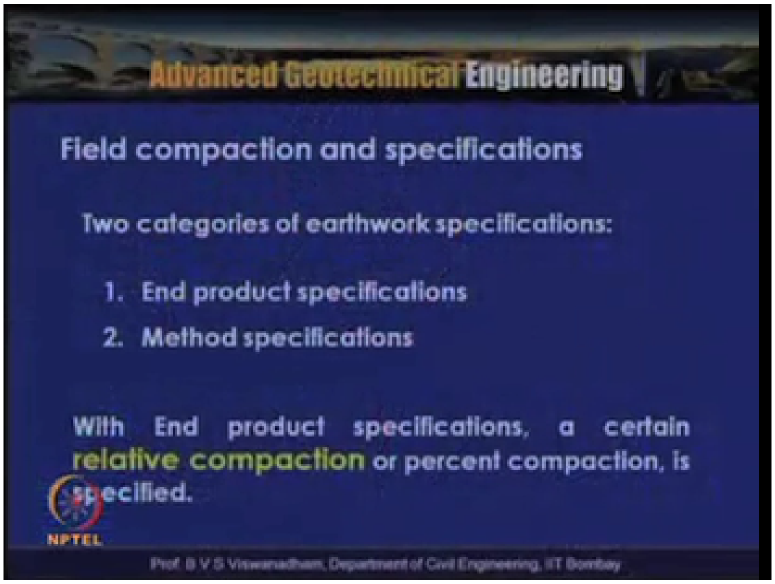

When it comes we actually have 2 categories of earth work specifications one is that end product specification and method the specifications so we will discuss as far as the end product specifications in which a certain relative compaction or a percent compaction is specified, so here if you are actually having a course grand soil then we actually ensure the relative density of a particular soil so if you wanted to have a adequate compaction we will say that 70% relative density or 80% relative density as to be archived or when we are actually having say especially for fine grain soils the relative compaction is used so relative compaction is nothing but a ratio of the unit weight of the soil.

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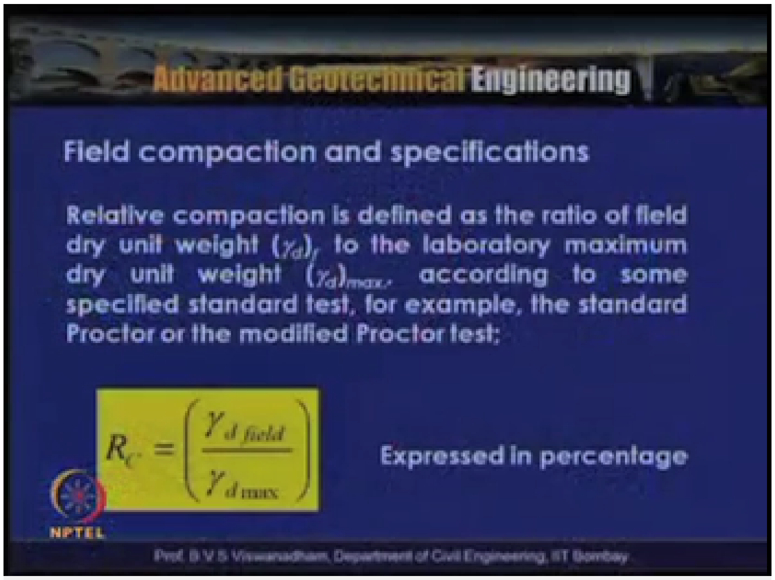

Which is actually in the field and unit weight of the soil dry unit weight of the soil which is actually obtain maxiuamum dry unit weight of the soil in the laboratory this maxiuamum dry unit weight of the soil can be obtained either from the modified proctor compaction or form the light compaction test.

This is depending up on the type of this specifications this Rc cannot be one unit because 100% compaction cannot be achieved so these generally the relative compaction is defined as the ratio of the field dry unit weight to the laboratory maximum dry unit weight according to some specified standard test for example standard proctor or modified proctor test and this is basically expressed in percentage.

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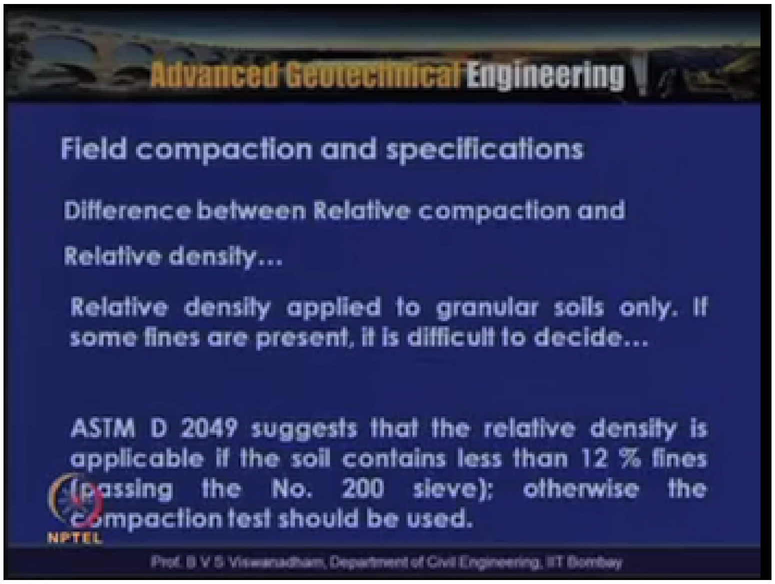

So difference between relative compaction relative density if you are looking to it the relative density is basically applied to granular soils and if some fines are present it is difficult to decide whether to adopt for relative compaction or relative density according to ASTM D 2049 the if the relative density is required to be performed if the fines that is passing 75% microns see you less than 12% if there are actually more than 12% fines then the relative compaction need to be adopted. So otherwise the compaction test should be used.

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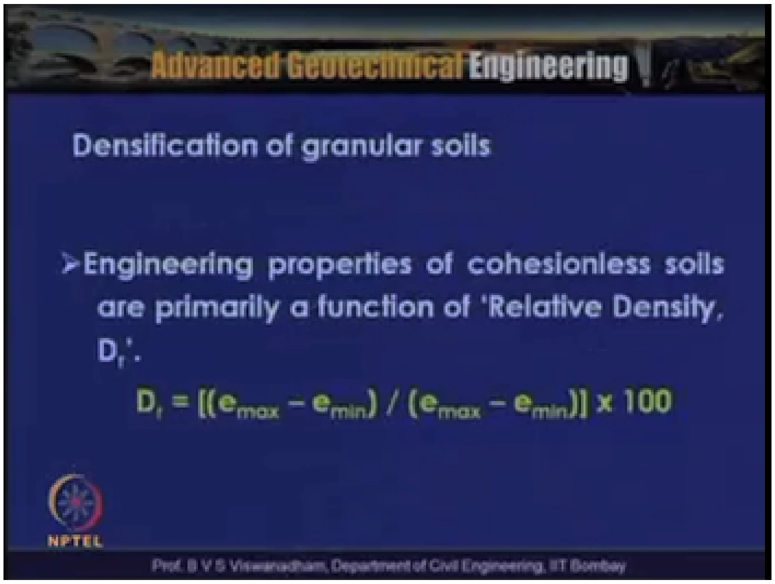

So here what the relative density is basically defined as which is interrelation between maxiuamum void ratio minimum void ratio and incentive void ratio here which is wrongly return here the relative density is nothing but e max – e / e max – e min x 100 so engineering properties of cohesive soils cohesive less soils are primarily a function of relative density Dr.

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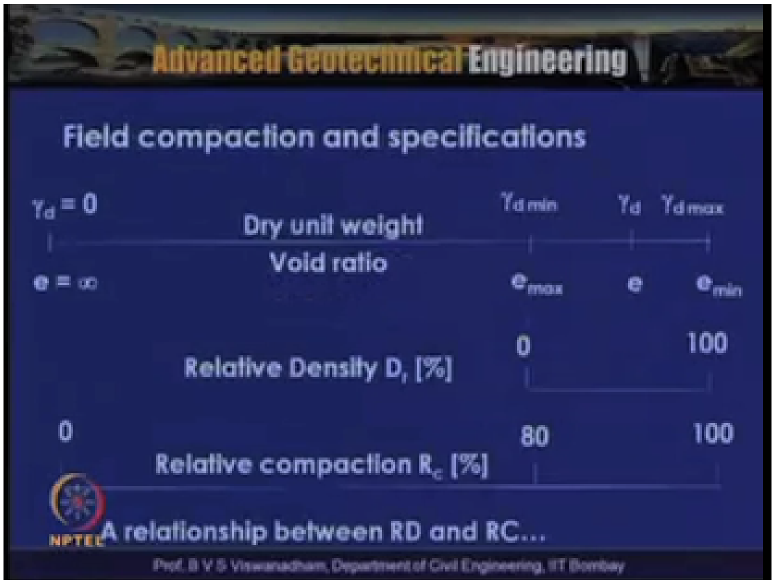

So in this particular slide a relationship between relative density and relative compaction is shown here as can been seen here with void ratio infinity γd = 0 for in case of say gradual soils and the e max which is at γd minimum e minimum at γd max in suit to void ratio at e = at γd so the relative density is region from 0 to 100 from a give project where the specifications says about 70% that means that at this point in suit to void ratio of certain void ratio as to be achieved in case of relative compaction it appears like it is regions from this place to this place this point to this point. So this is somewhere if your specifying say 90% compaction so some where it actually it can result here.

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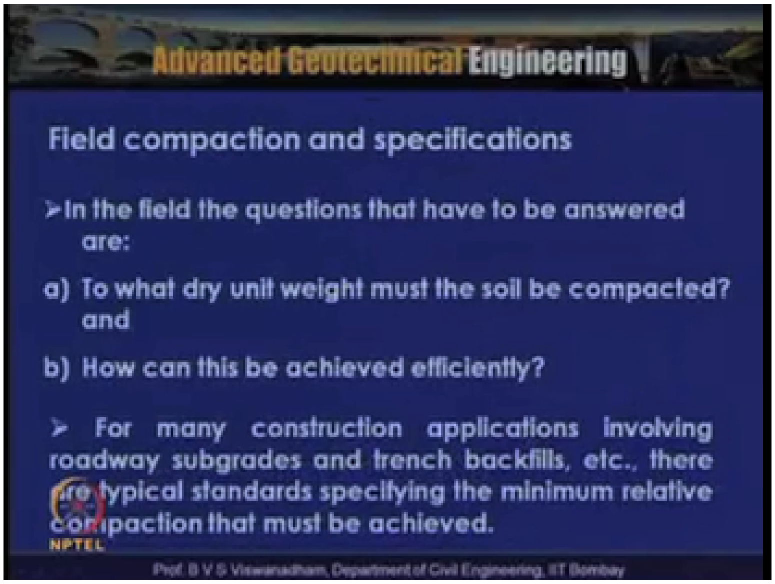

So in the field often the questions have to be answered are to what dry unit weight must the soil be compacted so what should be the dry unit weight the soil should be compacted and how can this be achieved efficiently and how this can be verified weather it as be achieved are not so we have actually field density test which are actually destructive as well as non restrictive test so for many construction applications in involving road way sub grads and trench backfills there are typical standard specifying the minimum relative compaction that must be achieved.

So for many contraction applications involving the road way subgardes and trench backfills there are typically standards specifying the minimum relative compaction that must be archived.

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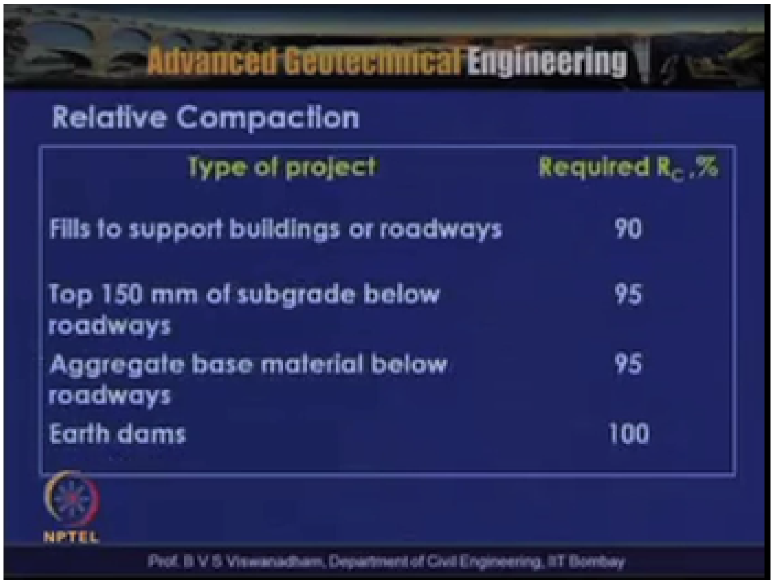

So in this particular slide typical compaction of a soil for different projects it is shown here fills to support buildings are road ways minimum which is required to be ensured is 90% that means that 90% of laboratory compaction density should be achieved top 150 m of subgrade below road way should have 90% of 95% of compaction and aggregate base material below road ways as to achieve 95% and in earth and dams 100% as to be ensured so that there will not be any sea page and distress due settlements and all.

So the relative compaction different types of relative compacted threshold limit which are required to be ensured is actually give n in this slide.

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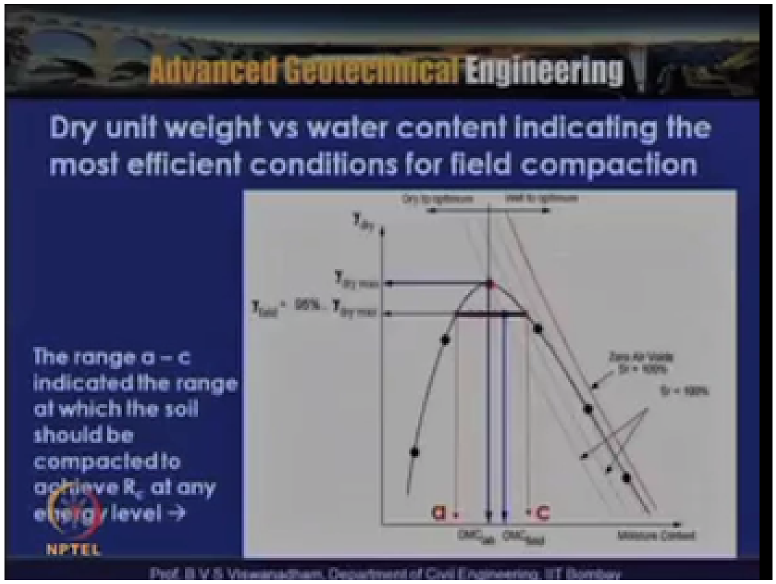

So here if you look into this particular slide a slide which is a actually shown here the dry unit weight vs water content indicating the most efficient conditions for felid compactions.

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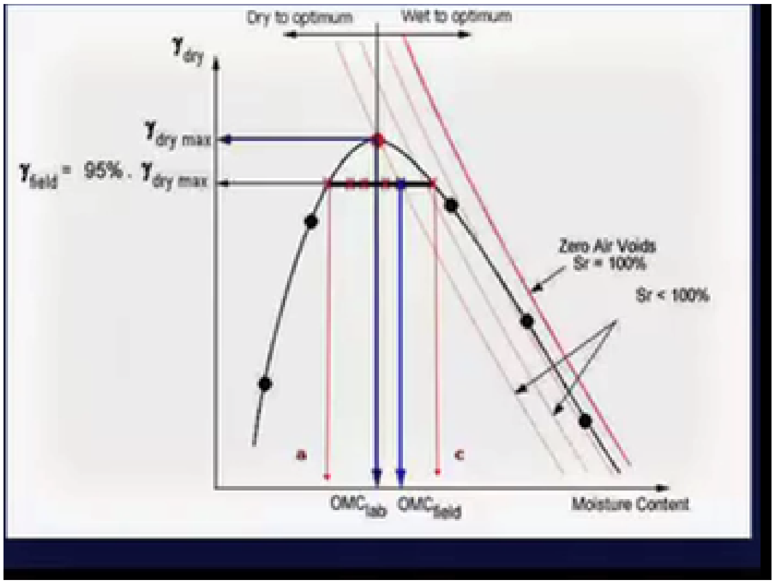

So the range here if you look into this here this is the dry set of optimum that is dry to optimum and this is wet ser of optimum and these are the 0 air voids line and these are void saturation lines which are actually having less than 100% saturation 90, 80, 70 like that and if you look into this air at point A and point B there is a this water content is dry set of optimum and this water contain is say wet set of optimum so γ field which is nothing but 95% of γ dry max that comes out here that means that we have got 2 ranges of water content 1 is actually having the dry set of optimum other is on the wet set of optimum with same you know density so the range AS indicated the range of which is the soil should be compacted to achieve relative compaction at energy level.

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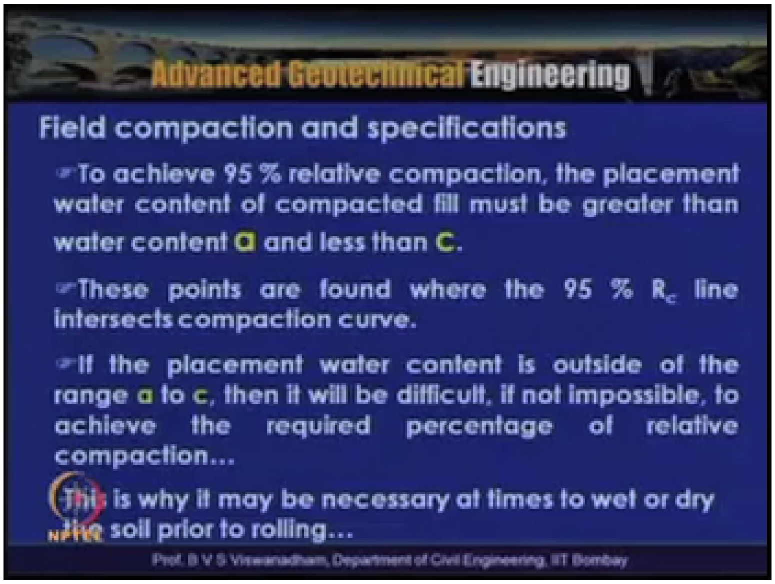

So here to achieve 95% relative compaction the placement water contain of compacted fill must be greater than water contain a and less than c that means that in order to achieve 95% compaction the placement water content of a give soil must be greater than water content a that means that whatever is dry set of optimum let us say 0m- 2 and less than 0mc +2 let us say if the point happens to be c and that is OMC + 1 it should be less than that.

So if you say that 95% compaction 95% relative compaction the placement water content of compact and field must be between these 2 regions and these points are found where the 95% relative compaction line intersects compaction curve and if the placement water content is outside the range of a to c then it will be difficult and if not possible to achieve the required percentage of the relative compaction. That is the reason why it may be necessary at times to wet or dry the soil prior to rolling.

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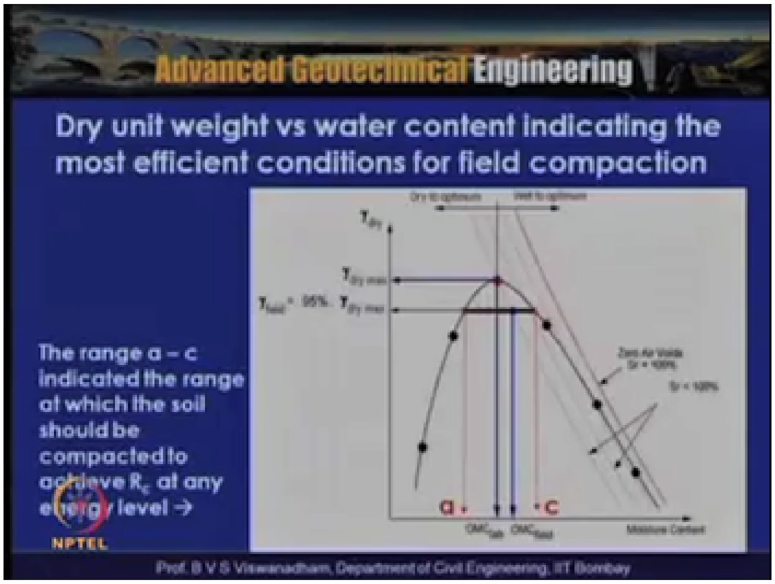

So if the water contains are if they are not within the, this range it may require wetting or drying of the soil so that to ensure this so called 95% of the compaction.

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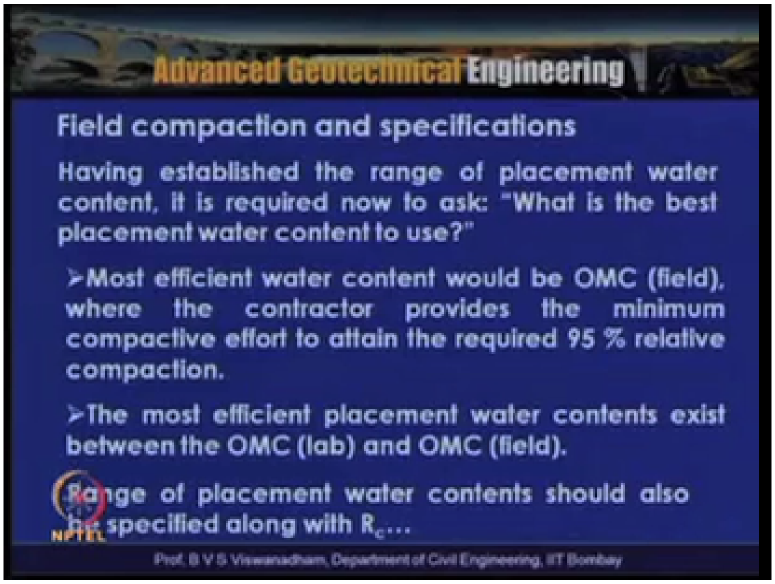

So when further when you discuss about the field compaction and specifications so having established the range of the placement water content if required to what is the best placement water content use so most efficient water contain should be that OMC where the contractor provides the maximum compact effort to attain the required 95% relative compaction, the most efficient placement water content exist between OMC lab and OMC field so it must be also noted that the most efficient water content exits between OMC laboratory and OMC field the range of placement water content should also be specified along with Rc.

So the compaction when we are actually doing when the barometric as been identified when it has been characterized in the laboratory so the range of the placement water content should also be specified along with the relative compaction that ensures that the proper compaction in these slight.

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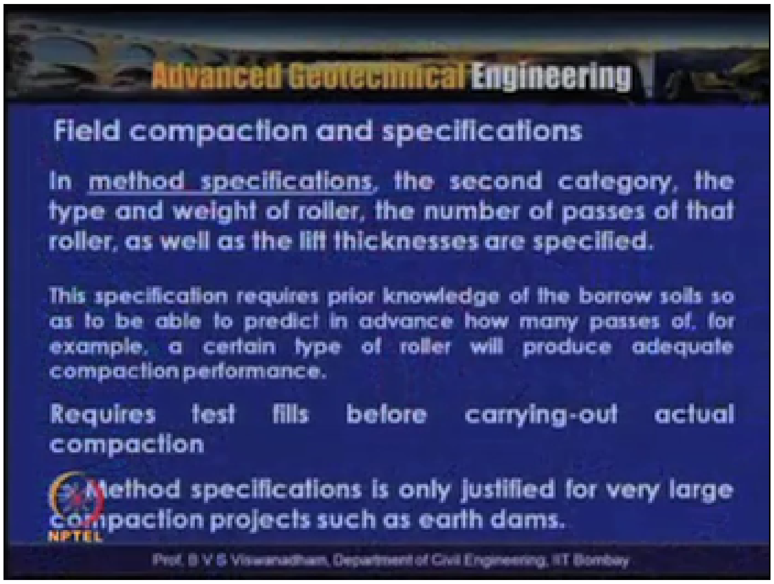

So in the methods specifications what we have actually indicated earlier the second category the type and weight of roller and number of passes of that roller ad well as the lift thinness's are specified so this specification requires prior knowledge of the barrow soils so as to be able to predict in advance how many passes are for example a certain type of roller will produce adequate compaction performance so this requires test fields before carrying out actual compaction. So methods specifications is only justified for very large compaction project such as earth and dams.

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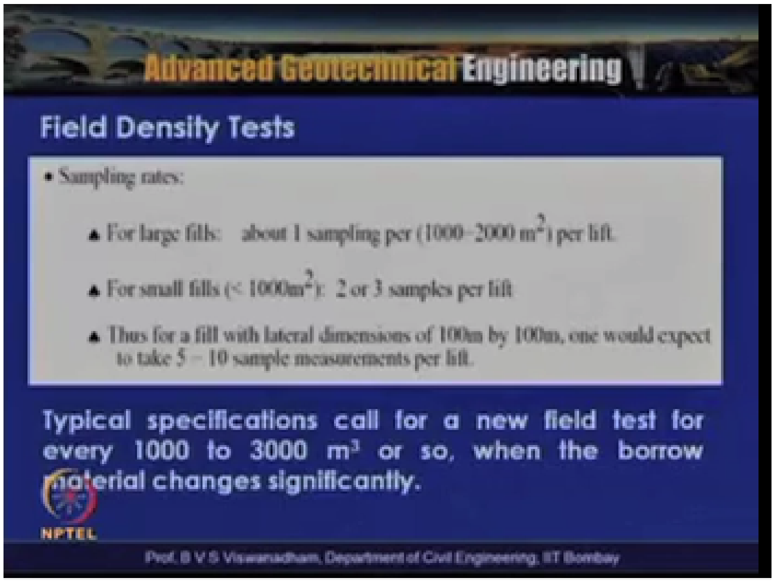

So having discussed about the type of equipment for ensuring field compaction and some specifications to ensure proper compaction we need to discuss about field density testing methods first of all the question will come is that how many number of tests have to be carried out so for large fields about 1 sampling per 1000 to 2000 square meter area per lift, per lift means per layer compacted layer and for small fields which are actually having less than 1000 m^2 2 to 3 samples per lift and for fill with lateral dimensions 100/ 100 m.

One would expect to take 5 to 10 samples measurements per lift so if you are having a fill by 100m / 100m size one would expect to take 5 to 10 samples per lift so typical specifications call for a new field test every 1000 to 2000 cubic meter are so when the borrow material changes significantly suppose if the borrowed material changes the test location should be located there otherwise a thumb rule is that 1000 to 3000^3 m of soil a new field test as to be carried out.

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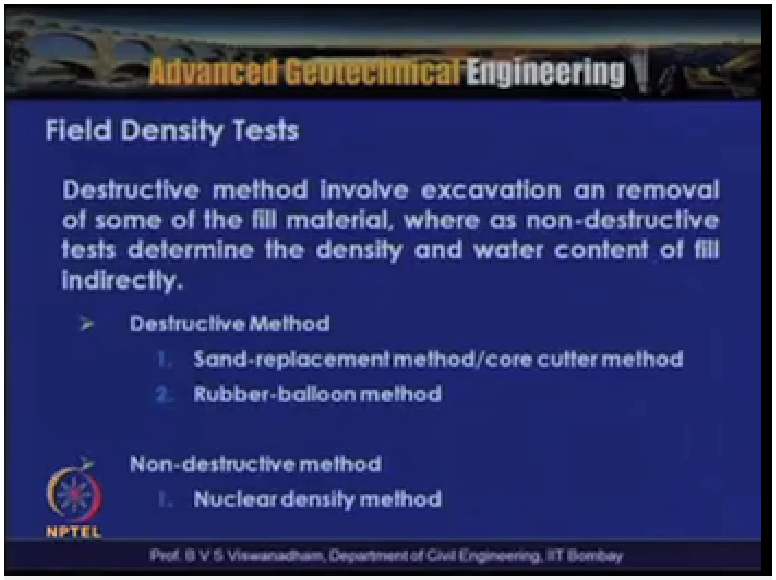

So the field density test are basically 2 types one is destructive test other one is non destructive test , destructive method involves excitation and removal of some of the fill material where as non destructive test determine density and water content of the fill indirectly without destroying the compacted layer destructive methods are basically divided into 2 methods one is sand replacement method and core cutter method other one is rubber balloon method where if you have got improper soil profile.

Then the rubber balloon method can be use particularly if your excusing unit weight of solid waste deposit the rubber balloon method are very useful none destructive methods include the nuclear density methods which we will be discussing in further slides destructive methods are time consuming.

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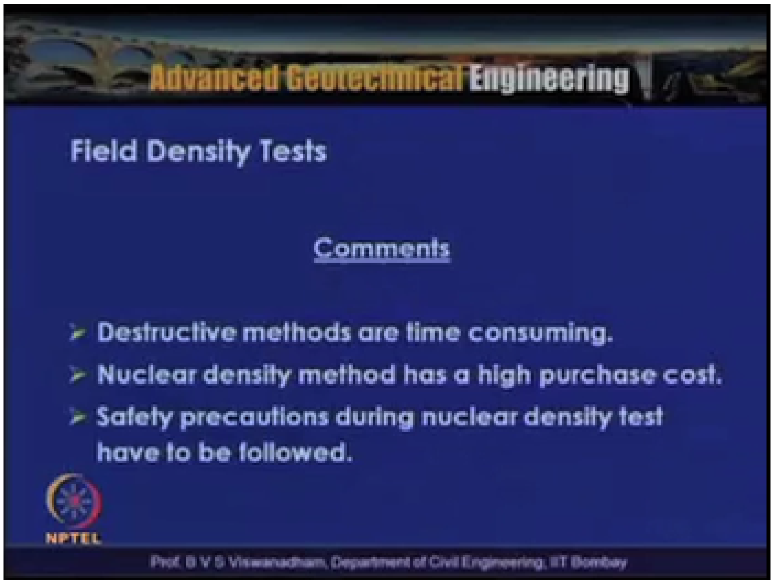

And each and every location the layer as to be distributed and the and also it requires determination of water content so the dry density or dry unit weight can be determined nuclear density method has high purchase cost and safety precautions during the nuclear density test methods have to be follow the safety precautions during nuclear test have to be followed the sand.

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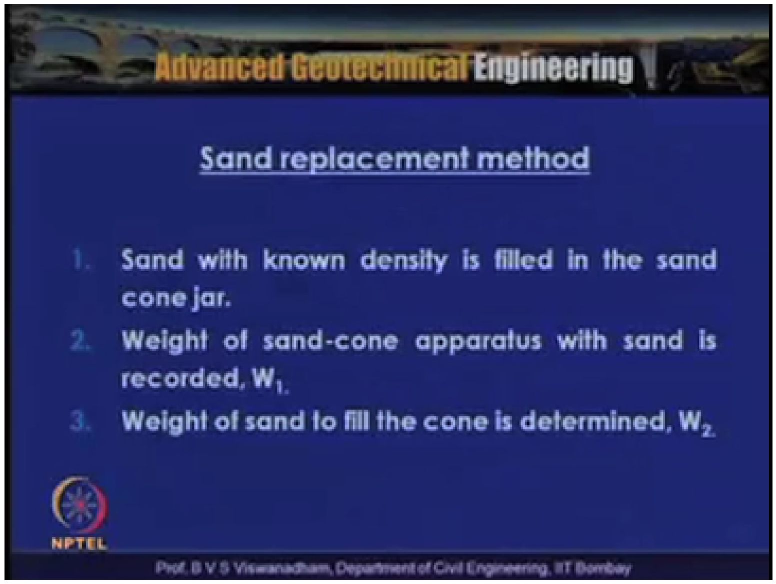

Replacement methods or sand cool method which is nothing but sand with known density is filled in the sand cone jar and weight of the sand cone apparatus along with the sand which is recorded, so here for a certain type of standard in to be use and if that weight of sand cone apparatus with sand is say W_1 and weight of the sand to fill these δ cone is to determine these, so that is for the weight of the sand to fill the cone is said W_2.

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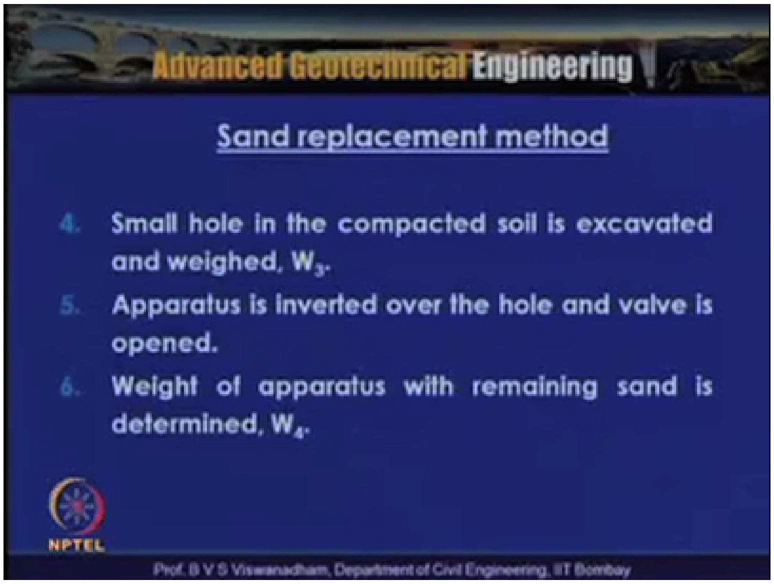

And if the sand whole in the compacted soil is excavated in weight if suppose in the small hole in the compacted soil is say excavated and weight, so if you want to determine in particular layer so what you will do is that we will excavate a small whole and way the soil and that we it saying W_3 the apparatus is inverted all the whole and valve is opened, so we will release in the sand into the partial way the soil has been removed compacted soil has been removed so weight of the apparatus with remaining sand is determined and that is W_4.

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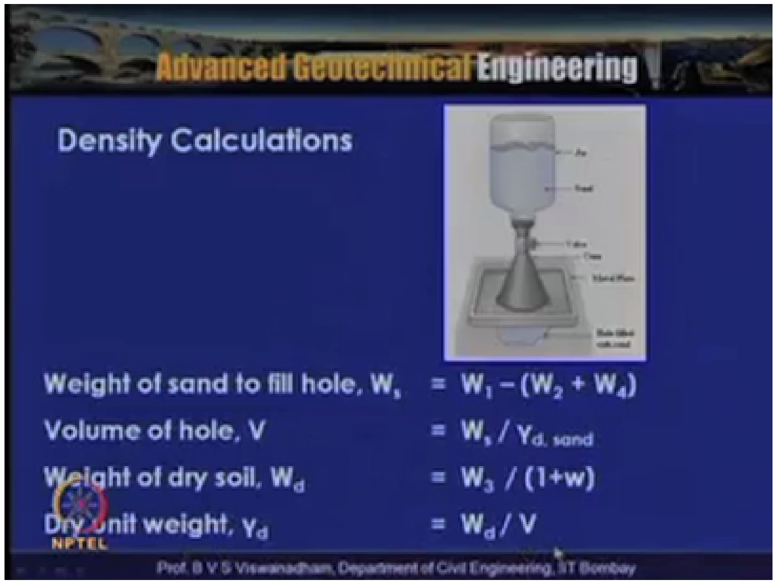

So once we if you can weight of this sand to fill the whole if you are able to get that can b obtained by $W_1 - W_2$ + w4 within brackets and the volume of the whole can be obtained as weight of the sand divided γd sand so weight of the dry soil can be obtained by w3 which what we are actually obtained by removing the particular soil from the portion what it is shown here ands divided by 1 + w will get the dry weight of the soil and the dry unit weight can obtained as Wd / V volume see volume V is nothing but volume of the whole is nothing but the dry sand unit weight in bellowing and.

Ws that is the weight of the sand so once I know this that is weight of the sand to filled the whole divided by this I will get the volume of the whole so with that the dry unit weight W2 the way can be determined

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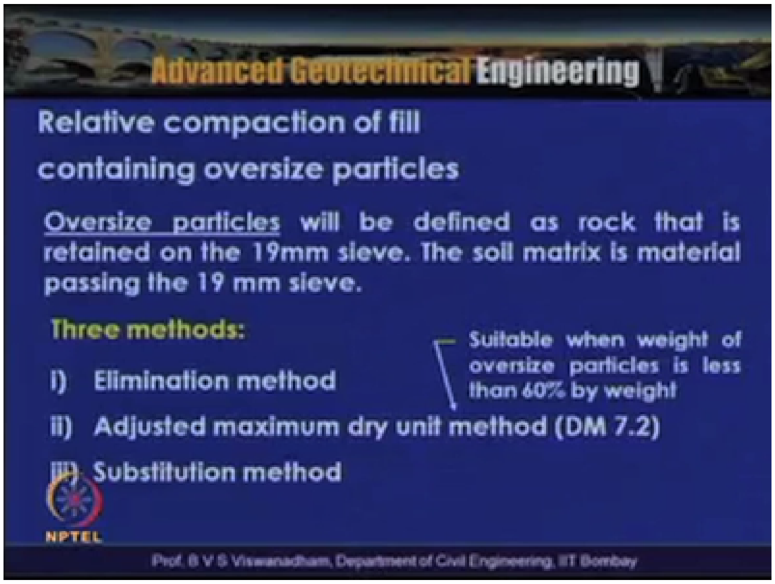

So in most of the cases we have situations where the relative comparison of the fill containing over size particles consider the picture, so sometimes this needs to be you know corrected otherwise the field density is measured may it can be miss lending so lot of size particles will b defined here as the rock that is retained on 19mm sieve, so soil matrix is pass unit from the sieve so if you are having a fraction which is actually say passing retain in 19mm sieve and that is actually called as fraction of the valve size in particles.

So there are three methods we will b discussing one method that is elimination method so this three methods are elimination methods adjustable maximum dry unit may the method this is according to DM 7.2 and this is suitable then the weight of the war size particles is less than 60% by weight and substitution methods out of these two within increasing this over size part way fraction the elimination method the total density is predicted by elimination methods will be on the higher side.

Both adjustable maximum dry unit weight method and substation method they are close enough to you know account for the corrections which are actually possible because of the presents of the oversize particles.

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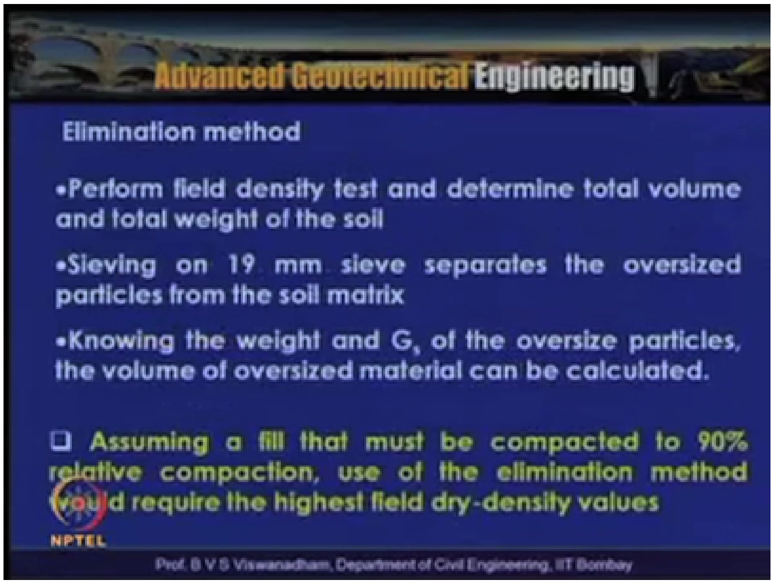

So this elimination method involves that perform the field density test and determine the total volume and total weight of the soil sieving on 19mm sieve separates the all size particle from the soil matrix with that you know the weight of the that is the travel fraction, so knowing the weight and the specific gravity of the oversize particles the volume of the valve size material can be calculated, so assuming that a fill that must be compute or compacted to 90% that compaction so uses of the elimination methods will required the highest fuel density values so this implies that assuming a fill that must be compacted to 90%to comparison.

The use of elimination method will require the highest field dry density values so here in this slide according to.

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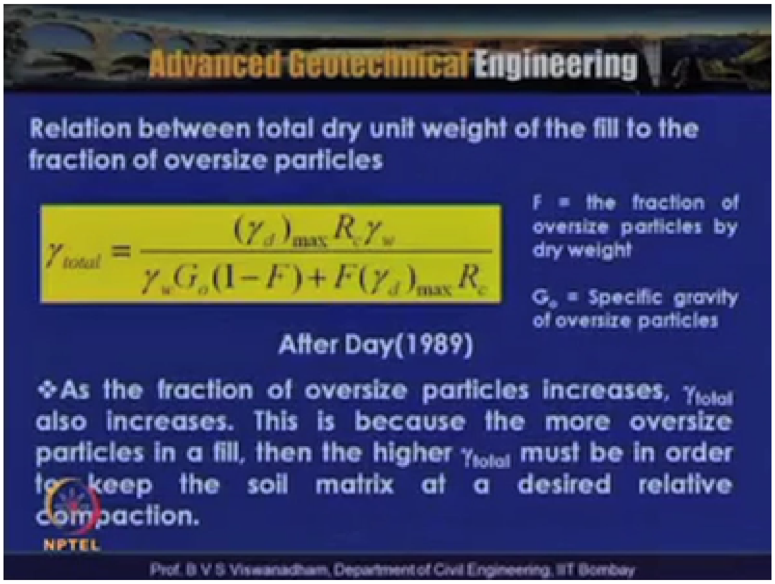

Day 1989 the three methods which have been sited here I will be discuss by day 89 a day 1989 the relationship between the total dry unit weight of the fill to the fraction of oversize partiles is given here γ total is the total weight of the soil matrix and the γd max is the maximum dry unit weight of the soil that soil in the lab rotary RC is the relative comparison γW is the unit weight of water and γW is unit weight of water again G0 is nothing but the specific gravity of the oversize particles and F is nothing but the gravel fraction.

And γD_{max} is again the laboratory compare dry compaction value maximum dry unit weight of the soil so the γ total is given by γdmax RC γW, γW G0 into 1 – F + F into γd_{max} into RC so if you substitute for the given type of soil with certain characteristic of more size particles it show that as the fraction of oversize particles increases γ total increases this is because the more oversize particles in a field then the higher γ total must be in order to keep this soil matrix it desired return compaction.

So while using this particular expression in the discussion it is possible to account for the presence of oversize particles in the soil matrix and this needs to be considered if we are having a particles which are actually more than 19mm are retained in the 19mm the while testing the field density method by using sand density that is sand cone method.

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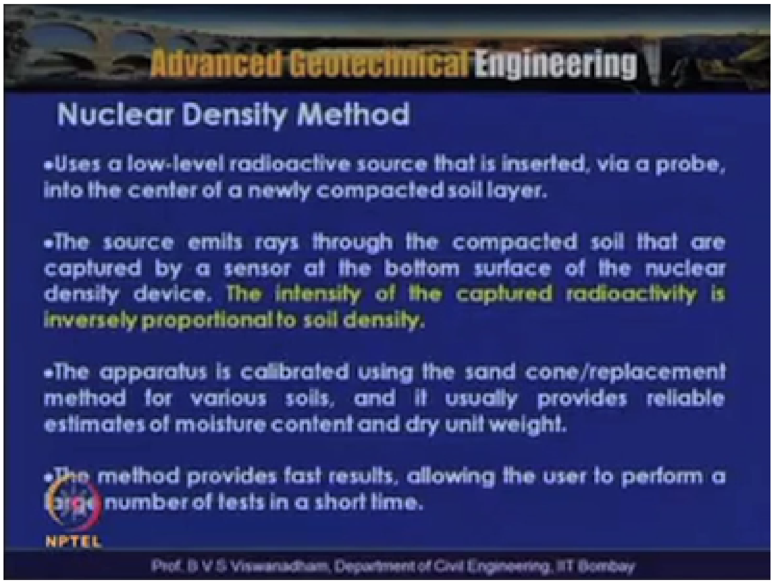

The next method which we have said is the nuclear disunity method this uses the low level radioactive way source that is inserted via a probe into the central or central of the newly compacted soil layer, so this is one type of method in which is small tinges is made and the low level radioactive source is inserted but there are also some sources where the nuclear density measuring apparatus will be on the surface of the soil in touch with the soil and then we will also will be measure.

The source basically emits race through the compacted soil that are captured by a sensor at the bottom surface of the nuclear density device, so the in density of the captured radio activity is inversely proportion into the soil density the intensity of the captured radio activity is inversely proportional to soil density so this apparatus is calibrated using sand cone replacement sand cone or sand replacement method of various soils and it is usually provide reliable estimates of moisture content and dry way.

So this needs to be calibrated by using you know conventional method once this is calibrated then this particular method can be used very rapidly to get the densities and water contents achieved after the compaction, so this method provides fast results allowing the user to perform a large number of tests in a short time and also enables to release the layer must lift compaction immediately.

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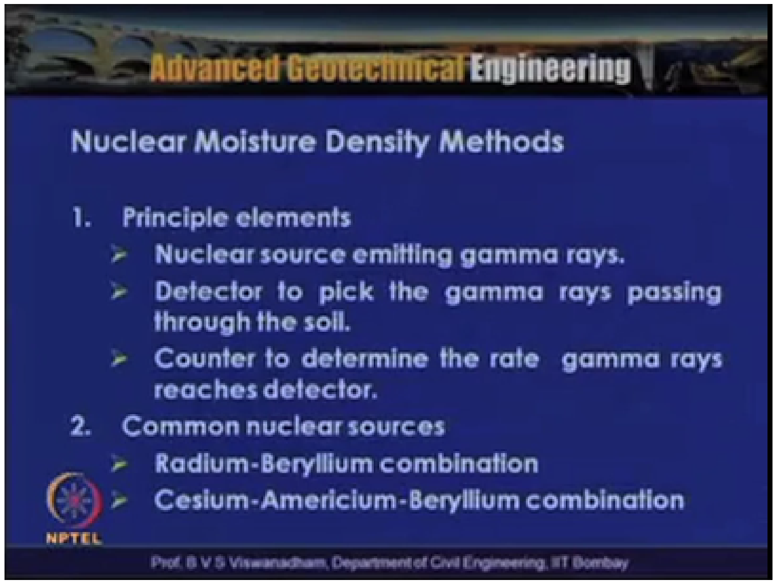

So the nuclear moisture density methods the principles elements include nucleus source emitting the γ race and detecting to pick γ rays passing through if there is a detector which picks the γ rays passing through the soil and counted to determine the weight of γ rays reaches the detector so it actually has got 2 3 fundamental elements once is that emitting γ rays other one is a detector other one is the counter, so common nuclear sources are radium- Beryllium combination and Cesium-Americium and Beryllium combination.

So these are the common nuclear sources which are actually used in nuclear measuring moisture density methods.

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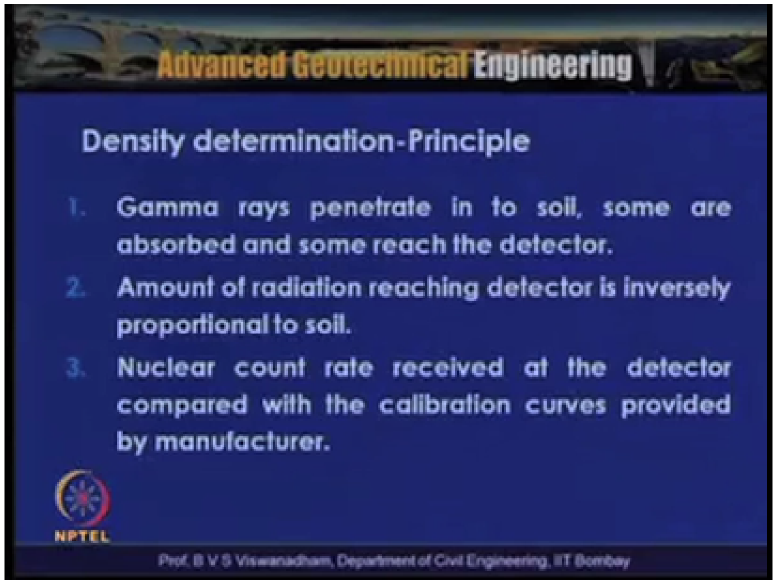

So density determination that principle involved is like this γ rays penetrate into the soil and some are absorbed and some reach the detector amount of radiation reached is detect reaching detector is inversely proportional to the soil and basically soil density and nuclear count rate received at the detector compared with the calibration provide by the manufactures so nuclear count rate received at the detector should be have to compared with the calibration counts provided by the manufacture.

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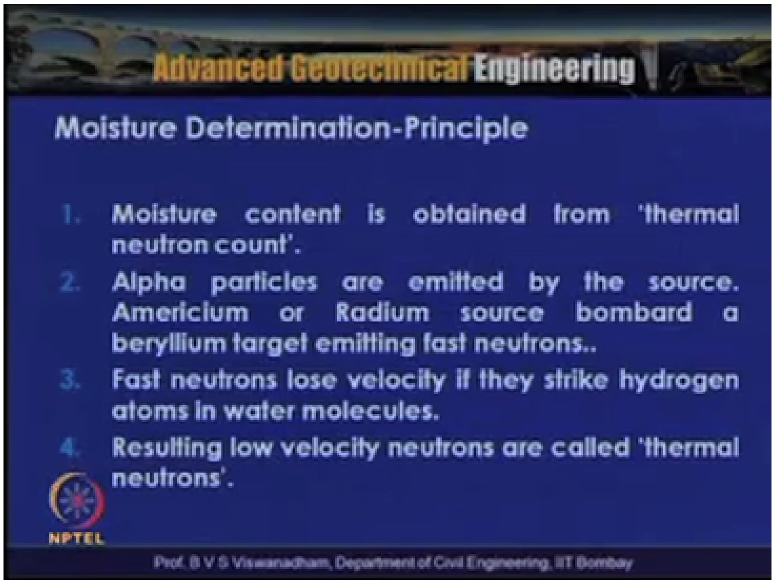

Similarly for the moisture determination moisture content is obtained from the thermal neutron count alpha particles are emitted by the source americium or radium source which bombard a beryllium target emitting fast neutrons the fast neutrons lose velocity if the strike hydrogen atoms in water molecules so resulting low velocity neutrons are called as thermal neutrons.

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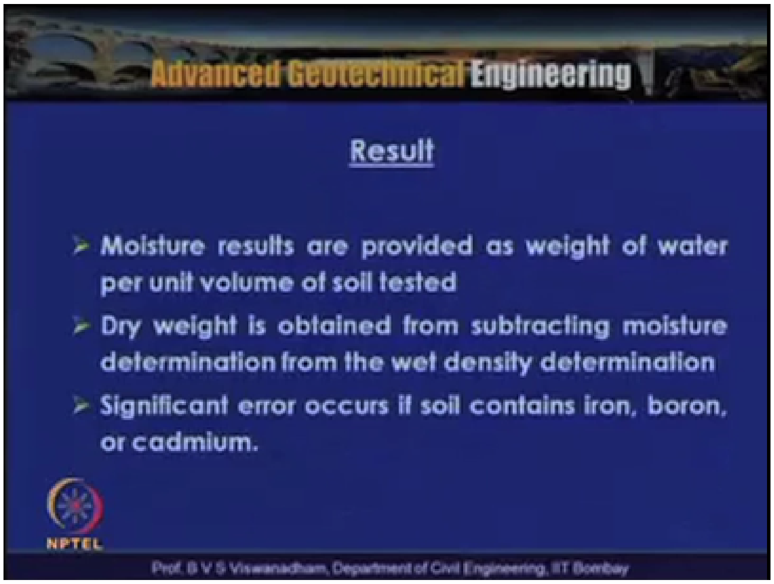

So based on this the estimation of water content is done through in the nuclear density methods so moisture results are provided as a weight of per unit volume of soil tested and dry unit weight is obtained from the subtracting the moisture determination from the wet density determination so significant error occurs if soil contents iron, boron or cadmium so there is a possibility that one of the limitations is that a significant error can occur if the soil be compacted are compacted contains iron, boron or cadmium.

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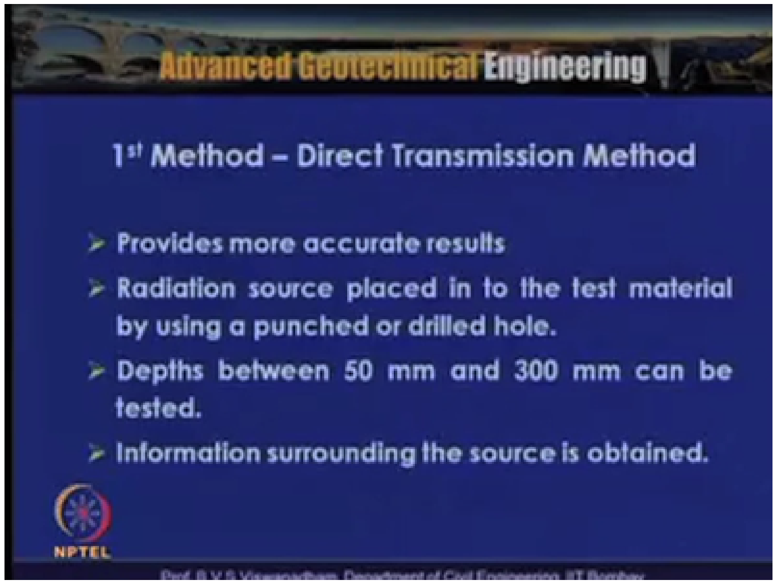

Elements see first method is actually shown here provides more accurate results and radiation sources are placed into the test material by using punched and drilled hole and depth between for 50mm to 30mm can be tested information surrounding the source is obtained.

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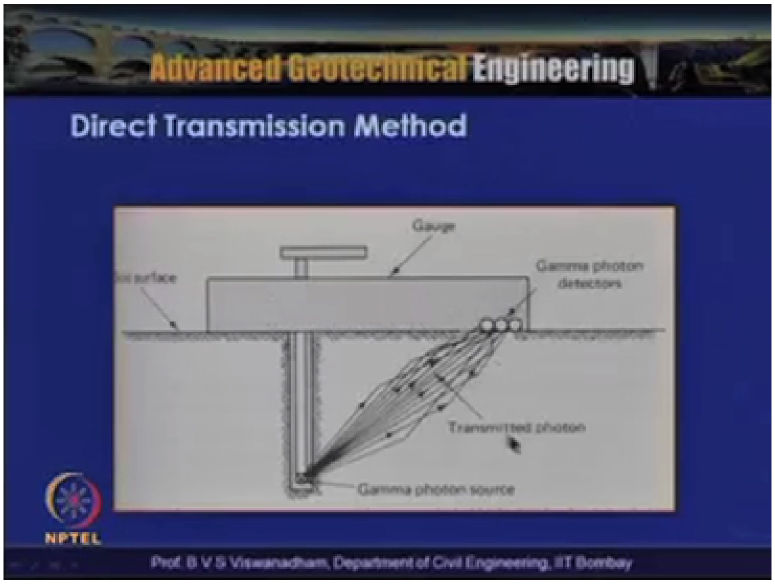

So this is shown picture here this is the trench which is actually place and it actually emits the γ rays and then this γ photon detectors are here and this is the nuclear gain which is actually in touch with the soil in case of second method.

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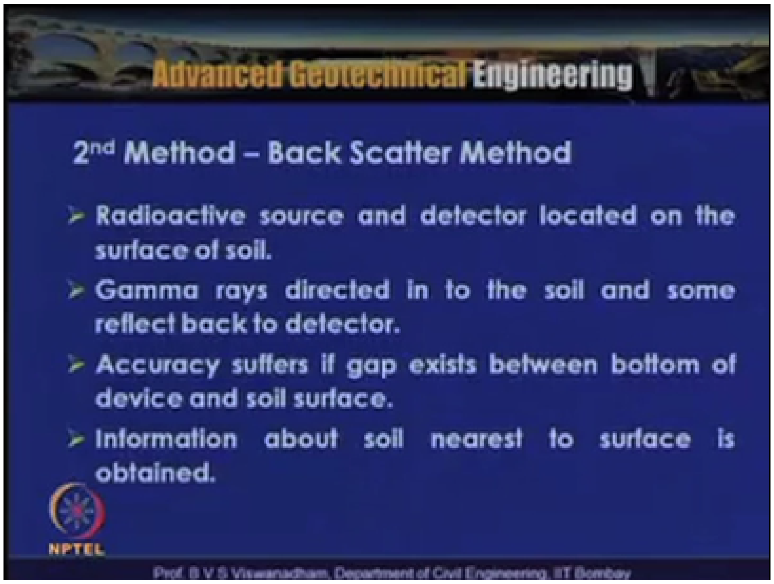

Back scatter method which it is called radioactive source and detector locate launch is service of the soil itself this is actually widely used in moisture of the equipments of the equipments available and γ rays directed into the soil and some of the or some reflect back to the detector and accuracy suffers there is a gap in just between the soil surface and the nuclear density device so information about the soil nearest to the surface is actually obtained.

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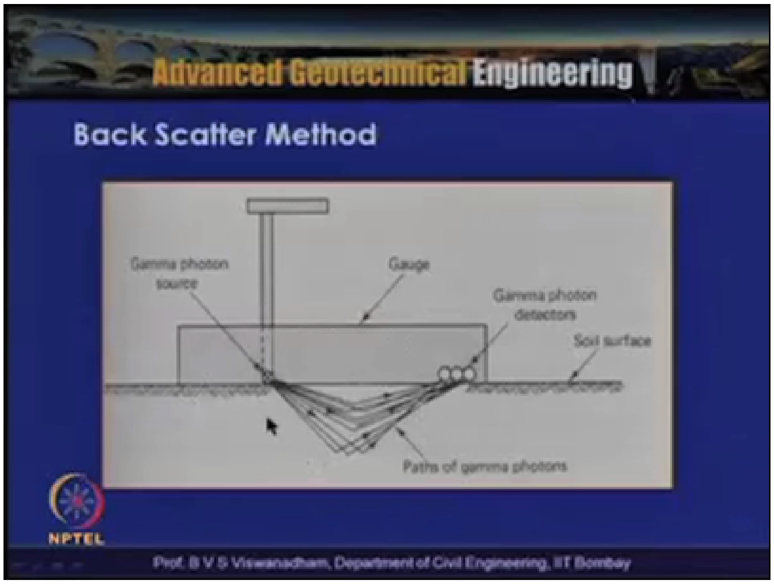

So in this method in the back scatter method where you have got the detector and this source they are actually at the same place and it has to be in touch with the soil and it is possible that information from the surface soil can be obtained very effectively.

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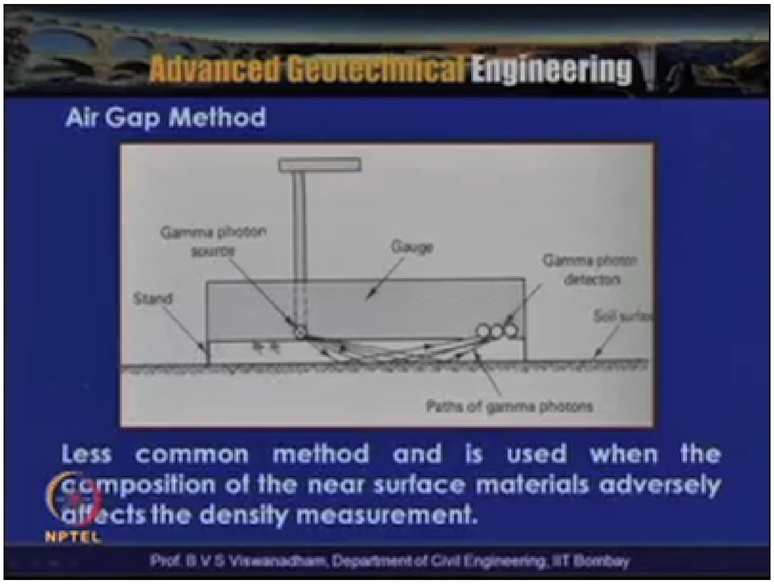

The third method is the air gap method which is basically a less common method and is used when the composition of the near surface materials adversely effects the density measures then sand is provided and the density is measured on the surface.

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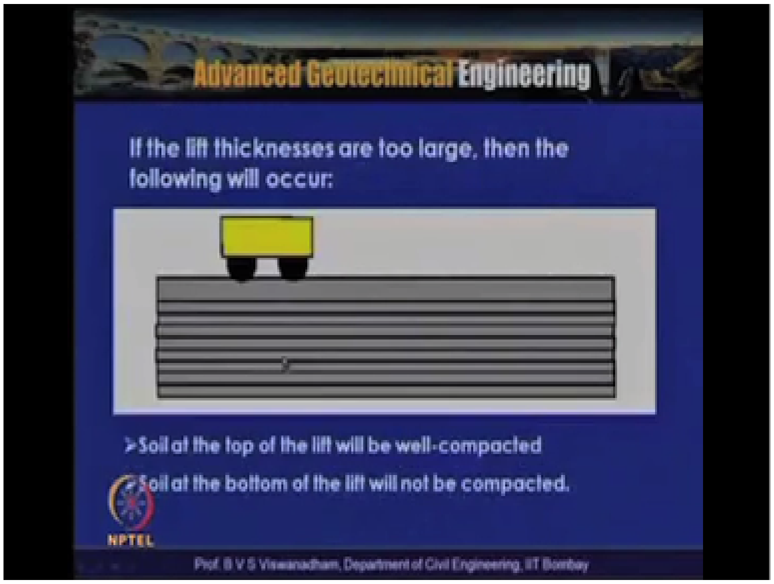

So this as I said that the soil is compacted in different lifts and if the lifts thickness are too large then the flowing can occur soil at the top of the fill will be well compacted and soil at the bottom of the lift will not be compacted data so if I have a lift thickness of the say more than of a mere or then soil at the top of the lift appear to be compacted and then give the missionary results.

And then overall what will happen is that when we got the number of layer compared to like that this leads to the stress and leading to the performance and the serviceability of the structure which is been used for a particular application so soil at the top of the lift will be well compacted and soil at the bottom of the lift will not be compacted at all.

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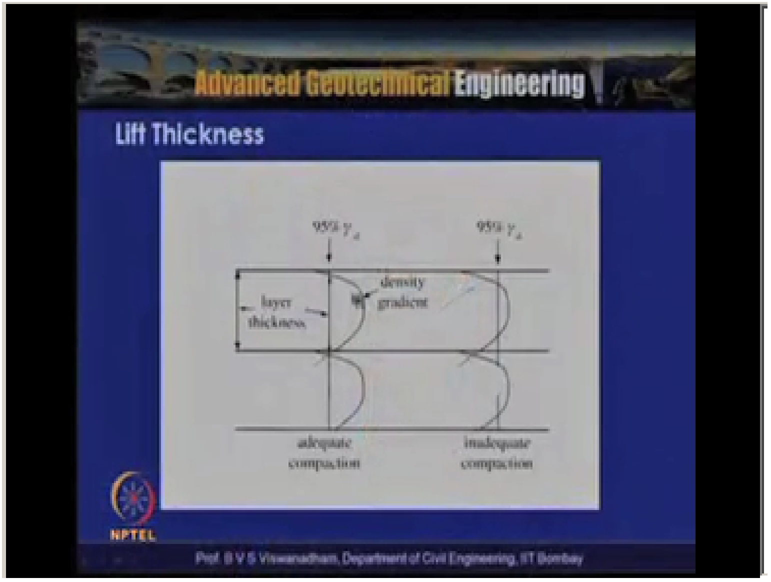

So here in this slide a particular lift layer thickness if it is there you can see that this soil at the middle portion is compacted very well at the interface point there is the possibility that the compaction is not accurate at all so that it has to be ensured that the lift thickness should be such that the minimum compaction is actually meted all points so that if this is the you know 95% compaction will is actually required then this particular zone is actually shows that the lift thickness is such that this is actually has compaction.

But if you have a lift thickness such that there 95% compaction is achieved then this is actually preferred here this is with adequate compaction and this is with inner equate compaction and here in this particular slide field dry density versus number of passes is shown so the dry density versus number of passes and if you have got a wetter soil the number of possess will not actually help because as I said here the pore water pressure which actually increases and lot allow this soil to compact.

And similarly with natural soil with increase in some in case of dry soils the increase number of passes can be somewhat appeared to be effective here may not be initially but with higher number of layers for the dry soil for the higher density can be achieved so here at one moisture content with different thickness it can be shown here so the dry density achieved with number of posses you can see that with increase in number of increase layered thickness the density achieved for the given number of passes is less but increasing number of passes with more of passes within is not having particular influences.

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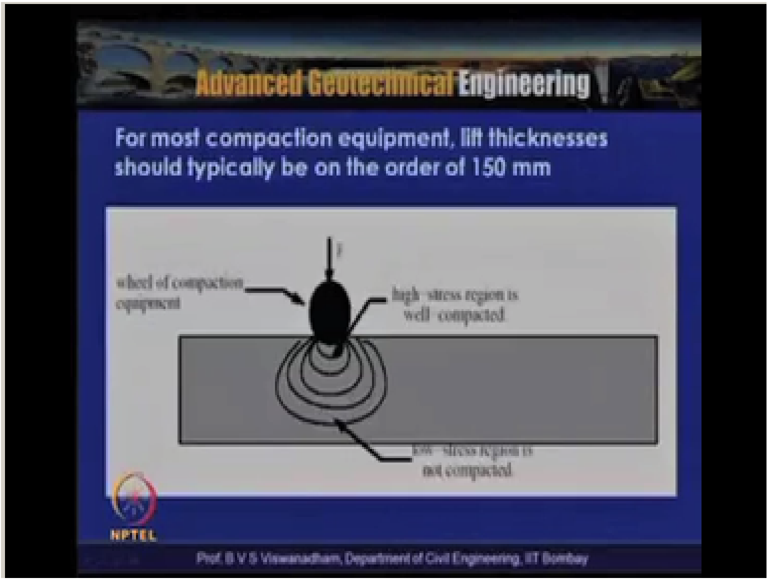

And mostly for compaction acquirement the lift thickness should be typicality the order of 150mm or 300 mm so in that case what will happen is that the wheel of the compaction element likes a pressure bulb it actually has got high stress to your region as well as the most stress region, so if this is ensure this possibility that the compaction can be effectively can be ensured in the field.

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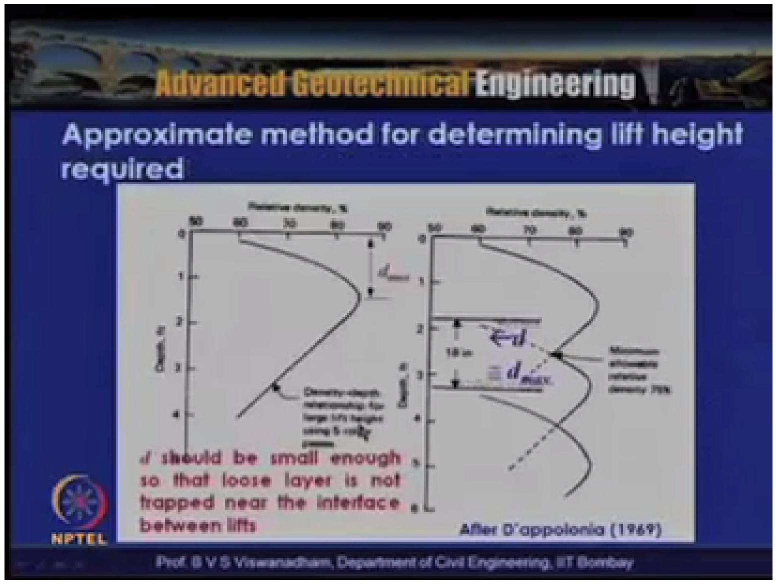

So the approximate method for determining the lift height in the field is according to appolonia D, appolonia 1969 is that first for a given for large lift height you with a particular number of passes determine the you know rate to density with depth. So if you have if it is virtue for a largest lift height say d_{max} so the density depth relationship for the large lift height using the 5 roller passes, if that used to be d_{max} that d should be small enough so that the loose layer is not trapped near the interface between the lifts.

So this particular d should be small enough so that the loose layer is not trapped between the two compacted layers so this is one layer lift compaction this is another layer lift compaction and we have to ensure that as it was shown in the previous slide that this particular point is actually well above the desired wheel to density or desire degree of wheel to compaction.

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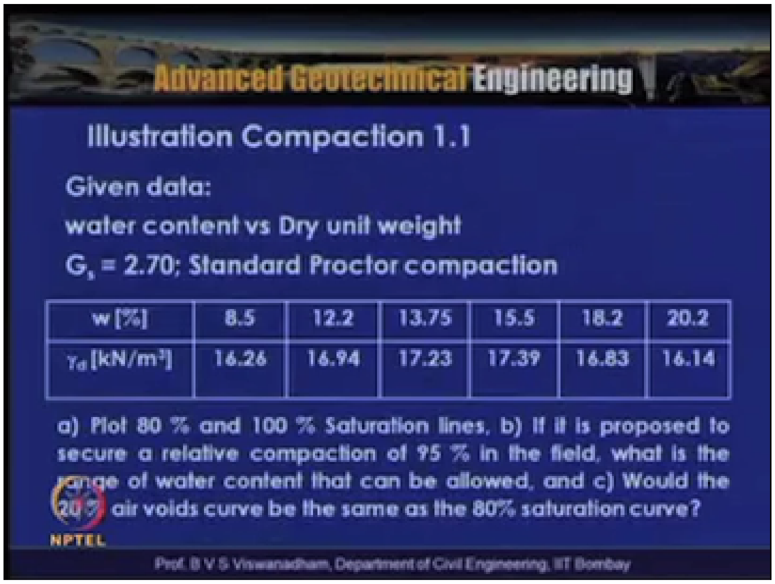

So in this particular problem, particular slide we will see a problem on the compaction the given data is that water content verses dry unit weight and we need to plot the compaction curve and water content data and the unit weights are given and we need to plot 80% and 100% saturation lines that is part a, part b is that if it is proposed to secure a relative compaction of 95% in the soil what is the range of water content that can be allow and would the 20% air voids curve e same as the 80% saturation curve.

So we have discussed in the previous lecture that they are not same but let us see how that can be illustrated with the help of this problem.

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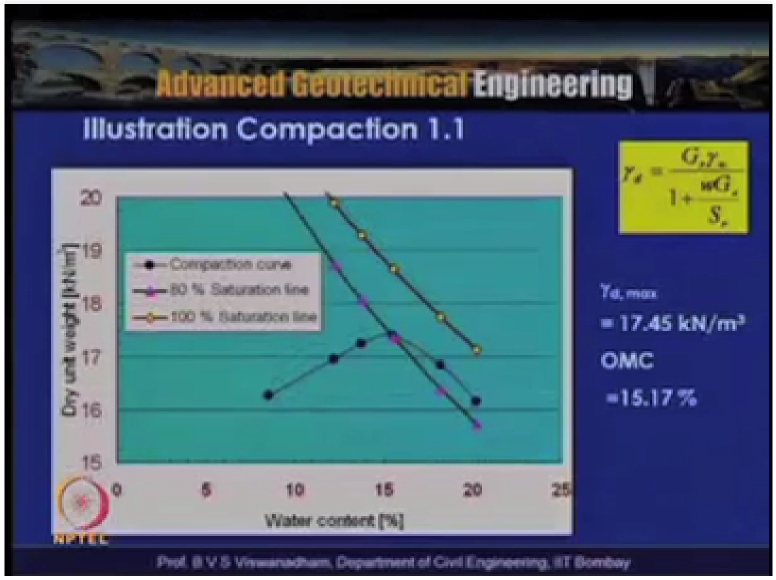

So based on the given data if the graph is actually plotted with dry unit weight of the y axis in kN/m^3 and water content on the x axis then this is the compaction curve. By using this $\gamma d=Gs\gamma w$ +1wG, 1+wG/Sr we can actually determine the 100% saturation line so the $\gamma dmax$= 17.45 that is this density this dry unit weight and water content after wash the content of 15.17% so this particular data for a given soil which he has got the maximum dry unit weight of 17.45 kN/m^3 and optimum moisture content of 15.17% and this is 100% saturation line and this 80% saturation line.

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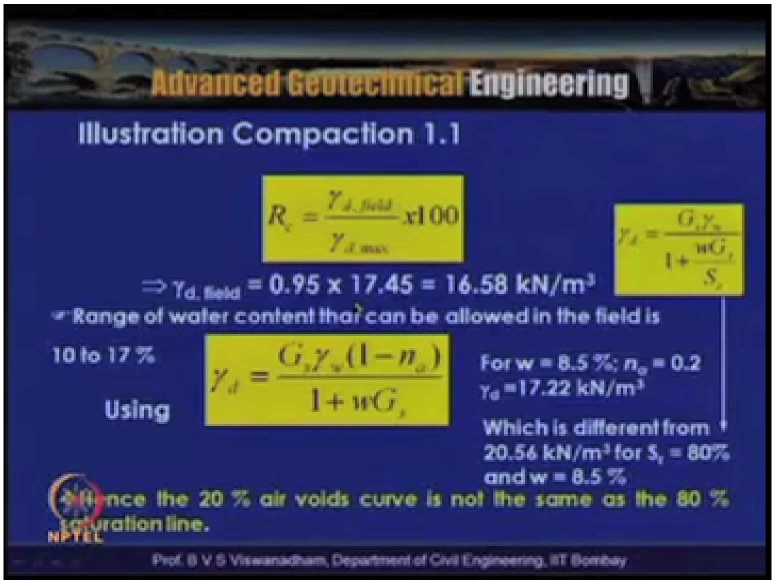

Now in continuation of to determine the rate to compaction with 95% rate to compaction is specified, so γd field which is actually required is that 0.95x17.45 is 16.58kN/m^3. So range of water content that can be allowed in the field is 10 to 17% that is from this field for that particular density 95% of this is the range of water contents allolonia can be allowed in the field is ranges from here to here.

That is now the discussion about 20% air voids curve and 80% saturation line whether they are same or not, so we knew that 20% air voids line means we can actually compute γd=Gsγwx1-n_a, n_a is nothing but the percentage air voids plus 1+wGs and this yields for a n_a=0.2 that is 20% air voids and at water content of 8.5% the γd as 17.22kN/m^3 which is actually found to be different if you try to compute for 80% degree saturation γd=Gsw,Gsxγw+1+wGs/Sr well Sr=0.8 and water content is equal to that is 8.5%.

The density which is actually obtained is around 20.56 so this density is actually different from what we actually obtained from this one, so if they are have to be same then we need to actually get the same values. Hence we can say that the 20% air voids line which is actually air voids curve is not the same as the 80% saturation lines similarly air content lines also.

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So these all methods what we discussed is about the shallow compaction methods, but there are situations where we have got requirement to compact the soil at deeper depths and further that are member of techniques which are actually available traditionally that terra probe method which was available and now currently the one which is actually being use id vibroflotation and building sand compaction piles, blasting and dynamic compaction and these are actually covered in detail in ground improvement subject.

But in place densification of granular soil is very much required now a days if you are building a structures which are rusting on saturated sandy or slity sandy soils and this to as a remedial measure for preventing liquefaction sustainability in the future. So they have been successfully used for compaction ensure to soils especially granular soils.

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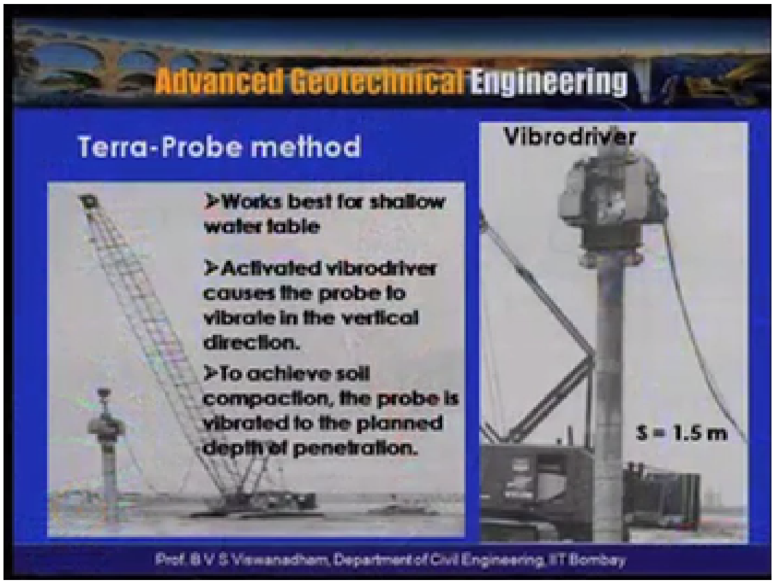

So in this slide terra probe method which is actually shown here and what is best for shallow water tables and activate it actually has got activated vibrodriver causes the probe to vibrate in the vertical direction for probe actually vibrates in vertical direction and to achieve soil compaction the probe is actually vibrated to the planned depth of the penetration, so the spacings are generally 1.5m which is actually place and this area is actually compacted.

So here this particular photograph shows the process of compaction by using the terra probe method.

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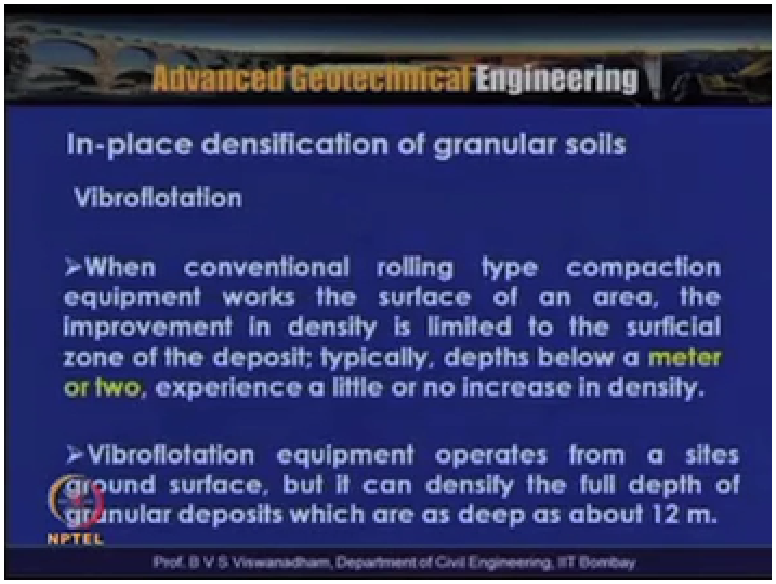

In place densification of granular soils that is for vibroflotation when conventional rolling type compaction equipment works the surface of the area the improvement in the densities limited to the only one or two meters, but if you have a requirement of compaction at the deeper depths then these instead to densification which is actually required to be after up to certain depths means then vibroflotation is a vibal option.

So vibroflotation equipment operates from sides at ground surface but it can densify the full depth of the granular deposits which are deep as about 12, 14, 15m. so after 15m the vibroflotation equipment generally can use for densify the soil even at depper depths now it is being try.

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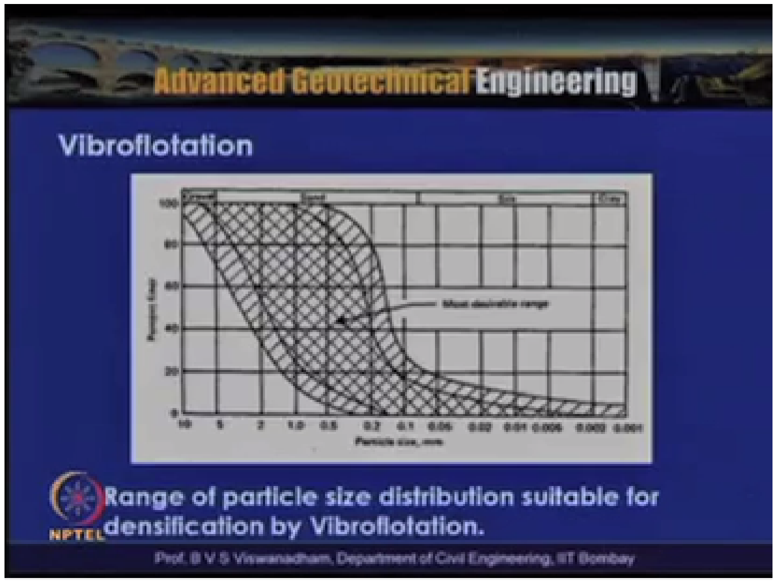

And the ranges of the soils or particle size distribution which are actually possible for adoption is here the particularly the range of the particle has distributions suitable for the densification by vibroflotation which actually shows that the soil should be gravel or sandy if they are in the loose state then it is possible that they can be compact. But you can see here when it comes to clay the usage of this method is actually limited then we have to adopt appropriate methods.

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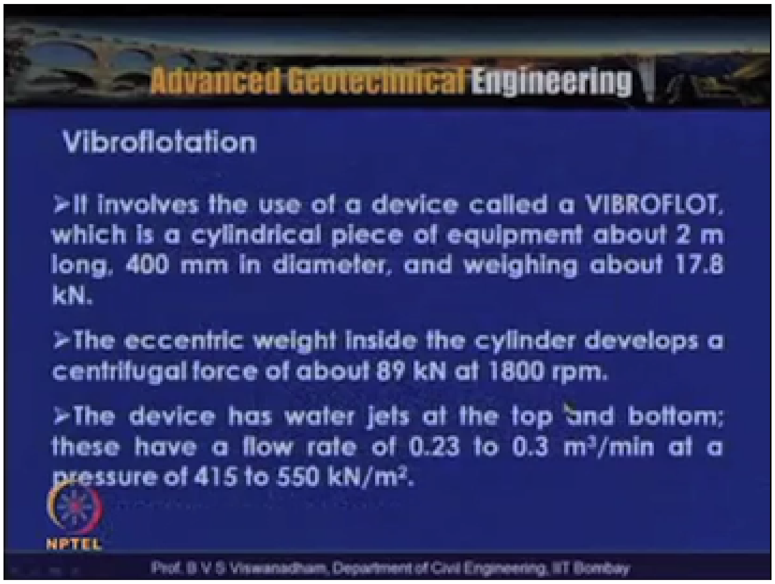

The vibroflotation method involves using a device called vibrofloto, vibroflot which is a cylindrical piece of equipment about 2m long 400mm in diameter and weighing about 17.8kN. So what it does is the vibroflot this exits vibrations in vertical as well as the lateral directions this makes the soil particles to arrange into the denser configuration. The eccentric weight inside the cylinder develops a centrifugal force of about 89 kN at 1800 rpm. The device has water jets at top and bottom so this water jets actually will allow to the probe to penetrate at this it rapid rate and the flow rate is about 0.23 to 0.3m^3/min at a pressure of about 415 to 550 kN/m^2.

So that means about 4 to 5 bar pressure the device can actually operate and jet the water so with that what will happen is that the penetration of the probe takes place very easily.

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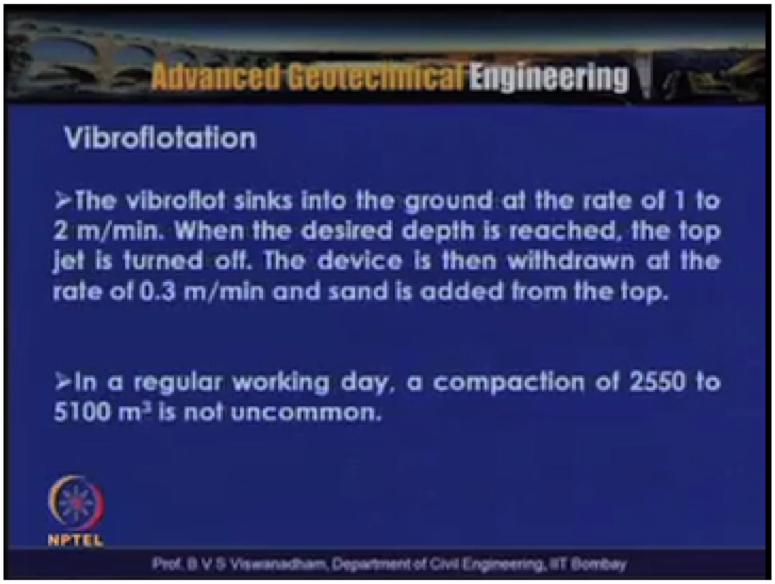

And the vibroflot sinks into the ground at the rate of 1 to 2m/min when the desired depth is reached in the top jet is turned off and the device is then withdrawn at the rate of residing rate is about 0.3n/min so the sinking rate is about 1m to 2m/min and withdrawal rate is about 0.3m/min and the sand is actaully added from the top and if you are actually adding other materials then is called as vibro replacement.

So in a regular working day a compaction of 2550 to 5100m^3 is not uncommon by using this method.

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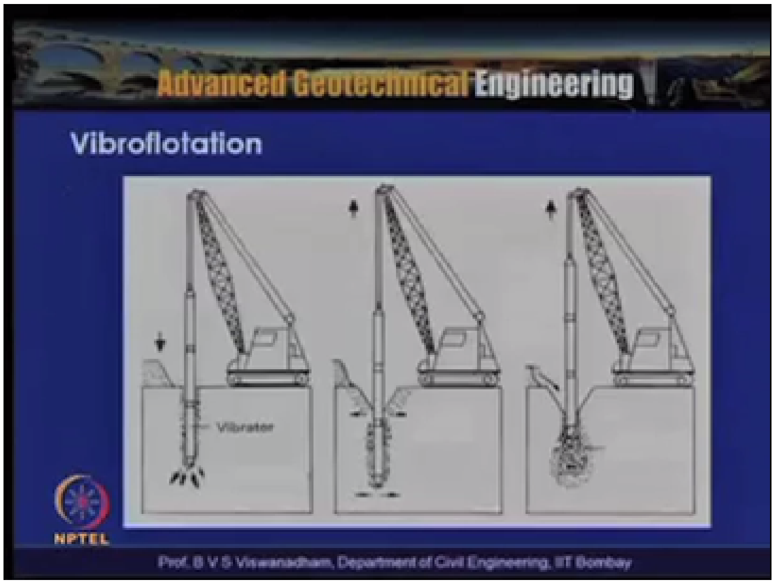

So the process is actually shown here pictorially the jetting of the water and then the compaction and then withdrawal here, so here in this process what will happen is that the deeper soils can be compacted and when you do it at certain grid of spacings covering the large area then entire soil needs gets densified.

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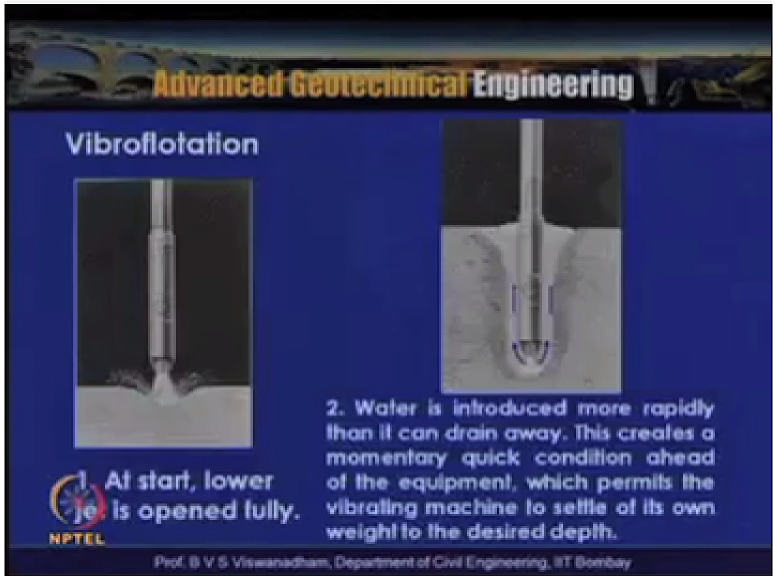

So here at start lower jet is open fully and here at the portion this slide 2 water is introduced more rapidly than it can drain away, so this creates a momentary the so called quick condition ahead of the equipment which actually permits the vibrating machine to settle it is own weight so the weight itself is actually sufficient to settle the probe up to the desired depth.

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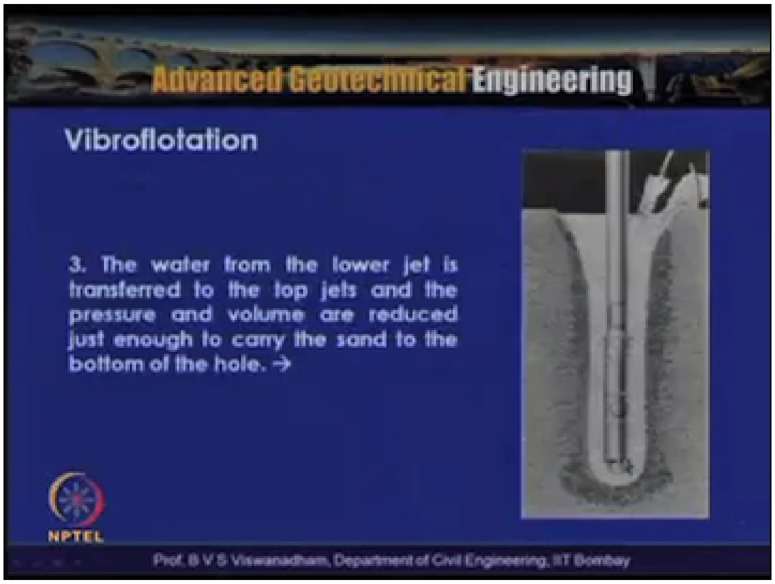

Once in the third step the water from the lower jet is actually transferred to the top jets and the pressure and the volume are reduced just enough to carry the sand to the bottom of the hole, so with that what will happen is that the and again the sand which is actually introduced there is compacted by using the vibroflot which is actually available at the surface. So this process actually makes.

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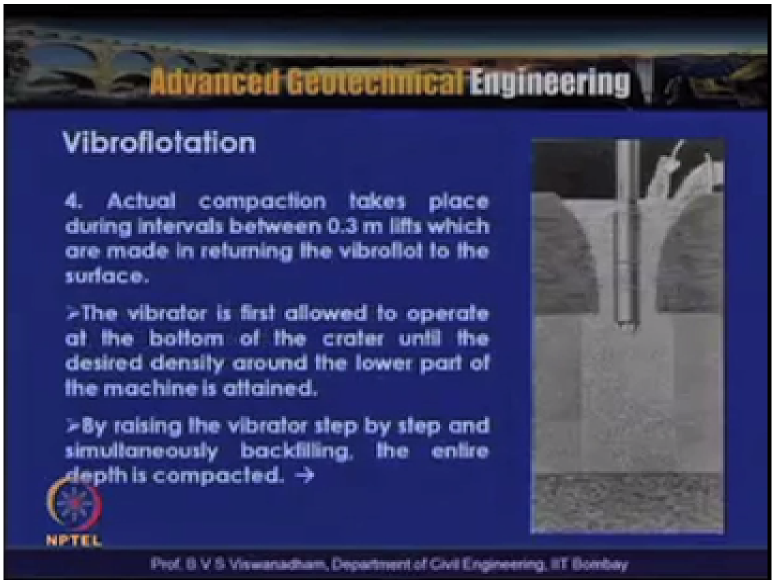

A replacement of the loose soil with a densified column or densified column actually haing densified sand so actualcompaction takes place during intervals between 0.3m lifts which are actually made in return with vibroflot to the surface. So this is how the process of the vibroflotation is actually done.

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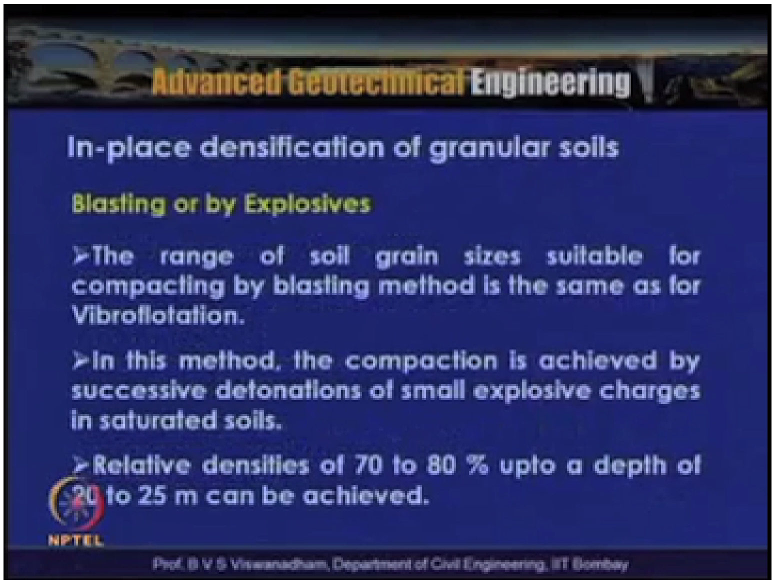

The other technique which is called as the blasting so this general is adopted when you are actually having top layer also a loose soil, suppose if you are having this blasting is nothing but arranging a creating a soil, the soil densification by supplying a explosive energy. The range of soil grain sizes suitable for compacting by blasting method as same as the vibroflotation. In this method the compaction is achieved by successful determination of small explosive charges in saturated soils.

Relative densities up to 70 to 80% up to depth of the 20 to 25m can be achieved but one important caution is that if you are having a dense sand layer on the top and blue sand layer at the base then in such situations this particular technique need to be avoided because it can lead to the loosing of the top sand layer in the process of compacting the looses and layer than the dense sand layer.

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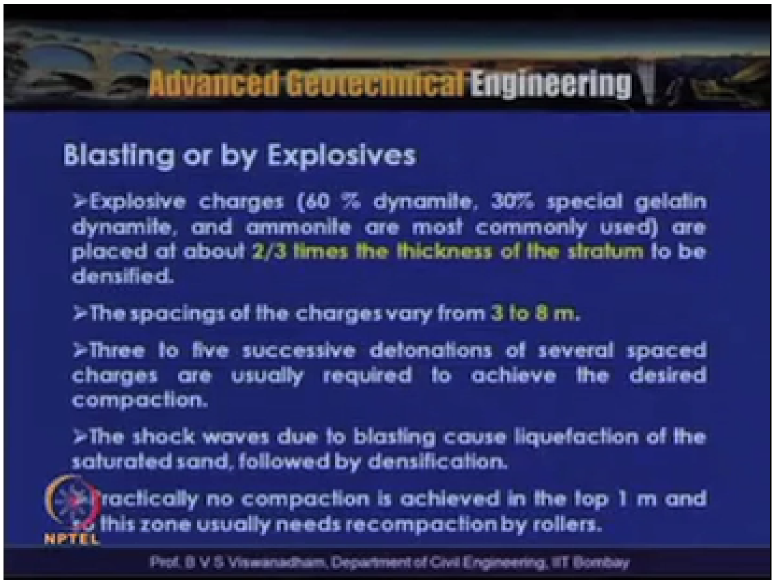

So these are the, in the explosive charges are basically 60% of dynamite 30% special gelatin and ammonia are most commonly used and they are placed generally about the 2/3th times the thickness of the stratum and the spacing generally vary from 3 to 8m and there are five to successive detonations are placed so that this soil can be arranged into the dense configuration. So the shock waves actually create a sort of liquefaction and make the soil compacted into denser configuration.

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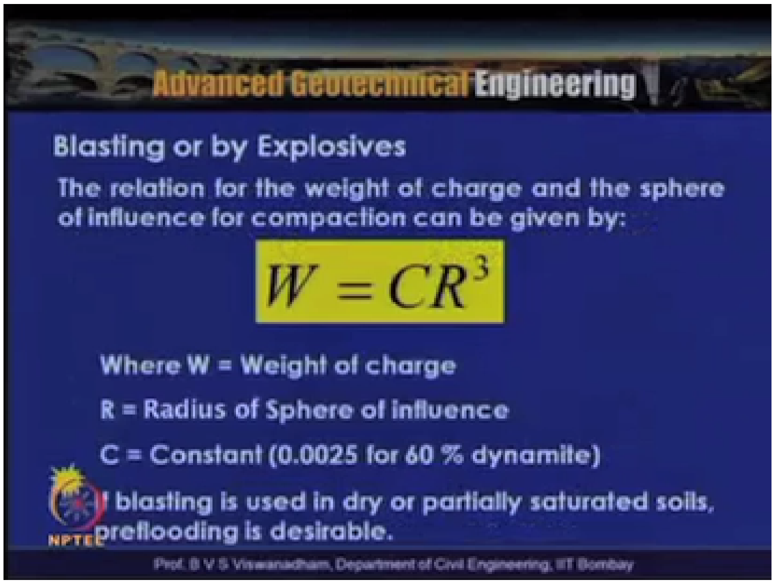

So this is a particular relationship will gives weight of charge to speed of influence of that energy $W=CR^3$ and R is nothing but this sphere of influence and C is nothing but the material constant that is 0.0025 for 60% dynamite.

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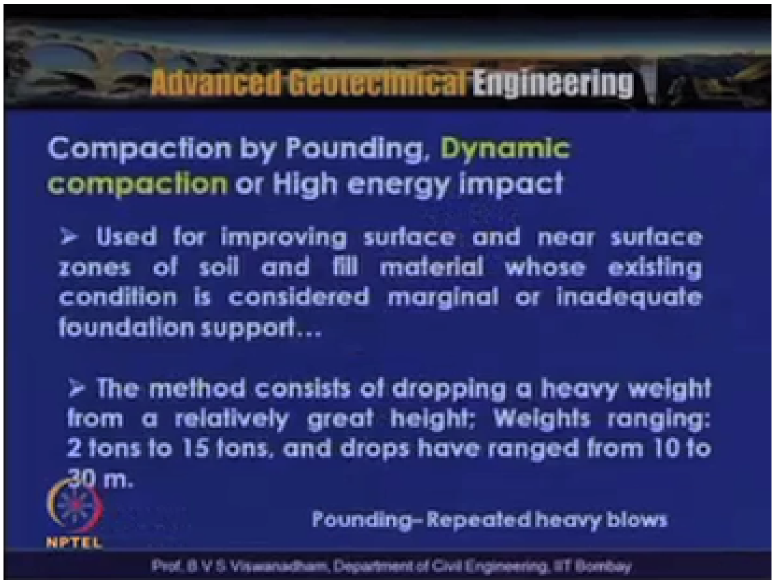

So the last method what we have actually said is the dynamic compaction which is nothing but the dropping of a known weight from a known height which actually creates a sort of primary waves and secondary waves and these, this is actually when it is done in a soil it creates the so called rearrangement of the soil particles and makes the soil particles depressed to the denser configuration, so this method consisting of dropping of a weight from relative to be greater height.

So the weights ranging from two tons to 15 tons and drops having ranged from 10 to 30m have to adopted.

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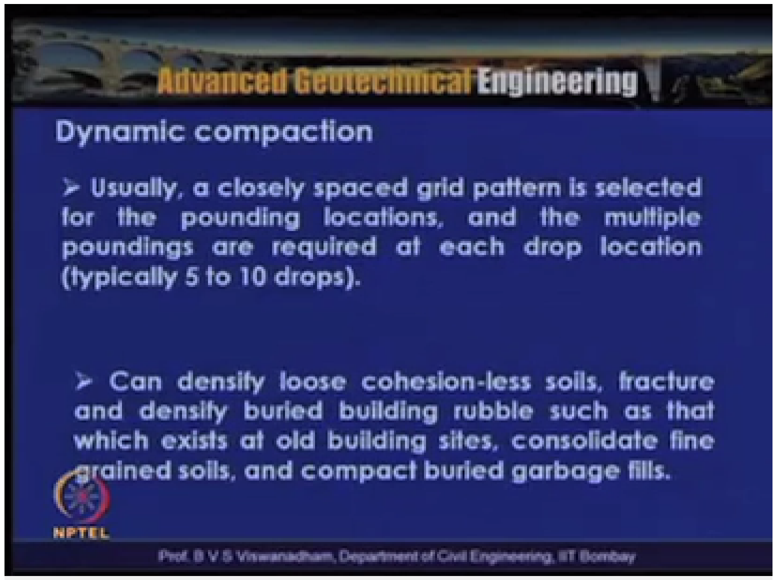

So usually the close spacing gird pattern of like 6m/6m is called as a prince spacing need to be adopted and each we have primary pass secondary pass, territory pass this can densify loose dense cohesion less soils and fracture and density buried building rubble and now a days old buildings sites are construction debry or some waste plant fields are also being compacted by using this method.

So in this lecture what we have actually introduced is that field compaction testing methods their assessment of the field compaction the field and then we also discussed about how we can actually correct in case if you are having all size particles and then in addition to the shallow compaction methods what we discuss we also have discussed about an introduction we have given to different methods which are actually existing for densifing the soils at greater depths, this is required for strengthening the soils against liquefaction sustainability.

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