Geotechnical Engineering I
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Lecture-14
Compaction Characteristics of Soils-I

And today I will be discussing about the compaction of soils or in other words the compaction characteristics of the soils. This is a very significant discussion and most of the infrastructure which has been developed in present day as well as in the past has been mostly by utilizing the properties or the characteristics of the soils when they are compacted. So, it is a very significant discussion in the realm of geotechnical engineering.

It is so unfortunate that most of the practicing engineers, either they have forgotten the subject or they do not practice it properly in the field. And that is the reason that most of the structures are yielding, they are failing and I would say what a shame in 21st century where we cannot even compact the soils properly to make the infrastructure of importance.

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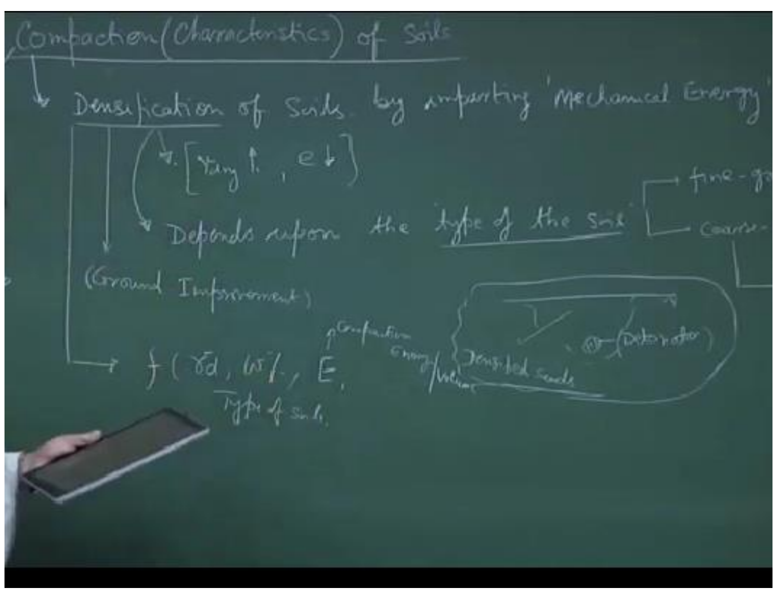

So to begin with the compaction process is basically the densification of soils by imparting mechanical energy. That the whole idea of compaction is when we say densification what it means is that the gamma dry of the material is increasing and the wide ratios are decreasing alright. So, this is what densification is. It mostly depends upon the traditional characteristics of the soils.

The type of the soil and when we say type of the soil it is a big matrix which has to be defined primarily if I say that this is the fine grain material or the fine grain soils or the coarse grain soils. So, primarily depends upon the type of soils which you are dealing with. It so happens that the fine grain soils can be compacted in different by applying different techniques.

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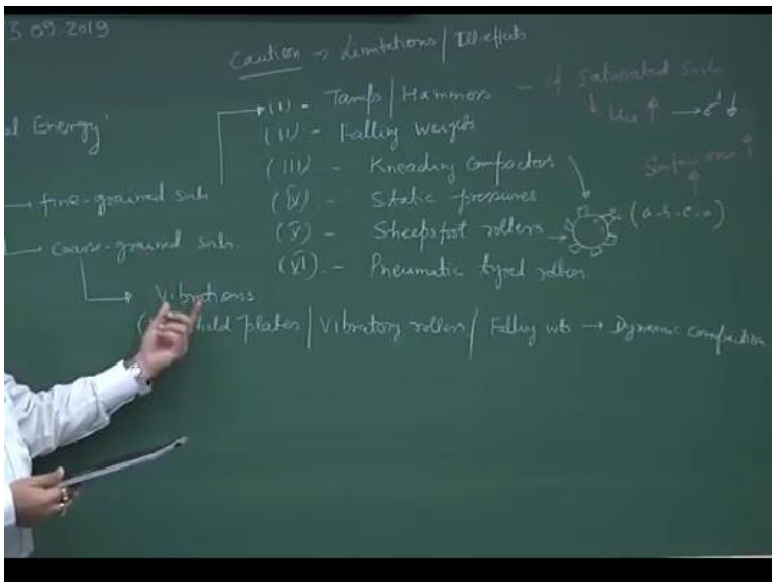

Mostly we use tamps or hammers, one of the word of caution here would be when you are dealing with a fine grain soils. And then you are tamping them and if the soils happened to be saturated the chances are that pore water pressure will develop. So, we have to be careful when we are tamping the whole thing. I hope you understand what are the issues associated with the water pressures when they develop in the soils.

So, water pressures develop the effective stresses decrease. Sometimes the fine grain soils are also compacted by falling weights, check it on net some good examples of how these compaction techniques are being utilized for creating different strategic. And important infrastructure most of the time the airports and the seaports, we have leading compactors, sometimes the compaction can be done by static pressures.

The most classic example of fine grain soils being compacted is sheeps foot rollers, this images are available on internet you can just type and you can see how the sheep foot rollers would look like. If this is a drum on this drum you will find foot rollers like this. So, this becomes a sheep foot roller. Basically the philosophy behind creating these type of rollers. This also gives you the needing compaction, you are enhancing the surface area of the compactor by creating these types of you know protruded elements.

So, each time when this system enters the soil mass this surface is available for compaction process. Not only the small a to a by providing these type of protrusions I have enhanced the surface area to a b c a. So, in other words, the surface area gets enhanced and hence the compaction can be done better. You can impart energy up to great extends to the soils. Sometimes the pneumatic tires are also used.

These are different distinct of compaction and the tools which are used for compacting the finding the materials. The general word of caution is try to understand their limitation and ill effects before you use them. On the contrary, the coarse grained soils are compacted, not compacted we cannot compact coarse grain material. Remember, we densify them by using vibrations. So most of our devices which are utilized for compacting the grain materials would be a sort of a compact vibrator.

This could be handheld plates, whenever you get time please go through the net and realize that why structures are failing because of lack of proper compaction. And ultimately the whole matter goes into a court of law. All big companies to small companies are facing this problem. And big projects are in litigation. And this is where people like you can help the profession by pursuing the case of your client.

So these are handheld flicks vibratory rollers, sometimes we also use falling weights. This is called as dynamic compaction. I have been involved in several projects in the middle east and in certain parts of Russia, in Rome country in the deserts, where it becomes very difficult to compact the soils. And then you have to design a scheme of densification of coarse grain materials which becomes very interesting.

By the way, Indian Army also uses this concept when they do ballistic tests of detonators. So, this is a very interesting subject to pursue research on and to help the country and the society. I can do densification by passing the shear waves alright. So imagine that this is a soil mass, and somewhere here if I am having a detonator or a weapon alright. And then if I charged this I can densify the sands.

So, this becomes densified sands, most of these schemes are taught when you take this advanced course in ground modification or soil improvement. So, these techniques are normally applied for ground improvement. My session is please go through the videos which are available on modification of the soils by using different techniques. As far as the compaction is concerned, what is the basic objective.

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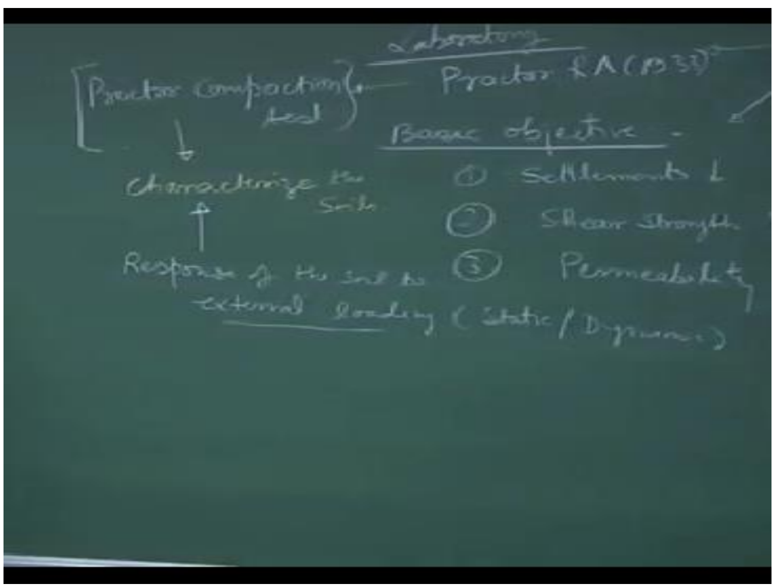

So, the basic objective is I want to reduce settlements. Subsequently we will be talking about how to compute the settlements of the foundation and the infrastructure which is made up of the soil and resting on the soils. So, most of the disasters which I showed you in the problematic soil sometime back in the PPT, the main cause of most of the failures could be the lack of compaction or pore compaction.

The another objective is to enhance the shear strength of the soil. And third objective is to reduce the permeability, you know say this is sort of a treatment which you give to the soils which are ailing. So, when somebody approaches you to give a solution to a situation if so happens that if I want to reduce the settlements, I have to compact the soil, I want to increase the shear strength or the bearing capacity of the soils I might have to compact them or if I want to decrease the permeability, I would like to compact the soil these are the objectives.

Incidentally, the compaction procedure in the laboratory was proposed by Proctor RA 1933 and hence the test which is normally done to check the compaction characteristics of the soils is known as Proctor compaction test. This becomes a benchmark for testing the soils alright. I am sure you must have realized that I have used the word compaction characteristics. So, one of the clever ways of using these characteristics would be to classify the soils.

So, one of the ways I can classify the soils would be based on the compaction characteristics. So, if I say that Proctor compaction can also be used to characterize soils. So I am sure you must have realized that there are several schemes of classification of soils which we have developed by this time, studying from genesis to creation to the transporting agencies to the 3 standard techniques of you know USCS, ISSCS, AASHTO, USBR.

And then now I am using the compaction characteristics. Philosophically, when you say that I would like to utilize this property to correct to understand how easily compaction can be done. This is the response of the soil to external loading particularly external loading could be either static or dynamic. In soil mechanics, geotechnical engineering one course, mostly I will be dealing with the static pace.

But when you become a consultant you will be dealing with a lot of dynamic issues and one of the dynamic issues I have talked about over here that, you know military of the country would like to test the weapons. And one of the best ways to test them would be in deserts or the second one could be go to the sea and detonate your weapons and see what is the you know destruction capacity of the weapons.

Now the compaction characteristics would depend upon some parameters. Here I was talking about this. So densification would depend upon the gamma d, the moisture content, the compaction energy. So, e I am using as compaction energy. Normally, we quantify this as compaction energy per unit volume of the soils, type of soil and sometimes also under the conditions whether it is a lab test which you are doing or a field test. So, this is the matrix, these are the uncertainties associated with the compaction process.

The compaction will depend upon the gamma dry moisture content, compaction energy type of the soil is a very you know big term it would mainly talk about the plastic index, particle soils distribution characteristics, especially gravity also, organic matter alight and so on carbon. So, organic matter one of the shoots of the organic matter could be percentage carbon content. When you deal with the industrial issues there you find that carbon is the most notorious thing.

What it does, it absorbs moisture and then it creates lot of problems as far as the compatibility of the soil is concerned, alright.

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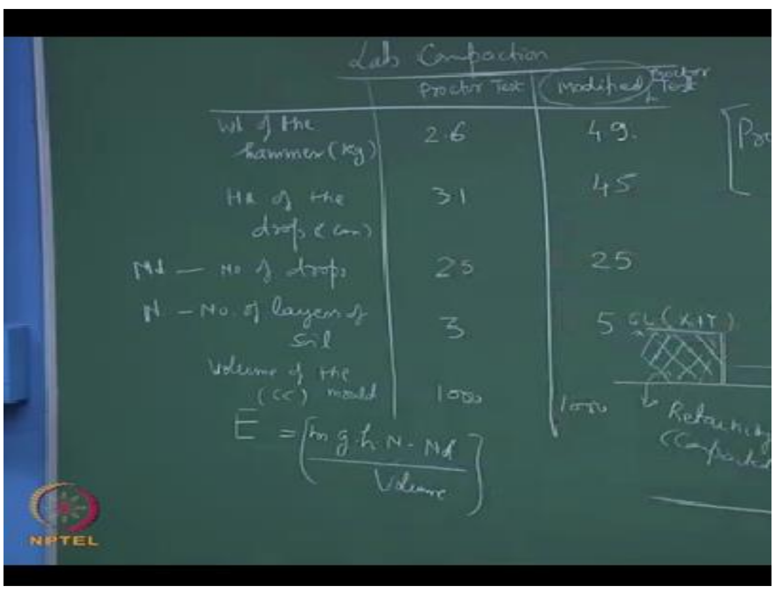

When we say compaction process in the laboratory, there are few parameters on which they are depends if we first a weight of the hammer. This you must be doing in laboratory I am sure. And this is the modified proctor. I will talk about this slightly later. So, weight of the hammer, height of the drop, number of drops, number of layers of soil, volume of the mold. So, basically you are mimicking what can be done in the field by creating the situations in laboratory.

It so happens unfortunately that whatever can be done in the field cannot be 100% replicate in the laboratory particularly for the materials which require vibrations. So it is very difficult to do vibration of coarse grain soils, in a proctor test normally this is 2.6 kg and modified proctor test is 4.9 kg, height of the drop is 31 centimeter and here it is 45 centimeters. Basically why the name modified has got added up to the proctor test because we are modifying the compaction process.

So I will show you how the energy can be computed. And number of drops are normally 25 here we keep them same number of layers are 3, 5. So if I am compacting a soil mass, suppose if I have to create a filling alright, this is the existing ground level and I want to create a villa for you let us say which are sea facing. So, somewhere here, if I want to store water, I have to compact the soil. So, this becomes a retaining a structure alright.

So, this is the complicated soil, this becomes the compacted soil mass and in the process what I have done is I have elevated the ground level from some value to x + y. This is engineering depending upon the requirements I can create a situation, I can create a property line for which I will charge to my client alright. The thumb rule is the geomechanics is something which has to be practiced as you remember.

So, when you practice something you do not practice anything free of cost as money is involved everywhere, the standard proctor if you compute the total energy which will be equal to m into g into h multiplied by number of layers, if I define this layer as n and number of layers say L alright, number of drops I will define this as Nd and this has divided by the volume, volume normally we keep constant as 1000 cc.

So, if you compute energy is the height of the weight which is falling of this magnitude, number of layers, number of drops, number of layers and per unit volume. So if you compute that we will be getting some numbers like 593 kilojoules per meter cube and in case of the modified proctor you will be getting to 2704 kilojoules per meter cube you need not to mug up all these things, what is the methodology of doing this compaction in the laboratory.

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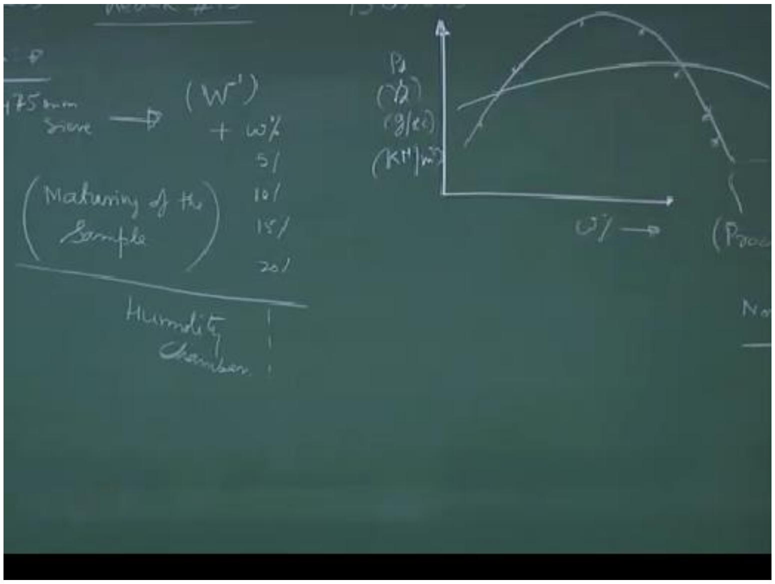

And what are the interpretations of results. That is very important to understand. You take the dry soil sometimes oven, oven dried alright. I hope you understand what type of soils have to be over dry and whatever soils the not to be oven dried weigh it and pass it through 475 micron sieve, whatever gets passed over, we add water to suppose if I use the term W p or let it be the W, I think it will give wrong message let us say this is w prime alright, to this w prime we add moisture content in stages.

Normally we add 5% 10% 15% 20% and so on depending upon the material. And then you leave the sample for maturing, what is known as maturing of the sample particularly when you are dealing with fine grain materials. So, the procedure is that you take the soil is spread it on a thin polyethylene sheet uniformly, use a hair sprayer and sprinkle water, keep the entire thing in the polythene bag and by using your hands but without touching the soil you rub it.

So, the moisture becomes uniform and then the whole system is normally kept in a humidity chamber. Fine after 3, 4 days, you should be performing the test to get good results. So, I will be discussing the interpretation of the results which is very will be useful for understanding the compaction characteristics of soils. It is a typical way of plotting the graphs or the data from the compaction test, on y axis the plot gamma d gram per cc, though I am using the word or the symbol gamma d, it should permit me to use gram per cc though technically it is not correct.

So, I can change this to kilonewton per meter cube also alright it depends upon what you are using, on x axis moisture content you know how to obtain moisture content. So after 3, 4 days of humility chamber storage of the samples you take them, keep them in 3, 4 packs, weigh them, dry them, again weigh them, find out the difference of the moisture which has been last and that gives you the moisture content.

So, typically we get some points like this exponential leaders alright, point number 1 most important thing always remember in life, whether you are even if you become a CEO of a company, you have to appoint a geotechnical engineer to establish your industry alright. Industries cannot be operated in air, they have to rest on the foundations and the soil system. So, this is the contractors try to loot you, cheat you.

Because whatever goes beneath the ground, nobody knows. Looking at this graph, I can get the complete understanding of the material. A typical bell shape alright indicates a material which is quite easily compactable. Remember when we are talking about the PSD particle soils distribution. You are talking about 3 types of soils gab grated, well graded, poorly grated and this is that I had used the word the you know well granted soils only can be compacted properly.

So, this appears to be a well graded material. The particle packing is such that all the bigger particles will allow the finer particles and finest particles to get assimilated in the matrix in such a way that you get a very good density of the mixture. Mostly these type of relationships is depicted by, exhibited by Silty, sandy, clay material soils alright, clay cannot be compacted so easily.

So, if somebody asks you to plot the graph, putting on the merging on the same graph as of this, the relative position of the clay could be something like this. What this indicates is clays cannot become compacted, why electromagnetic forces cannot bring the particles closer to each other.

And that to buy and applying mechanical energy because remember, this is the response of the soil when you are applying mechanical energy to this.

So, by virtue of fine grain material being fine grain material and lot of electromagnetic forces which are active on the surface of the grains of the clays they cannot be compact it is going to be a flat curve sands very difficult to compact by this type of compaction unless you go for the vibrator system. So, proctor compaction curve is what is known as a proctor compaction curve. Rather than saying curve you can also use the word characteristic, characteristic is more scientific and technical and I can interpret it the way I want.

So, this is proctor compaction characteristic sands cannot be so not valid for sands alright, what should be done vibrate them, create a vibrator system and densify the sands. Next time when you go to IIT Jodhpur is a beautiful example of how sands have been densify to lay the foundations in the dune or what we call them as the alien type of soils which I was discussing some time back. So, the point I am trying to highlight is just by looking at the nature of the graph, or the compaction curve, I can infer that what type of soil I am dealing with. And hence this becomes an interesting way to classify the things.

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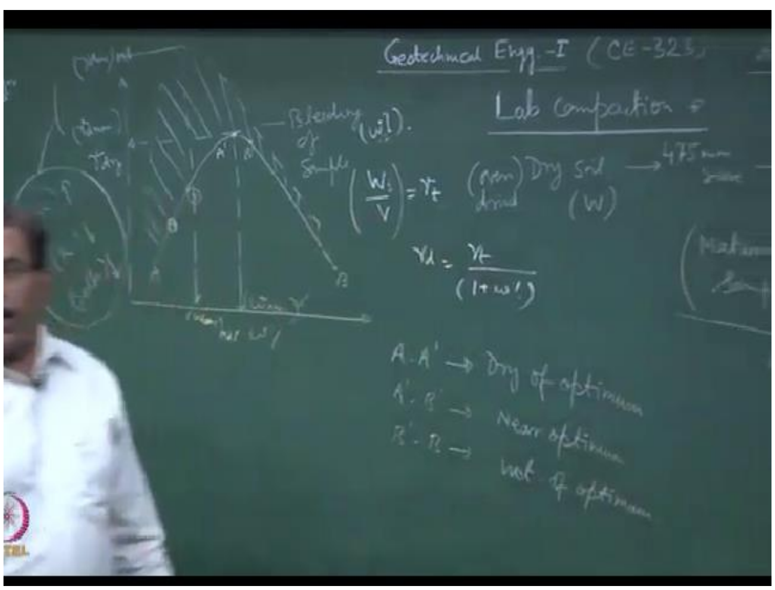

Now what is the interpretation of the curve, if I say this is gamma dry and moisture content, if this is the graph proctor compaction and I am sure you must have realized the moment I enhanced the energy of compaction it becomes modified proctor. So, if I superimpose for the same material proctor compaction and modified proctor compaction, this is how the curve would shift, alright this point is designated as W OMC.

The way you carry an ID card, the way you carry a roll number and believe me I still remember my roll number of B. Tech that was 2062 because this carries a lot of information, you know why there is a significance of this. So, for a material this W OMC is a fingerprint. Now, how you want to utilize this fingerprint of a material depends upon you as a technologist, clear. So, this is one of the fingerprints of the material with your capture.

Coming to this one, this is what is known as gamma d max clear. So, the moment I have described 2 parameters gamma d max and W OMC, I need not to bother about the material properties anymore, because these 2 are the characteristics of the material when it is getting exposed to external loads, as an engineer I am more interested in observing how the soils are going to behave when they are exposed to external loading, static loading clear.

Is this fine, the logic here is when you have enhanced energy, the particles become much closer and the water retention decreases. So, this is the W OMC corresponding to modified proctor and what happens is gamma d increases, this okay is this part clear. So, if you remember the matrix which I wrote that y is equal to densify the soils. The first objective was to reduce the settlements. I have a system more stronger.

Imagine when you started from this point where the densities are extremely low. You added a bit of moisture and what water does in the veins of the soil, it reinforces the particles provides more strength gamma d increases alright, you keep on adding water what is enhancing gamma t total and gamma t upon 1 + W is gamma dry. So, the more and more moisture you add up to a certain extent the gamma dry will get changed it will increase a peak value comes beyond which it drops down fine.

In modified thing the water retention drops because the pores have become absolutely small and this water is going to sit in the pores if you remember. So, modified proctor compaction is the characteristic of the soil which gives you the minimum possible moisture holding capacity at optimum. However this gives the maximum possible density which a system can attain. Now, this is a domain in which you have to work as a technologist ,as an engineer, you got it.

How best you can compact things at the site would define how best you are utilizing the material are this statements okay, are you able to follow this. So, the trick is how much I can utilize this material to create a system, which is very dense. The moment I have achieved this, the shear strength is going to be maximum, the permeabilities are going to be less, settlements are going to be extremely less and hence, I have done engineering with the soil mass. Is this part clear. Any questions, yes, use the mice.

Sir according to the formula like gamma dry is equal to weight of solids upon total volume, so when we add the water the volume increases but the weight of soil does not increase. Just give me 5 minutes I will clear all your doubts just hold on for 5 minutes alright, anything else then we can discuss ok, what are the stands SS shear strength of the soil, hydraulic connectivity of the soil mass compacted soil mass remember shear strength of the compacted soil mass.

Hydraulic connectivity of the compacted soil, settlement of the soils which are compacted okay, any other question. Anything else, if you follow the logic what water does to the soil. So when you add little bit of moisture, the water gets remain into the pores. Air is expelled out, weight of the water is more than the weight of the air. The unit rate of the soil water matrix increases, beyond a certain point this is also what is known as the maximum capacity of the soil to retain moisture.

Because if you start compacting beyond this point, water being incompressible will come out of the compacted soil mass and this water cannot be retained over there. So, now answering your question, the way we do yes, w 1 is actually saturation point. No, no, I will introduce the concept of saturation after 10 minutes alright, let us go in stages. You understand the basics then all these terms will come automatically you need not to bother.

Suppose let us talk about his point first. At this point, normally what we do is we know the weight of the soil alright. We know the volume that means we know the gamma t remember no confusion is this okay. So, the mold which you have taken in which you have tagged the soils in number of layers by imparting number of drops clear you have created a dense matrix, you know the weight of the compacted soil in volume gamma t is known.

Take some of this soil obtain moisture content by over drying and compute gamma d is this okay, this the right way of doing things. Is any confusion now, I am plotting this moisture content with respect to gamma d. Remember, when I was teaching three phase diagrams, I had used the word gamma d is a normalized form of gamma t. So gamma t has been normalized with 1 plus moisture content.

The tendency of the analysis which normally geotechnical engineers adopt is to filter out the moisture, what I have done here by normalizing the total unit rate with moisture, I am getting rid of the moisture component and I am talking about the matrix which is in the dry form it is okay right. What does the question this is what you have been asking how to compute gamma d, but in this case with the gamma t will always be constant, it need not be constant.

So, remember you started from point 1 alright, point 2 so what happened you have added more water and that is what I was giving you the logic. In a dry soil when you add water, the air gets expelled. Later the water is higher than rate of air. So, what you are doing is you are traversing on a curve where the gamma t is getting becoming more and more as the moisture content increases.

Gamma t is also increasing and all r w is also increasing, what is R w moisture content yes, that is right. So, from point number A to A, what has happened, the more and more moisture you include in the system and compacted, the total density increases clear. And because of that, gamma d increases okay. At this point, when the optimal is reached, this is the maximum possible water holding capacity of the soil beyond which if you compact water being incompressible will come out of the soil matrix it will start draining out.

We call it as a breeding of sample. It is okay. Further additional moisture what is going to happen is going to reduce the gamma t itself clear because now the soil is becoming more and more dispersed. I will use this terms in another 5 10 minutes clear and hence the gamma t is dropping down but moisture is still increasing. So, it is becoming a sort of a slurry but not a full slurry it is a semi solid material which has been compacted is this okay.

According to a normal formula gamma dry is equal do weight of the compacted soil upon volume. So, as we are getting the monster content volume 1 minute, 1 minute w corresponds to each observation point of the sample, volume is fixed, gamma t is known clear corresponding to this state W is known and hence gamma d is known. So, that means this point is known I can plot it over here.

In the same soil mass you enhance moisture. So what is happening you are traversing on the right hand side of the x axis by adding more moisture, this point comes over here. Rate has also increased now, this way w has become w 2 okay, volume remains constant, gamma t has increased, w has become w 2 and hence gamma d has become gamma d 2. So, this process goes on from a to a very close to the optimal is that basically what happens is you are displacing a lighter fluid air by a denser fluid water.

So, compaction is the process by which you are expelling out air from the voids of the soils. Is this okay, by filling the voids y it is okay. So hold on for another 10 minutes and I will respond to your query also. And that should give you a complete idea about what we are discussing. So, typically, if I say to A prime and A prime to B prime to B any compaction curve will have 3 parts. Now this is what is known as dry of optimum alright. Let A prime to B prime will be near optimum and B primed to B wet of optimum, is this okay.