Ground Improvement
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Module No. # 02
Lecture No. # 04
Mechanical Modification

This is the lecture 4 in this NPTEL course on ground improvement techniques.

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We will be talking about mechanical modification, in which you improve the properties of soils by using mechanical means, for example, using shallow compaction methods and deep compaction methods.

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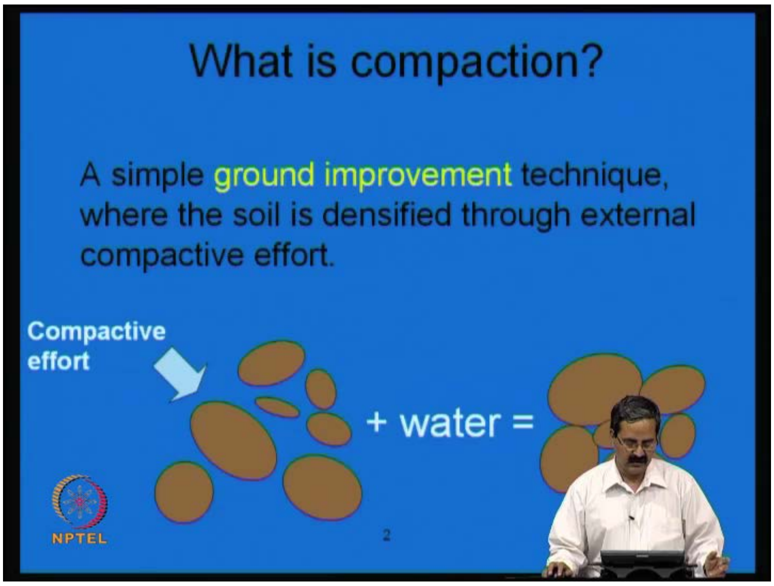

This compaction is especially ground improvement technique, in which the soil is densified to an external compactive effort. For example, in the case of the compactors, or the any other mechanical immense of densification what happens is that, the wide ratio that you have in initial stages reduces in the presence of water. The advantages of compaction of that is it increases shear strength that is in a way that improves the bearing capacity, it reduces the compressibility, which means the settlements on the improved ground are going to be very less, and it also reduces permeability. There could many field situations in which you have lot of seep age, because a wide ratio is higher there, and the permeability is going to be higher.

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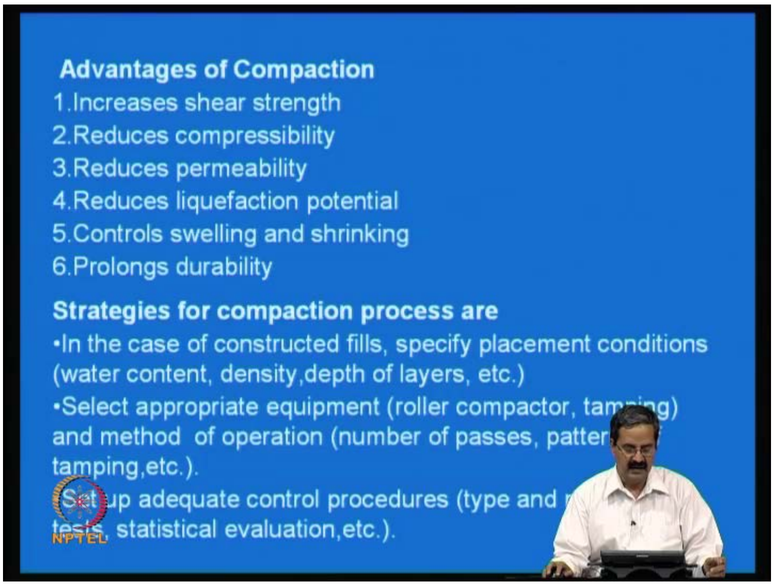

So, in which case, you would like to reduce permeability, and if you compact that soil, you are trying to achieve the increase in shear strength, and reduction permeability as well as compressibility.

It also leads to reduction liquefaction potential, as I just mentioned a the case of the some one of the dam failures during the burj earthquake. There is one dam called change dam, in which, it totally collapsed, because the compaction of this soil in the initial stages was not very good, and people were using methods like flooding for compacting sand, which means that it goes to relative density, say about 60 to 70 percent. Whereas, if you want to really get very good resistance for liquefaction, you must be able to compacted to very high densities, and if you that is only possible by resorting to good compaction techniques.

The compaction also enables control of swelling and shrinking, and it also prolongs the durability, say for example, the gully erosion that we see in many of the deposits, like if the compacted soil is present, the tendency for the erosion is less.

And the strategies that we follow for compaction process are in the case of constructed fields, say for example, in the case of embankments. We need to specify the placement conditions, like you must be able to say what should be the water content of the fill, what should be the density and the number of layers.

And we should be able to suggest them the the appropriate equipment as well. Say for example, roller compactor or tamping and the method of operation also. For example, this includes the number of passes patterns of tamping etcetera.

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Detail	Standard compaction	Modified compaction
Mold volume,cm³	1000	1000
Diameter,mm	105	105
Height,mm	115.5	115.5
Rammer diam,mm	50	50
Drop,mm	300	450
Mass,Kg	2.7	4.9
Number of blows	3	5
Blows /layer	25	25
Energy input,KJ/m³	596	2703

Then, he should also have adequate control procedures, because the compaction is something that is very sensitive to errors in the sense that, if that the compaction curve, as you will see that it is somewhat sensitive to many of the changes, and to obtain the compaction curve we need to have we have certain standard procedures. Wherein you take a standard mold and compact the sample, you have two procedures, one is the standard compaction and the other one is the modified compaction. In one case, you have, because the height of drop is, say for example is about 300 mm, the energy input required are the stored energy into the system, of the compacted system is about 596 kilo joules per mid cube.

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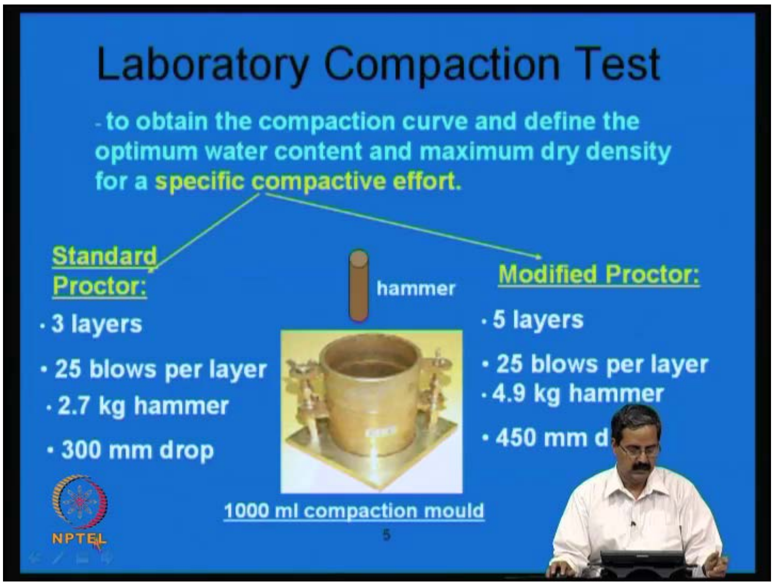

Whereas in the modified compaction, the height of top is about 450, and even the number of blows is higher. In the previous case, about the 25, and then, so this leads to, the, say for example, this is what I meant, there you have in the modified proctor, you have 5 layers, 25 blows, and then the with 4.9 kg hammer, you have higher energy input, whereas in the case of standard proctor, you have comparatively lesser energy input. So, you can see that the objective here is, in the case of compaction curve, you need to define the what is called optimum merge water content on the OMC, and then maximum density for a specified compactive effort.

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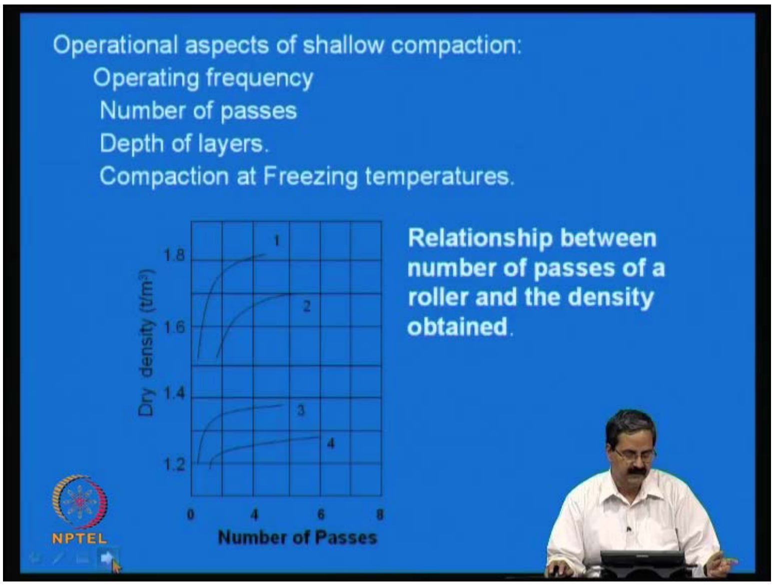

And there are couple of issues that we need to address in the case of compaction, once you get the field laboratory compaction, like a compaction curve in the field, you must be able to specify what is operation frequency, the number of passes in the depth of layers and compaction freezing temperature also going to be critical issue.

You can see that the depending on the type of soil, like this all 1, 2, 3, 4 soil types, there are some fixed number of passes beyond which there is a good, there density becomes maximum. And say for different soils have different densities, like say for example, the flashes and other material they have low densities, for example in area of 1.2 to 1.3, whereas sands and silts and other clays they have higher densities.

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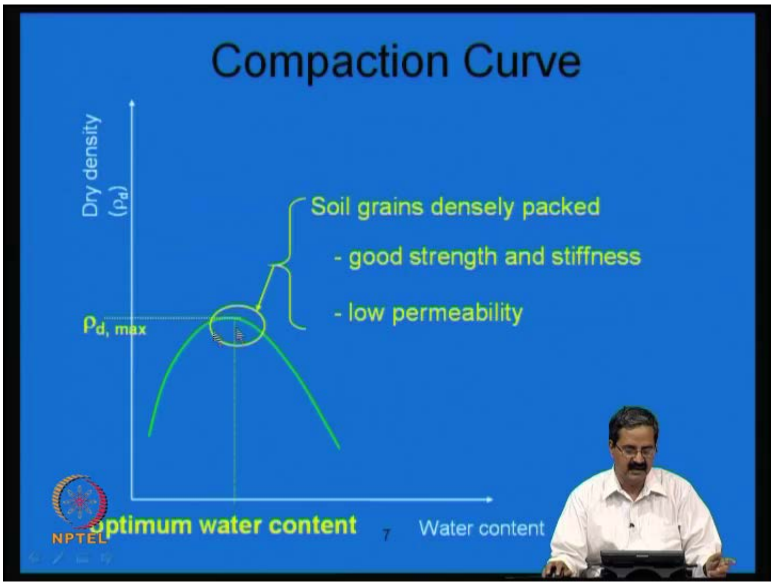

That is what I was just mentioning, the advantage of the compaction would be to obtain this condition, wherein the soils are densely packed and it leads to good strength and stiffness, and also low permeability, of course, a compressibility is also quite less. And you can see that if the curve is somewhat the way it takes off, particularly in the case of clays, is something very it is curve, which means that it is very sensitive to water content changes.

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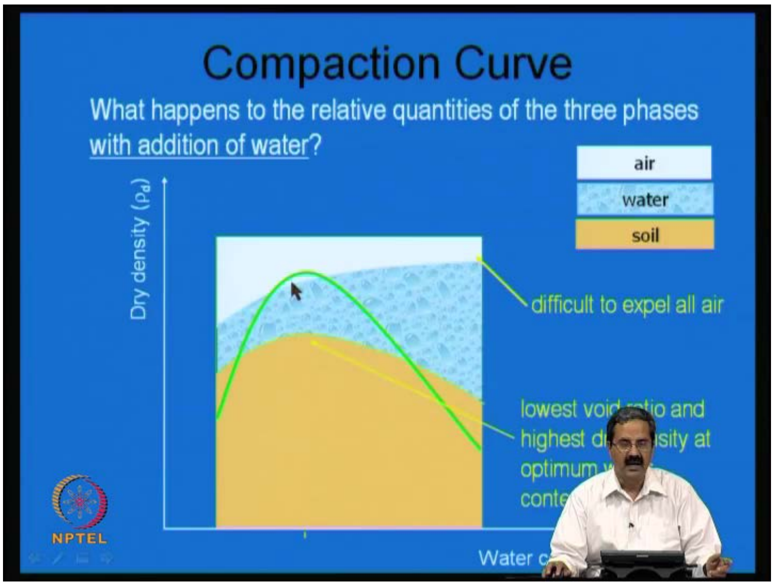

And one needs to understand, because what is going to happen during the processes of compaction that one needs to understand. And the thing is that, if the compacted sample, if you are able to really plot a curve of the soil alone, this could be the soil component and then this could be the water presence, and then this could be, the gap could be the air presence.

What it means is that, the it is not possible to, you will have the degree of saturation, it cannot be one, close to the optimum merged content are close to this range. Actually, this is also very useful, because you can see that the you will get, if it is fully saturated, the strength is going to be merging less.

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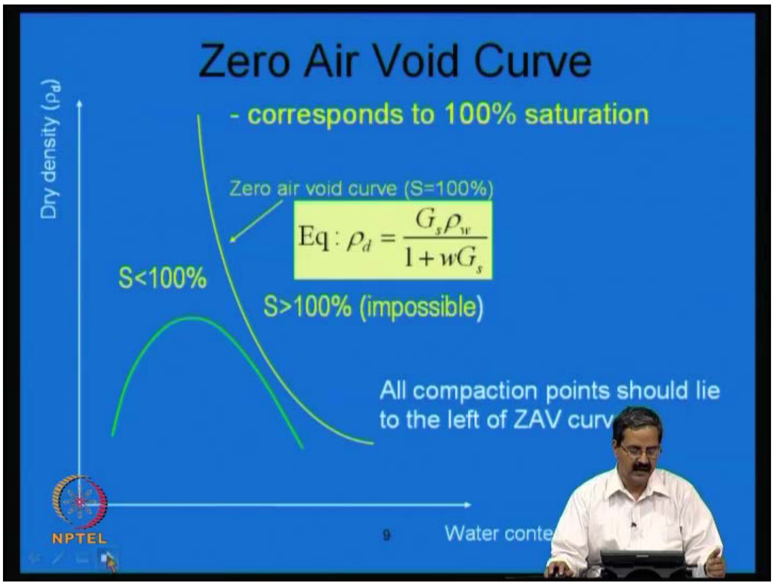

Whereas, if it is a unsaturated or partial saturated the advantage would be, because the degree of saturation is going to be lesser, you will have higher the strength. It is always good idea to plot the compaction curve in relation to the zero air void line, because this gives the range of water contents, like, say for example, this is a 100 percent saturation line, we have a 90 percent line here, 80 percent line here and 70 percent lines here.

The advantage would be that you will be able to understand the relative magnitudes of water content changes, as well as the density changes, because of the influence of degree of saturation. This is very important from field point of view, because when the material gets saturated, you should be able to understand what should be the changes in density, what should be the changes in, like for example settlements, and these are all very important.

And so, this is an expression for updating the zero air voids line, and then one can similarly obtain with simple modification of this equation from fundamentals, one can get different air void lines.

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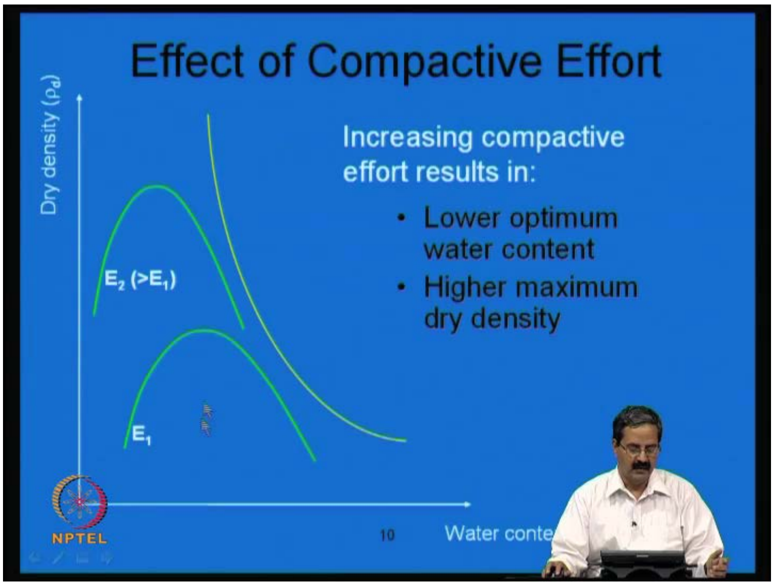

Another important point that we need to notice here is that, the because of the energy input, so this is for example, the compaction curve could be different, and actually this gives a motivation also, going for higher energies also in the field. Say for example, if it is possible, if there is a standard proctor test, and then if this is a maximum density, and this is the maximum water content at which you can get the density, so you can see that that can be really taken care of by, or improved by going for higher compaction, this is what I meant.

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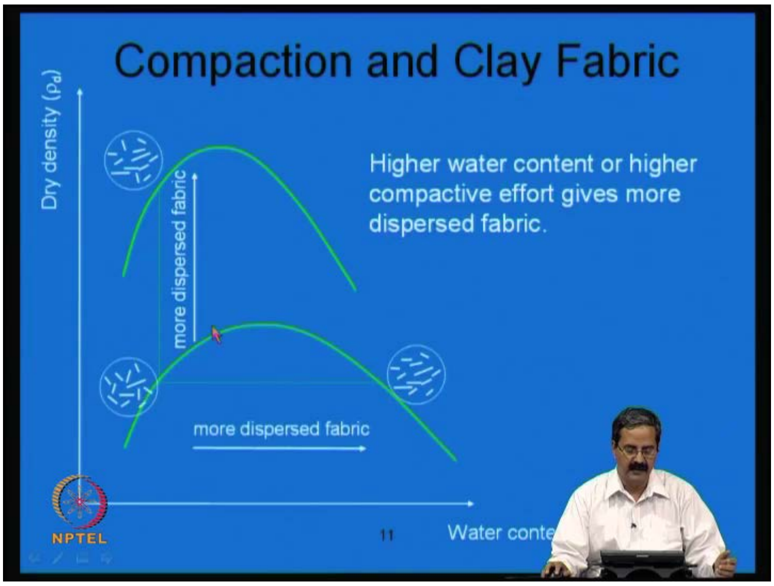

Say for example, if I have higher compactive effort, what it means is that instead of the… actually what happens is that, as a density increases, shear strength also increases for the same effort that is a reason.

We also know that the energy input in the case of the sample with higher energy input is going to be higher. Energy input is higher, which means that if you want to share the sample, the energy has to overcome, which means that the strength is also going to be higher. This is another important point that one should understand, that the orientation of the particles along the dry side as well as wet side, one can see that on the dry side we say that the sample has a flocculated structure, whereas in the case of wet side you have a dispersive structure, and may be the tendency will be much less here. And particularly when we increase energy input, it will be more dispersed, and the consequence of dispersion effect is that you will have higher permeability here, whereas lower permeability here.

So, one should really, say for example, if you are talking about dams, nowadays people the people, the energy inputs are going to be higher, and the permeability is an important factor in the, many of the, like, say for example seepage and other considerations. So, one needs to really decide which side of compaction one should do, in the case, say for example, a dam, definitely when you see that, it could be on the wet of optimum, the permeability could be lower, so the seepage pressures could be lower.

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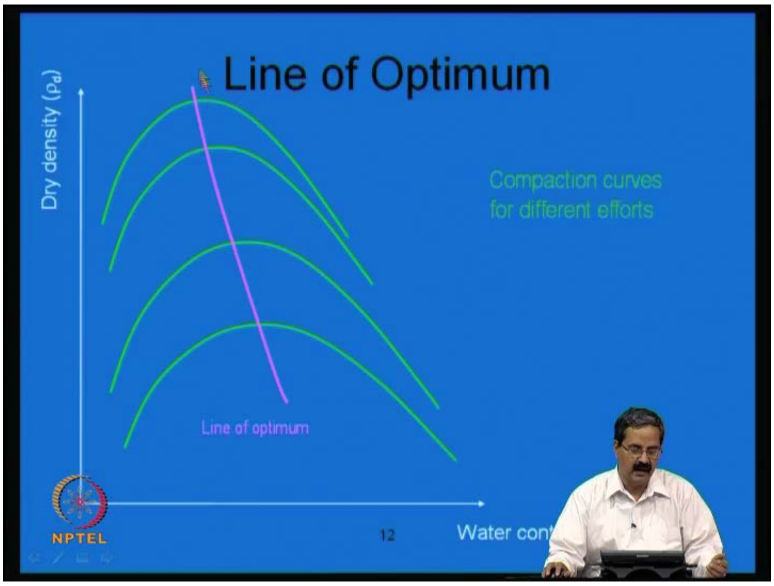

And there is another important point that one needs to understand, that if we increase the compactive energy, say for example, you can have different compactive energies like one can even extend his line up to, like this is a, say for example, the that zero air void line could be even extended that to meet the specific gravity.

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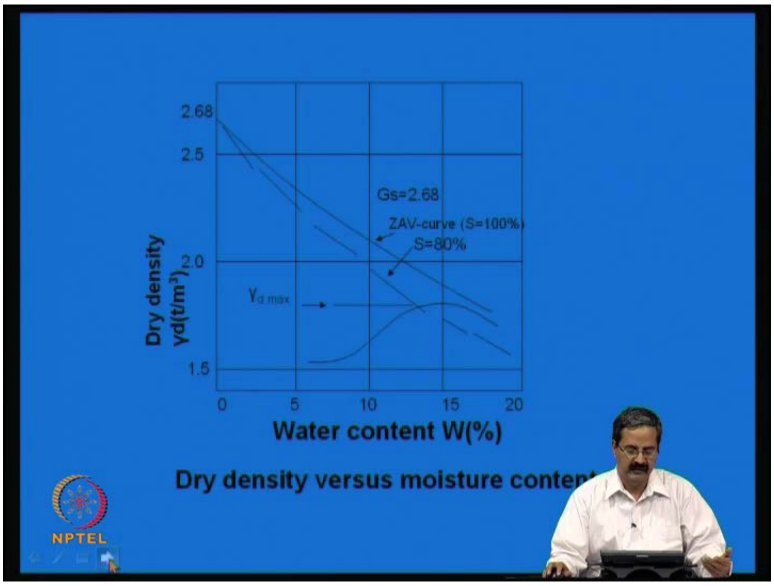

Then, this is another plot just I would like to show, where in this case, for example, it is the actual case, where the degree of saturation in this case is about 80 percent, which means that, in this the optimum lies somewhere between 80 to 100 percent, so this is what we understand, from may even in our lab we will see this some of these things.

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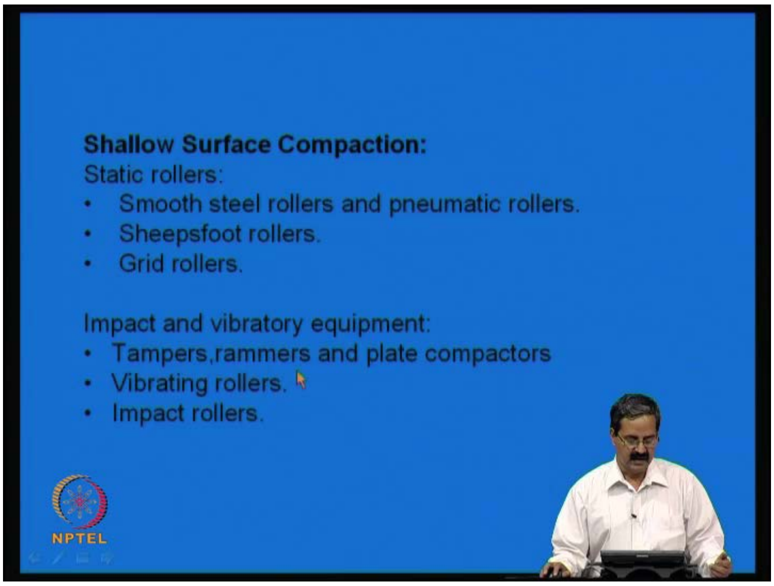

And to achieve this in the field, you have number of techniques, we call, what you call static rollers, then we have smooth steel rollers, pneumatic rollers, sheeps foot rollers, grid rollers. Then one can go for impact and vibratory equipment, where you have tampers, rammers, plate compactors, vibrating rollers and impact rollers. And these are all the different types of rollers, like it can be a simple impact roller and this another road roller type that we see this is a sheeps foot roller, and this is a drum roller, this is impact loader, so varieties of equipment are possible.

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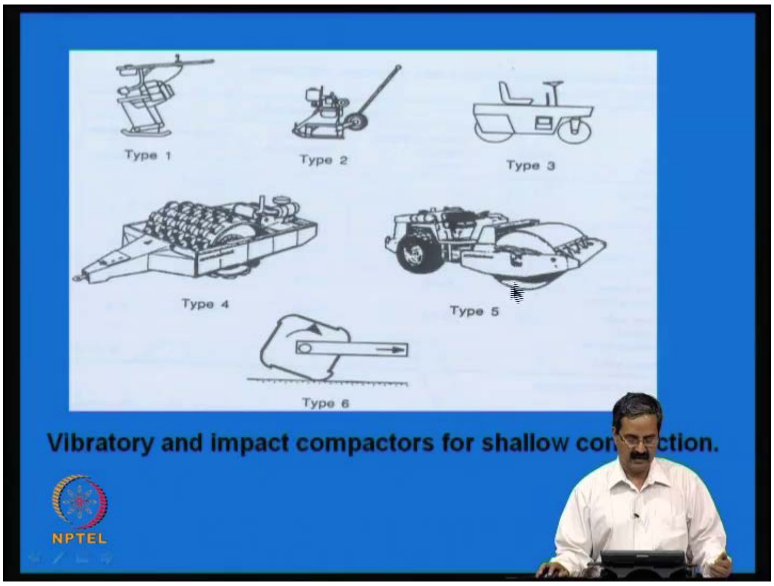

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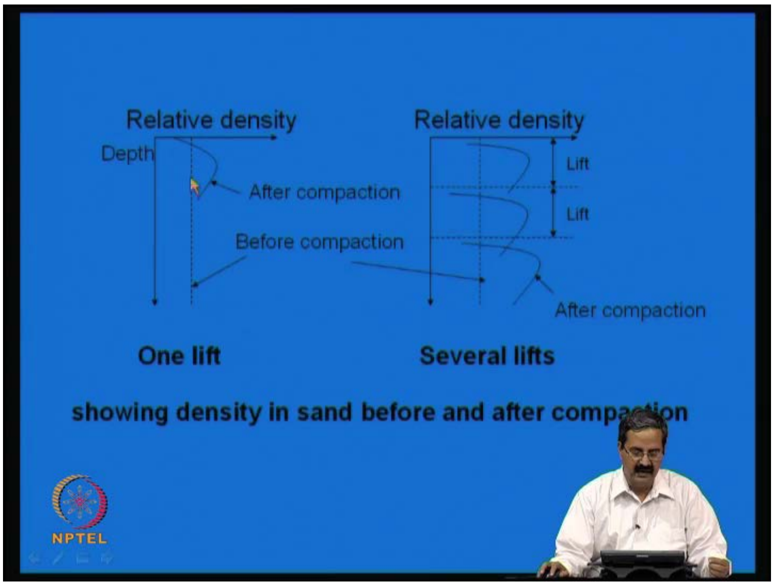

Here, what we do is that, the advantage actually you must have used, specify normally based on the laboratory test, the compaction specifications you give, and you make one, do some rolling, and then this is with definition depth. Then you specify some density, and you have to specify some density. And actually assuming that if this is as minimum before compaction, there is some density of 16 kilometer per meter cube, and if you compact it, you will have a density like this.

So, one needs to really see that, the for example, you must be able to specify some number here for which the density is same, more or less same, that is the objective here, and that has a specific thickness here like the depth. And it is very important to specify that depth also, that is a reason, the function is that, the objective here is that, the density has to be same everywhere. What happens if the density is not same everywhere, and if there is a loose density, the probability is that, that is going to be a week zone, and we do not want week zones in the case of dams and other important structures.

So, you normally try to do this by calibration the field, like you have already some rollers, try to take somewhat is before compaction, you have some density and try to take some samples at different locations, and then say for example at 0 .3 meters, 0.6 meters and 0.9 meters something like that, and you see where is the density. So, one can really come out with this compaction lift thickness specification, could it be 50 centimeters or 30 centimeters or whatever, you normally specify like that in the field, it depends on the compaction effort or the type of compaction equipment you have.

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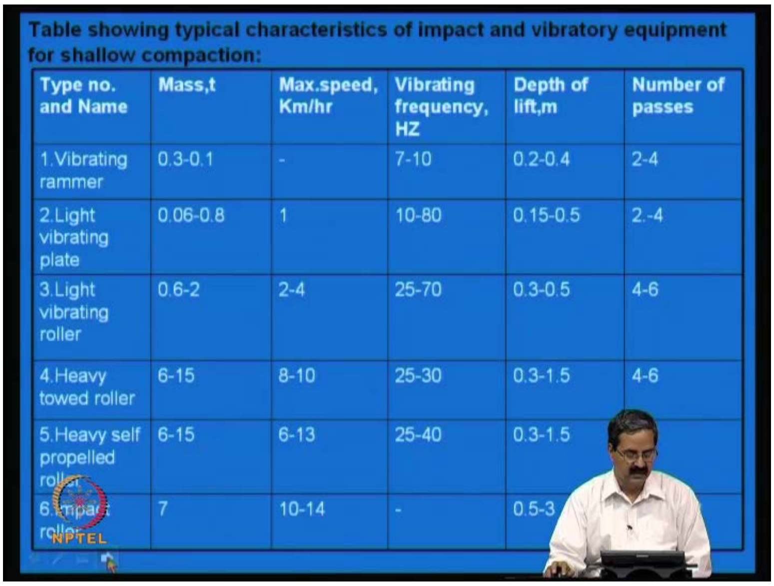
Table showing typical characteristics of impact and vibratory equipment for shallow compaction:

Type no. and Name	Mass,t	Max.speed, Km/hr	Vibrating frequency, HZ	Depth of lift,m	Number of passes
1.Vibrating rammer	0.3-0.1	-	7-10	0.2-0.4	2-4
2.Light vibrating plate	0.06-0.8	1	10-80	0.15-0.5	2.-4
3.Light vibrating roller	0.6-2	2-4	25-70	0.3-0.5	4-6
4.Heavy towed roller	6-15	8-10	25-30	0.3-1.5	4-6
5.Heavy self propelled roller	6-15	6-13	25-40	0.3-1.5	
6.Impact roller	7	10-14	-	0.5-3	

And to give an idea of that, you can have that, you have 1, 2, 3, 4, 5, 6 refers to the type that I showed you in the previous thing, these are the respective weights, and this is the frequency of those machines. In the depth of lift is given here, 0.2 to 0.4 meters, 0.15 to 5 meters, 0.3 to 0.5 meters, so this. And then, even a one can, if you have a heavy towed rollers, you can even go as 1.4 meters, and even impact rollers, it could be 3 meters, which means that one can really like depending on the type of equipment that you have, one can the thickness of the lift could be different, so one needs to really calibrate this in a proper way, and of course this also depends on the numbers of passes. As I just showed you in a previous diagram, the number of passes in the range of 4 to 6 could be reasonable in most of the cases. Once you get those numbers of passes, what we will see is that whether the density is satisfactory, or whether it is say, for example, finally again you must be able to do a shear strength test or a compressible later, and see if it is satisfactory.

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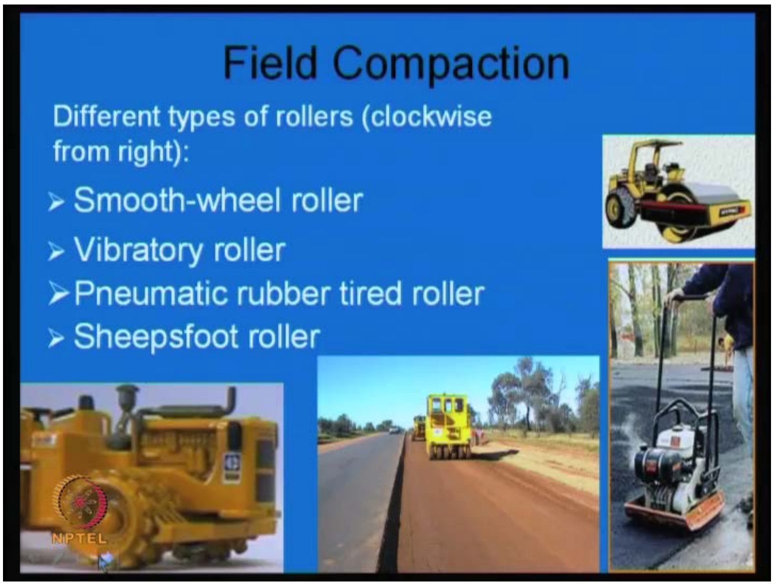

So, in the case of impact roller, it could be much higher like has as high. So, you can see varieties of figures here, like this is the smooth wheel roller, this is a vibratory roller, this is a pneumatic rubber tired roller, you can see that rubber tires here, and this is a sheeps foot roller.

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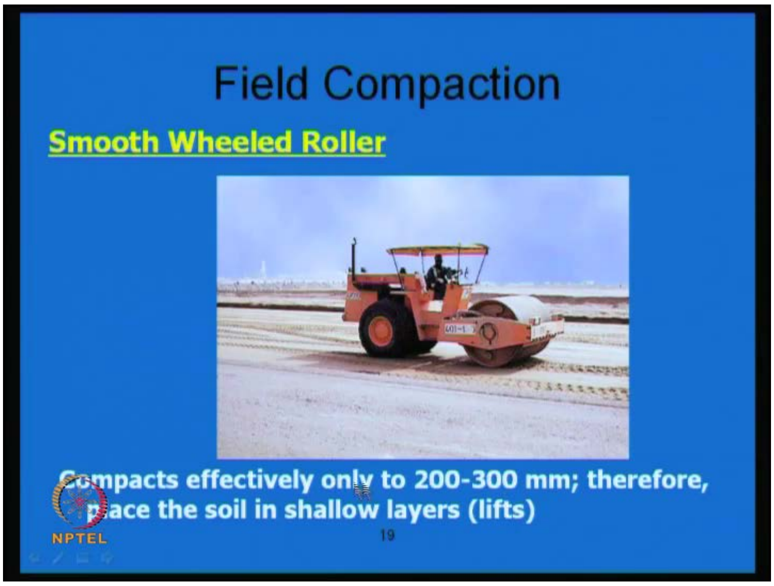

So, essentially, these are all some of the equipment that we have in the field practice, and one should do this, take and this is samples from this places, and then try to find out its water content and the density and to see if the sample that we have has the required properties. in This is in the case of smooth wheeled roller that we see normally in many places, and it compacts very a effectively to over 200 to 300 mm, and therefore it is very good in for shallow compaction.

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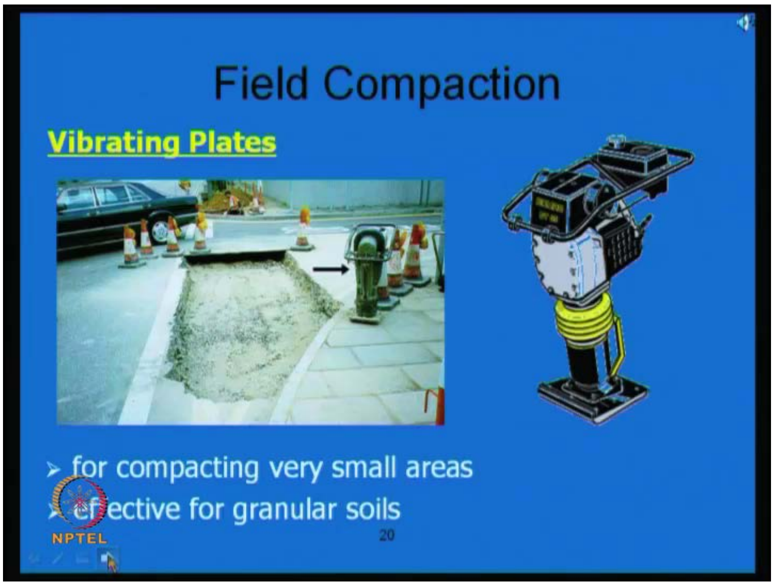

And vibrating plates, for example, for compacting, say for example, close to a parking lot, you can take this particular thing and then compact it.

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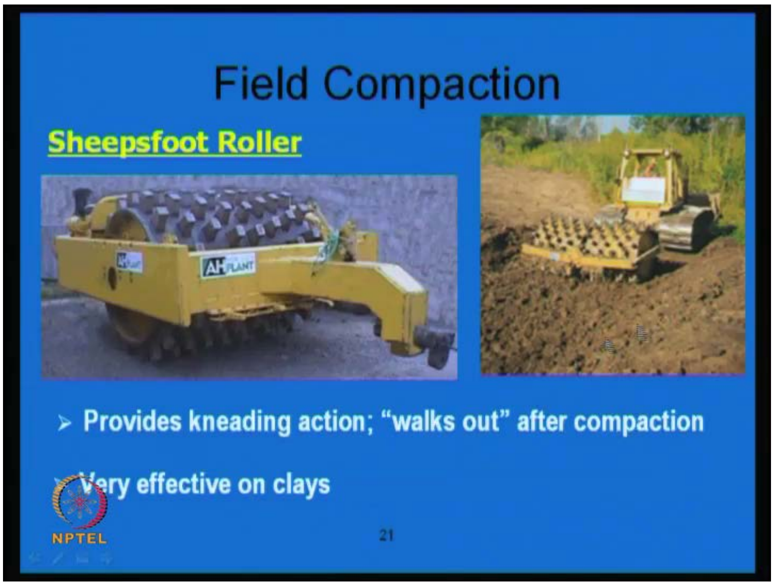

And sheeps foot roller is something that is very useful in the case of clays, remember that it provides a kneading action, like it just walks out after compaction it needs, very effective on clays.

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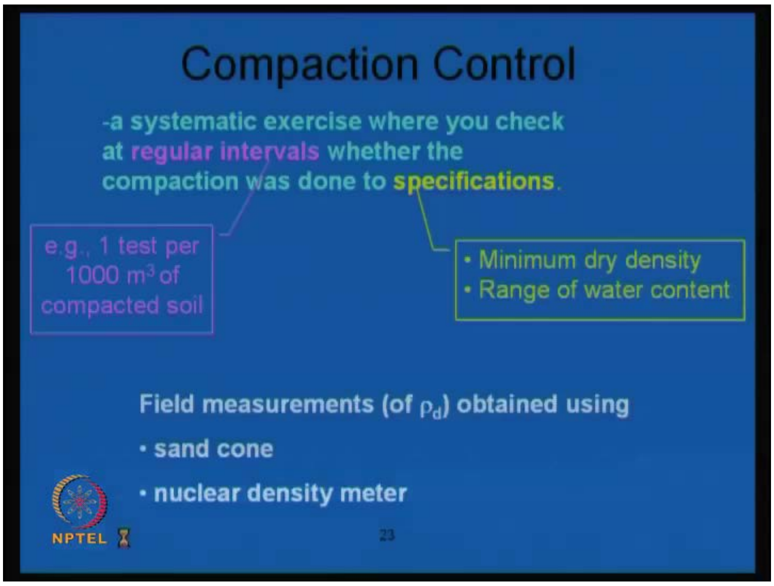

And the impact roller is something that also is very useful, but the number of rotations required is very huge, and provides deeper compaction, which is quite useful. In this what we essentially need is that the compaction we try to measure, and you must be able to really have good compaction control, this is essentially an exercise, where it check the compaction, whether it is satisfactory or not at regular intervals. And then there could, standards specification should be like this, like say for example, if you have 1000, one test per1000 meter cube of compacted soil, or it could be at 500 meters, for the example in a national highway, you should take.

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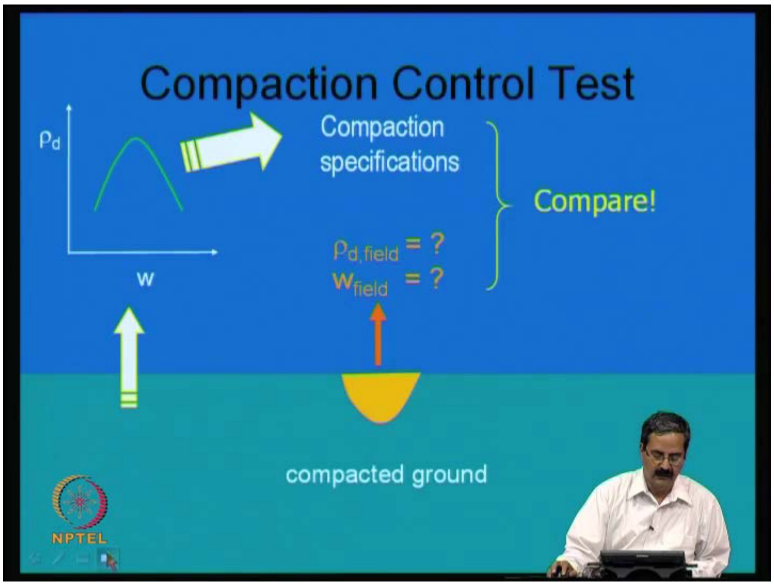

So, this is what i just meant, like you take a sample and this sample here, then what is its water content density, you try to compare with field specifications, that is what we do. And if you there is some more criteria into that, which we will be able to understand little latter.

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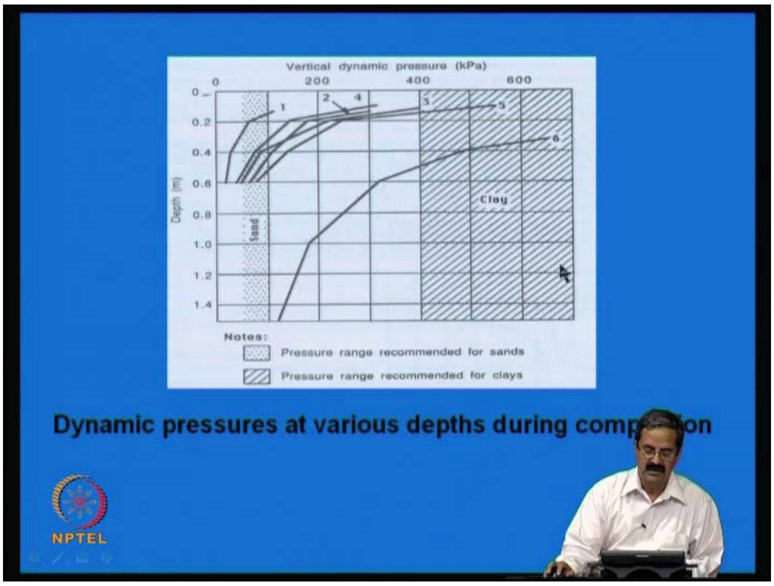

The advantage here would be that, whether it is a clay or sand, one should remember that the dynamic pressures that are induced into the system are different depending on the type of material. Say for example, in the case of sand, the vertical dynamic pressure induced are less, and in the case of clays, it is going to be higher. So, this is an important point, because if you are trying to choose an equipment that can only give low energy inputs, it may not be very useful. For example, in the case of sands, if the simple equipment which has low energy inputs cannot be chosen, and it can be chosen, whereas in the case of clays, you need to have higher energy inputs, which is a useful consideration here.

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Before we proceed further, we must be able to understand the properties of compacted soils. What it means is that, what are the properties of the soils that we have to see, and how do you really see the effect of compaction. As I just mentioned, we are looking at the increase in shear strength, reduction incompressibility and reduction in permeability. So, people have been trying to look out to what extent, see this is unless you understand the compacted soil behavior, we should not be able to, we cannot comment on the improvement and so we will be able to see some of them here.

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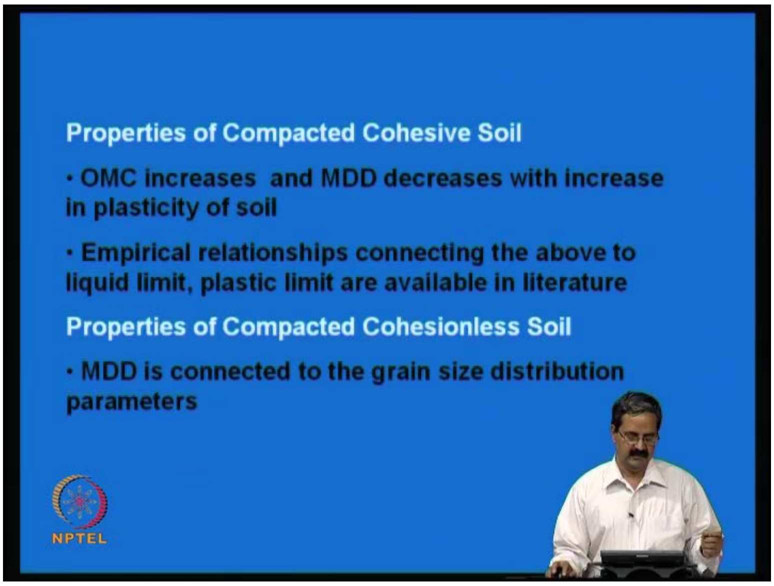

And one of the important characteristics that affect the properties of the, or the response of the compacted soil is that the type of soil itself. We must have a clear demarcation with reference to cohesive soils and sands. Say for example, in a compacted soil, we are only looking for optimum moisture content and maximum dry density. And if there are different types of soils, what is going to happen is that, as the OMC increases and maximum dry density decreases with increase in plasticity of the soil. You have number of soils in the construction of roads; you should be able to understand that this particular feature. One thing we know that, is that, with increase in compactive energy, the maximum dry density increases, OMC decreases.

So, apart from that, with regard to the nature of the soil itself, one should be able to know that OMC increases and MDD decreases with increase in plasticity of the soil. Say for example, if you are looking for a the higher density, then you should go for a less plastic soil. Say for example, the plasticity in the sense, liquid limit plastic inlet, plastic limit and shrinkage limit; these are all we say that the limits on which one can classify the soil behavior. In fact, there are some equations developed in literature to connect the liquid limit, plastic limit, to say for example OMC or MDD.

In fact, one can do this also in a big construction project, where you do what the advantage of this relationships is that its plastic limit, say for example, we know that the plastic, the red soil that we test, the plastic limit of the soil is say 23 percent plastic limit, and then the OMC is20 percent, so you can say that the OMC is p l minus 3 percent, so this is an empirical relationship.

So, like that for many soils people have developed relationships based on lot of experiment studies, and they are very useful in quality control programs, and trying to cross check the data that you have. For example, the liquid limit as I just mentioned higher is the liquid limit, higher will be its OMC.

Like we have observed, say for example, in the case of black cotton soil, the liquid limit is about 80 percent, and the its plastic limit is about 33 percent, then it is OMC will be about 30 percent. So, you can see that there is a good relationship between the plastic limit and the OMC, and the even the liquid limit index of the soil also. People have been able to relate these limits as to even to dry densities that one can use, and of course these empirical equations need to be treated with caution. And one should develop site specific equations or they may be useful for some cost seeking purposes, but it is very essential to really conduct in all the test results in a proper manner. And one is not a substitute to other, say for example, if you have only plastic limit, you should not stop doing an OMC compaction test. There is an equation available, but you should check it does not mean that one should really use only plastic and get it's OMC.

One should really check what this relationship is, and may be the relationship is useful, you can just; it can be a checked nothing more than that. So, this is in the case of compacted cohesive soils, and in the case of corrosion less soils, and even flashes and the other things, the maximum dry density is connected to the grain size distribution parameters, because the grain size distribution means d 10, d 60, d 90 and all those parameters. What we do is that, we try to, say for example if it is a well graded material, d 60 and d 10 they have some ratios, or d 90 and d 20 they have some ratios. Or say for example, if this material is not well graded, they are same, they are in the same range, like that is what it means.

So, the grain size distribution characteristics, if they are they are related to maximum dry density, why because, if the density of packing is very good, what it means is that the bigger particle have a bigger wide, so if the well there is a well graded material, the small material get into that, and then there is a good packing, and then it will have a very good relationship with grain size characteristics.

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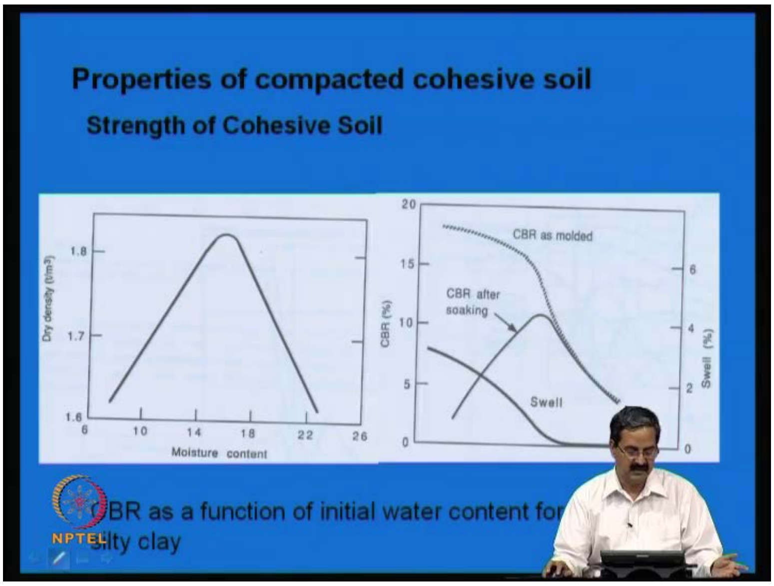

So, these are all in a simple way, some of the aspects that one needs to examine when you are looking at the properties of compaction. There is another important relationship, because we know we do compaction, and then we should know, say for example, you got a compaction curve like this, then what is it is implication? What does it mean?

So, like if 06 to 26 percent there is a water content here, so if you are able to, say for example, this is the water content at a very dry state, and the CBR is about 17 to 18 percent, and then as water content is increased, CBR comes down. But then, you can also do a socked CBR after testing, which means that like you can take samples here, and then soak them, and then do a CBR test, and then soak them. Like for example, what it means is that, this value after soaking has come down this much. So, initially, it may be in some cases what happens, if the soil is very dry, say for example 5 percent water content, you will get a very high CBR. The moment you soak for four days, this CBR comes down to 4 percent, this is a very risky.

Whereas, in some other soil, which is compacted well and all that, and as close to this case. For example, the in this area, the soil has maximum density, and water content is also optimum, and all that, the difference between CBR in the molded condition as well soaked condition is going to be less.

And after that, see this line almost, the degree of saturation is going to be close to 1 or 0.8 or something 9, so the thing is the differences or minimal, whatever; this is a simple example, but you do not they do not need to coincide here, but then one can say that the differences in CBR of as remolded and soaking are very important, and then that is the reason why you need to really compact the sample very well, so that you will not have a very big difference between a molded or and then soaked values. The another important thing, like if you do not compact well, what happens that there is if the moment you add water, in particularly in some clays, there is a tendency for swell, so thes well potential also comes down as the water content is increased. In the case of low water content, the swell is higher, but as it is close to OMC and other conditions, the swell is minimum, and as higher water contents are added, the swell is going to be minimum, so this is a very important aspect of the compaction.

Why we should do the compactness, only because of this reason that we do not need to have abnormal changes in water content or the shear strength. CBR is a measure of shear strength of the soil, is it not, so the CBR in fact represents the penetration resistance of the sub grade, so you should see that that penetration resistance in socked conditions and unsocked conditions is going to be less, or if it is more, it is we should only take the socked strength in design considerations.

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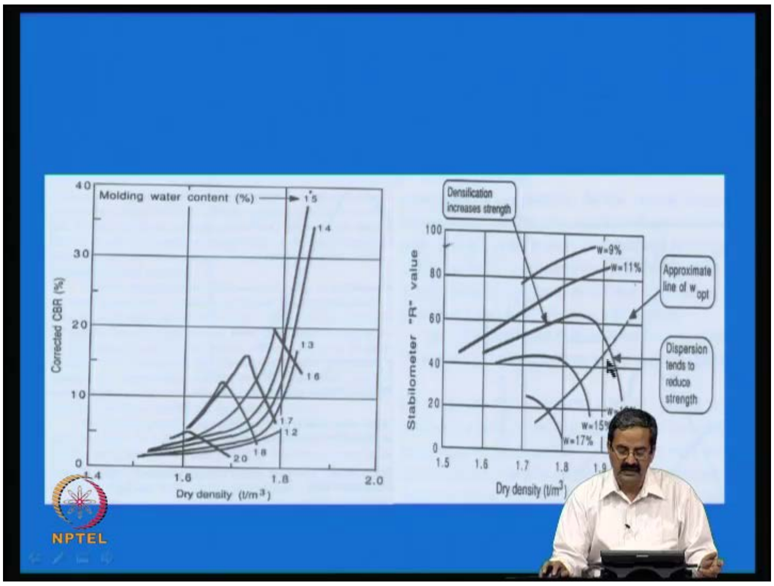

Then, there is another important point, like you can see that the CBR versus the molding water content, for example, the molding water content is nothing but the water content at which you prepare the sample. as about This is 15, and this is 14, this is13, 16, 17, about 20, you have different degrees of different water contents here, and you can see that the responses are different, like the if you do a CBR test, CBR is a penetration test, so the strengths are least when the water content is going to be very high, like 20 percent. But, you can also see that the strength is very high, like as CBR values is about 30 to 40 percent, when they if it is dry condition. So, this is some implication that you need to really understand, the variation of a CBR as a function of molding water content, water content, the water content which you test the samples.

This is another important point, like on the same during, there is another test called stabilometer R value, we actually we use this in payment engineering where this also gives the resistance to penetration, some resistance or the strength parameter similar to that. Where one can see that as we in the case of dry state the water content, you have the values in this range, and water content like this is 9 percent, this is 11 percent. And as the water content is increased, you can see that the, it is somewhere, the it as a low values.

This plots, are they increase, they in fact they show you the line of optimums. In fact, if you draw an optimum curve, it could be somewhere here, and these are all the lines of optimum values. So, one more thing is that the dispersion and the compaction, like you know if this will be in the wet site of compaction, if the soil as that the dispersion structure, what happens is that it is easier to share, whereas in the case offlocculated structure, the strength is going to be little higher. So, when the water content is same, the shear strength is going to be higher in the case offlocculated structure type of soil, and whereas in the case of dispersed structure, it is going to be less; this point one needs to realize as the same water content.

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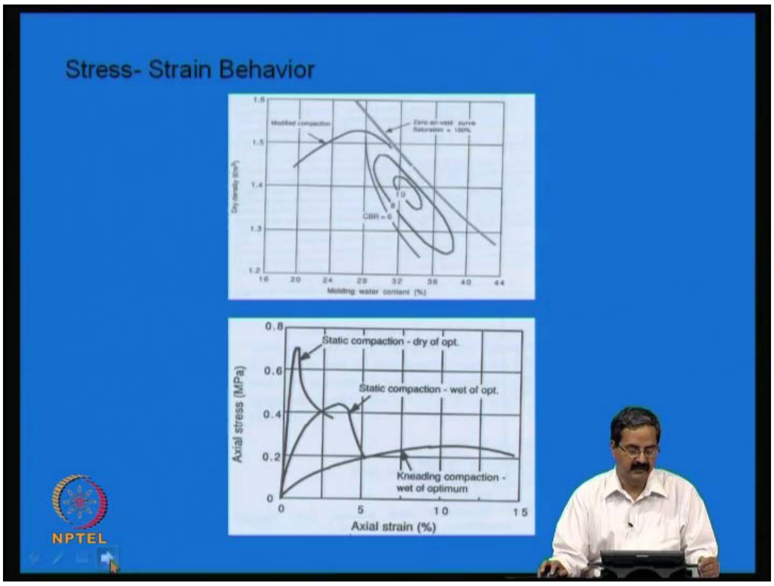

There is another important point like the you have the effect of the compaction on the stress and behavior. Say for example, if you do a good compaction, and then have, this is the actually close to a compaction curve, you have plotted a zero air void line, and you also have this particular thing, so you can see that, as we here somewhere it is about, CBR is about 6 percent, its 8 percent here. And as you go to this side, the CBR value is going to be higher, like that is what this shows. And actually these are all some set of results one can get, any set of results depending on the type of soil that you have, these are all indicative with the method or the indicative of the significance of compaction.

Then, the another important point that we need to understand is that, how is that stress and curve going to be different when the soil is compacted to needing static compaction and then the dry of optimum, wet of optimum. Say for example, here we can see that in the case of needing compaction, the wet of optimum where the water content is going to be little higher, the need the shear strength is somewhat like this stress and responses like this, where it is somewhat flatter.

Whereas, same soil, when it is compacted and in the same range of water content, the you have a better, I mean better stress and curve, in the sense that the stiffness is higher here, like in the case compare to this stiffness here.

So, whereas, the same soil, which is compacted to dry of optimum, you have much better curve, what it means is that, the compaction, the type of compaction as a significant influence and also the straight of compaction, whether it is a dry of optimum, or a wet of optimum, it has a big difference in influencing the type of the stress and response.

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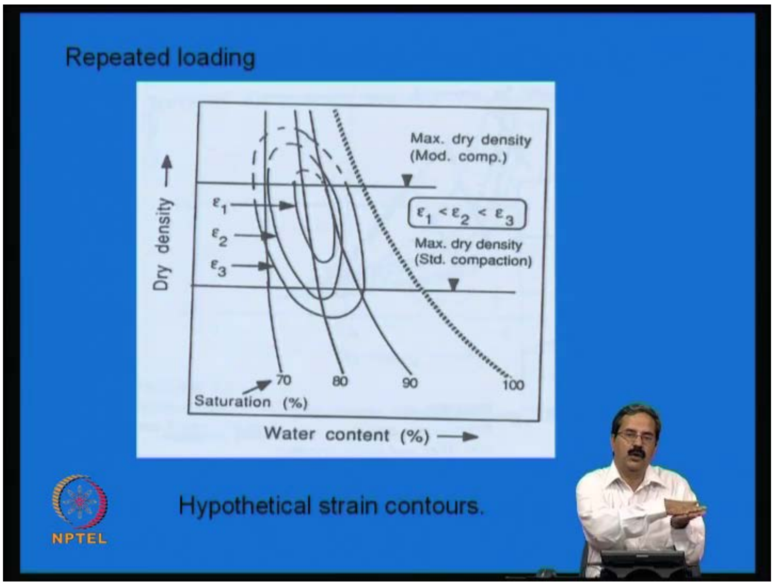

This is another important point that one needs to understand particularly with reference to its compaction curve, say for example, the compaction curve will be somewhere like this. So, one can calculate the shear strains in samples, like the, thing is, why we are doing compaction is that we will have a higher shear strength, which means that the shear strain at any level have to be lower. so like Actually, this is some result from published literature, in which, the used repeated testing like cyclic triaxial test they have used, in which you would be interested in knowing what are the strain levels. Say for example, if I am talking about a payment structure, the repeated loading that you have, the shear strains it will introduce number of traffic simulations, for example, it is a 100 million standard axel loads or 1000 million standard axel loads, it has a big different. And then it introduces some sort of shear strains into the system, and when is the shear strengths going to be minimum, or what is it? we If you want to understand from compaction behavior, one can see that, say for example, if I just say this is E1, epsilon 1, the epsilon 1 is least in this region, which is nothing but it is close to gamma d and OMC region, which means that if you do good compaction, the strains are going to be very less, and we should take advantages issue in the case of payment design.

Like if you are trying to understand any of the phenomena like rutting and fatigue in pavements, strains are very important. The moment the strains develop what happens, you will see the formation of ruts, then after that it leads to part holes and all that, so you do not want to do that, so that is a reason the compaction as a very big influence in the case of pavements. Of course, to all the geotechnical structures, it is very important, but some of these things will be very evident in the case of failures, in the case of payment.

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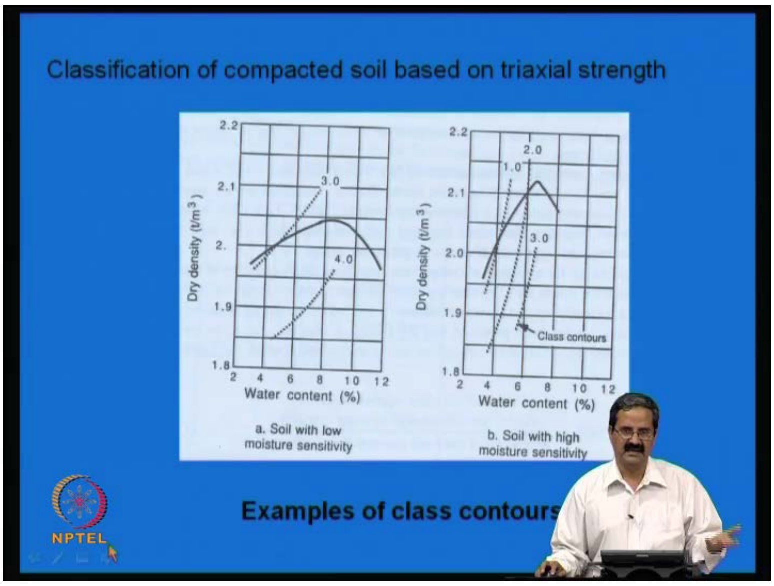

In fact, in some places, people try to classify soils based on their moisture sensitivity, like as I just mentioned in the previous examples. We saw that the water content has suppose a particular soil has lot of tendency for strength variations we say that it is very sensitive, and we should worry about that type of sensitivity.

And in fact, in an Australian research, they have classified that in terms of a some particular number, and then they came out with, for example if I have a compaction curve like this, the sensitivity numbers are plotted here, so it they are nothing but some ratios in which 3 indicates a good material, and whereas 9 indicates a poor material, like the material is subjected to lot of variations in shear strength, as result of variations in water content it means. So, you will normally have a in the range of 3 or 4, or 2 or something, it is supposed to be a good material. You can see that the soil with low moisture sensitivity is like this, soil with particularly here, these also like another example.

See the actually what it shows is that, the shape of the curve itself, shape of the curve here, you can see that the shape of the curve is something like this. So, the even the shape of the curve tells you about the changes in share the density with respect to changes in water content, it is very important that one should really get the compaction curve properly, as nicely as possible, because this is something very important particularly from field control, and also to in trying to understand what is to, what extent soil is sensitive to changes in water content.

So that if you want to specify that soil, it should have a good basis, otherwise we have seen some soils where after some compaction, they have lot of, they become like shear strength is so low, that it will be a problem.

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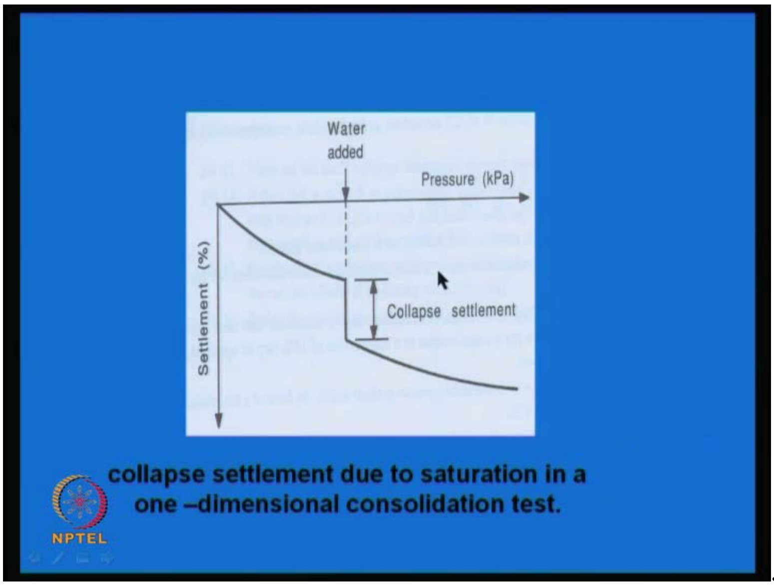

Then one important point that one should realize is that many of this soils have a tendency to go for collapse, say for example, they as I was just mentioned, the compacted samples have unsaturated soil component like air is present in the soil. So, if you add water, what is going to happen is that air is removed, and soil becomes totally saturated, and this becomes the saturated, but then there is a collapse that leads to some changes in settlement.

Say for example, some mm of the settlements could occur, in fact I must tell you an example here, about some time back I visited a particular plant in close to one of the costly areas in Andhra, they laid a raft foundation, and the thing is that that raft foundation was constructed last year in the month of May, and then it got, then it was given clearance.

But after that, as there was severe rains, and then the rains were so much that there were four days of inundation in the whole area, and settlements after that they measured, settlements are the order of about 170 mm or 200 mm, which means they are now even wondering. Because for a raft foundation, the allowable settle, the total settlement is 100 mm, but when you observe settlement of about 170 mm, you will be worried whether things are ok or not, whether the problem is of the compacted was the compaction is good there, there are so many issues.

So, it leads to lot of problems, because they did not realize that the collapse is one of the reasons, possibly they would have, in the beginning itself they should have allowed all the area after compaction for wetting, so that this could have not taken place, and they would have really gone ahead with the construction. Now, even now people are worried whether they may construct high, they may place lot of machinery there, whether the raft foundation is going to be stable, that is a question.

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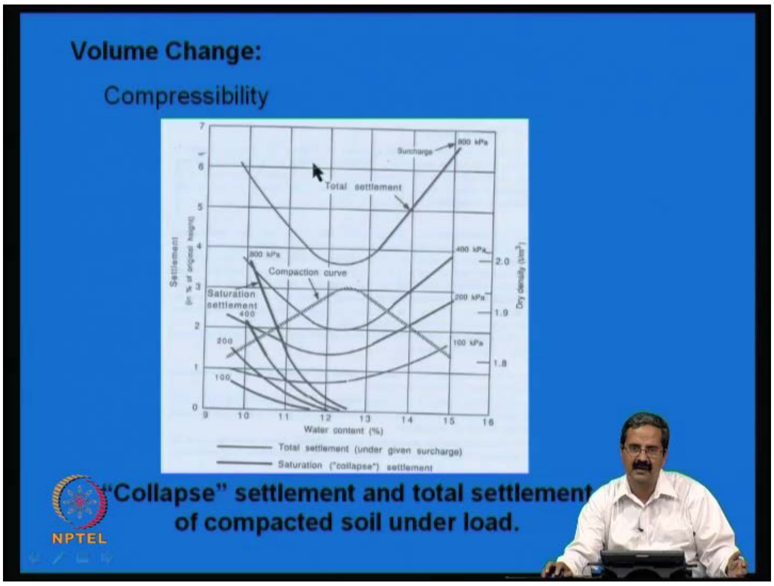

So, to continue about the same aspect here, what you saw I would just earlier was about the influence of compaction. And what is going to happen to strength, and if there are variations in the water content, how this strength is going to get influenced and all that here, in this some more information, like say for example, one can do this in the lab also, like you have a soil, and then you have a compaction curve like this nicely, and you have100 kPa, 200 kPa, 400 kPa, 800 kPa, assur charge pressures, like you do a consultation test. And the thing is that the you can have a sample set, say for example, you can take, this is a compaction curve, so you can take a sample here, and then put a surcharge, then you measure the settlement. The settlement is about, here the settlement is given, it is about some units like 6, in actually in some 6 percent or something, whatever some units are here.

So, definitely you take a sample here, and then apply a pressure of 800 kPa, it will have very high settlement, because pressure is very high. Then same sample if you have only 100 things, the settlement is little less, like it could be just in the range of about 1.5 percent. So, what it means is that as you apply load, see these are water content at which the material is there, so 10, 20, 30, 40, the settlements are going to be higher. So, that is on the wet of optimum.

On the dry of optimum also, like you take this particular material, and settlements are there, like say for example, so what it shows is that settlements are expected on any side, but close to this OMC and gamma d you can see the trough here, the valley type, sorry valley, in which you can say that the total settlement is minimum, like it is in the range of about 3.5 percent compare to any of these things, you now like you can see here.

If you take 400 percent, the settlement is here, like say water content is about 12 percent, the density is about, density of course whatever density it has the settlement is minimum, so you can see that if you are able to close the compacted sample close to its optimum moisture content and density, the settlements are going to be less, this is a very important implication here like.

On the other hand, you can even see the collapse, say for example, as I just mentioned the case of one example, where there is lot of inundation and then it led to collapse and the collapse. Collapse increases as the load is higher, say for example at small loads to collapses may be less. Say it is at 100 kPa, the collapse is hardly about less than 1, but when the pressure is 200, it is about 1.5. So, as the load is increased, like I showed you one diagram in which you actually you take the sample in the consolidation test, then apply 100 or 200 kPa, add water, it just collapses.

So, measure the difference in the height, and then calculate collapse so that collapse actually is very high in case of 800 percent, 800 kPa, actually it is about 3.5 percent when the water content is about 11. See the case at 12 percent which is close to OMC, this value the collapse is very less, so what I want to say is that the compaction has a bigger role in many of this engineering response, one should be able to compact the soil very well close to its maximum dry density, and whatever is measured in the laboratory and that should be put into the field.

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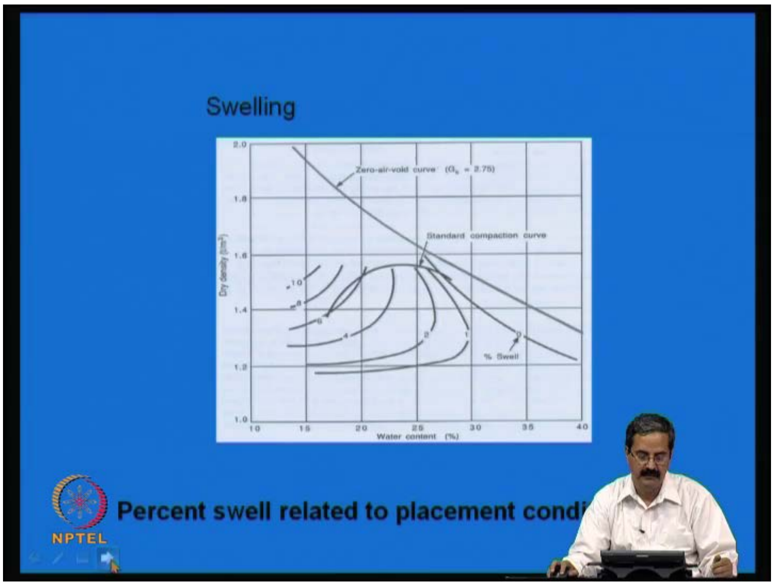

This is another important point related to swell potential, like the swell potential can be measured like you add you take a set of a sample in the consolidation test, allow add the water, allow it to swell, so you will get some swell percent difference, like say for example 3 percent or 4 percent, or whatever, so that is a vary again. May be in some cases it causes collapse, in some cases it cause swell also, it depends on the type of soil.

So, you can see that when this is a standard proctor curve, and you have the compaction zero air void line here, and the water content in the range of 25 to 30… Like this is 0 percent swell line, see, which means that I have taken the sample and set up and added water, then still there is no swell. It is a very interesting result here that close to the degree of saturation line, and then close to OMC, you do not get good, there is no swell at all.

But then, if we just move little down, like say for example, the if the degree of saturation is little lower, and say for example, if the densities are also going to be little on the dry side, you can see that, say for example, it is 0 to 1, 2, 4, 6, 8 and 10 percent swell, you can see that, the tendency is that there is a tendency for soil to swell also on the dry side, particularly when the degree of saturation is lower.

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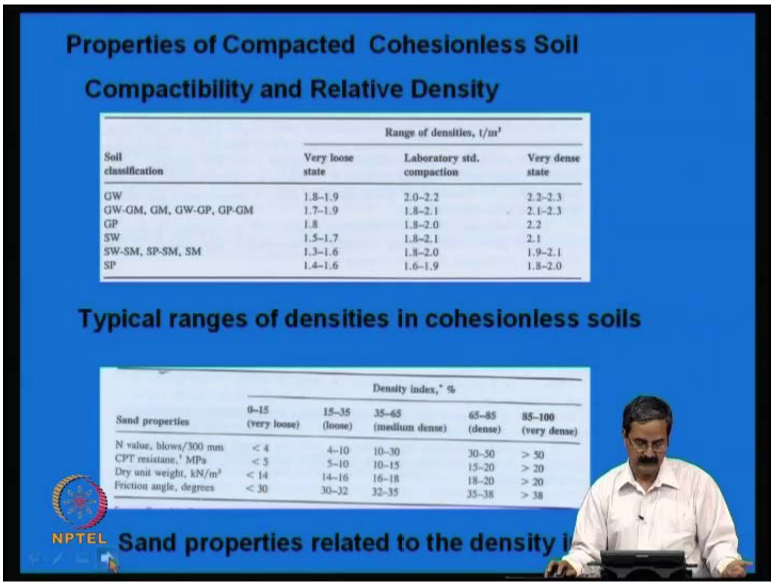

So, these are all very important point, because these are all …very the one of these the why we should do compaction is what we understand from this. Then, see the thing is that the one should be able to have a rough idea of the type of soils that one can have on the relative densities, for example, well graded gravel, lose state it will have this sort of densities 1.8, 1.9, very dense 2.2, 2.3, whereas poorly graded sand like 1.4 to 1.6, it could be 1.82. So, once should to have an idea of that, to it depend on the laboratory compaction, say for example field compaction. There could be many categories and depending on the type of soil that we have, depending on particularly in the case of corrosion less soils. Like these are all corrosion less soil, and you must be able to identify the densities that you get.

Say for example, if somebody ask you what should be the density that you are expecting, you must be able to say these numbers, otherwise you are not considered to be a very good engineer, particularly when you are trying to do field control.

Very important point in this is that the densities are related to, say for example the definition of relative density or a density index in which you need the what is the density, what is the minimum density, or what is the maximum density, based on that you use you get the density index. And say, the densities in the range of 0 to 15 percent, if we have, you say it is very loose, and 15 to 35 it is loose, medium dense, then dense and very dense. So, then why is it so, if you are able to really have this information, you can say what should be the N value, you can expect particularly in SPT value, something that is very important in field response, if it is a very dense material, the SPT will be in this dense - medium dense 10 to 30, or if it is very good, you say more than 50. CPT is also same thing, CPT value is another important variable, like you do so many institute tests for quality control of compacted soils that we will see, where you try to measure the SPT values or the CPT values and also sometimes friction angle, you take it to the laboratory and then measure its friction angle.

You can see that the friction angle also is quite big, like say for example, when it is a very dense systems, it could be 38 percent, whereas in the case of loose materials, it could be less than 30, base on this alone you may tentatively suggest a few things that in this particular side, i think that the compaction was not good may be, or you can say that the density that you are getting, since it is a well graded gravel, if the density should be little in this range, and not in 1.8 to 1.9, because I expect that there is a good compaction.

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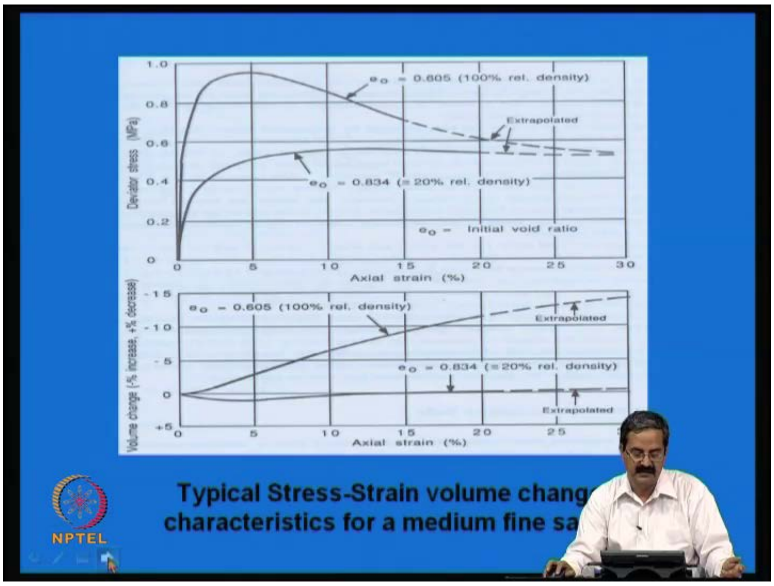

So, like that one can make some observations, and say that one can comment on the results. So, this is another important point, where you have, say for example, typical example of stress and curves indicates of how the void ratio, e naught is the void ratio; relative density is 20 percent, and relative density in the case of its see it is very high, say void ration is 0.834, in this case, it is 0.605, void ratio of the sample at which it is tested.

You can see that it is a very strain, we know that, we studied in basic soil mechanics that there is a soil is loose, it will have a behavior like this, if it is dense sand, it is like this, is it not? So, what we see is that you will get a very good understanding of what type of densities you have, what type of responses you can have in terms of the stress strain, and so this is very important from field implications.

Even in volume change also you can see that the volume change has not been much in the case of very dense system, whereas in the case of loose system, the volume change is about, say for example, if you go to maximum strain of 30 percent, it is very high, about 15 percent, so the axial strains are also very low in the case of dense system.

So, what is important is that the compaction is a very very important variable, and very I mean it has a significant influence on engineering performance, whether it is shear strength, whether it is compressibility, whether it is swell behavior, whether it is collapse behavior, whether it is stress strain response, whether it is moisture change, susceptibility to moisture changes also, one needs to really look at it into very carefully, and see that this is all implemented in the actual practice in a proper way.

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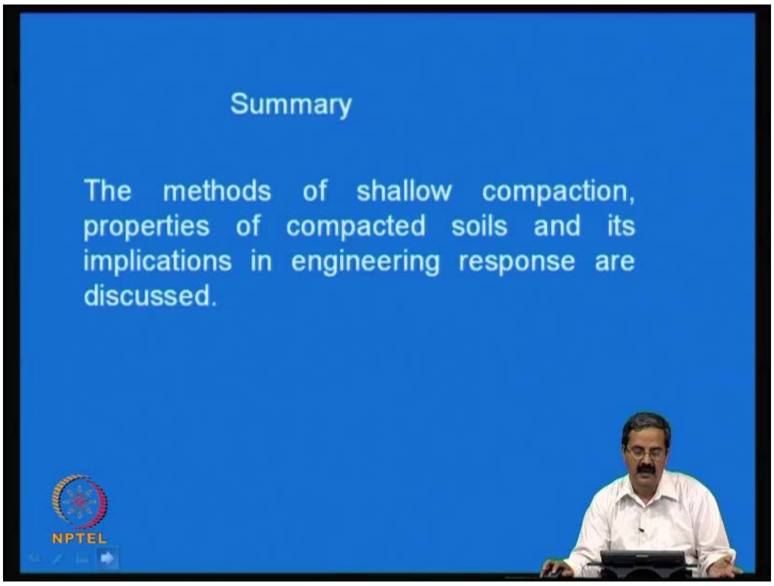

So, there are some more points that I should mention, that normally we do a compaction test for the material passing through 19 mm, but if the material is higher, say for example, in the if lab is different and the field is different, the codes have some way of mentioning, that should be corrected. Because, to what extent the field, the laboratory curve is relevant to field, you should be able to correct for the grain test characteristics available in the field also.

There are some methods prescribed in literature, where if the percent say you normally through, you select say particular grade of material for compaction. So, if there is that grade, if you go to the field and find out that that material is only 50 percent possible, then you have to appropriately correct the maximum dry density and OMC. There are some methods available and that is another important variable. Another important point in this compaction is that, the when you do the compaction in different layers, there is a possibilities of formation of week zones, like see, you are expecting, you say that I am constructing a homogenous embankment of 10 meters or 5 meters or whatever, and there is that 5 meter embankment is came in, lifts up a 0.5, 0.5, 0.5, 0.5, like this.

And see at each 0.5meters thickness, there is, you must be able to see that both layers are very integral to each other. Then what otherwise, what is going to happen is that if you do not have proper info like, so you to use proper scarifies in the field, and then see that they are interlocked properly, so that, that does not, should not form a week joint.

So, for example, the seepage occurs, the seepage could be, the water is easiest to pass, and then if you if there is a dam, and if there is some seepage is coming, and then that should not become a failures of its later, so this is very important that even in the field also, like you must be able to observe many points like the good quality in compaction, and also the way it is constructed, and the proper choice of the compaction equipment, soil, the type of soil, the compactive effort.

And the type of engineering response that you are expecting should be, you should do test typical few tests are to see I am getting, I have a CBR of this, will it be sufficient. If I just change the water content in this manner, say because this is the range of water content that is which the flooding mac, the flood, because of the flooding the material may be subjected to.

So, finally, it should not lead to collapse, so all that needs to be examined in a proper way. And particularly in this compaction, many people know about compaction, the way it can be done, but then actual practice is that it has lot of implications and final aspects into design. And if you do not do compaction properly, many jobs in geotechnical engineering, you can I mean you cannot be done properly, whether it is the construction of shallow foundations, construction of dams or even construction of retaining walls.

Like you know you have to construct behind a retaining wall, the back fill, if the back fill is not properly compacted and then what happens, the pressures and the retaining walls are going to be higher. See other important point that may be in this is it is not mentioned, the say I will tell you the example of retaining wall itself. Like see when the we know that the compaction pressures are like k naught, k naught is minus sign phi, so 1, it is 1 minus sign phi, when phi is going to be higher, say for example, we have just seen, in the case of phi the dense sand, phi equal to about 38 degrees, and whereas in the case of loss material, it is 25. So, 1 minus sign phi is that k naught will be lower for dense material, so a coefficient of at pressure, so that is very important.

So, some of this, no the pressure that it you can induce on the retaining wall would be lower in the case of dense systems, and that is an important variable. So, I feel that the compaction is important variable one needs to study carefully. And we will see how the compaction control could be achieved in the field in the subsequent classes; thank you.