Soil Mechanics

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Lecture - 14

Compaction of solids - IV

Welcome to compaction of solids lecture number. In the previous lecture, we have studied about factors influencing compaction and also introduced field compaction and different compaction equipments. In this lecture, we will understand much about the in depth effects of soil structure and soil compaction. We will be introduced to field compaction equipment and different types of equipment which are available for compacting the soil in the field.

The main determinants of the natural man made deposits are: If you look into it the soil has been transported from one place to another to compact it or make it into a suitable shape of the structure. For that nature of the soil in the borrow area depends upon the grain size that is the particle gradation, the composition of the particles and plasticity, the plasticity characteristics whether soil is in the plastic range or highly plastic soil or low plastic soil or water content that is the natural moisture content at the borrow area.

The nature of the soil content in the borrow area is governed by three properties: one is the grain size that is the particle gradation or plasticity and water content. The transporting arrangement for constructing man made fields basically is also done hydraulically using water in the form of slurry. This fill construction is called a hydraulic fill construction. It is adapted for acclaiming the land in the large areas, for example, over hectares of area to develop the land with a highly compacted soil base. For that this hydraulic fill construction is used.

The soil is transported with the help of water in the form of slurry and then deposited in the desired area and the water is decanted and the hardened soil base is ready for the future construction at the site. Otherwise the transporting agent is manual, by human laborers or animals in some sites or mechanically soil also is transported from one place to another place using the earth moving machinery. This is how the transporting arrangement is done in the man made fields.

The processing and placement conditions are very important for compacting the soil in the field because the processing and placement conditions govern the performance of the structure. Here, if you look into this processing and placement conditions; one is the removal of the some of the constituents. We have discussed earlier that the presence of organic matter can influence the structure behavior. For that what we do is, some of the organic constituents which may cause the compressibility to the field will be removed.

And addition of the other soils for example, a clayey soil some sandy soil is added to reduce the plasticity, cement and chemicals. So some processing in the form is stabilization which we call as soil stabilization where the soils are used as mixers or cement stabilization is also a very popular technique or some chemicals like lime stabilization is also a popular technique.

Another processing and placement conditions are using rolling and compacting devices. We will be discussing this in this lecture. Determinants of the nature of man made deposits are the nature of the soil in borrow area is one category, the second one is the transporting arrangement and the third one is the processing and placement conditions.

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In the previous class we have discussed or introduced the soil structure variation for particularly a clayey type or fine-grained soil. Here in this diagram the dry unit weight is plotted on the y axis and the water content is plotted on the x axis and four different points B, C, D and E. If you consider here, we have discussed earlier that the soil structure at B is different from soil structure at E. So here the soil is having less water content that is W_B is the water content at B and at E the water content is W_E which is greater than the water content at B.

The soil structure we discussed about is that a highly flocculated here and here is in the dispersed nature. When we go to maximum dry unit weight and optimum moisture content we see that the soil structure undergoes a rotation of the plate like particles and transforms that slowly into dispersed structure that is what we have discussed. We will throw some light into this with the explanation between the attraction and repulsion between these plate particles. Then we will compare this with coarse-grained soils and then try to understand why the coarse-grained soil behaves different from fine-grained soils.

Here if you look into it, as the water content is less the pore water pressure is predominantly negative. That is, the water or soil has got a capability or it is sucking more water. The pressure here is less than the air pressure so what will happen is that the pressure is negative. Under exposed atmosphere when air pressure is 0 then the pore water pressure at this particular point is negative. with abundant availability of water the pore water pressure is not so negative, we knew that in the compaction condition the soil can never be reached to the saturation condition. For that case, it is said that the pore water pressure is not so negative by keeping the partially saturated condition for a compacted soil under consideration. These points B, C, D and E actually form a discussion for us where we will see a change or transformation of soil structure.

The transformation of soil structure from flocculent or flocculated structure to a more or less dispersed structure is what we can see here. This transformation can influence the engineering behaviour of a compacted soil. As we have discussed earlier the swelling for a soil compacted in water content B is more than the soil compacted at water content E. That is, in water content E the soil can swell less because already there is an abundant availability of water surrounding these particles or the full development of the adsorbed water layers have already occurred here.

What is shown in this diagram is that the attraction is very very large compared to repulsion here. And as you go the attraction is slightly greater than R and when you come towards the wet side of the optimum what you are seeing is that attraction is equal to repulsion so it is a fifty-fifty situation. And once you reach the farther wet side of the optimum what you are seeing is that the attraction is less than repulsion hence mostly the particles will try to repel. The entire energy that is given is actually going in the form of a futile bumping of the soil at that particular point.

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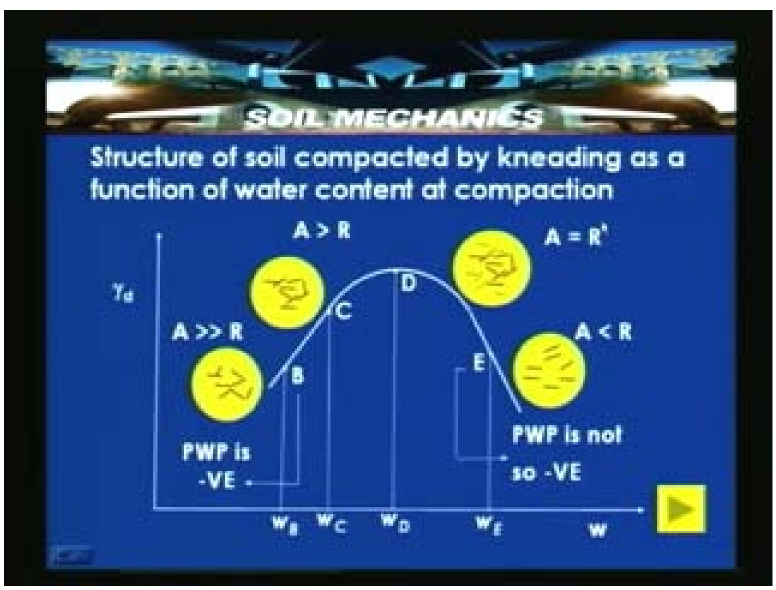

We will try to look into the structure of the soil compacted by kneading as a function of water content at compaction. So, if you look into the reason for an inverted V shaped curve, we said that the reason for an inverted V shape curve for fine-grained soils can be explained in terms of soil structure by T.W. Lambe (1958). The reason for inverted V shaped curve that is compaction curve for a fine-grained soil can be explained with the basis of the soil structure after Lambe (1958).

As you all know the clay mineral particles which are a major constituent of the fine-grained soils have a net negative electric charge of them. The reasons are discussed in the previous lecture. The faces of these particles are negatively charged whereas, the ends are positively charged, because of the breakage of the bonds the ends of the particles are positively charged and all the faces are electrically negative charged. So this causes attraction and repulsion depending upon the availability of the water in the soil.

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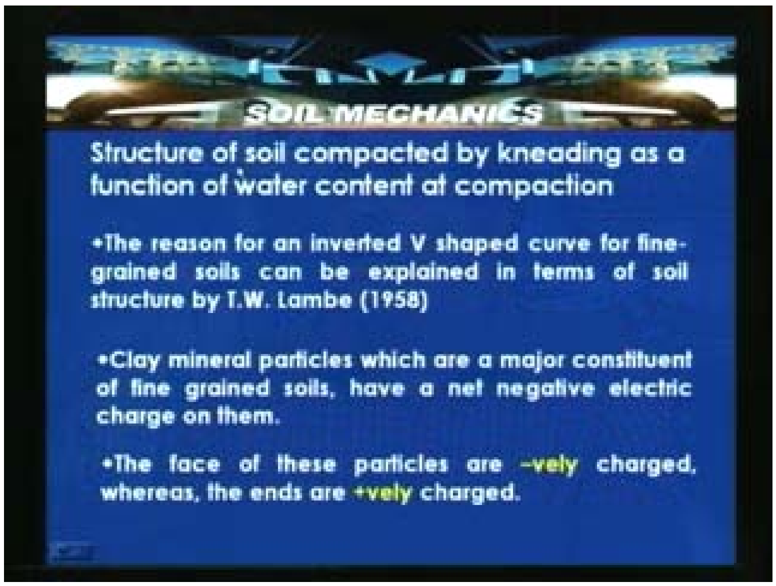

Once you look into it, at point B, let us draw the same diagram here for ready reference. The gamma d is plotted on the x axis and water content on the x axis. This is compaction curve and this is zero air voids line. So let us indicate this point as B. Let us indicate point E, D and C. At this point water content is W_B. At this point water content is $W_{E.}$ At this point the water content is W_D which is equivalent to optimum moisture content. This is nothing but $\text{gamma}_{d\ max}$ that is maximum dry input. So let us try to discuss one by one the difference in engineering behaviour between the point B and point E and how this inverted V shape is explained by Lambe (1958).

Now let us look into the slide, at B: when a small amount of water is added (to achieve water content B), there are not enough water molecules to neutralize the charge on the surface of the particles. The adsorbed water layer is said to be depressed. When compaction stresses bring particles together particles align themselves with a very open arrangement of particles with very strong contacts. So with these arrangements what will happen is that, at this point the soil structure is something like face to edge orientation. You see that very open arrangement of the structure is possible something like truss like arrangement is possible with a flocculated structure.

Flocculated structure with face to edge or face to face orientation to some extent, basically the structure is an open arrangement something like a truss-like connection. So each joint has got sufficient connection strength to restrain or to support the load. So at this point B basically we are discussing at this point B: When a small amount of water is added, there are not enough water molecules to neutralize the charge on the surface of the particle. Still there is some negative charges are prevalent, with that what is happening is that there is some attraction which is taking place. The adsorbed layer is said to be dispersed in nature. So with that what happens is, when compaction stress brings particles together, they align themselves with a very open arrangement of particles with very strong contacts. The contact between these particles is very very strong here. The structure with attraction is much more than repulsion, we are naming it as flocculated structure. So this implies to this type of structure with open arrangement truss like connections.

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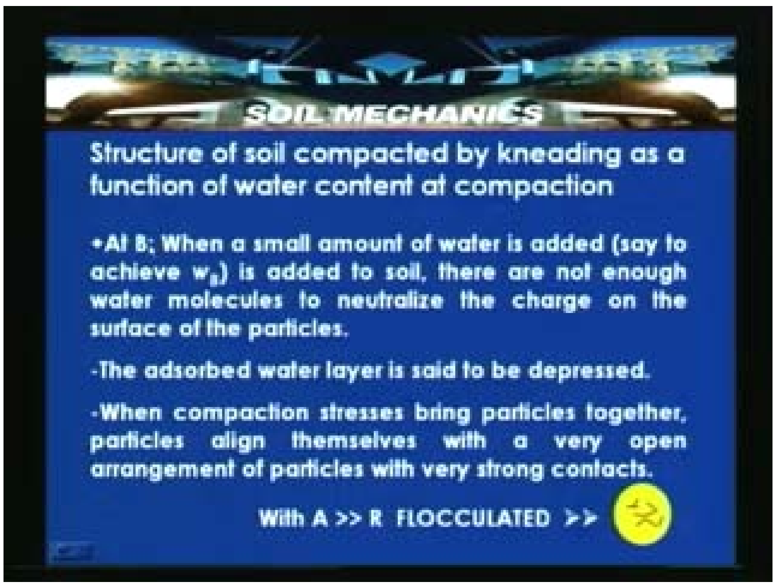

The analogous to this explanation is given like a truss-like connection with very strong contacts. At this point when you progress along this curve if you add a little amount of water that is more than W_B then now you are supplying more amount of water to the soil so there is a certain development of adsorbed waters and because of the decreasing tendency of these connections between the particles there is a decrease in the tendency of neutralization. What will happen is that the attraction is just still more than repulsion but still the structure is not transformed into a dispersed structure. But still what remains is that with an increase in water content that is W_C greater than $W_{B,}$ where W_C is the water content at point C and then this is the density corresponding to that point so W_C greater than W_B at this point C with an increase in water content the adsorbed water layer is not so depressed.

What we are discussing is that the particle forces would still be negatively charged but not as much they were at $W_{B.}$ These negative charges are decreasing because there is an abundant ability of water because of the water content at point C is more than water content at D. So upon being subjected to compaction stresses because same soil is subjected to compaction stresses most particles get aligned in a face-to-face configuration. So mostly now there is a tendency of switching the particles from face-to-face configuration but some get pushed into a face-to-edge arrangement. The resulting structure is still flocculated but with weak particle to particle contacts. So, the soil compacted at water content B has got more open arrangement and more resistance for the strength than the soil compacted at water content W_C. So the resulting structure is still flocculated but with weak particle to particle contacts. This is one thing which is important to be noted.

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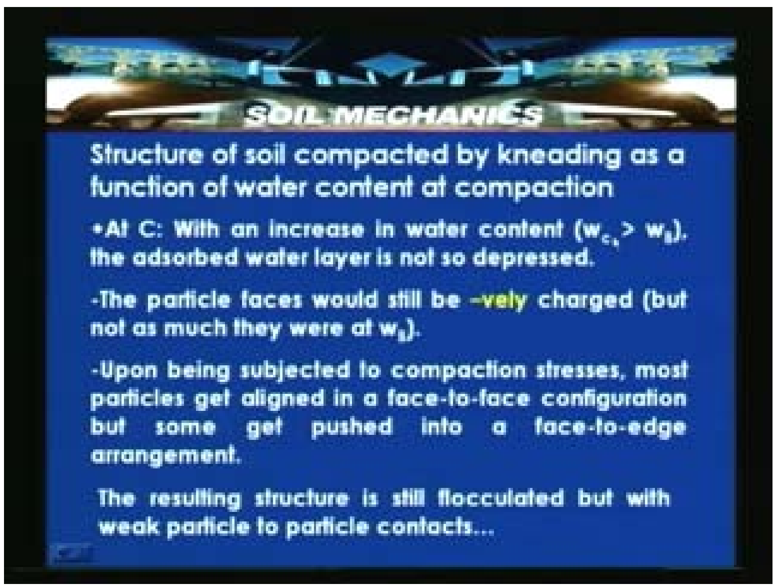

Now, let us go to point D that is nothing but maximum dry unit weight and optimum moisture content. At point D upon the addition of yet larger quantities of water that is here what we did is that we started increasing the water gradually and reached the peak. So this point is said to be the optimum moisture content for this soil and the vertical ordinate here is the dry unit weight which is nothing but the maximum dry unit weight $gamma_{dmax}$. With this the addition of yet larger quantities of water, the trend described above continues to operate and compacted soil of higher and higher unit weight with structures which are less and less flocculated is obtained.

Now, the structure is undergoing a transformation from flocculated structure to a dispersed structure. Until the water added produced optimum water content $W_{D.}$ At point D upon the addition of yet larger quantities of water the trend described above continues to operate and the compacted soil of higher and higher unit weight with structures which are less and less flocculated is obtained. So here why this happens? We have discussed all these things in the principles of compaction.

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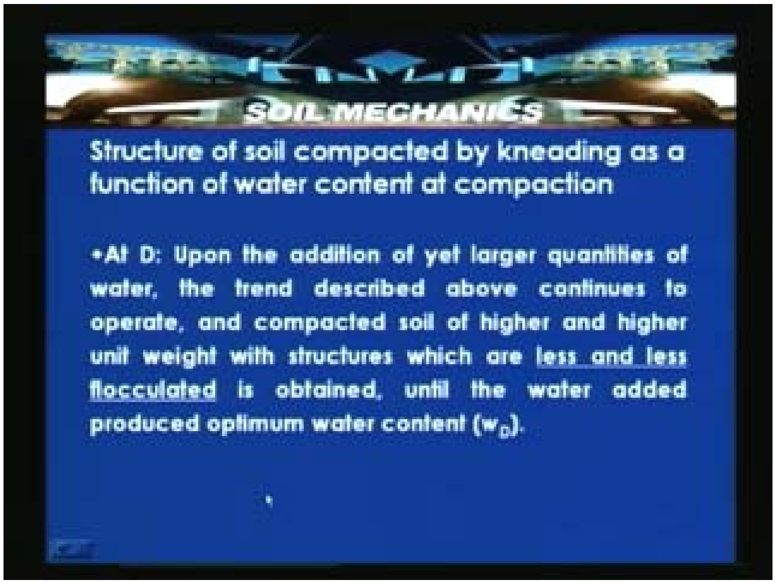

Now let us try to migrate to the wet side of the optimum that is at point E water contents above optimum. The adsorbed water layers surrounding particles are well developed and most of the electrical charges on clay particles are neutralized. At water contents above optimum that is at point E, the water content corresponding to this point W_E is greater than all these water contents. The neutralization of clay particles has occurred.

During the compaction process these well developed adsorbed layers surrounding clay particles interfere with each other and prevent particles from coming close to each other. So during the compaction what will happen is that these well developed adsorbed water layers surrounding the clay particles interact with each other and they hinder the particles coming close together because the adsorbed water layers are now completely developed. With that what will happen is that during the compaction process these well developed adsorbed layers surrounding clay particles interfere with each other and they prevent particles from coming close together. So the energy supplied gets dissipated in futile bumping that means what will happen in the compaction test?

If you observe in the laboratory compaction test, if this is the mould under consideration suppose this is the layer under going compaction at wet side of the optimum. If the hammer energy is supplied then soil undergoes a typical failure called as heaving failure. Heaving failure will occur in the surrounding area where the energy supplied to the compacted soil. This is in the compacted mould at wet side of optimum and soil appears to be something like water loosing out of the soil or it is also called as bleeding of the soil. So during this compaction process what will we have before this energy is transferred? That means, without transferring this energy to the particles to make it into dense positions what will happen is this soil fails. In the process, the energy gets dissipated in futile bumping. This is actually a typical bumping which is shown here with failures like this.

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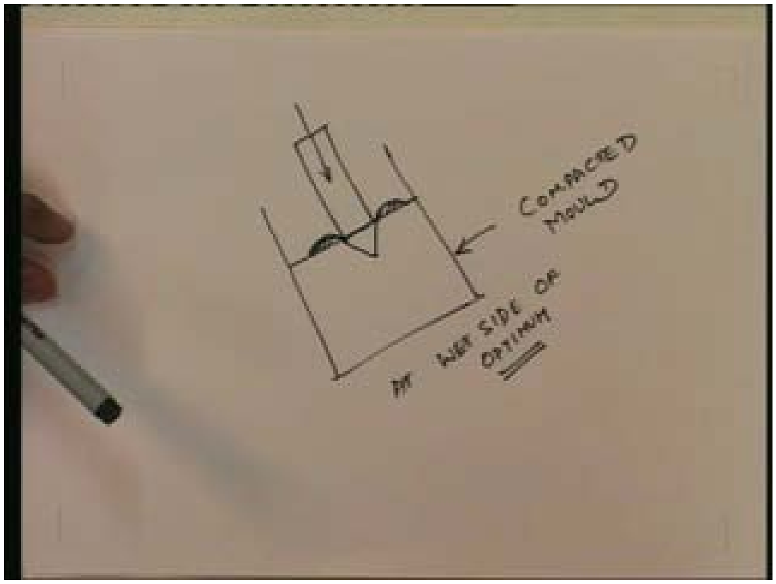

During compaction process these well developed adsorbed water layers surround the clay particles interfere with each other and prevent particles from coming close to each other. This is the case which can happen on the wet side of the optimum. That is why it is very difficult to compact clay soils on the wetter side of the optimum. So this is a typical resulting dispersed structure which is shown here.

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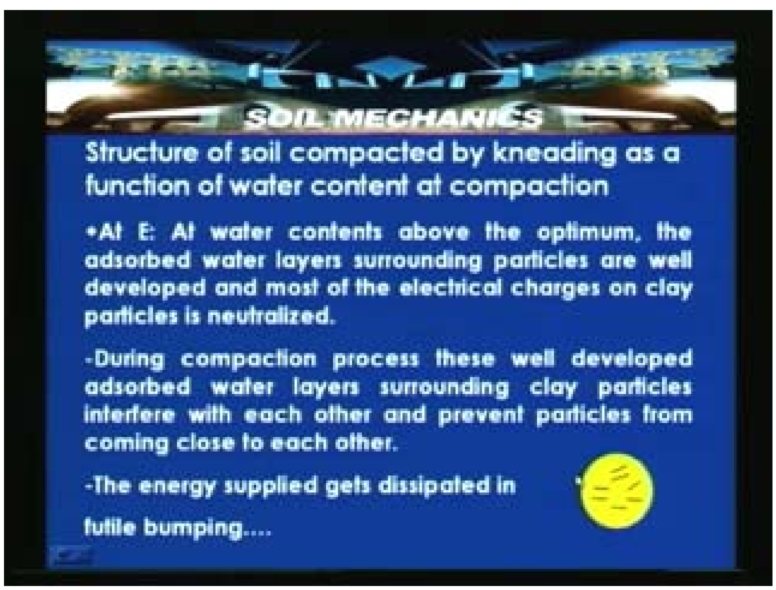

What we have discussed in this particular example is that how the soil structure is transforming as we are proceeding from the left hand side that is on the dry side of the optimum to the wet side of the optimum. Now let us see the influence of the soil structure on the type of the compaction. Suppose, if you have got static compaction or impact compaction or kneading compaction, these are the three different types of compaction we have introduced in the previous lecture.

If you see in this table, a static compaction can produce water contents like dry side of optimum, that is, this side is called dry side of the optimum and this is called wet side of optimum. That is wet side of the optimum is on the right hand side and dry side of the optimum is on the left hand side. Here the static compaction does not influence the soil structure much. The soil structure remains flocculated, that means whatever energy is created with the static compaction remains something like a flocculated, and the structure is flocculated both on the dry side of the optimum and wet side of the optimum. Impact compaction to some extent produces flocculated to dispersed structure on the wet side of the optimum and it remains something like a flocculated structure on the dry side of the optimum.

If you adopt kneading compaction that produces something called a flocculated structure on the dry side of the optimum and dispersed structure on the wet side of the optimum. In the type of the compaction like static, impact and kneading where the dry of OMC produces mostly flocculated structures or open arrangements or a truss-like arrangements and wet of OMC produces flocculated for static type of compaction, flocculated-dispersed for impact type of compaction and dispersed for kneading compaction. This actually is to be decided depending upon the type of the structure under consideration.

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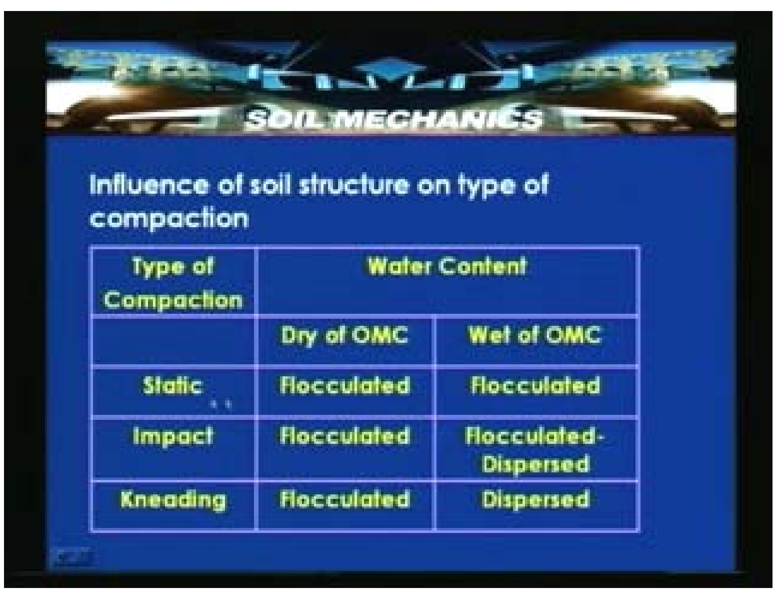

Suppose, if it is a load bearing structure something like a highway embankment or railway embankment where the soil is compacted on the dry side of the optimum. Suppose, if it is some earth dam or a compacted clean liner for a land fill, then it is compacted on the wet side of the optimum to have the sealing efficiency. Influence of compaction conditions on soil structure can be summarized as follows: The soil structure becomes more dispersed as the placement water content is increased.

On an average if the water content is increased, the placement water content is increased then the soil structure tends to change to dispersed. As the amount of compaction is increased it shifts to the left hand side of the dry side optimum, where more air is removed quickly. With that little increase in the amount of compaction then also the soil structure tries to transform towards a dispersive nature. By using a type of compaction induces more shearing action in soil during compaction process.

Suppose, if you use a type of compaction which induces more shearing action then that also can change the soil structure from flocculent to dispersed nature. Soil compacted at water content OMC would be more dispersive. The soil compacted at water content greater than OMC would be more or less dispersed structure. Soil compacted at water content more than OMC would be more dispersed.

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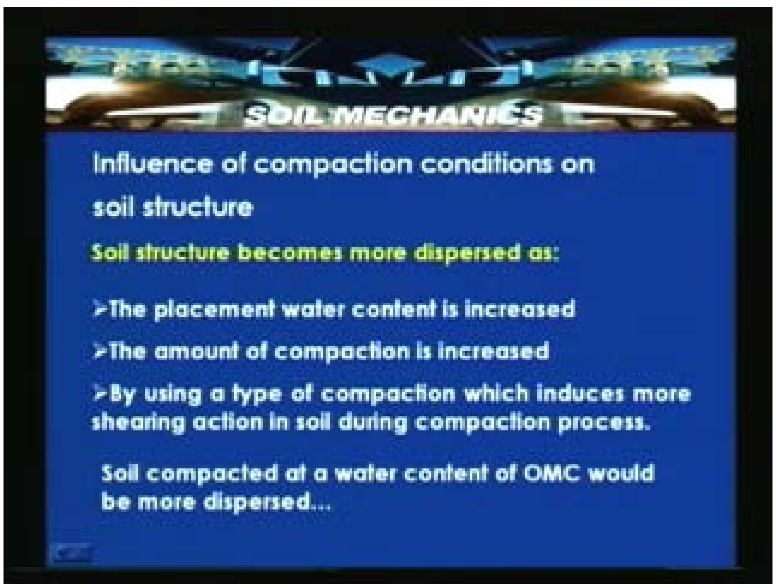

Having seen this, now, let us look at the engineering behavior as a function of density and structure. We have seen how the soil structure changes from the dry side of optimum to wet side of optimum. Now what we should try to do is that to link this behavior to the engineering behavior like swelling, shrinkage of soil, permeability that is the capacity to drain the water, strength that is basically how the stress strain properties change for a given soil and compressibility of a given soil. Let us try to select swelling, when the samples of soil from B and E are given access to water which would swell more? That is the question we have already asked. If the soil sample is compacted at water content B and water content E where water content B is on the dry side of the optimum and water content E is on the wet side of the optimum. Then which soil would swell more. The answer is that the soil at B swells more because the soil at B has greater thirst for water and also the charges are not neutralized. The tendency here has got more affinity for water attraction. With that what happens is that the soil compacted on the dry side optimum swells more that is soil compacted at point B swells more rather than the soil compacted soil at water content E.

Now you come to the second parameter that is shrinkage. Upon drying, soil at B will begin bodily to interfere with each other because soil at B has got an open arrangement like a flocculated net like arrangement or pack of cards like arrangement, where they derive high connection strengths. With that what happens is that soil at B as a bodily try to interfere with each other and will not allow the soil to shrink. So the shrinkage of soil at B is less than the shrinkage of soil at E, whereas soil at E will approach each other without hindrance as the soil is dried and hence high shrinkage. The reason explained here is upon drying, soil at B will begin bodily to interfere with each other and will not allow soil to shrink whereas the soil at E will approach each other without hindrance as the soil is dried and hence high shrinkage is caused. The soil at this point has high shrinkage and the soil at this point is having low shrinkage. So this is high swelling and low shrinkage whereas here it is low swelling and high shrinkage. These are the contrasting phenomenon which we should note here.

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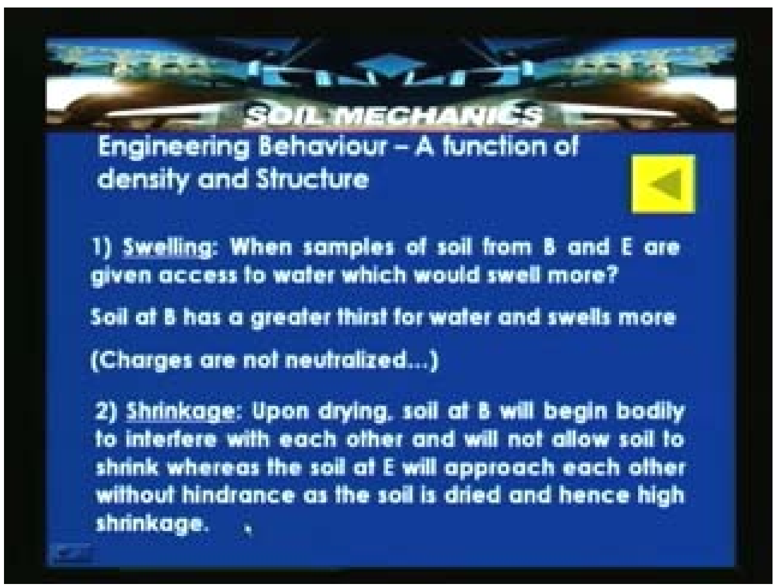

Then second one is that another parameter which we have forgotten is the construction pore water pressure. Higher magnitude of pore water pressure are reached with soil at E than with soil at B since at B the soil is still drier and initially has more negative pore water pressure. When there is more negative pore water pressure, the construction pore water pressures, first they will try to neutralize and then try to increase above that. With that what will happen is that, it has more rigid structure.

Higher magnitude of pore water pressures are reached with soil at point E than with soil at B, since at B the soil is drier, has initially more negative pore water pressure and also has more rigid structure. So the construction pore water pressure is more at point E rather than at point B. The second point is a very important point which is the permeability. Soil at B will exhibit the same permeability in all directions whereas soil at E will be more permeable along particle orientation than across particle orientation.

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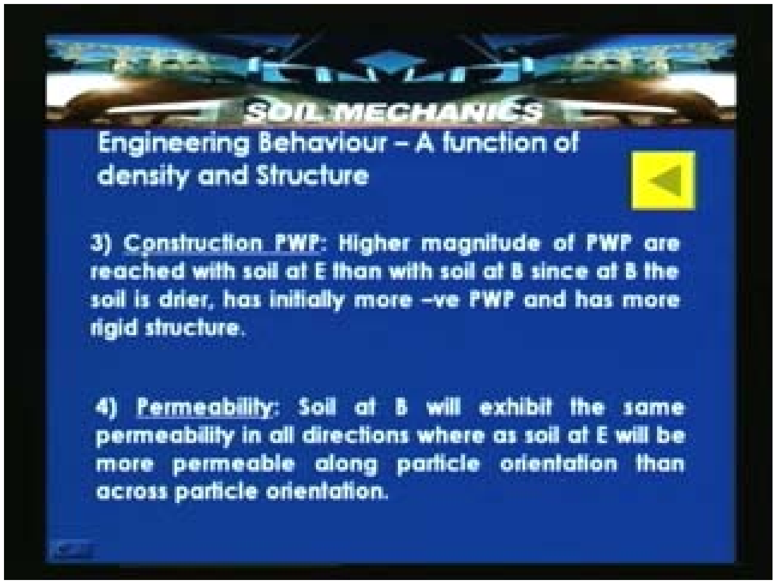

Let us try to look at this. Let us assume that an open arrangement like a truss-like arrangement which is shown here. Then soil at point B with flocculated structure and soil at point E with dispersed structure. Now we are seeing permeability, soil at B will exhibit the same permeability in all directions. Suppose, if I put this as X and Y, then the soil at the point B has got identical permeability in both X and Y directions.

Similarly, the soil at E along the plane perpendicular to its plane of these platelet particles, the permeability is less and along the plane of the particles, the permeability is very high. That means water cannot flow through this easily but water can flow along the particles. So in this direction K_x is greater than K_y that is the one thing with the dispersed structure. What we are trying to see from this slide is soil at B will exhibit the same permeability in all directions. That is here at flocculated structure soil exhibits identical permeability both in X direction and Y direction. In this case perpendicular to this plane that is the permeability is less compared across the particle orientation. That is one important consideration from engineering behavior point of view should be noted.

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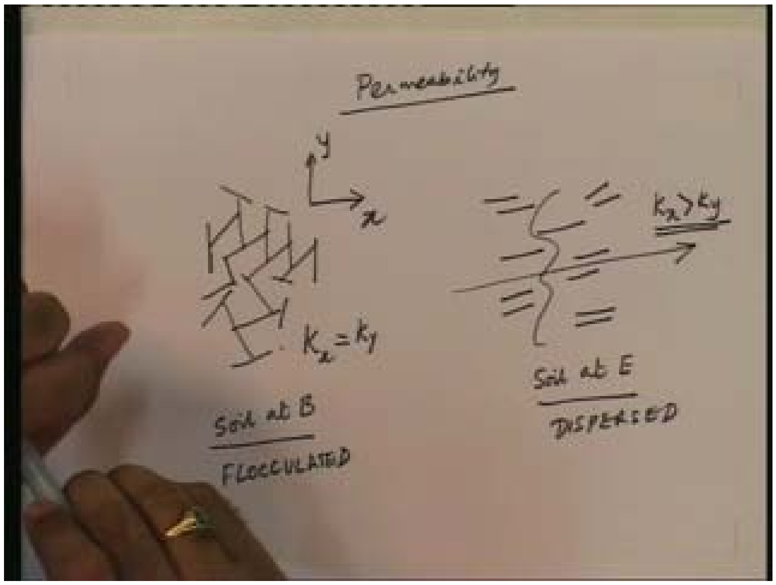

Now coming to the compressibility, compressibility at low applied stresses the dispersed soil will undergo sizeable volume change whereas the flocculated soil would be less compressible on account of the truss-like arrangement of particles with strong contacts. If you again consider point B and point E, the soil at point B would undergo less compressibility compared to soil at point E. The soil at point E will undergo a sizeable volume change at low applied stresses whereas soil at B would undergo less compression because of truss-like arrangement of particles at this point. That is this is attributed to a flocculated structure which is prevalent here and it is because of the strong particle contacts.

At some limiting stress the truss-like arrangement would collapse and the soil would exhibit high compressibility in relation to dispersed soil. As the applied stresses are increasing what will happen is that the prevailing truss-like arrangement would collapse and they change into a dispersed structure. At high applied stresses, the initially flocculated and the initially dispersed would have similar structures and would exhibit similar compressibility. So at low applied stresses, the soil at point B exhibits less compressibility compared to soil at point E that is on the wet side of the optimum.

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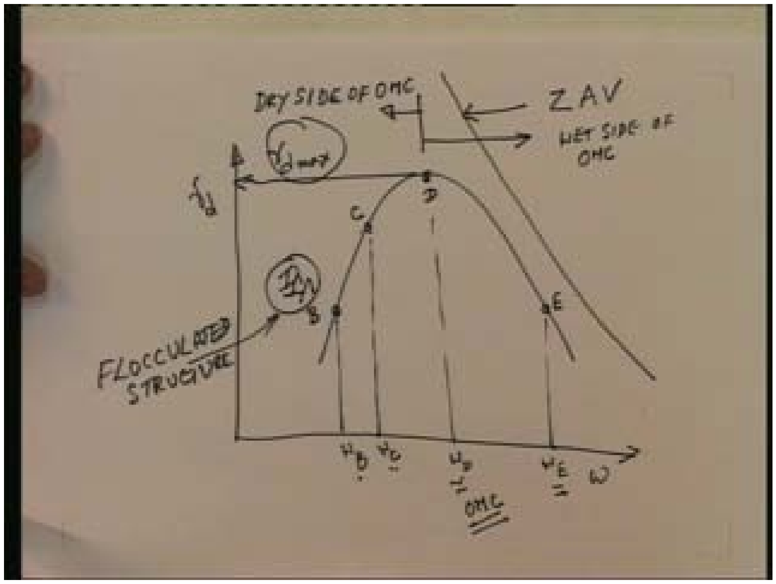

At some limiting stress, what will happen is that this truss-like arrangement collapse and they switch over to a dispersed arrangement. But at very high applied stresses both the soil which is initially flocculated as well as the initially dispersed will have the same structure. So they will exhibit the same compressibility. This is the very important point that should be noted and it will be carried out for understanding the consolidation behavior of soils.

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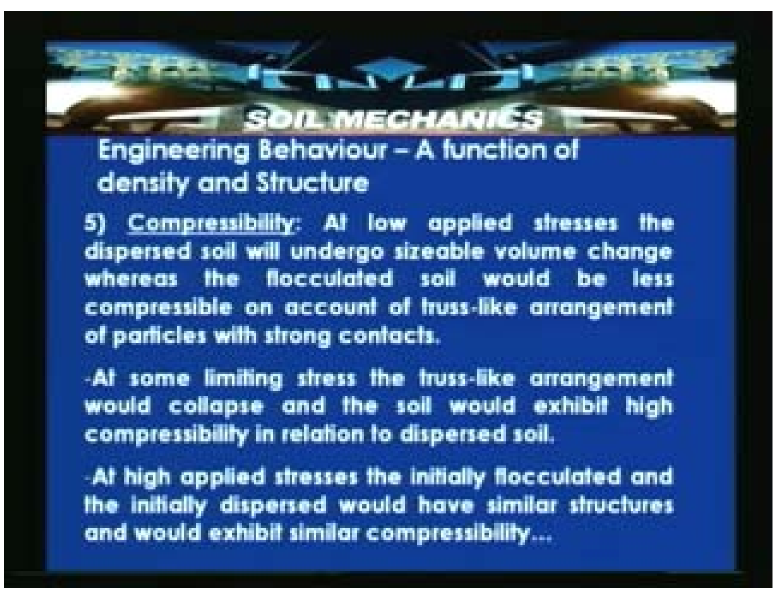

The next one is the stress-strain behavior of the soils because now what we are trying to do is that we are playing with the compaction curve. We have selected four points B, C, D and E, where B and C is on the dry side of the optimum, E is on the wet side of the optimum and D is at the optimum. With reference to stress-strain, upon application of stress the soil at E will deform steadily whereas the soil at B with its truss-like arrangement will resist deformation and the stress-strain curve would rise to peak and drop down when the flocculated structure suffers a collapse. If you consider a stress-strain behavior of a soil compacted with water content at B and water content E, let us try to compare in elementary terms but this will be introduced while discussing stress-strain.

Let us give a preliminary idea about the stress-strain behavior of the soil. If you put stress on the Y-axis and strain on the X-axis, the dispersed structure will increase steadily. That is what, upon the application of the stress the soil at E deforms steadily whereas the soil at B with its truss-like arrangement will resist deformation and the stress-strain curve would rise to peak and drop down when the flocculated structure suffers a collapse.

What is being told is that, this is for soil at water content B on the dry side of the optimum and this is for soil at water content E that is at W_E which is at the wet side of the optimum. Two distinct behaviors are seen with reference to stress-strain behavior for flocculated structure as well as dispersed structure. If you see here, for a flocculated structure initially modulus is very high and it reaches peak at this point.

What will happen is that the structure starts or this stress like connection starts collapsing. In this process what will happen is slowly the structure again transform to a dispersed structure again. At the breakage of bonds or strong contacts particles starts here. Still that point, soil is able to generate up to peak strength then structure starts breaking and then changes out to this particular point where the dispersed structure profiles here. At high strains, soil samples from B and E will have essentially the same particles arrangement and will thus exhibit the same strength.

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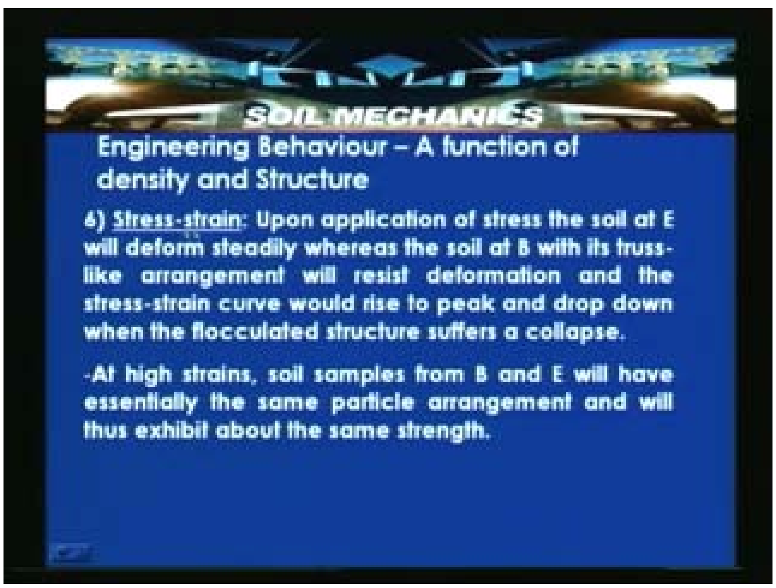

Here the soil structure is same, similar to compressibility but there are high applied stresses. We said that both the soils have got the same structure so they exhibit same strength. Similarly here, at this particular point all these truss-like connection particles which are there earlier are broken and reduced into a dispersed arrangement. With this what will happen is that the soil is exhibiting now with same strength with higher strain. So that is why an important parameter should be noted for explaining the stress-strain behavior of the soil which will be discussed in length during the shear strength of a soil.

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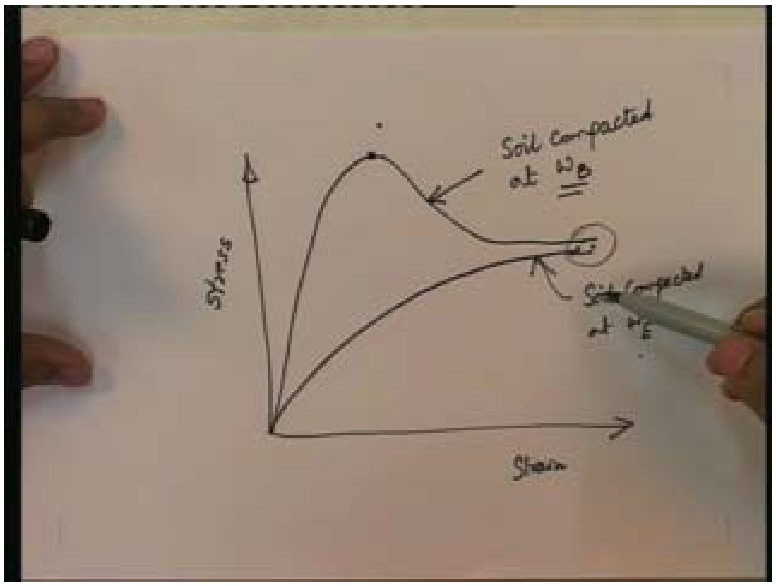

Having seen this effect of soil structure and the type of the compaction let us try to again compare the distinctive behaviors between coarse-grained soils and cohesive soils that is, fine-grained soils. We said that coarse-grained soils initially experience a reduction in the dry unit weight and then after increasing the water content the films which are surrounding the particles or grains will disappear and slowly they will allow the particles to come closer to produce maximum dry unit weight. In contrary to this, the fine-grained soil has got inverted V shaped curve. The variation in density is very high for a fine-grained soil when compared to a coarse-grained soil.

Let us look into this: Upon compaction the behavior of clean sands or clean coarse-grained soils having fines less than 10 percent that is silts and clays less than 10 percent are different from that of fine-grained soil on account of two reasons: The sand grains are more or less equi-dimensional and not plate-like particles. We know that sand grains are more or less equi-dimensional and not like plate-like particles in a fine-grained soil. They are electrically neutral. When you compare the charges the sand grains or the quartz grains have got electrically neutral status on the surface compared to plate-like particles which are completely negatively charged. So they are bound to change depending upon the availability of the water.

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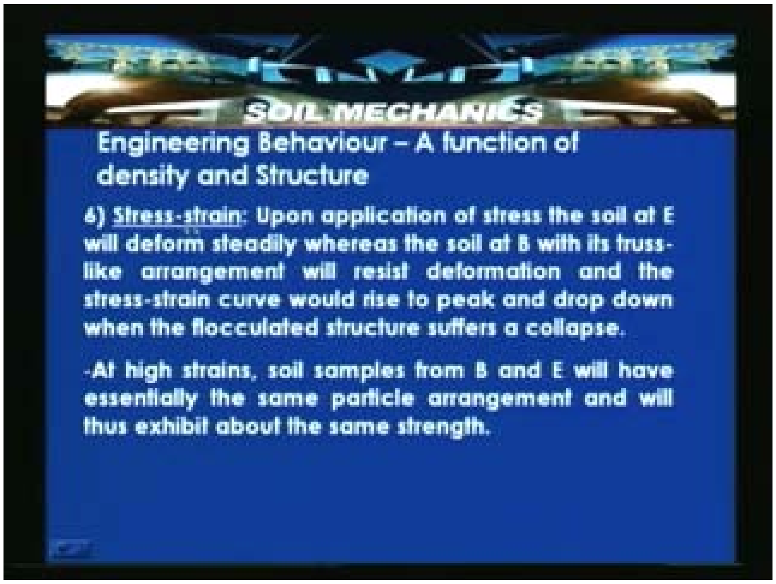

Let us look into the distinctive behavior by comparing these two diagrams; compacting coarse-grained soils where you can see a typical compaction curve drawn here. This is the dry unit weight at point A and at point B the soil exhibits decrease in the dry unit weight. Upon adding water the water content increases and closure to saturation and it reaches the maximum dry unit weight.

If you see the typical variation in the dry unit weight is very very less with increase in water content for a clean coarse-grained soil having fines less than 10 percent, this is the zero air voids line and this is compaction curve for a fine- grained soil. Thus, total variation of dry unit weight sand compacted at different water contents is small compared to the variation possible in fine-grained soils. This is what we explained in the previous class, these are the solid grain, uniform grain particles which are surrounded by water particles present here. With that what will happen is that because of this capillary tensions developed with the water films surrounding the particles they create something like apparent cohesion and because of that the soil exhibits low density or low unit weight and upon adding water these films get washed allowing the particles to come closer. That is the reason you are seeing the degree of tendency of a capillarity effect decreases and then you see an increase in the density.

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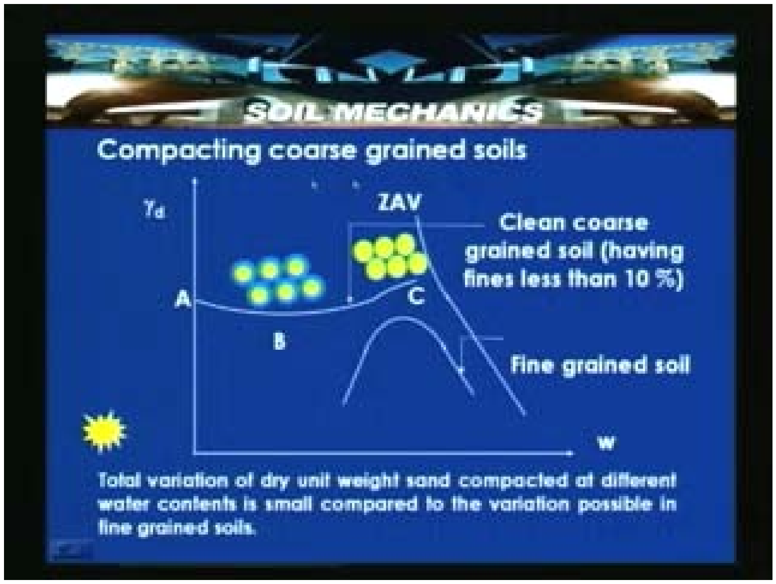

Having seen the distinctive behavior now, it is time for us to again introduce the compaction equipment or a compaction plant. We said that different types of rollers are used and as we have seen the distinct behavior between the coarse-grained soil and fine-grained soils we are supposed to understand the type of equipment useful for rollers and the type of equipment useful for compacting the soil in the field. Like we have introduced in the last class they are predominantly rollers, rammers and vibrators.

Once we have got a soil classification or soil group from the particular borrow area based on that the typical type of equipment has to be selected to compact the soil in a field for a structure and also depending upon the function or the end serviceability requirement. Suppose if it is for a highway embankment the placement water content has to be decided and different types of rollers have to be used. Now let us look into different types of compaction equipments available to compact the soil. So compaction mechanisms what we said is that kneading mechanism, tamping mechanism, vibration and impact type. Vibration is basically used for coarse-grained soils, kneading and tamping to some extent is used for fine-grained soils and sometimes impact compaction.

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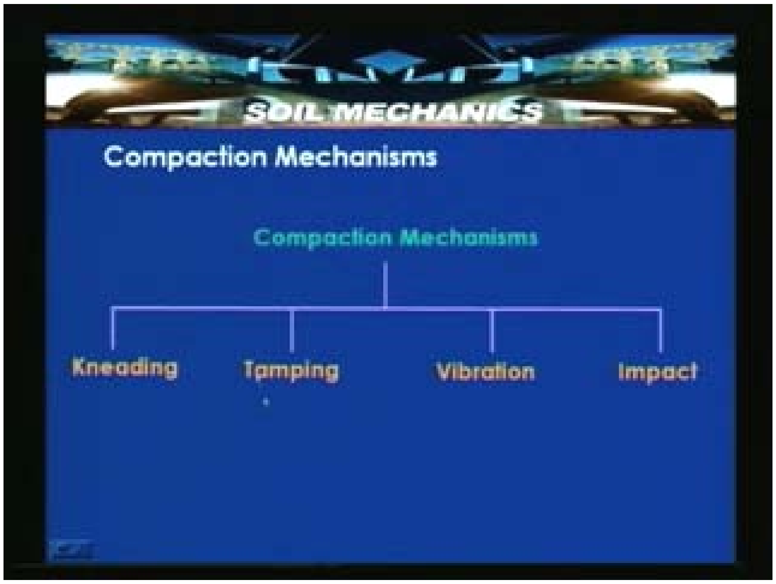

Compaction mechanisms as you see here in this particular chart, compacter zones of application and compactive efforts are given. For clay soils, a typical type of rollers called sheep's foot roller is basically used here. For 100 percent sand or clean sand, you know the compaction equipment changes here almost to the vibratory type. For rocky type soils in the rocky dams and all the rock damping and grid rollers has to be used. So here sheep's foot roller is used primarily for cohesive soils or fine-grained soils which are having more fines.

In tamping foot roller that is high foot tamping foot roller, as the clay transforms from 100 percent clay to 100 percent sand, we can see variation in the type of roller or type of compaction equipment used in the field. The variations are high speed tamping foot roller, tow tamping foot roller, heavy pneumatic roller, multi tired pneumatic roller, smooth steel drums roller, vibratory rollers and grid rollers basically for a rocky type stator. If you look into compactive effort, static, kneading and impact vibration that is here and static weight, kneading, impact vibration sometimes static weight will not help. So this vibration which is actually static weight as well as vibration is required to apply for compacting the coarse-grained soils.

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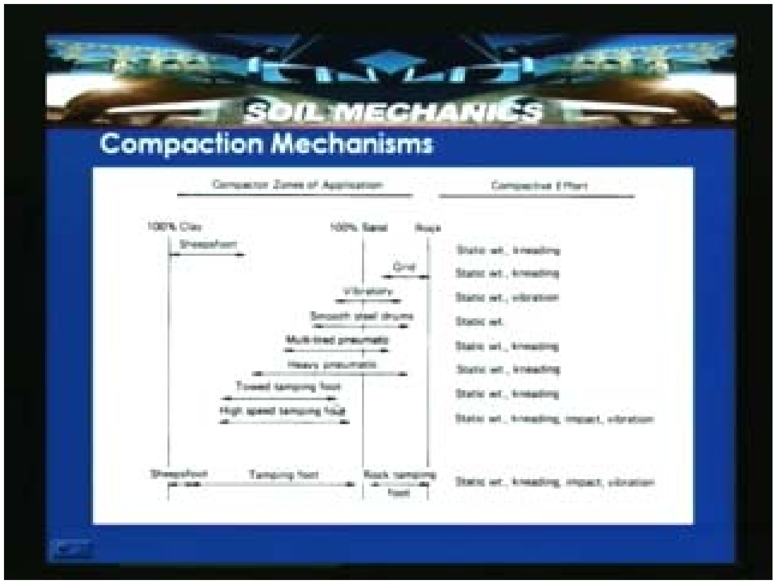

If you see, Cohesionless soils can be compacted by kneading, tamping and vibrating and cohesive soils by kneading, tamping and impact vibration that is what we have discussed.

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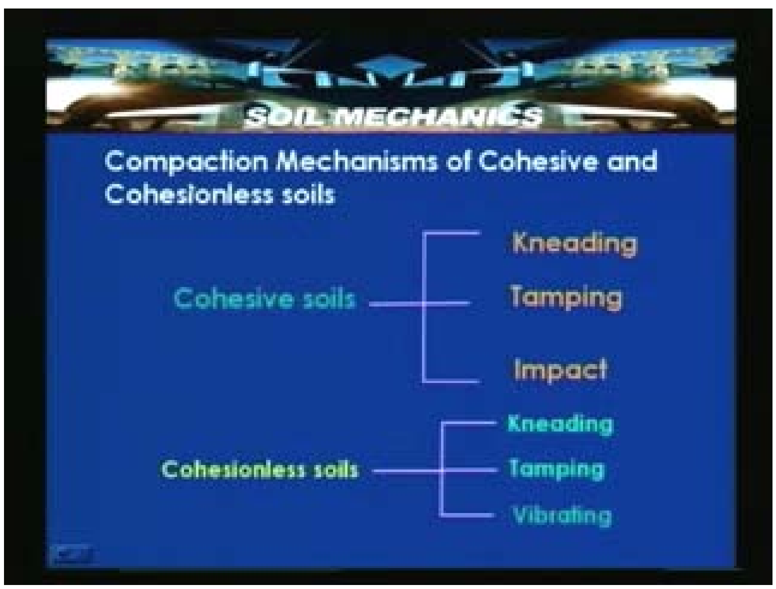

Next we will see compaction of cohesion-less soils. Cohesion-less materials are compacted by vibration, static load produces very little compaction of loose sand. We have seen this through demonstration test. Medium and fine sands do not compact easily when moist because of the shear strength developed by capillary forces because these films could not allow the particles to come closer. But medium and fine sand do not compact easily when moist because of the shear strength developed by capillary forces.

Dry or submerged sands can be compacted by vibrations. Dry sand or submerged sands can be compacted by a vibration technique. Submerged sands means completely the sand saturated with water. Clays cannot be compacted by vibration. That is one thing also seen by performing a simple experiment in this previous lecture.

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We have demonstrated that clays cannot be compacted by shaking, where the sand can be made to rearrange into new positions. Small amount of pressure is required to force the grains of clays with high water content. If you take the soil with very high water content, a small amount of pressure is sufficient to push the particles closer. Free water surrounds the particles and low viscosity that is also one thing is that the free water which is surrounds the particles in the low viscosity and high degree of compaction cannot be achieved because of the thick layer of water surrounding the particles. So the high degree of compaction cannot be achieved because of the thick layer of the fully developed adsorbed water layer which actually prevents the particles from coming closure. That is also another influence which actually inhibits the compaction. The types of the rollers are: The smooth-wheeled rollers, vibratory rollers, pneumatic-tire rollers and sheep foot rollers.

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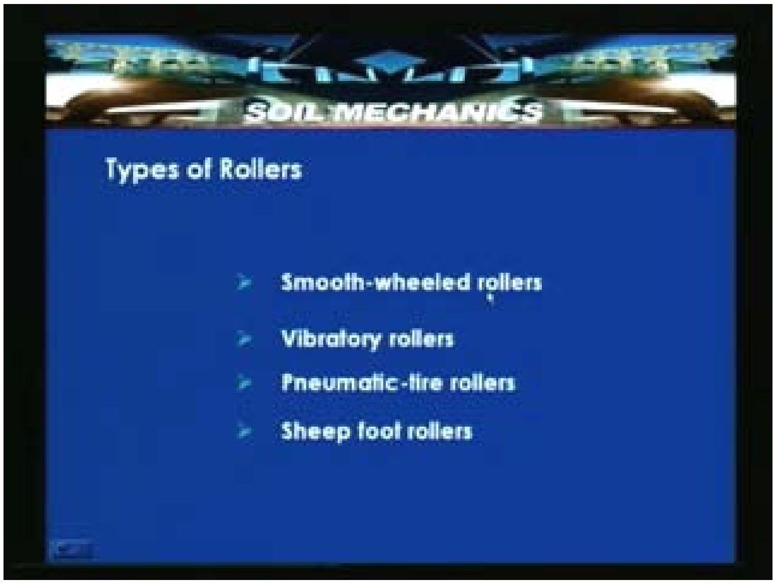

If you look into this slide, basically the rammers are: dropping weight or including the piling equipment, internal combustion type and pneumatic type. These are the different rammers which are used in the compaction field.

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What you are seeing here in the picture is a smooth wheeled roller with rubber tired roller with 80 percent coverage area which can actually induce 700 kPa pressures. So with 80 percent coverage area can induce up to 700 kPa. So 100 percent coverage area under wheel load with ground contact pressures up to 380 kPa. That is basically a general specification for smooth wheel roller. But this picture shows a rubber tired roller with 80 percent cover area with exact ground pressure up to 700 kPa. It is suited for firm cohesive and well graded granular fills (except the rocky types). This multi tired roller cannot compact or a smooth well roller cannot compact uniformly graded sand because of the roller pushing into the soil and because of this what will happen is that this is unstable in uniform sands due to roller pushing into the soil. So 100 percent coverage area under wheel load with ground contact pressures up to 380 kPa and suited for firm cohesive and well graded granular fills except the rocky types of soils this is used.

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Conventional smooth wheel rollers have 18 tons. Tandem rollers are 1 to 14 tons. Three axle tandem rollers have 12 to 18 tons. This is the conventional weight. The weight can be increased by ballasting the rollers with water or by a heavy sliding weight. So by ballasting with water or by with sand, the weight can be increased. The performance is affected by the load per inch width under the compaction rolls, and the width and the diameter of the rolls. This is about the smooth wheel rollers.

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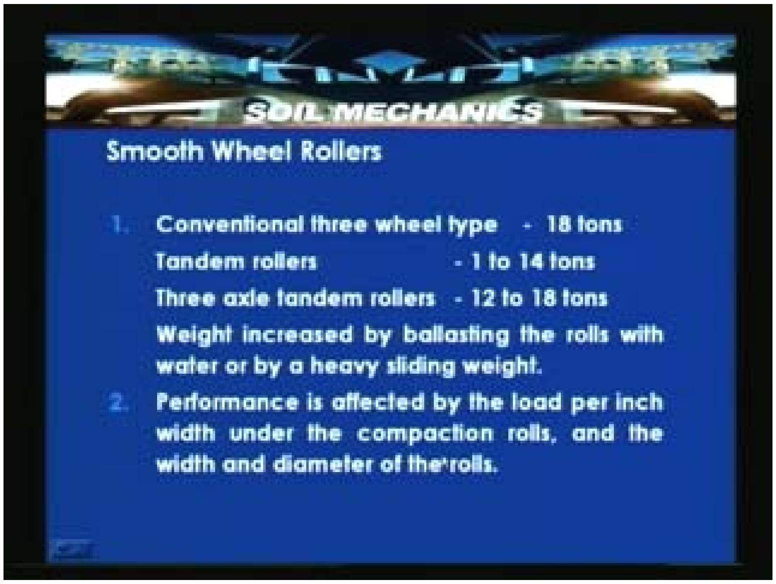

The third point is that load per inch width and diameter control the pressure in the surface layer of soil; dimension of the rolls affect rate with which this pressure decreases with depth. Another point is that suitable for gravels, sands, hardcore, crushed rock and any material where crushing action is needed. So smooth wheel rollers are suitable for gravels, sandy soils, hardcore, crushed rock where some certain extent of crushing is required then this technique will become handy.

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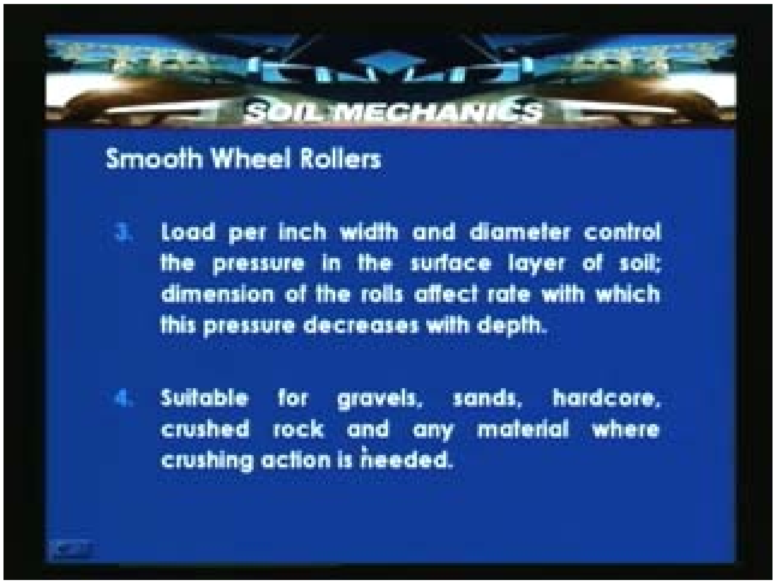

The moisture content should be adjusted to the optimum moisture content. The depth of the layer compacted is that sub grade is around 150mm and base of the embankments is around 450mm.

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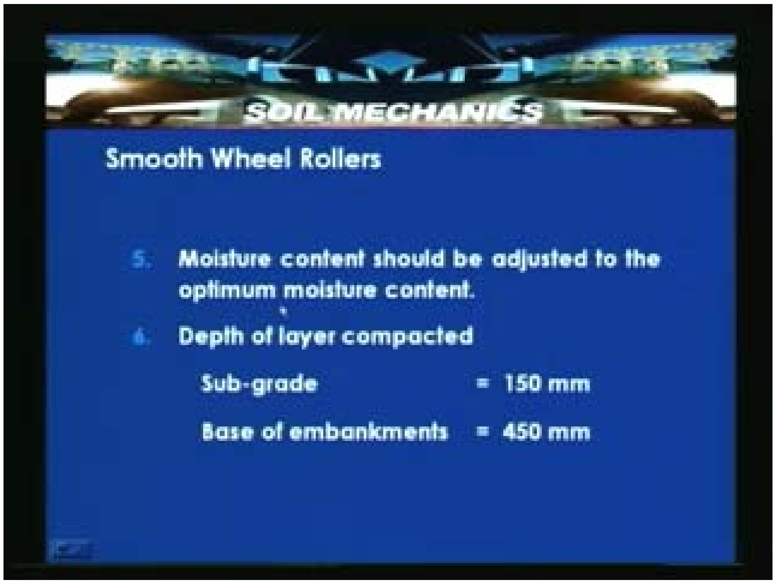

So this is about the smooth wheel rollers. There are also other type of rollers like pneumatic type rollers and sheep's foot rollers.

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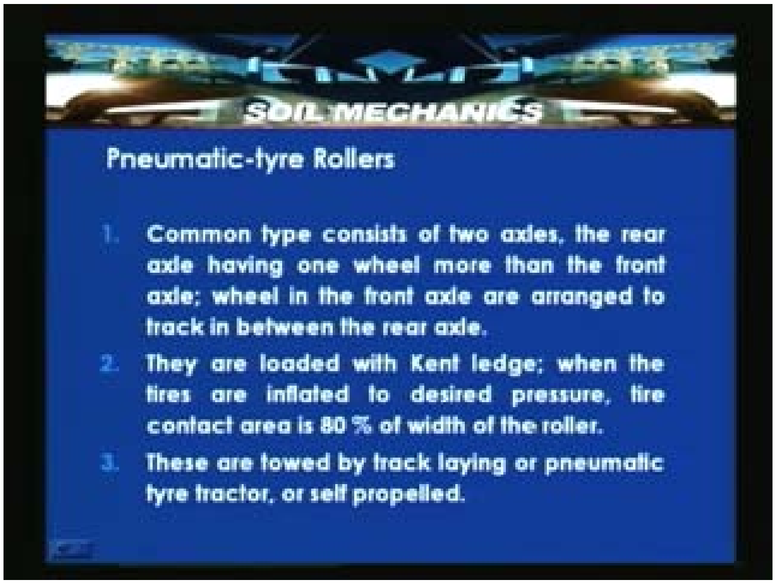

In the next class we will be discussing about the relevant equipment for sheep's foot rollers and their applications for different types of soil. Then we will try to solve one or two problems pertaining to the compaction. With that actually we will be able to see how a soil compacted in the field can be compared with the laboratory and assess the relative compaction characteristics of a soil because this is very important for us to assess the field compaction and compare with the laboratory compaction. So we define the term called relative compaction. Based on that we will try to define criteria and discuss about the specification required for field compaction.