Introduction to Transportation Engineering
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Lecture - 27
Pavement Materials - I

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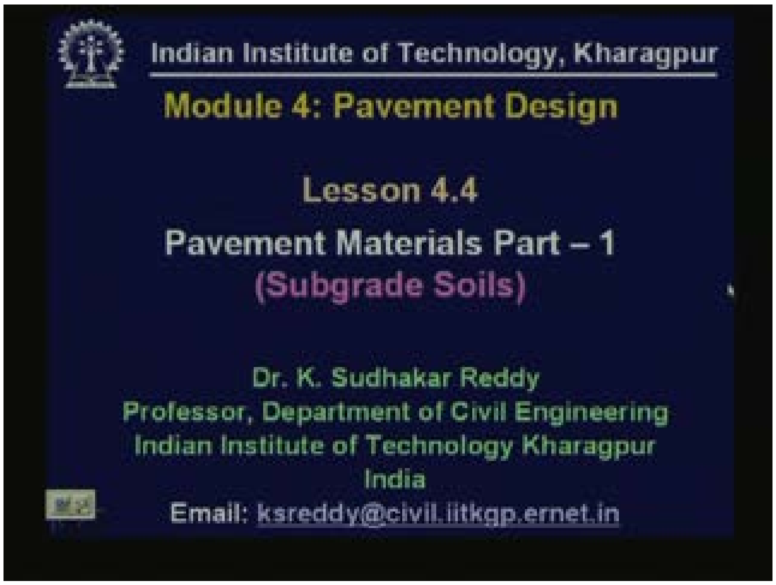

This lesson is on pavement materials which will be covered in different parts. Today we are covering part one of pavement materials. In this part we will be mainly be focusing on subgrade soils.

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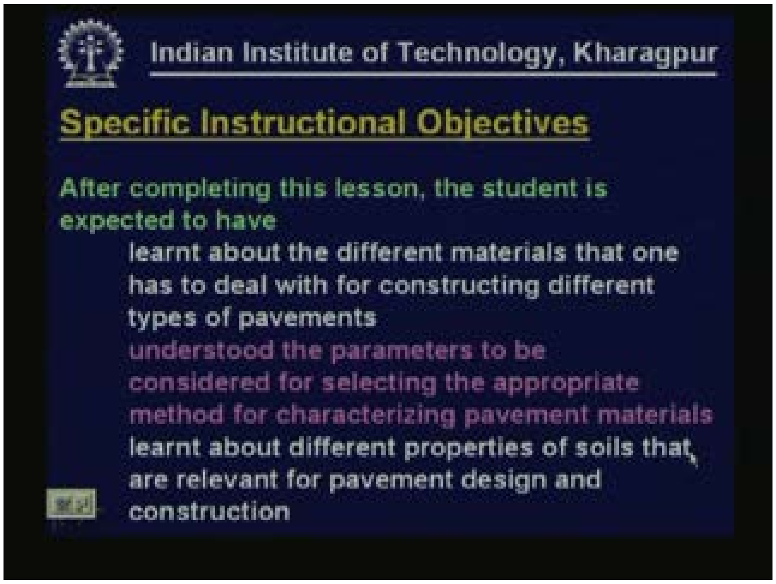

The specific objectives of this lecture will be after completing this lesson the student is expected to have learnt about different materials that one can use or one has to deal with for constructing different types of pavements. We are going to talk about granular pavement, bituminous pavement, concrete pavements and other types of pavements and we will learn about the materials that are going to be used in different types of pavements. It is also expected that the student would be able to understand the parameters to be considered for selecting appropriate method for characterizing pavement materials.

For example, if there are different layers that are used in a pavement, what is the parameter that is to be used it for evaluating, what is the parameter to be considered for subgrade, what is the parameter to be considered for granular material, bituminous materials, concrete pavement etc. so we will be considering those parameters that we have to adopt for design purpose and for evaluation purpose.

It is also expected that the student will be learning about the different properties of soils. As I said earlier we will be focusing mostly on subgrade soils so we'll be talking about various properties of soils that are relevant for pavement design and for pavement construction.

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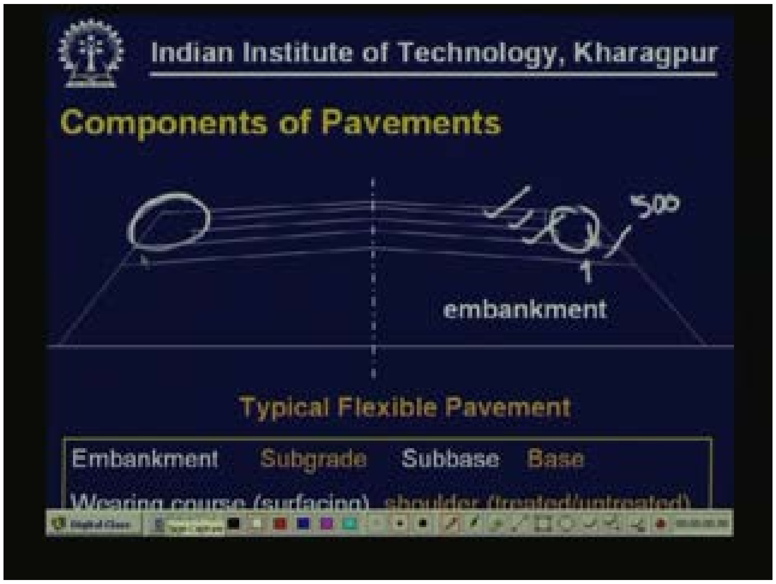

As we have seen earlier pavement has got different components. For example, if you take a flexible pavement it may be on embankment, it may be on cutting so as a result you may have embankment which consists of soils, you may also have subgrade, the top either 300 mm or 500 mm which is prepared to standard specifications, prepared to attain specified strength is considered to be subgrade so we can have embankment, we can have subgrade, we can have different layers of granular materials and we may also have bituminous layers and the shoulders can be either treated or untreated.

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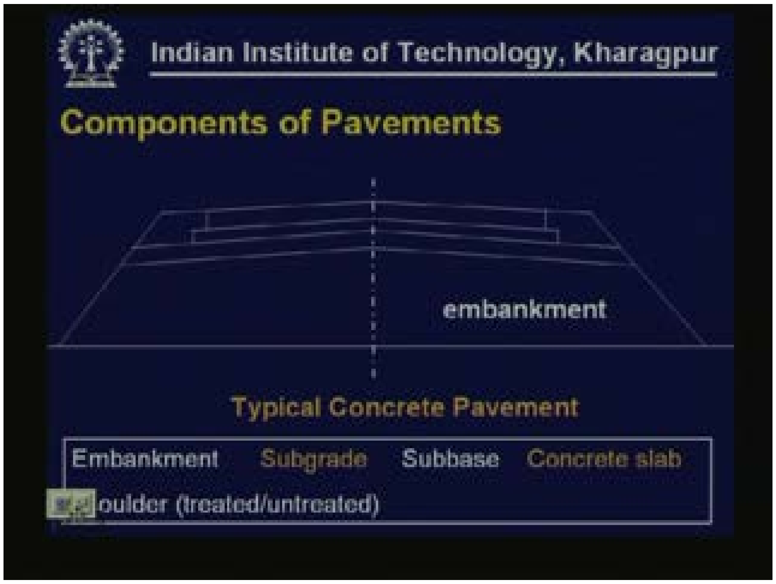

Similarly for a typical concrete pavement also we can have embankment, we can have subgrade above which we can have subbase which at times be considered as base over which we place concrete slab. Here again we can have shoulders which are either treated or untreated. So in the case of concrete pavement we have concrete slab, granular or treated bases, subbase and also the embankment material and then the shoulders.

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We use different types of pavement materials for different types of pavements. Obviously for bituminous pavements we are going to use bituminous materials, for concrete pavements we are going to use concrete slabs so some of the materials that we normally come across in the construction of pavements are soil for embankment and for subgrade, aggregates for different subbase and bases and also used in bituminous constructions and also for concrete pavements, these aggregates can be natural or artificial and then we have bituminous binding materials, either bitumen, tar, emulsion or cutbacks and among bitumens we can also have modified bituminous binders namely polymer modified, rubber modified and various other modified binders are available now-a-days. Then we have bituminous mixes which is a combination of different types of aggregates, different sizes of aggregates and bitumen or different types of bituminous binders.

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We also use cement and we have cement concrete of different types; plain, reinforced and pre-stressed cement concretes. We occasionally use stabilized materials especially for subbase and base, even subgrade also can be stabilized. We also use recycled materials. The existing pavement materials can be recycled and reused with certain modifications. it can be bituminous materials that can recycled, it can also be concrete pavements that can be recycled, recycle at the same place, it can be recycled in the recycle mill then removed and reused elsewhere. We also have other types of materials used for specific purposes such as geotextiles, geomembranes and other types of materials.

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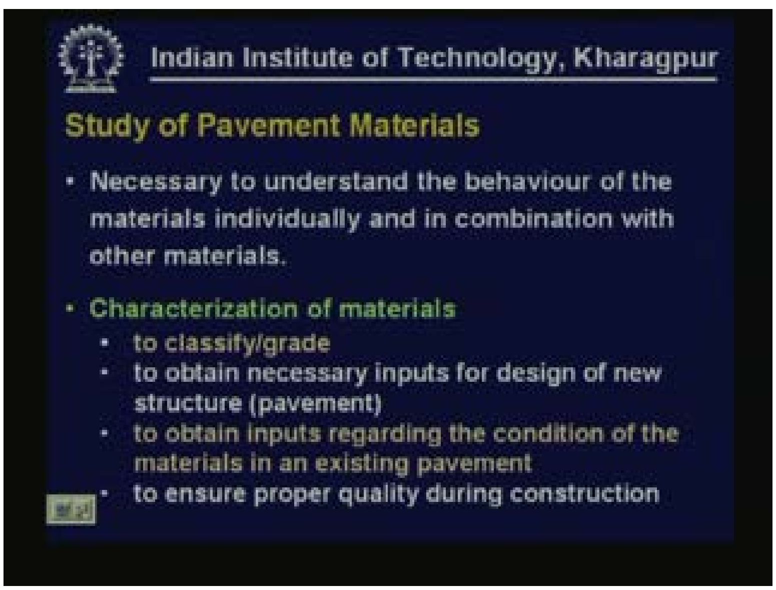

It is necessary to study about pavement materials because we need to understand the behavior of the materials individually and in combination with other materials. We normally characterize these materials for the following purposes that is to classify or grade. For example, cements of different grades, bituminous of different grades, cutbacks of different grades and each particular grade is used for a specific purpose. We also characterize or test or evaluate these materials to obtain necessary inputs for design of new structures, different design approaches require different inputs, certain approaches require elastic module or elastic properties of the materials, other approaches use viscoelastic properties of these materials and others use some simple parameters like index properties, gradation and some other simple strength parameters.

We also characterize the materials to obtain inputs which tell us about the condition of the material in existing pavement. The previous point we discussed about the inputs that are required to design new pavements whereas you may already have an existing pavement and we are trying to evaluate that find out its condition and see whether any reinforcement is required whether any strengthening is required. So whatever properties of materials exist in the field it is also very important to evaluate that and that is another purpose for which we characterize the materials. We have to carry out certain test to ensure that proper quality is being ensured during construction after construction so we also carry out certain tests for ensuring quality construction.

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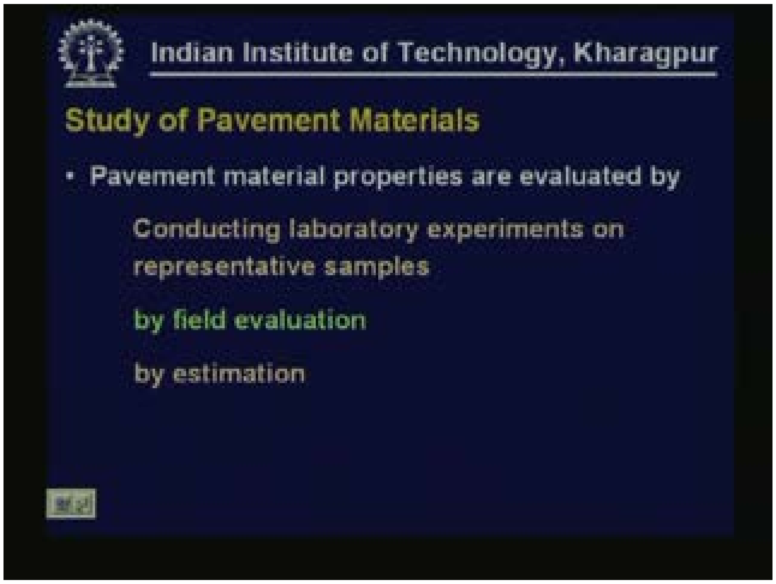

The study of pavement materials is usually done by conducting laboratory test on representative samples. Representative is a keyword. We should be able to select testing conditions and the conditions using which we are going to prepare this result in such a manner that their representative of the field conditions, representative of the conditions to which the material is going to be subjected to during its service life period and we also get these material properties by conducting field evaluation. That is, instead of bringing samples to the laboratory and testing them tests are conducted on the materials at the existing field under field conditions and get the material properties. These are normally useful for evaluating the condition of the in service pavements. If you cannot do either of these two that means we are not in a position to conduct laboratory test and we are also not in a position to go to the field and carry out extensive field evaluation test.

We can estimate the parameters that are required for design of new pavements or for design of over layers or rehabilitation measures by estimating those important parameters from some simple parameters that can be very easily obtained. There are certain parameters that we have to consider before we are able to characterize the materials properly and adequately. These are parameters which are very important for the performance of the pavements which have significance influence on the performance of materials during its service life period.

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Loads: We are going to deal with stationary loads, it may not be stationary forever but stationary for sufficiently long period and are they moving loads, if they are moving loads what is the speed at which they are going to be moving, are they very heavy loads, light loads, how is the load applied to the pavement, what is the nature of stress distribution, is it by impact, is it by normal stresses or they are going to be surface shear stresses. We also need to understand the climatic conditions that the material is going to be subjected to.

For example, if you are using bituminous materials, if you are using these materials at locations where we are expecting very high temperatures or very low temperatures these temperatures then we should be able to understand a range to which the bituminous materials are going to be subjected to because we know that bituminous materials have different properties at different temperatures.

Similarly, we also need to have information on the moisture contents, the possibility of some of these materials being under submerged condition or the levels of moisture content that is likely to be there during various seasons of a year and also we need to know whether this is a material that is going to be affected by the presence of moisture, if yes we have to select appropriate moisture content in the preparation of the specimen and in characterizing the material. Certain materials are going to be affected by weathering action, cyclic wetting and drying process, chemical action and cyclic freezing and thawing action, freezing and then melting action. So, if you are dealing with materials that are going to be affected by these phenomena then we have to evaluate those materials either in the laboratory or in field, what is going to happen to these materials, how this strength and performance of these materials is going to be effected when they are subjected to this weathering action.

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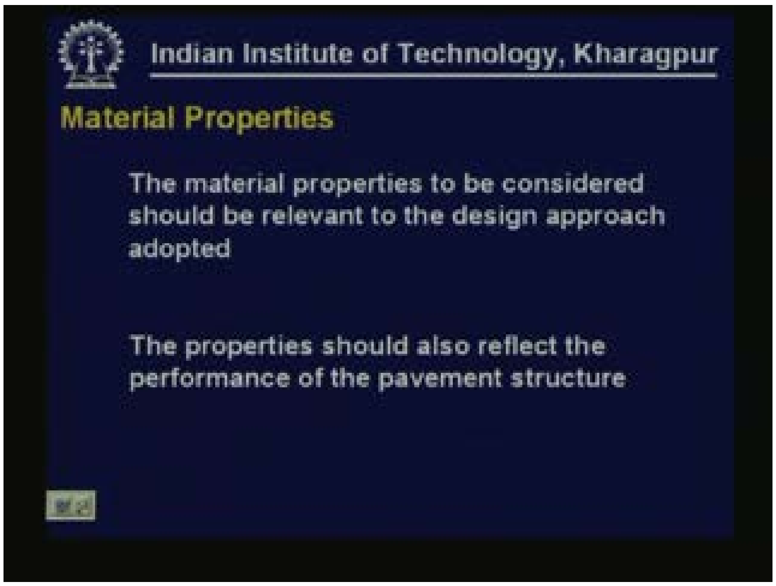

The material properties to be considered should be relevant to the design approach adopted, this is very important. each design procedure has got a framework and whatever material that is to be used for each material certain parameter or set of parameters are to be defined and those are the parameters that are to be used in design and redesign or overly design or evaluation. Just because we have sophisticated equipment available, just because new types of testing methods are being made available to us we cannot go on replacing the parameters that were there earlier with new parameters that can be determined by other procedures because the original design procedure has been developed by correlating the performance of the pavement with those parameters that have been listed in the framework of pavement design.

We cannot go on introducing new parameters in the system unless we have sufficient data to validate the correlation between the new parameters and the performance of the pavement. It is very important to keep in mind that we have to as far as possible use only those parameters that are there in the frame work of the pavement design. The properties should also reflect the performance of the pavement structure. If a pavement design has to be rational then we have to be talking about only those parameters which have some bearing on the performance of the pavement so each material has to be evaluated only for those parameters which have some bearing on the performance of the pavement during its service life period.

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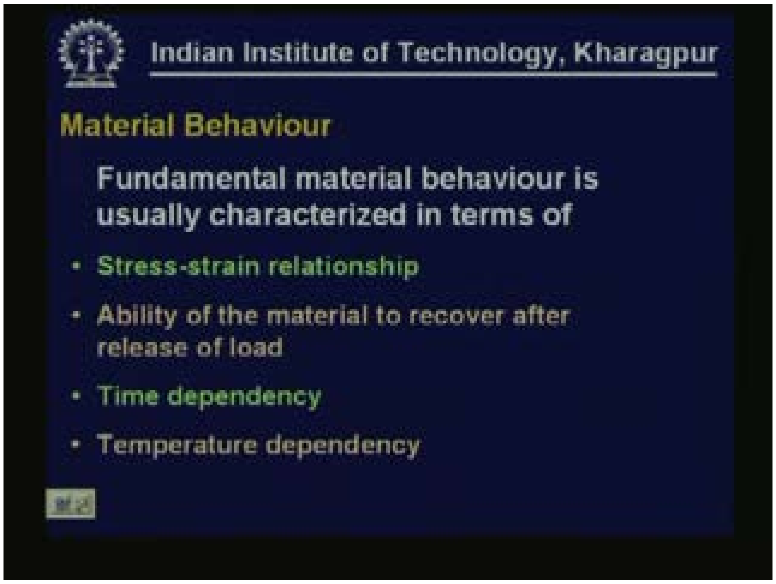

The material behavior can be characterized fundamentally in terms of the following relationship that we can discuss such as stress-strain relationship and the ability of the material to recover after the load is released and the time dependency of the material or the material behavior and similarly the temperature dependency of the behavior of the material.

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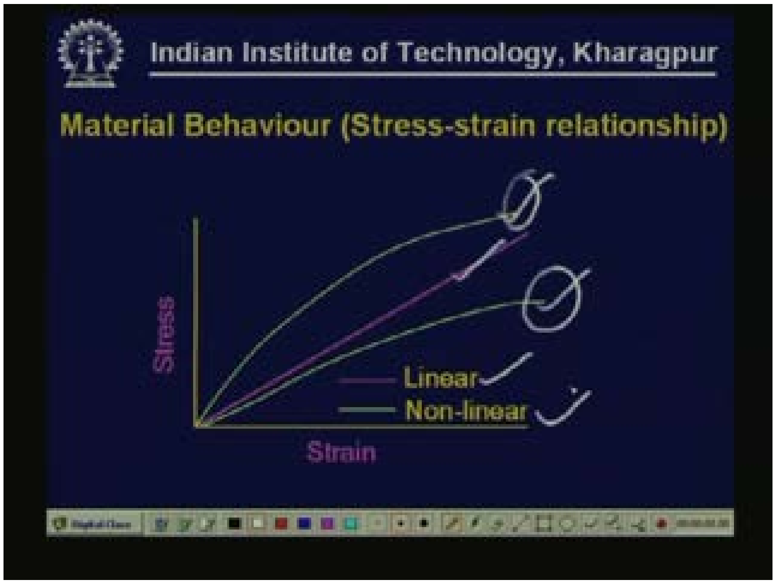

For example, if you consider the stress-strain diagram for a given material it can be represented by a straight line, such a behavior is considered as linear behavior. In many most cases when we talk about pavement materials it is not linear, the relationship between stress and strain is not linear it can take any shape, different shapes can be observed so such materials are considered to be nonlinear. Thus materials are either described as linear materials or nonlinear materials. Accordingly either linear theory or nonlinear theory is selected for analysis of pavements containing these materials.

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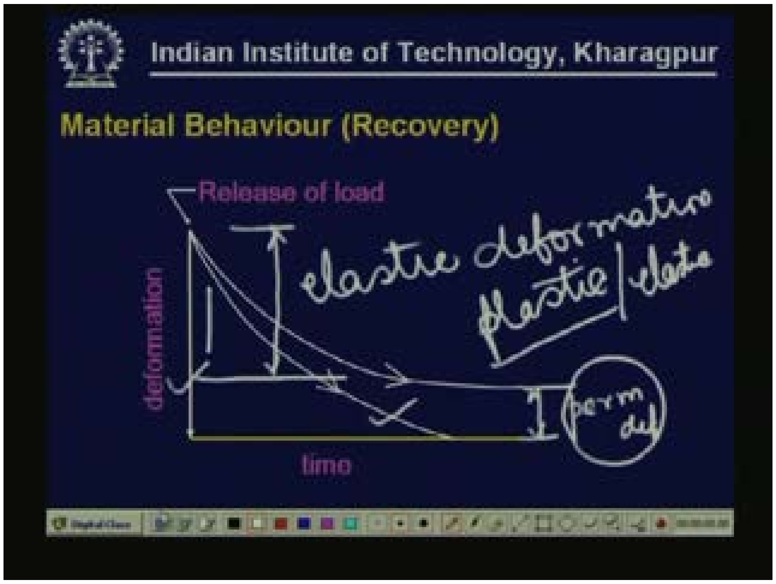

Similarly, if we examine the behavior of the material after the load is released, for example, this is the deformation at time zero which is the time we have released the load so some materials may recover the deformation instantaneously whereas some other materials may not recover the deformation over some time period it may be short time period or long time period but some of these materials may not completely recover the total deformation, part of the deformation is within practical time period and is never recovered.

This is permanent deformation which is not recovered and the part of deformation that is recovered is elastic deformation. Accordingly, the material is called either as elastic material, the material which exhibits complete recovery of deformation on release of load is considered to be elastic materials and materials which have partial or full deformation which is not recovered are called as plastic materials. So we use these two terms to describe the materials either elastic or plastic. Occasionally we use the combination of these terms that is elastoplastic which means a material that is displaying partly elastic recovery and then partly plastic deformation.

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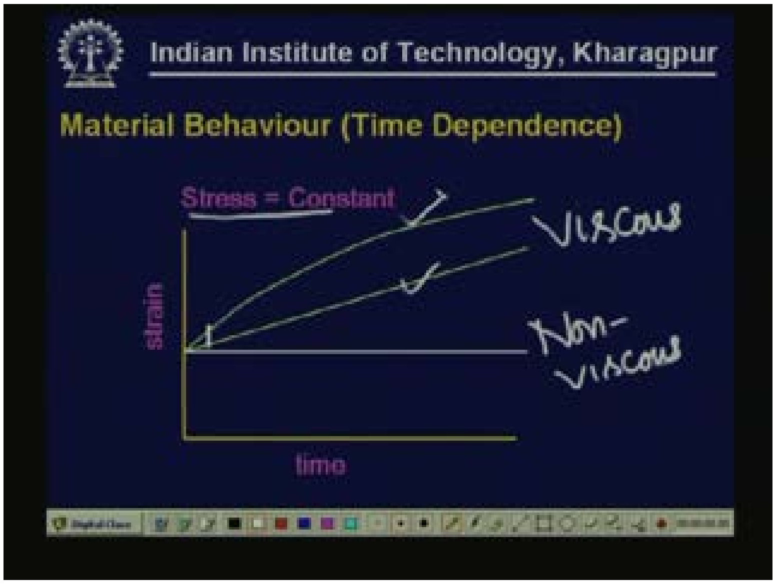

The time dependence of certain materials can be seen here. Under constant stress if the strain does not change with time this is considered to be non-viscous material whereas for a constant stress if the strain goes on varying that is in these two cases then they are considered to be viscous materials. In some cases the relationship between strain and time is linear or it can be nonlinear so we use various terms like linear, nonlinear, elastic, plastic, viscous, non-viscous etc.

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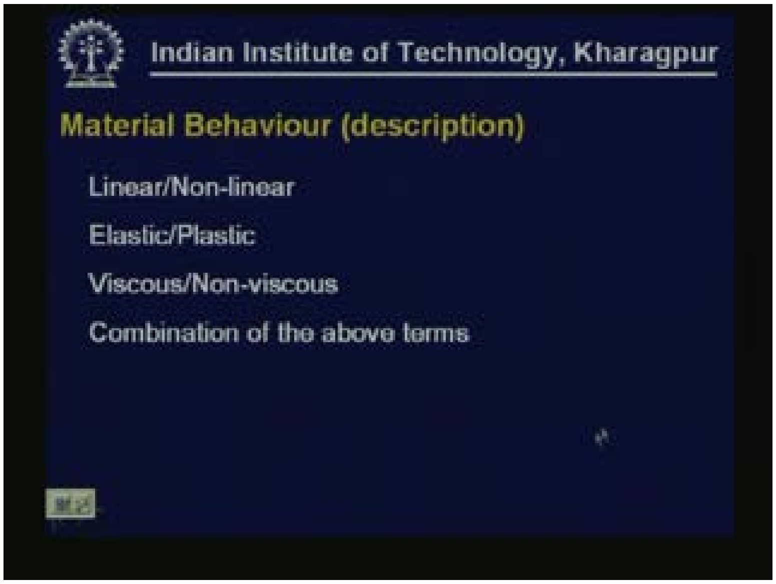

So the behavior of the material is normally described in terms of linear, nonlinear, elastic, plastic and a combination of these terms which are normally used.

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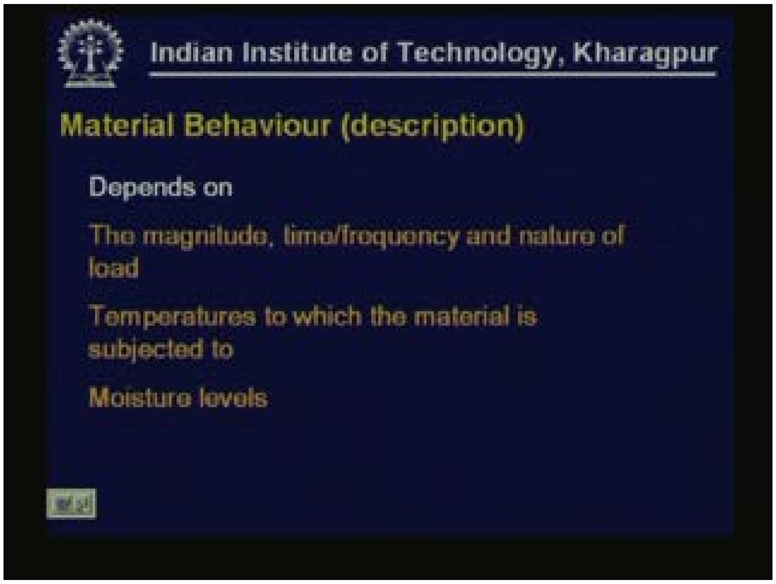

The material behavior normally depends on the magnitude of load as you have seen in the previous slides and some of these materials have dependency on the magnitude of load at different road levels, they have different properties, they are also dependent on the time and frequency of loading as how frequently the load is applied, for what duration the load is applied and also the nature of load. The material is also dependent on the temperature to which the material is subjected to. We have just seen that sort of a behavior in the previous slide. In some materials the behavior is depended on moisture levels.

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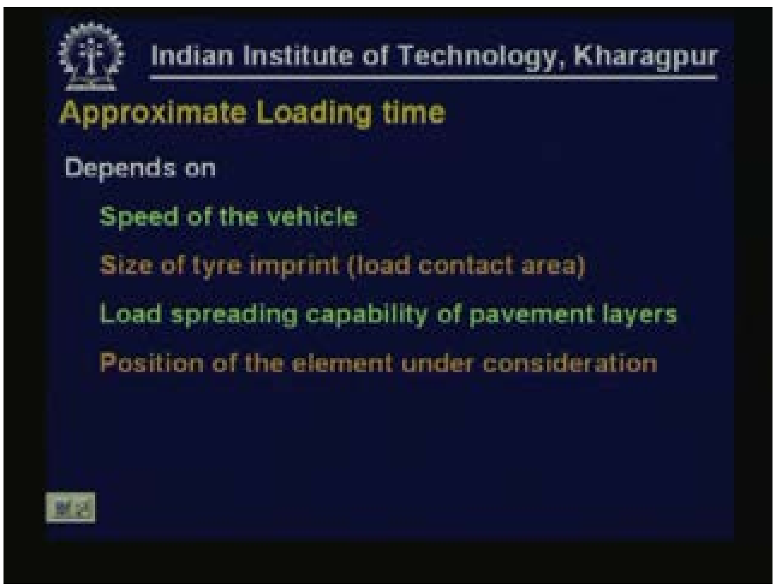

We have considered that loading time is important as far as the characterization of pavement material is concerned. Some materials are subjected to short loading times in the pavement and other materials for example those materials which are at the bottom of the pavement are subjected to much longer loading time. Accordingly the behavior of these materials is going to be different. So, the loading time is a function of the speed of vehicle, size of the tire imprint or the load contact area and the load spreading capability of different pavement layers and the position of the element or the layer that we are considering.

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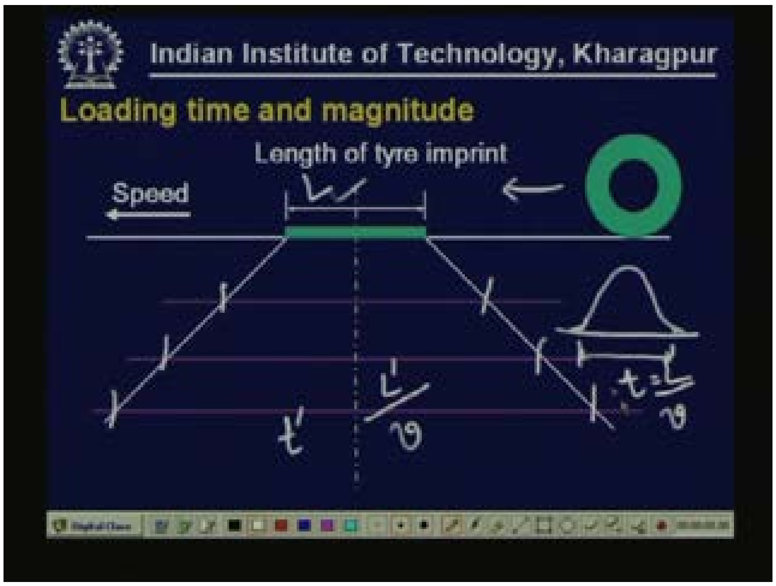

For example, if you consider a layer system and if there is a load that is applied which is moving in this direction then depending on the speed at which it is moving and if this is the length of the tire imprint that we have and if you assume this is approximately the manner in which the stress is going to be distributed so at different depths the stress bowl is going to have the dispersal area varying like that. At the top this is the area of stress dispersal so the loading time starting from the point at which significant amount of stress is considered to the time when stress becomes negligible if you consider this to be the loading time this can be obtained by the length of tire imprint divided by the speed at which the vehicle is traveling.

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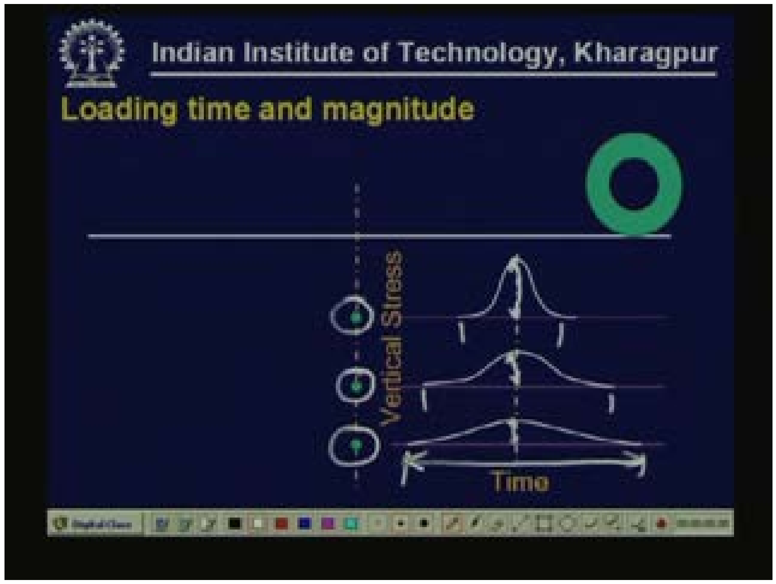

Similarly if you are trying to find out the loading time corresponding to this then this would be obtained by the length that we see here divided by the speed of the vehicle. So if you consider points at different depths in the pavement surface obviously the magnitude of the load or stress is going to be different it's going to be decreasing with depth but on the other hand the loading time is going to be increasing with depth. So at larger depths stress magnitude is going to be smaller but loading times are going to be larger.

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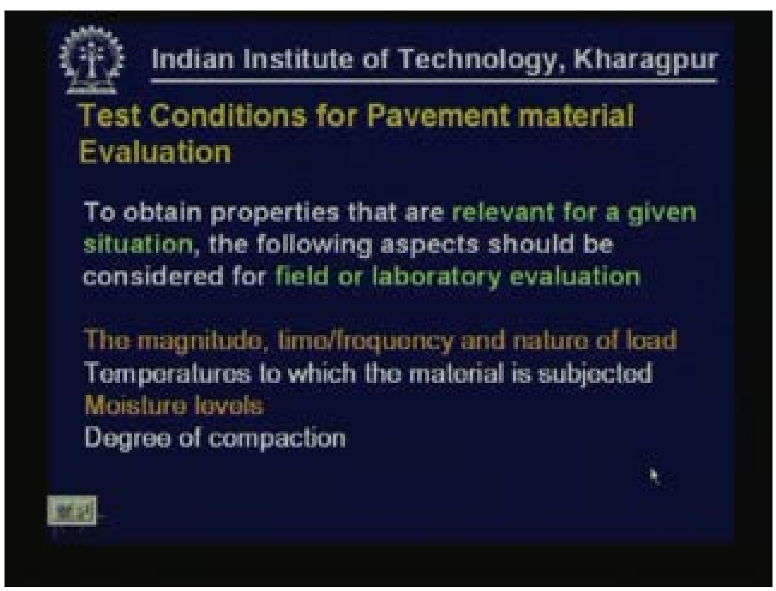

Therefore for conducting a test on different pavement materials this is done to obtain properties that are relevant for a given situation. For this we have to consider the following aspects either for field or laboratory evaluation. We should be able to simulate the magnitude, time and frequency and nature of load, the temperature to which the material is subjected to, moisture levels to which the material is going to be subjected to during its service life period and degree of compaction.

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As I have mentioned earlier in this lesson we are going to be focusing mostly on subgrade soils and embankment soils and we will be dealing with the other types of materials in subsequent lectures. Soils are used in embankment portion and in subgrade. Once again subgrade is nothing but that portion which is right below the pavement and which is prepared to standard specifications and prepared to attain certain strength which is specified by the design. Soils are also used in preparation of shoulders. Soil is used either in its natural form or in a processed or stabilized form. The most common properties that we determine are index properties or mechanical properties.

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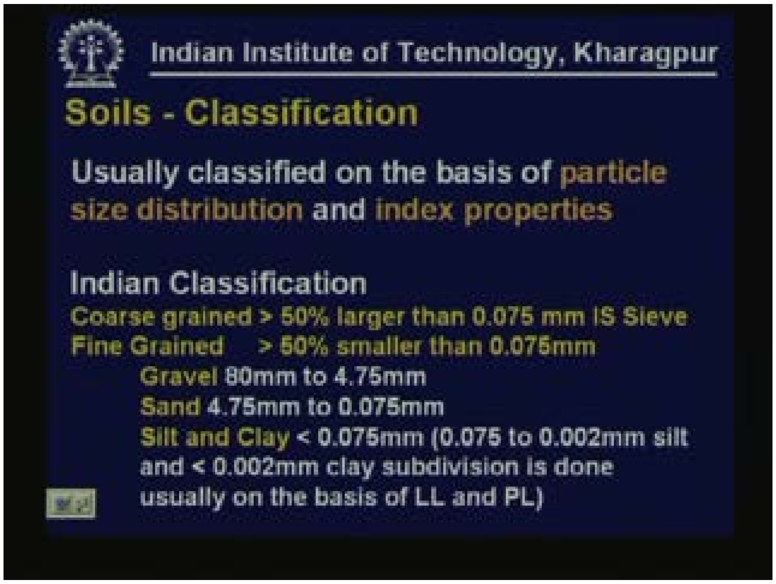

Soils are classified using various systems. They are usually classified on the basis of particle size distribution and some index properties. In the Indian classification soil is considered to be either coarse grained for that the soil should be having more than 50% of the particles larger than 75 micron size. The soil would be considered to be fine grained if more than 50% of the particles are smaller than 75 micron size. Typically the soil is designated in terms of gravels, sand, silt and clay depending on the particle size, 80 mm to 4.75 mm size is normally considered to be gravel, 4.75 mm to 75 micron is normally considered to be sand, less than 75 micron size is considered to be other silt or clay, sub division could be in terms of 75 micron to two micron is silt, less than two micron is clay. However, normally this sub-division is done on the basis of the index properties which are liquid limit and plastic limit of the soil.

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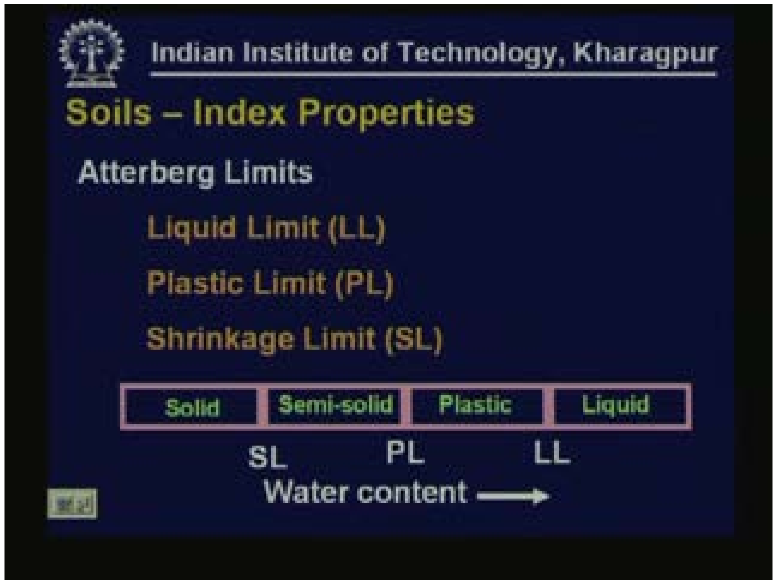

The important index properties that we determine for soils are called as Atterberg limits namely liquid limit, plastic limit and shrinkage limit. Liquid limit and plastic limit being more commonly used and are more important. Liquid limit is the moisture content which serves as a boundary between two different phases of soil between liquid and then plastic. This is the minimum moisture content at which the soil is going to be in liquid content. Anything more than this is going to be liquid and anything less than this is going to be in plastic condition. Similarly plastic limit is the boundary between plastic and semisolid condition. For moisture content more than plastic limit the soil is going to be in plastic condition and for less than this it is going to be reaching a semi-solid condition.

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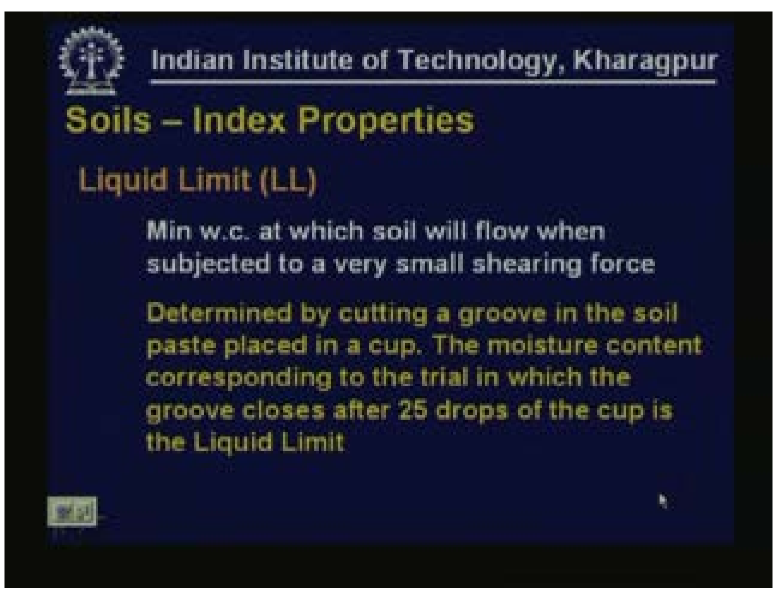

Liquid limit is defined as the minimum water content at which soil will flow when subjected to a very small shearing force. We are talking about moisture content which if exceeded is going to be leading to a flow condition. This is normally determined by cutting a groove in the soil paste placed in a cup. We are not going to discuss the details of the test procedure because these are standard topics that are normally covered in soil mechanics. The moisture content corresponding to the trial in which the groove closes after 25 drops of the cup is the liquid limit. After cutting the groove in the soil placed in the cup the cup is made to be lifted up and made to drop this is done for twenty five times. there is a particular moisture content corresponding to which the groove is going to be closed after 25 drops of the cup and that is defined as the liquid limit. Obviously we have to make number of trials with different moisture contents and then obtain the liquid limit.

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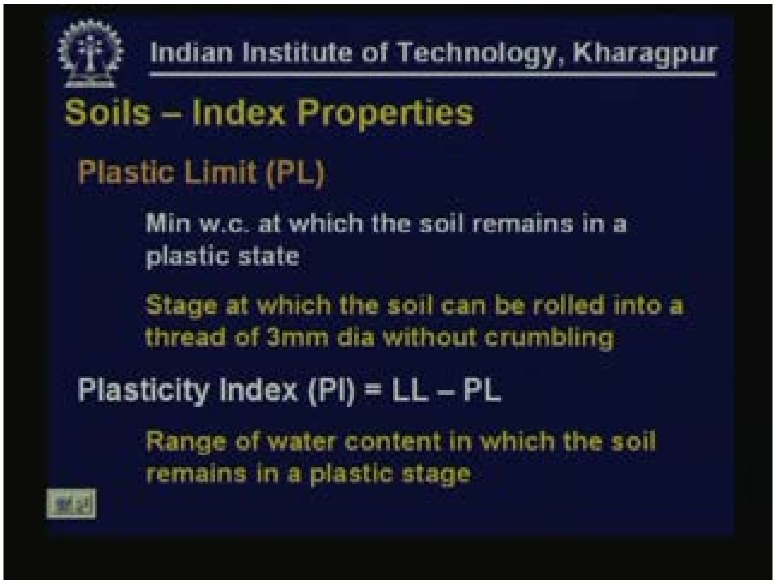

Plastic limit is the minimum water content at which the soil remains in a plastic state. Physically this is how we can identify this. This is the stage at which the soil can be rolled into a thread of 3 mm dia without crumbling. We start making a thread of 3 mm dia by rolling it and as we allow the moisture content to go on reducing the condition at which the 3 mm dia thread starts crumbling that represents the plastic limit condition. So the moisture content of that specimen of soil is determined and that is identified as the plastic limit. An important parameter which is known as plasticity index is obtained by subtracting plastic limit from liquid limit. Plasticity index represents a range of water content in which the soil remains in a plastic state.

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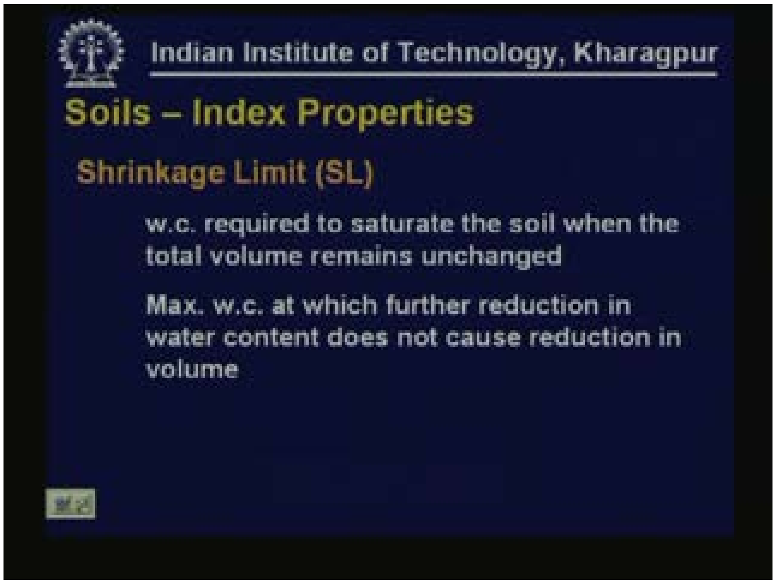

Shrinkage limit is the maximum water content at which further reduction in water content does not cause reduction in the volume of the soil.

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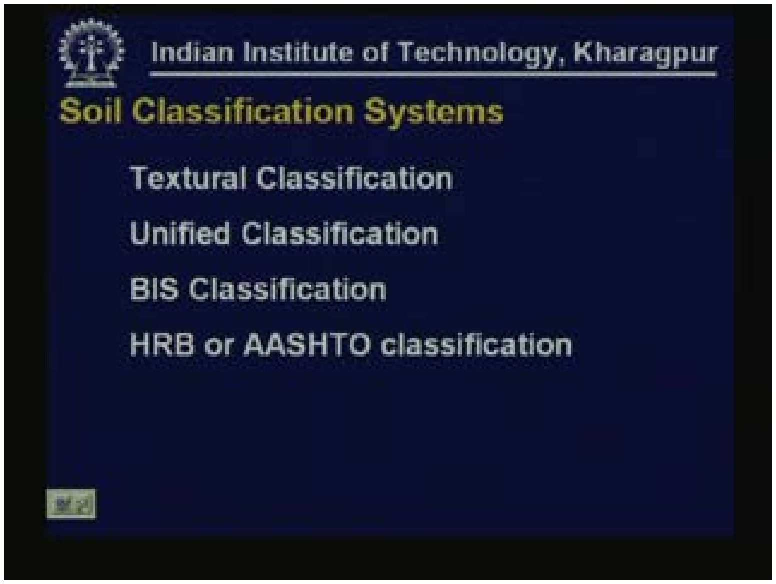

As I mentioned earlier there are various classification systems that are followed for classifying soil namely textural classification, unified classification, Bureau of Indian Standard classification and Highway Research Board and American Association of State Highway Transport Officials classification.

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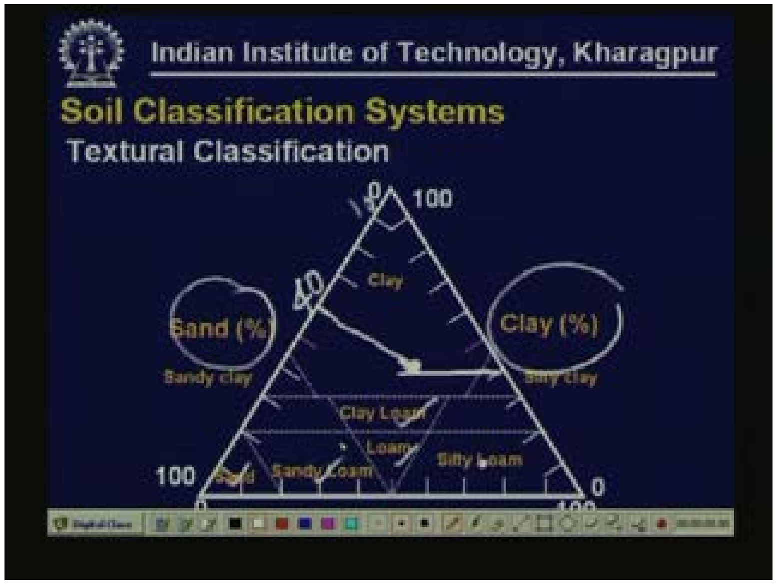

Starting with textural classification though a not very commonly used classification it is a very simple system which is based on the gradation or particle size distribution of the soil. As you can see in this triangular chart if we know the percentage of sand in the soil and percentage of clay that means if you consider the soil to be a system consisting of sand, clay and silt the bottom axis is silt so if you know any two of them obviously we know about the third value.

For example, if we have 40% sand and 60% clay that is 10, 20, 30, 40, 50, 60 so 60% clay this is intersection point and this is the zone within which it is going to lie so this is designated as clay. Similarly if you find a point designated in this zone depending on the percentage of sand, percentage of clay and percentage of silt then this would be called as silty loam, in this zone it is clay loam, loam, sand, sandy loam. This is a very convenient method but not very commonly used now-a-days.

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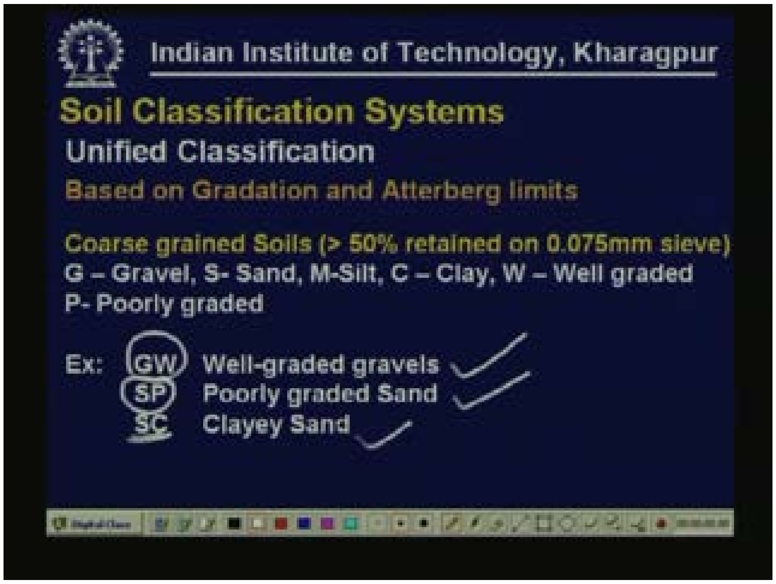

Coming to the unified classification this is based on both the particle size distribution that is gradation and also the index properties that is Atterberg limits. In this case also coarse grained particles are considered to be those having more than 50% retained on 75 micron sieve. We use different notations for identifying different types of soils; G for gravel, S for sand, M for silt, C for clay and if we are dealing with sands or gravels which are not clean that means those sands and gravel that contain clay or silt are designated in terms of clayey and silty but if you are dealing with clean sands or clean gravels then they are further designated in terms of their gradation whether they are poorly graded or well graded. For example, GW is the notation that we use for well-graded clean gravels, SP is the notation that we use for poorly graded sand and if the sand contains clay then it is designated as clayey sand.

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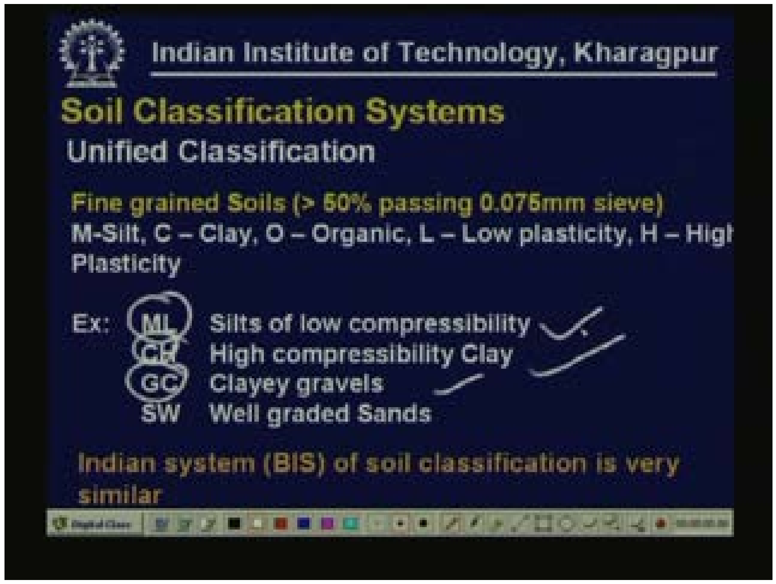

Fine grain soils are those soils having more than 50% passing 75 micron sieve. Here again we use notations such as M for silt, C for clay, if it is an organic soil O and depending on the plasticity of the material low plasticity materials with L and high plasticity materials with H. So ML means silts of low compressibility or low plasticity, GC clayey gravels, CH high compressibility clay and so on. The Indian system that is Bureau of Indian Standard Soil classification is very similar to Unified classification system.

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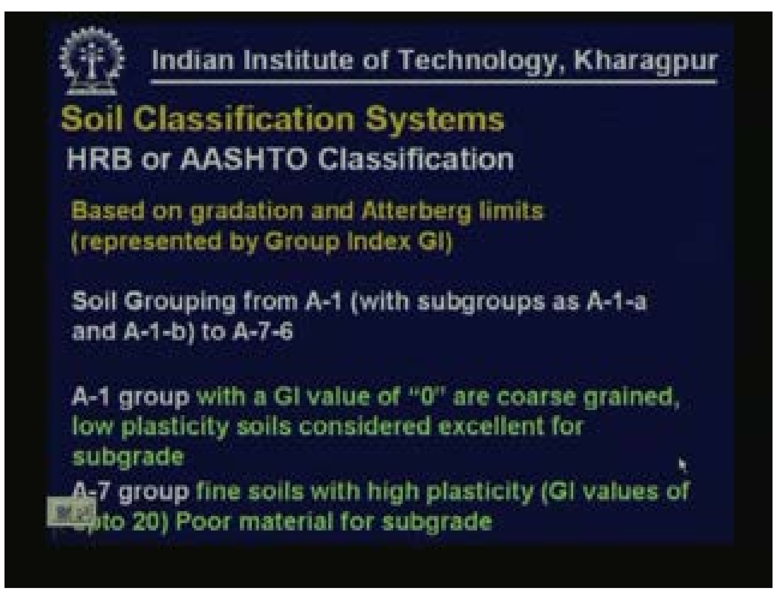

The Highway Research Board or the AASHTO classification is also based on the particle size distribution and the Atterberg limits. There is a parameter called group index GI which is used to designate or to carry out the classification of soils. We have different groups of soils in terms of ranging from A-1 to A-7-6. For each one of these groups we have subgroups. For example, A-1 has got subgroup ranging from A-1-a to A-1-b. A-1 group of soils are having GI values of 0 they are coarse grained materials, they have low plasticity and are usually considered to be excellent for subgrade construction. Whereas A-7 groups are fine grained soils with high plasticity and have GI values as high as 20 and are considered to be poor for subgrade construction.

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Various soil strength parameters are determined and for doing that we need to understand the factors that influence soil strength. Obviously the soil strength is going to be varying depending on the type of soil that we use. Granular soil usually has better strength compared to fine grained soils and the strength is also a function of particle size distribution which influences the coefficient of internal friction and cohesion that is mobilized. The strength is also a function of degree of compaction which greatly influences the strength.

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Strength again is influenced by the moisture content which in turn affects the density that is attainable cohesion and internal friction that can be mobilized. In some materials especially granular materials confinement plays a significant role, granular material are usually stronger when they are confined but without confinement they are not so strong. The permeability characteristics of the materials affect the effectiveness of drainage which in turn affects the shear strength of the material.

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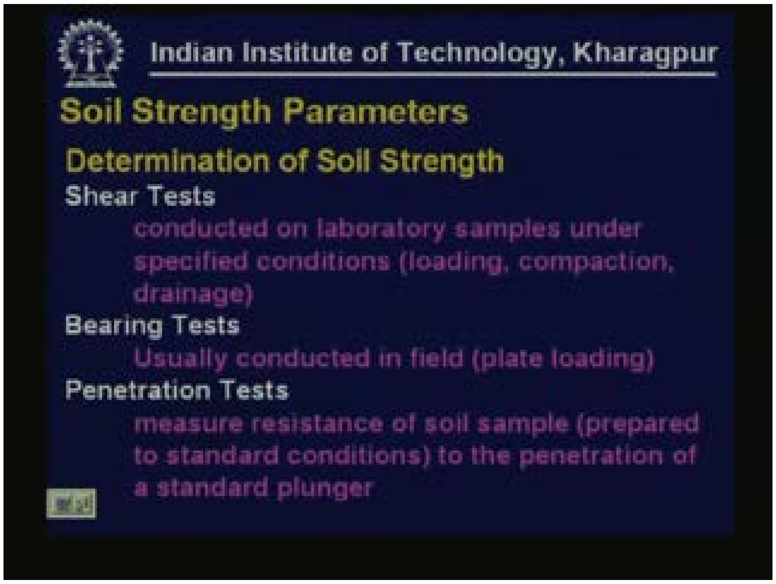

The soil strength parameters or different types of parameters are evaluated. For determining soil strength various types of tests are conducted. These are shear tests normally conducted on laboratory samples. All these stress can be conducted both in laboratory and also in field but shear strength tests are normally conducted in laboratory on laboratory specimens, under specified conditions of loading, compaction and drainage. Bearing tests are usually conducted in field. Again, it is usually conducted under specified loading conditions using specified loading area and specified rate of loading whereas penetration tests also are conducted either in laboratory or in field but more commonly on laboratory specimens. These tests give a measure of resistance of soil sample prepared to standard conditions to the penetration of a standard plunger or in some cases to the penetration of a standard needle.

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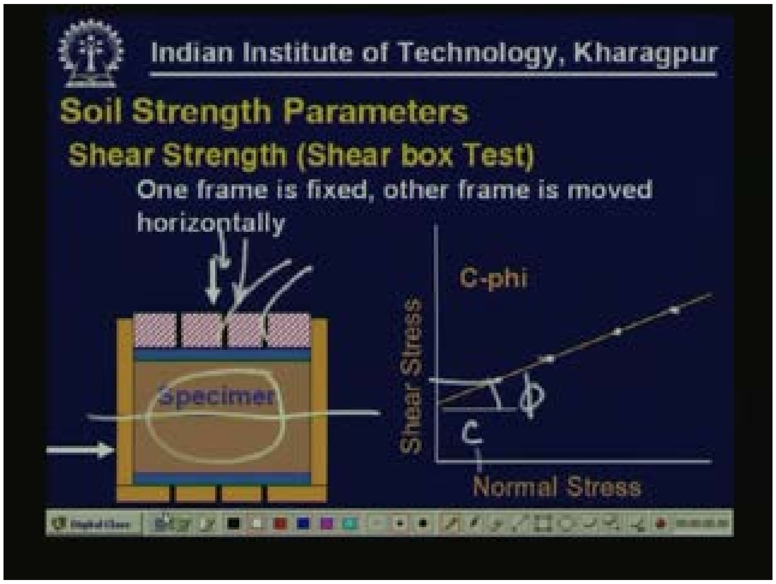

One of the tests that is conducted for evaluating shear strength is the shear box test in which this is the specimen that is prepared the soil specimen prepared to standard specification standard compaction using standard moisture content. As you can see this box is in two halves and there is normal load that is applied, there is also a provision for drainage of water if required so what is done is that there is normal load that is applied and one of these two halves is made to be slided by the application of the horizontal force. Thus what is determined here is by varying the normal stress different tests are conducted and the horizontal force that is required to cause sliding or failure of the specimen is recorded.

Therefore for different normal stresses the corresponding shear stress is noted and the relationship between the normal stress and the shear stress is applied. Since we know the horizontal force and the cross sectional area of the specimen we can calculate the shear stress here. Thus for different normal stresses that are applied here we can know the corresponding shear stress that can be obtained. Therefore from this relationship this gives the angle of internal friction phi, and this ordinate gives the value of cohesion that is C.

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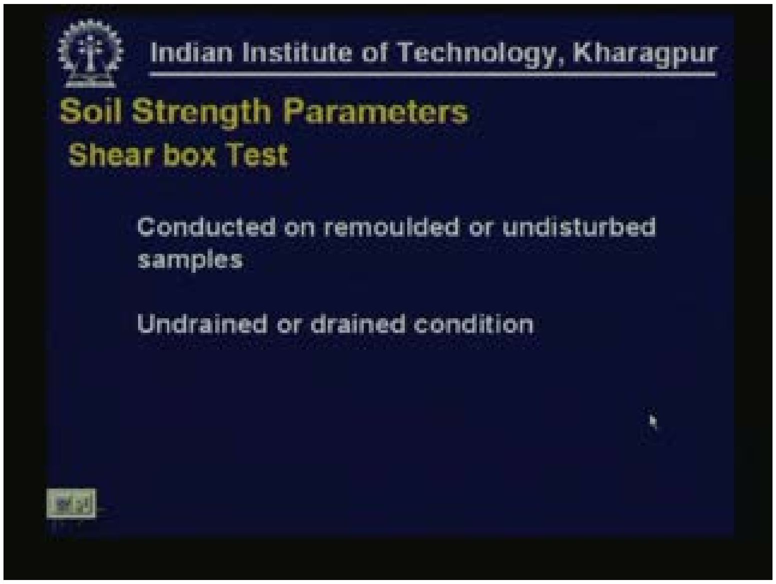

Shear box test is normally conducted on remoulded samples or undisturbed samples. It is conducted either in drained condition or undrained condition.

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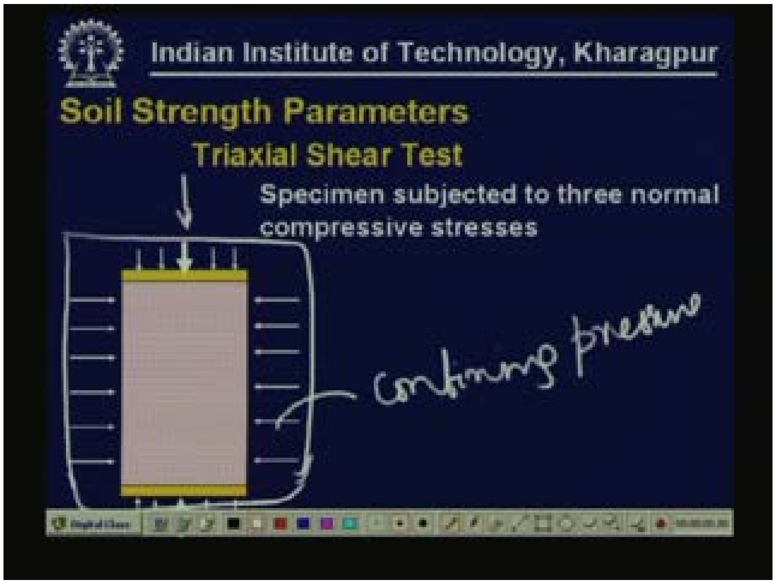

Another test that is normally conducted is a triaxial shear test. In this the specimen is subjected to three normal compressive stresses. Normally the specimen which is cylindrical in shape is prepared to standard compaction using specified moisture content, this can be conducted in drained or undrained condition.

This is normally put in a shell and then this is a confining pressure that is applied all around. This is the specimen confining stress or confining pressure and this is the normal pressure that is applied. Here again a number of tests are conducted. for a given confining pressure the stresses namely the normal stress and the vertical stress that are required to cause failure of the specimen is noted and various combinations of confining pressure and vertical pressure are noted.

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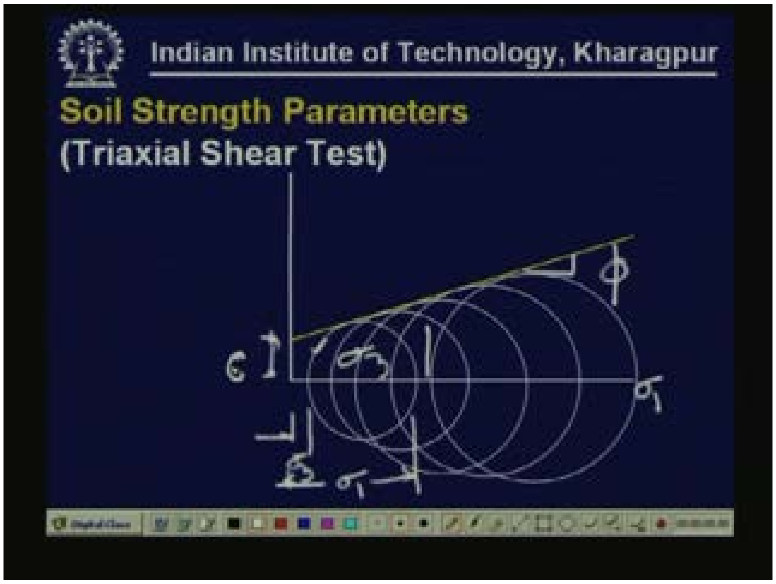

These are plotted as Moor circles. Each one of these circles represents one set of test conditions. For example, this circle has been plotted by knowing the confining pressure that is applied and the vertical pressure that is applied corresponding to failure. So, as you have different circles for different confining pressures and the corresponding sigma 1 if a tangent can be drawn for all these circles this angle gives us the phi and this value gives us C.

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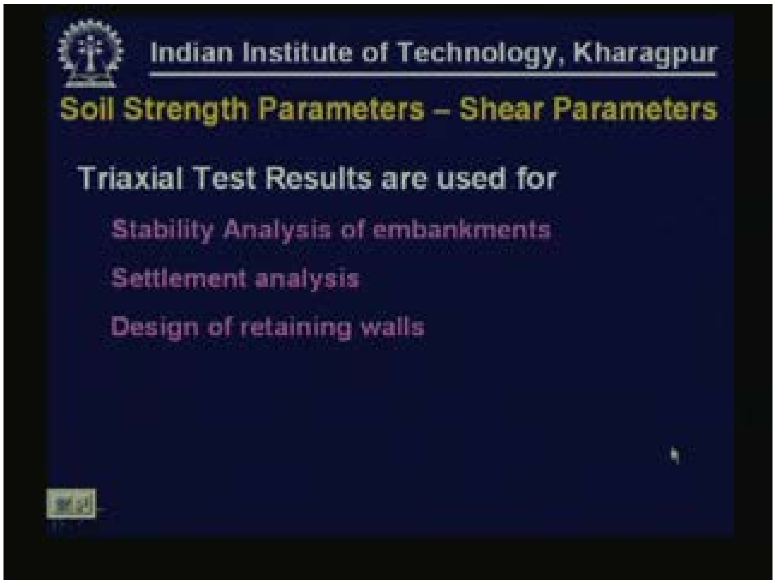

The triaxial test can be conducted either in static mode or repeated loading condition. Normally for pavements since we have cyclic loads repeated loads this test it is normally recommended that we have to conduct triaxial test under repeated loading conditions but if are trying to design embankments, foundations and other such structures or facilities it is sufficient that we conduct only static triaxial test. The static triaxial test results are normally used for stability analysis of embankments, settlement analysis and design of retaining walls.

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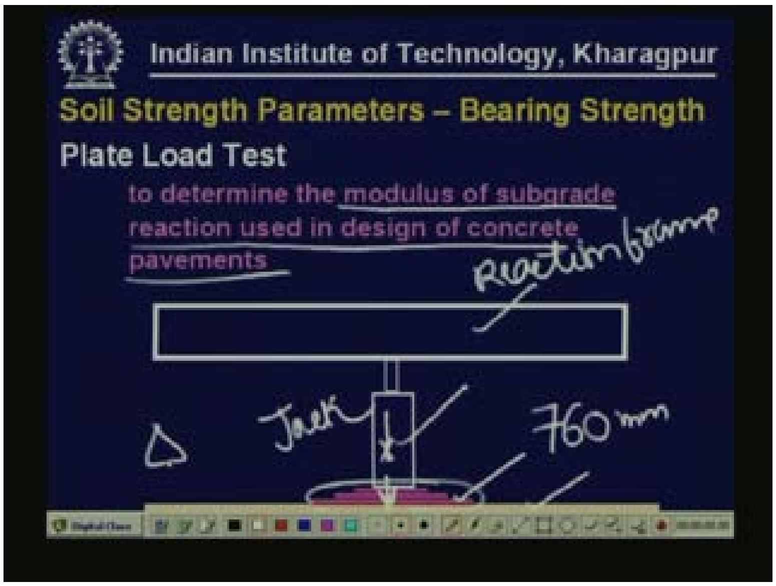

There is another very important test that is conducted for obtaining a parameter known as modulus of subgrade reaction which is used in the design of concrete pavements. In this what we do is this is the subgrade whose modulus of subgrade reaction is to be determined. A system of plates are placed on the subgrade, we use number of plates to stiffen the loading plate. The bottom most loading plate is normally having a diameter of 760 mm and load is applied through this reaction frame and this jack. So this load is gradually increased and the deflection of the subgrade at the center of the plate is recorded.

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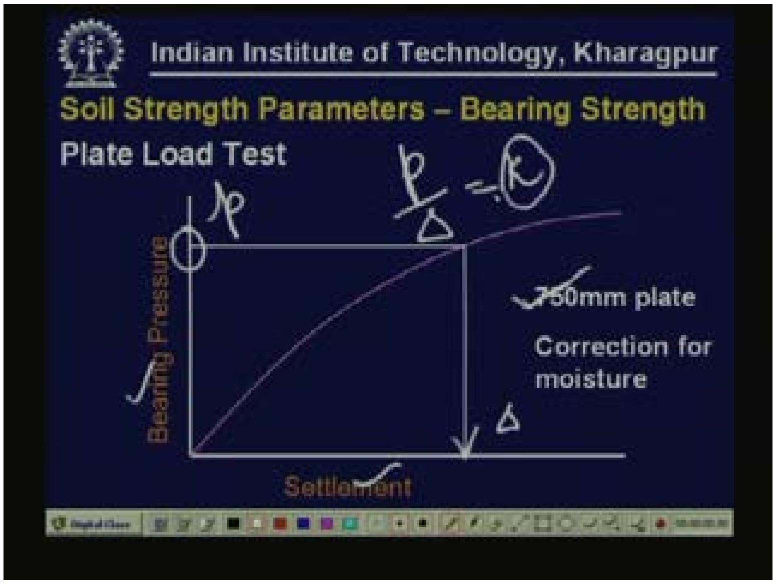

Therefore with increasing load what is the corresponding settlement or displacement? They are recorded and plotted like this. This is the bearing pressure that is applied which was gradually increased and there is a corresponding settlement using a 760 mm plate. The bearing pressure corresponding to a specified deflection is noted and the pressure divided by the corresponding settlement or deflection is known as modulus of subgrade reaction. This normally is determined for a standard plate size.

If for some reason we are not able to use this bigger size plate for this we naturally have to apply more load. If you are having to use a smaller plate then the k value obtained using a smaller plate will have to be adjusted corresponding to this larger size plate. Similarly normally the k value is determined corresponding to worst moisture condition. If you are not determining worst moisture condition k value then whatever is the moisture content at the time of conducting the test that moisture content has to be noted down and the k value will have to be adjusted to correspond to the worst moisture condition.

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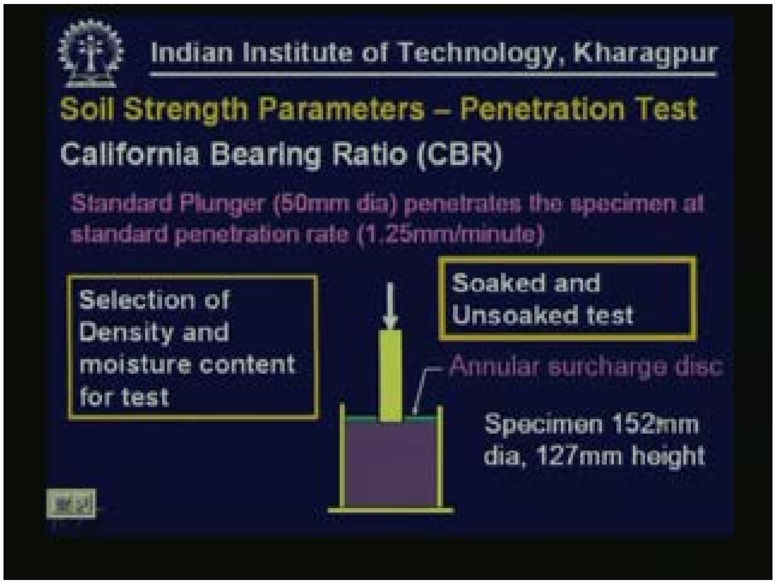

The most important test that is normally conducted on subgrade soils is the California Bearing Ratio test in which a standard plunger of 50 mm dia is made to penetrate into a soil specimen of 152 mm dia, 125 mm height prepared to standard density and moisture content. This test can be conducted either in unsoaked condition or soaked condition. The plunger is made to penetrate at a standard rate of 1.25 mm per minute. So, with penetration what is the resistance offered by the soil to the penetration of the plunger is recorded and plotted like this.

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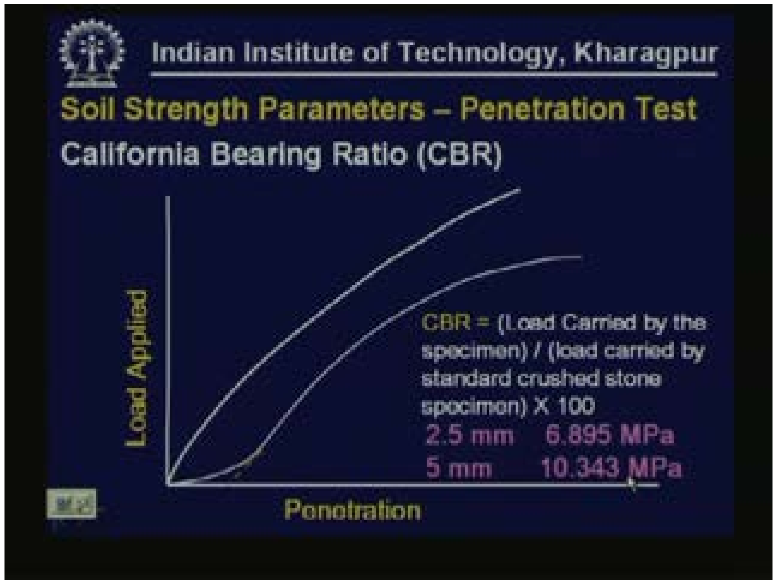

So here you have the penetration and the corresponding load applied. CBR is the ratio of load carried by the specimen to the load carried by a standard crushed stone expressed as percentage. If you are considering a penetration of 2.5 mm 6.895 MPa is the pressure that is considered instead of load that is a corresponding bearing pressure that is applied. If a 5 mm penetration is considered 10.343 mm MPa pressure is considered.

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Normally 2.5 mm CBR value is considered that is the ratio obtained corresponding to 2.5 mm penetration is used for design. It is normally more than 5 mm CBR value but if 5 mm value

happens to be more than 2.5 mm value the test will have to be repeated and then you still get a value for 5 mm greater than 2.5 mm then that is the value that has to be used.

CBR California Bearing Ratio is the most commonly used parameter for pavement design. However, the drawbacks are this is purely empirical, this does not truly represent any fundamental characteristics of material behavior; it does not explain how a material behaves, and what exactly happens when load is applied to the subgrade soil so this test normally is not in a position to explain the fundamental nature.

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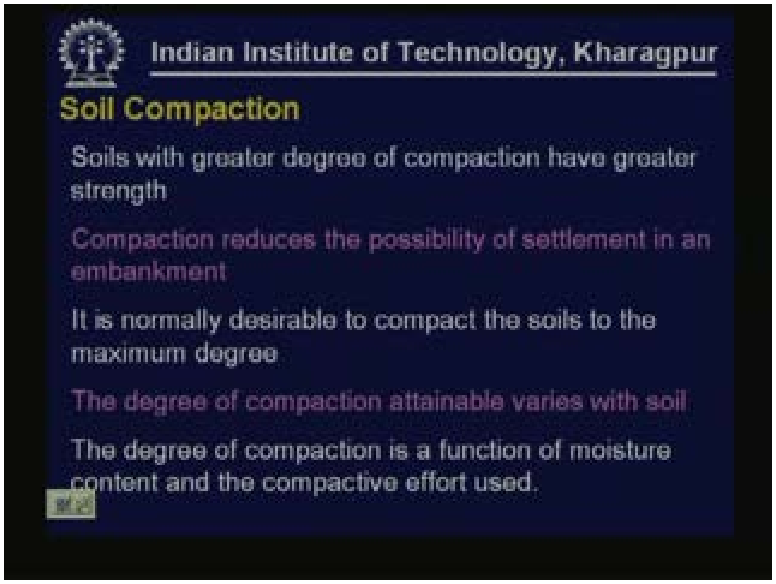

Soil compaction is another important phenomena that we have to understand. Soils with greater degree of compaction naturally have greater strength. Compaction reduces the possibility of settlement in an embankment. It is normally desirable to compact the soils to the maximum of degree that is possible. The degree of compaction attainable varies with soil. Also, the degree of compaction is very importantly a function of moisture content and the compactive effort used.

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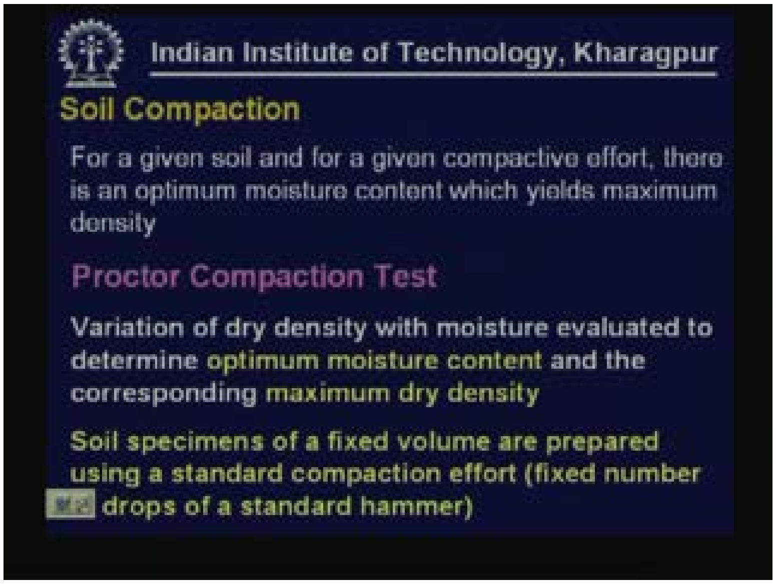

For a given soil and for a given compaction effort there is a moisture content which gives us maximum density. This is called as optimum moisture content. To determine the optimum moisture content and also to find out what is the density that can be obtained corresponding to optimum moisture content proctor compaction test is normally conducted which gives us the density of soil as it varies with variation in moisture content and thereby giving us optimum moisture content and also the maximum dry density.

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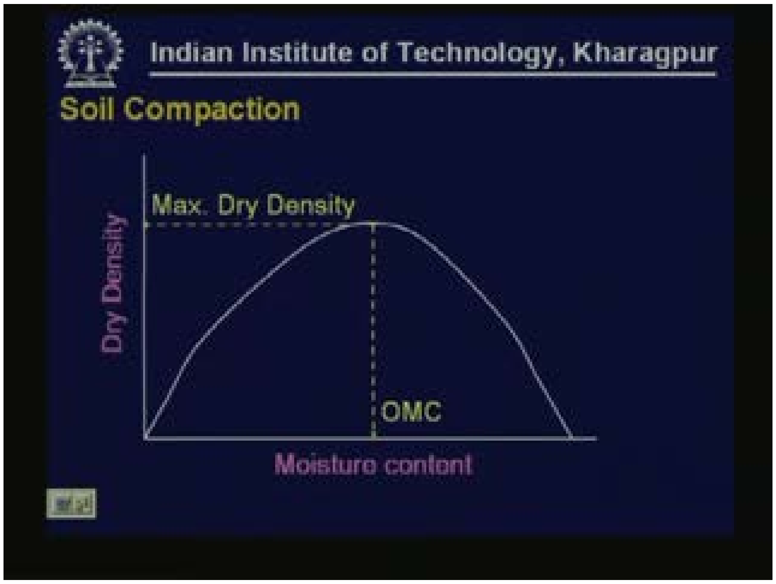

Typically moisture content is varied and the corresponding dry density is obtained and from this plot we can obtain the optimum moisture content and the maximum dry density.

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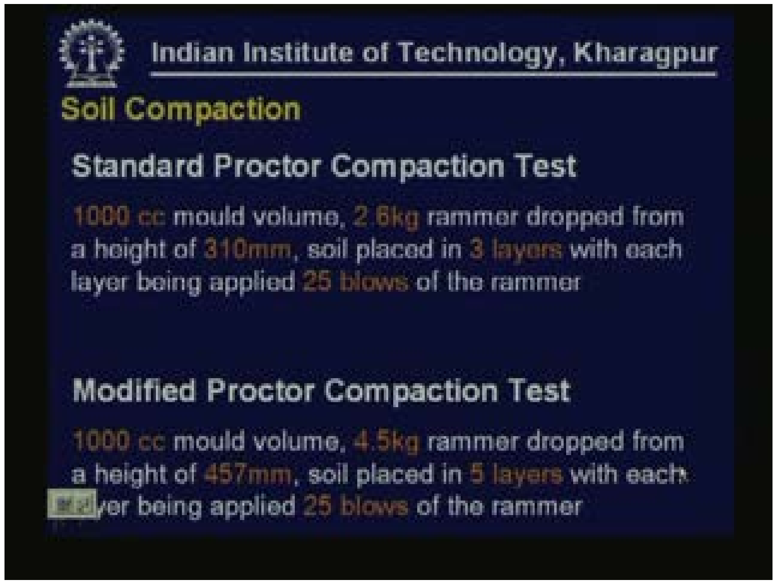

We can carry out either a standard proctor compaction test or a modified proctor compaction test by adopting different compactive efforts by varying the weight, by varying the size of the specimen, drop a number of blows so there are two types of compaction effort that we normally consider that is standard or modified.

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The selection of compaction effort and moisture content for test should be representative of the field conditions either new or existing pavements.

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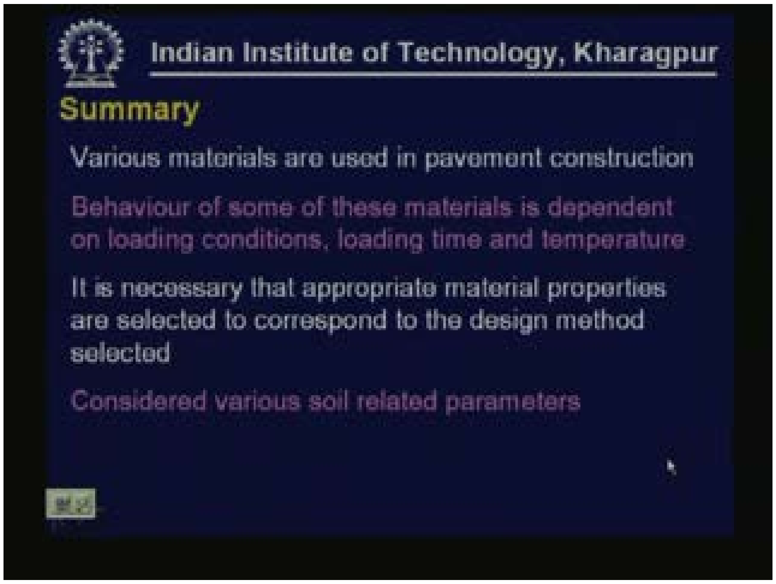

To summarize; in this lesson we have discussed about various materials that can be used in pavement construction. We also understood the need to examine the behavior of some of these materials which are dependent on loading conditions, dependent on loading time and temperature. We also understood that it is necessary that appropriate material properties selected correspond to the design method selected. And it is also essential that various soils related parameters are to be considered which have some correlation to pavement performance.

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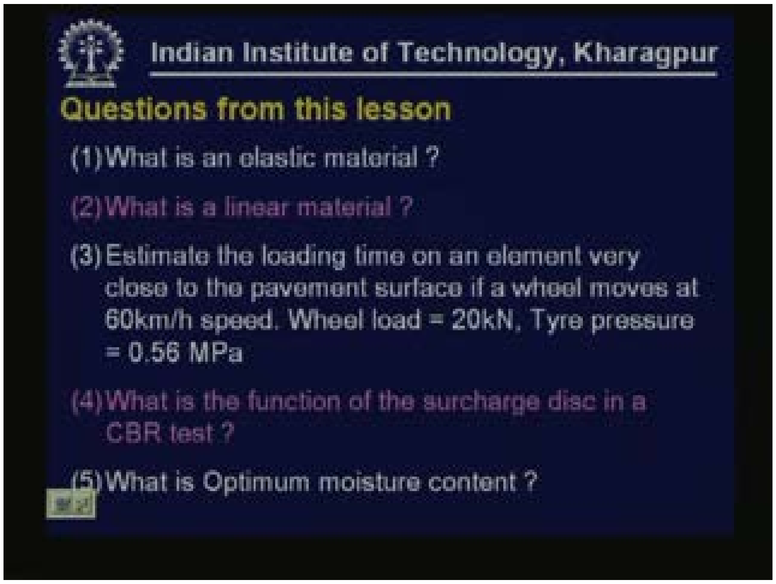

Let us take up some questions for this lesson:
What is an elastic material?

What is the linear material?
Estimate the loading time on an element very close to the pavement surface.if a wheel moves at 60 km/h speed wheel load is 20 kilo Newton tyre pressure is 0.65 MPa.
What is the function of the surcharge disc in a CBR test?
What is the optimum moisture content?

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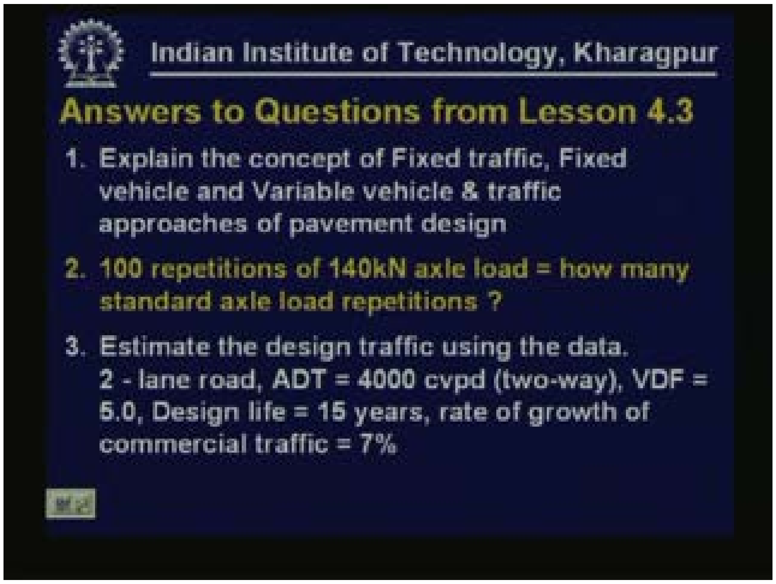

Let us consider the answers for the questions that we have asked in the previous lesson that was lesson 4.3.
The first question was, explain the concept of fixed traffic, fixed vehicle, variable vehicle and traffic approaches.
Fixed traffic: this is normally applicable for airport pavements in which we are concerned about very heavy vehicles and then the heavy vehicle is converted into an equivalent single wheel load. We are not really so much concerned about the number of repetitions. In fixed traffic we are concerned about very heavy load not about number of repetitions. In fixed vehicle we are concerned about the number of repetitions and we talk about a standard load.

Normally we talk about a standard axle usually 80 kilo Newton standard axle is considered. Whereas in variable vehicle and traffic approaches what we do is we are concerned about the loads we are also concerned about the number of repetitions of each load. This is when we are trying to calculate the cumulative damage caused by each one of those repetitions normally when we try to calculate cumulative damage caused by fatigue phenomena or permanent deformation caused because of repeated application of loads and that is when we consider variable vehicle wherein traffic approaches.

Hundred repetitions of 140 axle loads is equivalent to how many standard axle load repetitions?
This is simple; as we have seen earlier 140/80 to the power 4 into 100 so we can obtain the number of repetitions of 140 kilo Newton that are equivalent to 100 kilo Newton axles.

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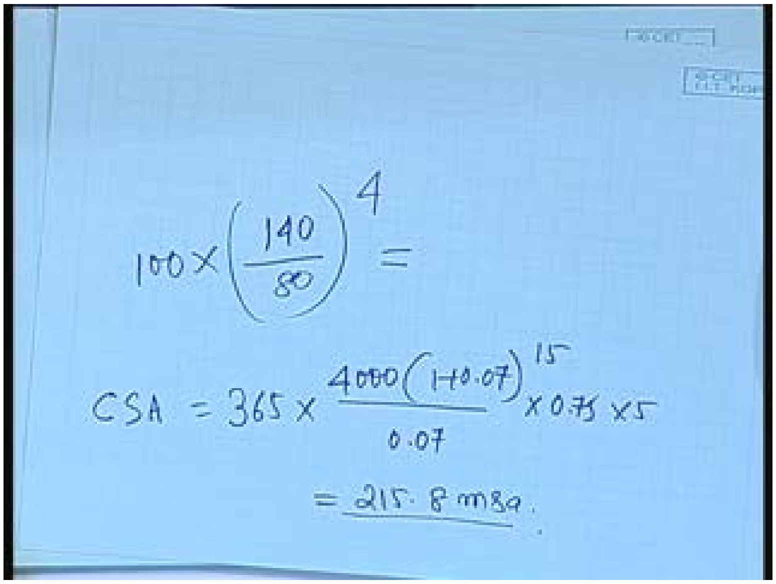

Next question is, to estimate the design traffic using the following data; there is a two-lane road we have average design traffic of 4000 which is a two-way, vehicle damage factor is 5, design life is 15 years, rate of growth is commercial traffic using the formula that we have given earlier cumulative standard axels can be given as 365 into 'a' which is 4000 into one plus .07 to the power 15 the design life period divided by rate of growth into 0.75 we have considered to taken into account the lateral distribution factor into 5 that is equivalent to 215.8 million standard axels, thank you.