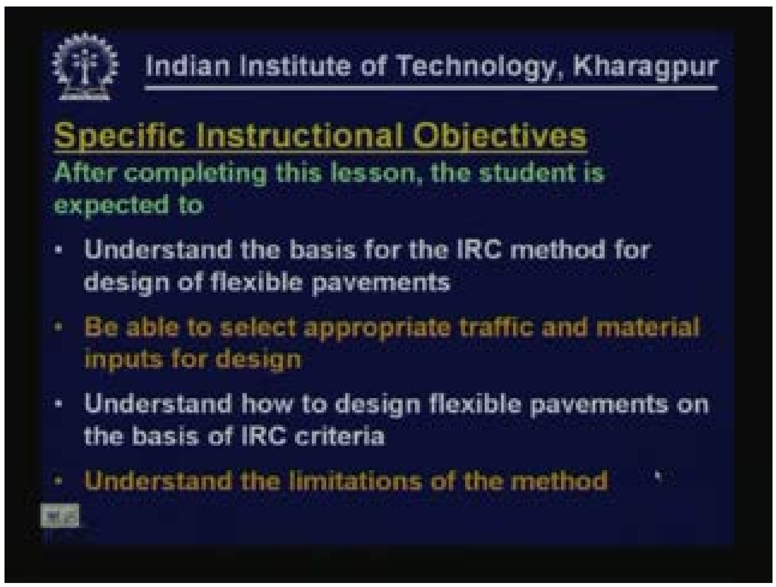
Introduction to Transportation Engineering
Prof. K. Sudhakar Reddy
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecture - 36
Flexible Pavement Design
Indian Roads Congress

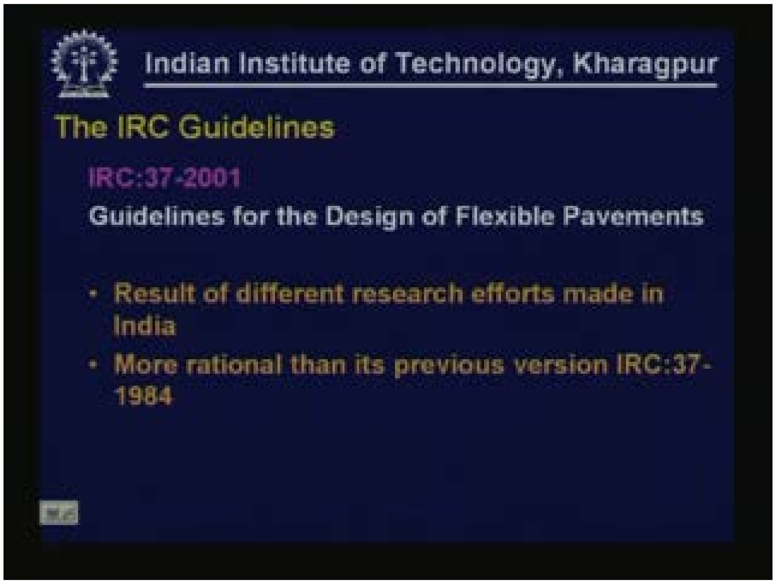
Hello viewers welcome to lesson 13 of module 4. Module 4 as you know is on pavement design. In this lesson we will be discussing about designing flexible pavements as per Indian Roads Congress method.

(Refer Slide Time: 00:01:11 min)



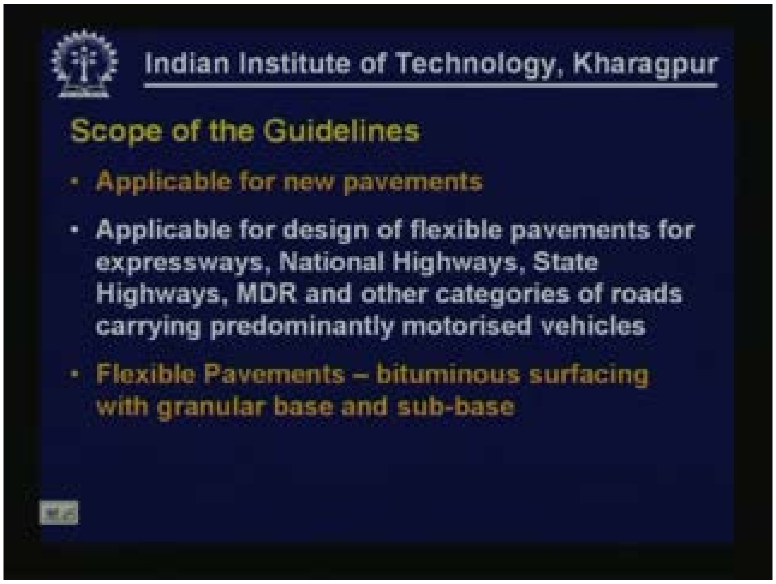
The specific instructional objectives of this lesson will be after completing this lesson it is expected that the student understands the basis for Indian Roads Congress method for design of flexible pavements. It is also expected that the student would be able to select appropriate traffic and material inputs required for designing flexible pavements as per Indian Roads Congress method. Also, you would be able to understand how to design flexible pavements, how to select layer thicknesses of specific design combination for a given situation as per Indian Roads Congress practice. It is also expected that at the end of this lesson the student would also be in able to appreciate the limitations of the Indian Roads Congress method.

(Refer Slide Time: 00:02:15 min)



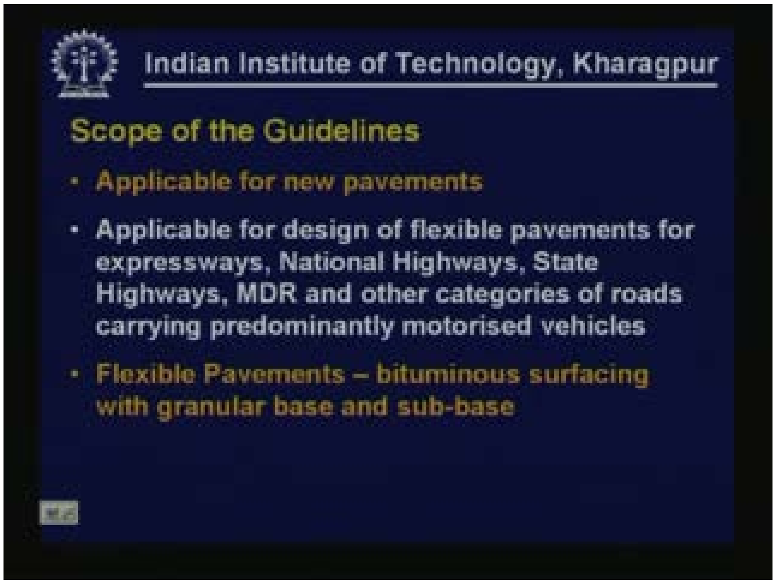
As you see here Indian Roads Congress guidelines for design of flexible pavements are given in IRC: 37. This is the number of the guidelines that is given by Indian Roads Congress, 2001 indicates the year in which the latest revision has been given. So we are going to discuss about the provisions of Indian Roads Congress 37: 2001. These guidelines are result of research work carried out by various institutions in India on the basis of performance data that is collected on different pavement sections in India and this version of IRC guideline 37 for designing flexible pavements is considered to be more rational compared to its previous version which was issued in 1984.

(Refer Slide Time: 00:03:11 min)



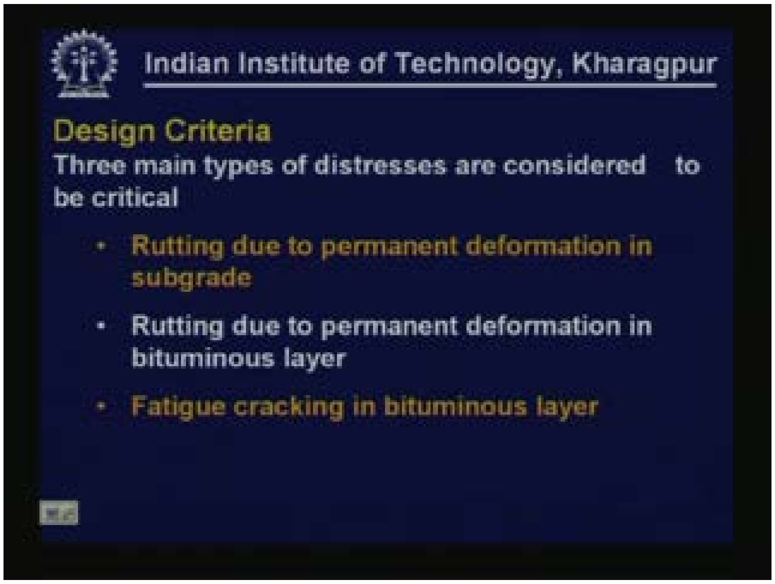
The scope of these guidelines that is IRC: 37 – 2001 are these guidelines are applicable for new pavements. Theoretically we cannot evaluate existence pavements and try to design overlays for those pavements using this IRC: 37 guidelines. Also, these guidelines are applicable for design of flexible pavements for relatively high volume roads such as expressways, national highways, state highways, MDR, ODR and other categories of road having relatively high volume roads. What we are trying to indicate here is these volumes are not meant for designing low volume roads such as village roads.

(Refer Slide Time: 00:03:59 min)



Also these are obviously meant for flexible pavements typically having bituminous surfacing with granular base and granular sub-base.

(Refer Slide Time: 00:04:13 min)

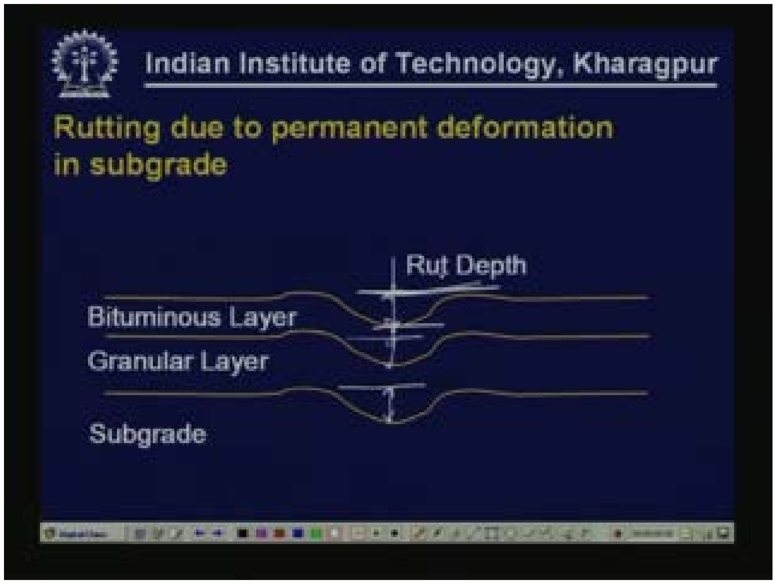


Basically there are three design criteria that have been considered to be important the design criteria that are considered in IRC: 37 - 2001 are, this is rutting failure due to the permanent deformation that occurs in subgrade that is the bottom most layer of the foundation. So the subgrade can undergo permanent deformation that can result in the form of rutting which can be seen on the surface.

Second form of distress or failure that is considered is permanent deformation occurring in thick bituminous layers. Bituminous layers also can undergo permanent deformation when they are subjected to heavy loads at high temperatures that also can result in rutting that can be seen in the surface.

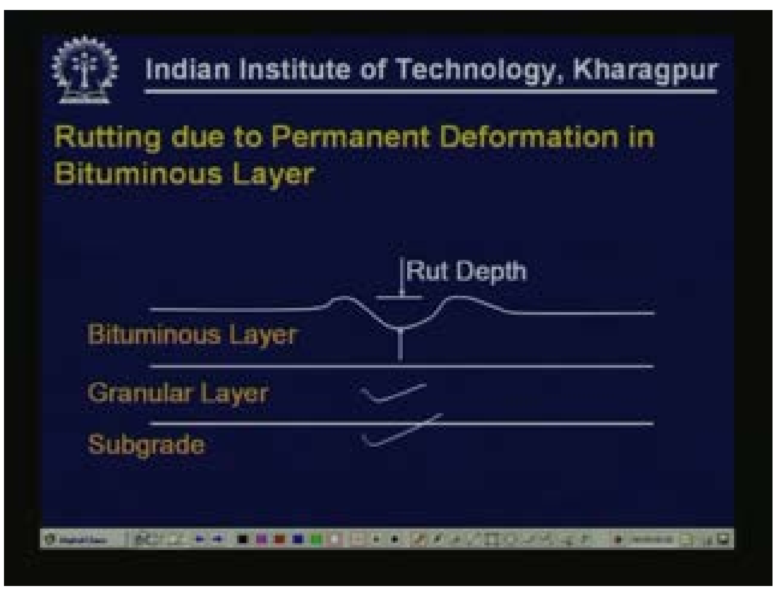
The other form or the third form of distress that is considered in IRC guidelines is the cracking of bituminous layers indicated as fatigue cracking of bituminous layers. So these are the three main considerations that are there in IRC: 37. But only two of these considerations have been taken into effect for providing design criteria for designing flexible pavements. So as you see here these are the three main criteria; rutting due to permanent deformation in subgrade, rutting due to permanent deformation bituminous layer, and fatigue cracking in bituminous layer.

(Refer Slide Time: 00:05:40 min)



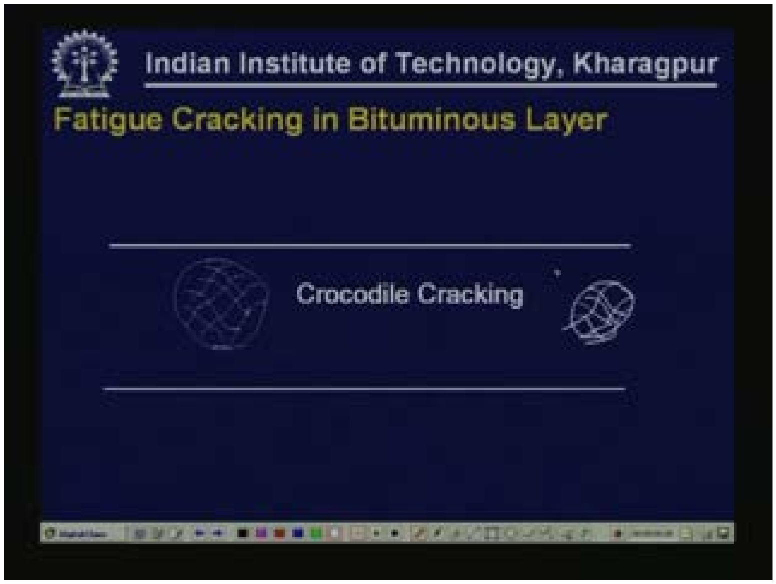
This sketch here illustrates the rutting that is occurring because of permanent deformation in the subgrade layer. So this amount of rutting or permanent deformation that is occurring in the subgrade layer is getting reflected in all the subsequent layers and obviously on the surface. So the difference in these two levels can be measured at the surface as rut depth. Rut depth may be occurring in any of these layers starting from subgrade, granular base or bituminous layers. But we normally consider two types of rutting that is occurring; one is because of permanent deformation occurring in subgrade like depicted in this sketch.

(Refer Slide Time: 00:06:34 min)



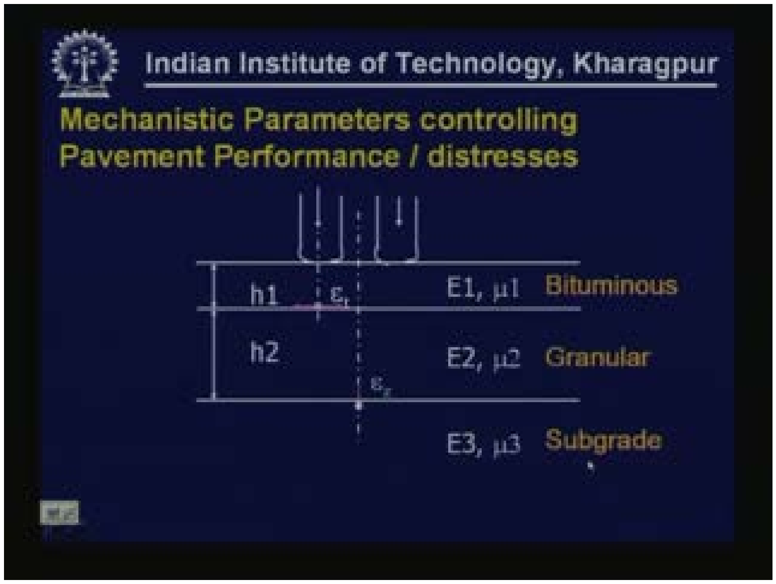
The next sketch shows the permanent deformation or rutting that is occurring at the bituminous surface because of permanent deformation occurring in bituminous layers itself. As you see here no permanent deformation is indicated either in subgrade or in granular layer but there is permanent deformation seen in bituminous layers so that is what is reflected as rut depth on the pavement surface.

(Refer Slide Time: 00:06:58 min)



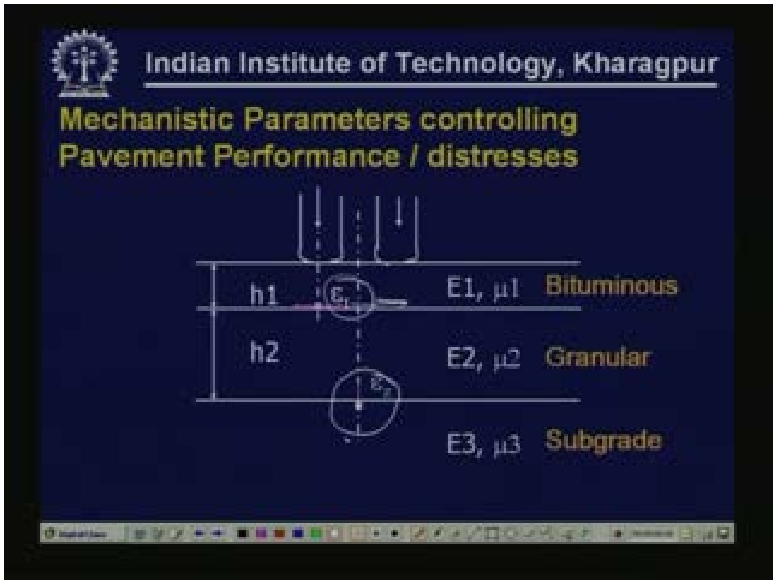
This is another type of failure that is normally seen in bound layers. Since we consider bituminous mixes to be bound layers they are susceptible to cracking because of repeated application of wheel loads. We see in this case a cracking of this form which is in chicken net or crocodile shape rather the back of a crocodile so this shape is called as crocodile cracking, this is a very common mode of failure that occurs in bituminous layers. Hence these are the three main forms of failure that are considered. Rutting is occurring because of permanent deformation in subgrade, rutting is occurring because of permanent deformation in thick bituminous layers and fatigue cracking occurring in bound bituminous layers. However, IRC: 37 in its performance criteria considers only the rutting occurring because of permanent deformation in subgrade and fatigue cracking in bituminous layers.

(Refer Slide Time: 00:08:06 min)



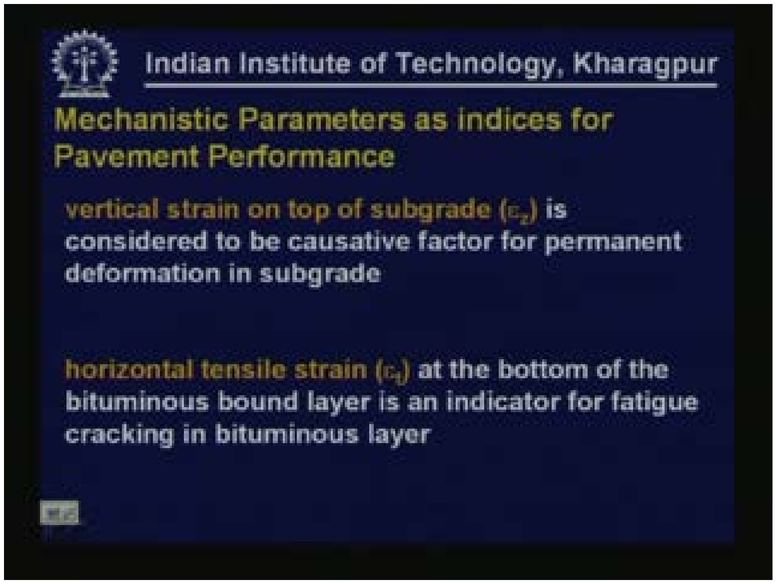
We have discussed about the general philosophy of pavement design in the very first class lesson 4.1. We also discussed about the analysis of flexible pavements, computation of stresses, strain, deflections in single layer systems, multilayer systems and so on. IRC: 37 is a semi-mechanistic design approach in which the performance of pavements is explained in terms of the mechanistic behavior of different components of the pavement. So the pavements are generally analyzed for determining critical parameters, mechanistic parameters that is critical stress, critical strain, critical deflection and these critical parameters are correlated to the performance of the pavement as to how the pavement is likely to perform in resisting fatigue cracking, how the pavement is likely to perform in resisting permanent deformation in different layers so this can be explained in terms of the magnitudes of stresses and strains and deflections in a newly constructed pavement. So typically these are the parameters that are considered.

(Refer Slide Time: 00:09:22 min)



For a pavement loaded by wheel loads the tensile strain at the bottom of the bituminous layer as you see here epsilon t is considered to be critical in explaining the fatigue behavior of bituminous layers. Similarly, the vertical strain on top of subgrade epsilon z is considered to be critical in explaining the permanent deformation behavior of the pavements. So these are the two parameters that have been found to have good correlation to fatigue cracking of bituminous layers and also permanent deformation of bituminous pavements. So one should be able to calculate for a given pavement system for a standard loading that is given. With these two parameters epsilon t at the bottom of bituminous layer and also vertical strain within the subgrade we can have some limits on these two parameters so that the pavement is going to perform satisfactorily both the fatigue cracking and also in permanent deformation considerations.

(Refer Slide Time: 00:10:35 min)



As we have just indicated these are the two main parameters that are considered to explain the performance of pavements. Vertical strain on top of subgrade epsilon z is considered to be a causative factor for permanent deformation in subgrade. If these vertical strains are excessive so one can expect that there is going to be excessive permanent deformation leading to the rutting which can be seen at the surface. Similarly, if there excessive horizontal tensile stresses at the bottom of the bituminous bound layer this is an indicator for fatigue cracking in bituminous layers.

(Refer Slide Time: 00:11:18 min)

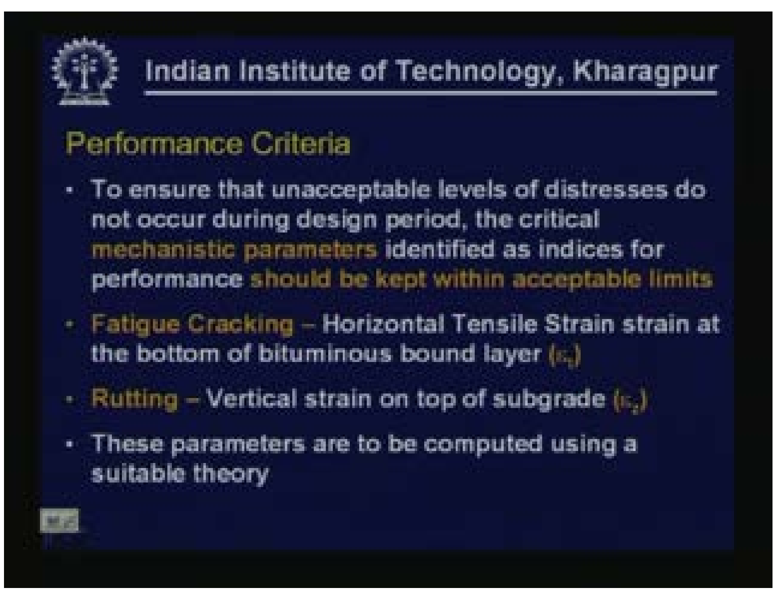
Flexible pavements should be designed to perform satisfactorily. For that matter all structures have to be design to perform satisfactorily without developing unacceptable levels of distresses during the design life period.

We have used certain keywords here ‘satisfactory performance’. We have to perform satisfactorily without the distresses being reaching unacceptable levels during the design life period. If the design life period of a pavement is say about 10 years that is what we have considered let us say then the pavement should not have excessive distresses during the design life period. What is to be done is we have to define what is the acceptable quantity of distress.

We have talked about two main forms of distress fatigue cracking of bituminous layers and rutting in bituminous layers. So if you measure fatigue cracking that means measure the extent of cracking that is there on the pavement surface we have to know what is acceptable during its design life period five percent ten percent 20% and similarly if you can measure the permanent deformation or rutting in bituminous layers how much is an acceptable value. Once you have the deflection so we can accordingly design the pavements. We can see the definition of what is acceptable for the two main distresses that we have considered that is fatigue cracking in bituminous layer.

Cracking in about 20% of pavement area is considered to be critical. That means if the cracked area is more than about 20% of the paved area then that is considered to be not acceptable. Suppose if we are evaluating a 1 km stretch then within that stretch if you measure rut depth periodically at different locations and if you take the average of that and if that average happens to be more than 20 mm this is the condition that is considered to be not acceptable. Hence in the case of fatigue cracking 20% of the area should not have cracking rather the cracked area should not be more than 20% similarly the average rut depth should not be more than 20 mm. these are the conditions that were trying to maintain during the service period of the pavement.

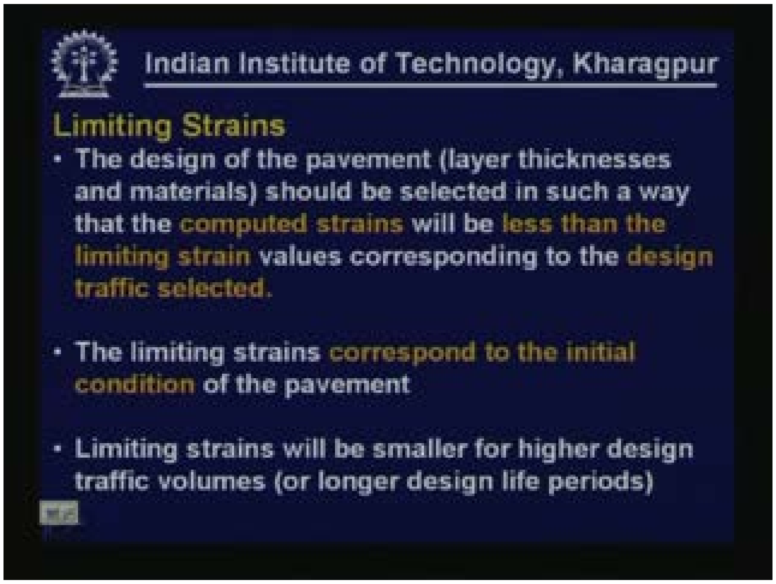
(Refer Slide Time: 00:13:52 min)



To ensure that these unacceptable levels of distresses do not occur during design life period, unacceptable level is just defined, the critical mechanistic parameters identified as indices for performance these you may recall or vertical strain on top of subgrade and horizontal tensile strain at the bottom of bituminous layer. These two parameters should be kept within acceptable limits. To ensure that the pavement do not have unacceptable levels of distresses fatigue cracking and rutting we have to keep the identified critical mechanistic parameters to within acceptable limits.

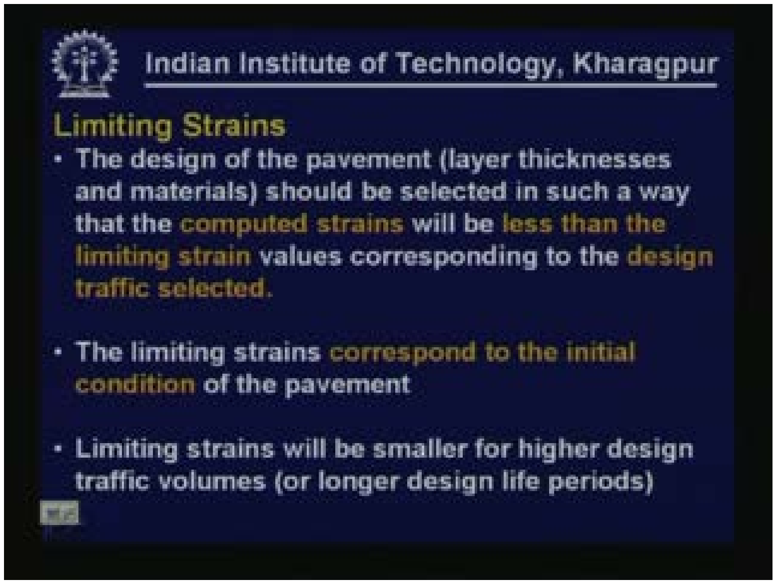
What will these acceptable limits? These limits will be different for different conditions. We will discuss about this subsequently. Just to repeat for fatigue cracking we have identified horizontal tensile strain at the bottom of bituminous bound layer epsilon t as a critical parameter, and for rutting it is vertical strain on top of subgrade epsilon z as a critical parameter. These two parameters these two strain values can be computed using a suitable theory. We have to select a suitable theory to analyze pavements then we calculate them and then we can decide for a given pavement depending on the values of these two strains whether is going to be an acceptable design solution or not.

(Refer Slide Time: 00:15:21 min)



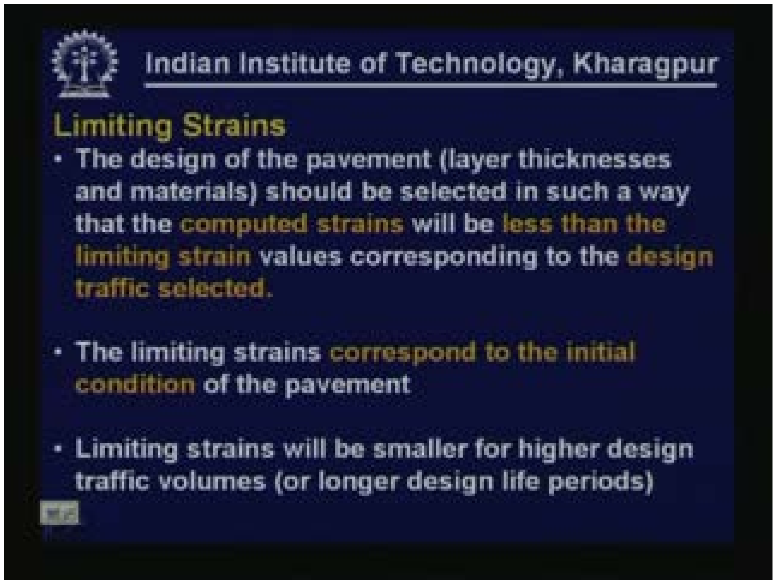
The design of a pavement is nothing but selecting layer thicknesses and also the layer materials and also the type of pavement. It includes what combination of materials we are going to use, in which sequence, thicknesses and material properties. So designing is nothing but selecting all these parameters. So the design has to be selected in such a way that the computed strains will be less than the critical value or limiting value given by performance criteria or design criteria. There have to be some criteria which will tell us what will be the limiting values for a given situation for epsilon t and also epsilon z so that the pavement can perform satisfactorily. So we are coming to what is known as performance criteria. This is the heart of any pavement design procedure. So, once we have a design performance criteria in this case we are talking about limiting strain criteria there are two distresses that we are considering, for each distress there is a critical parameter identified so for a given situation what is the maximum permissible value that this parameter can take epsilon t and epsilon z will be defined by the performance criteria.

(Refer Slide Time: 00:16:33 min)



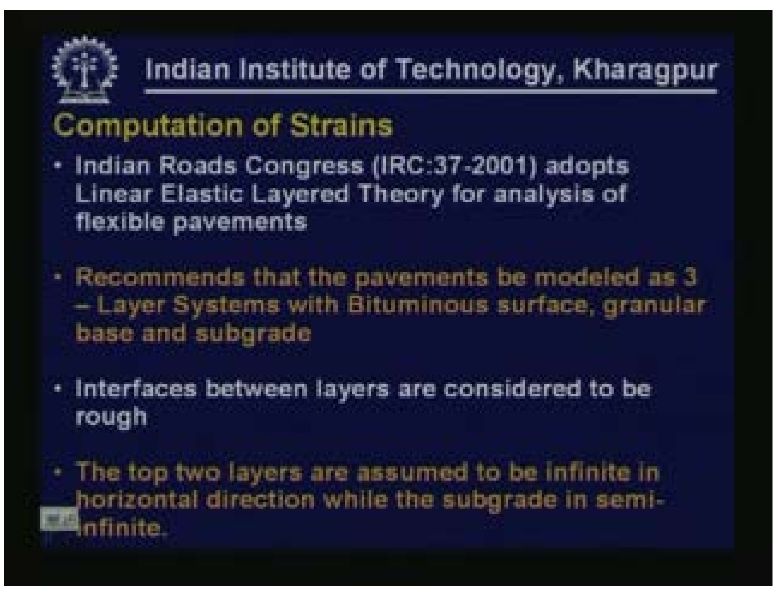
The limiting strains correspond to the initial condition of the pavement, this is very important. Because the design that we select layer thicknesses, material properties all these correspond to the initial condition of the pavement immediately after it's constructed. So the properties that are selected have to correspond to that condition. So the strains also correspond to the initial condition. Hence when a newly constructed pavement is analyzed and these two parameters are computed. If these two values satisfy the performance criteria then the pavement is going to serve for a number of repetitions or 10 years or 15 years whatever is the design life period. The analysis is done for the initial condition of the pavement.

(Refer Slide Time: 00:17:19 min)



The limiting strains will be smaller for higher traffic volumes. If you want the pavement to be lasting for more number of repetitions, more years obviously the limiting strain values will be smaller and smaller so as a result we will have to be providing stronger materials, thicker pavements if the traffic volumes are higher or for longer design life period.

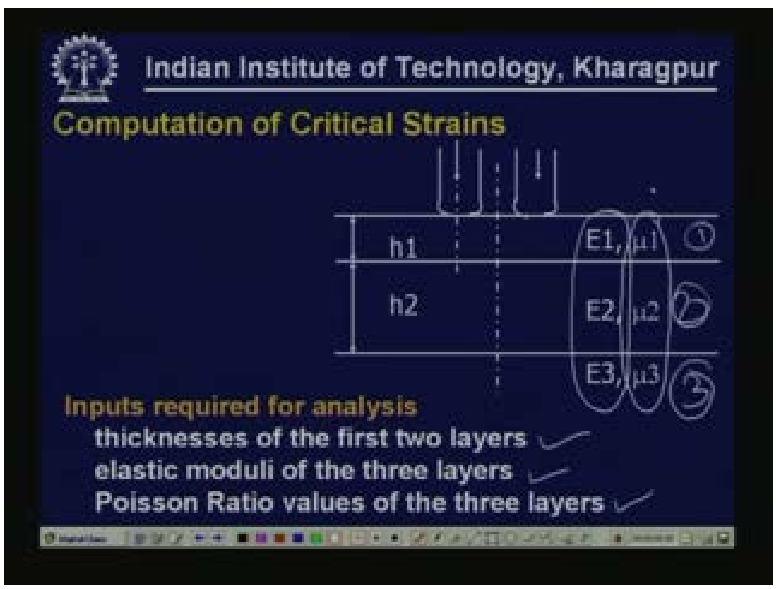
(Refer Slide Time: 00:17:47 min)



Indian Roads Congress adopts linear elastic layered theory for analysis of flexible pavements. In lesson 11 we have discussed the analysis of flexible pavements, we also discussed about the basis for selection of linear elastic layered theory, justification for linear elastic layer theory for analyzing flexible pavements especially for highway traffic. So IRC: 37 guideline consider linear elastic layered theory for analysis of flexible pavements. IRC also recommends that the pavements be modeled as typically three-layered pavement systems although we know the pavements can have more than three layers it can have sub-base, it can have a base and in bituminous layer itself there can be more than one layer so it can be an n layered system where four, five, six layers also can be considered. But IRC suggests that the pavement has to be analyzed as a three-layer system such as subgrade, granular base and bituminous layer.

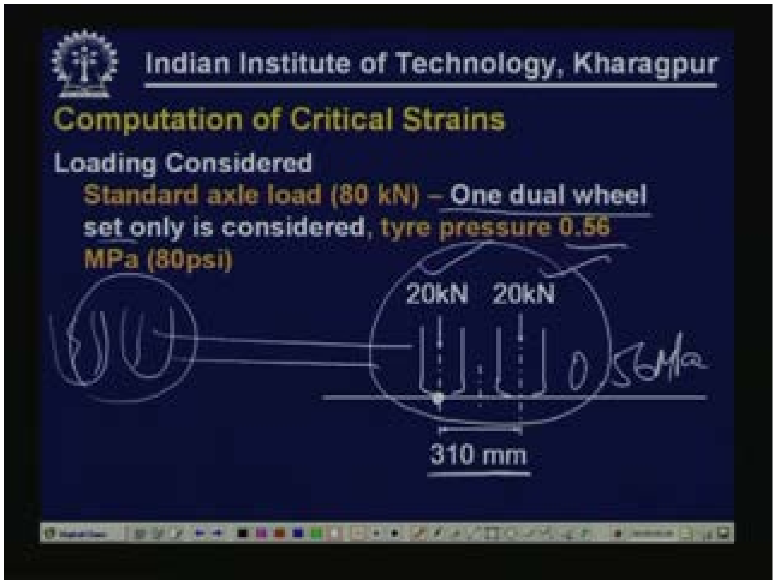
The interfaces between the layers that is bituminous surface and granular base and the subgrades are considered to be rough interfaces. We can analyze these pavements as smooth interface or as having rough interface also but IRC considers the analysis to be having rough interfaces. The top two layers are assumed to be infinite in horizontal direction. These are the assumptions that we made in the case of analysis of flexible pavements using Burmeister's layered analysis. The top layers are infinite in horizontal extent having finer thickness, the bottom most layer is semi-infinite infinite in vertical direction in the downward direction and this is a typical three layered system as per the module assumed in IRC: 37. So the inputs that we require are we have layer 1, 2 and 3.

(Refer Slide Time: 00:19:39 min)



So the inputs that are required are thickness of the first two layers H1 and H2. For analysis of this pavement we need elastic moduli value of the three layers E1 E2 E3, we need Poisson ratio values of the three layers mu1 mu2 mu3 so once we have this complete information we can analyze this pavement for a given loading system.

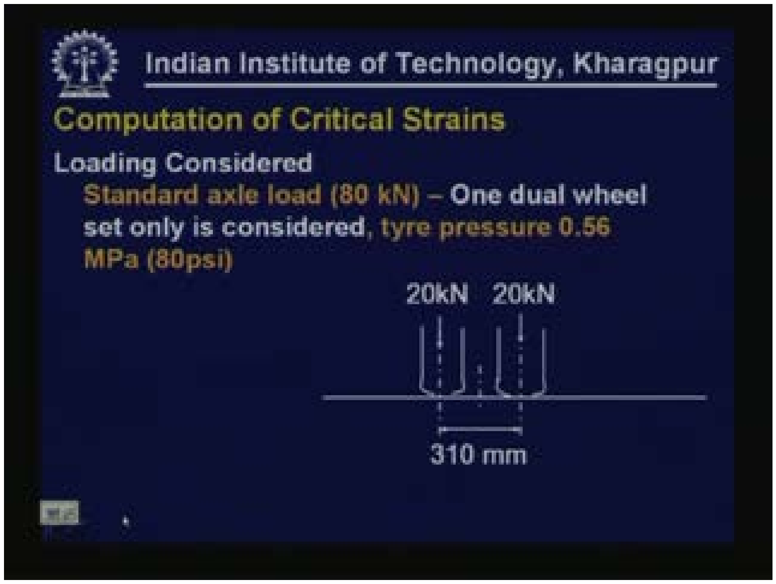
(Refer Slide Time: 00:20:21 min)



All these pavements for the purpose of design are analyzed for a standard loading condition, the standard loading being the standard axle load. We have discussed about the standard axle load in the previous lessons when we discussed about traffic considerations. Standard axle load is an 80 kilo Newton load distributed over two dual wheel sets on either side of the axle and with a tire pressure of 0.56 MPa that is about 80 psi. But for analysis we considered only one dual wheel system. Because the other dual wheel system is at such distance it will not have any significant effect in the parameter that we are calculating at these locations. So normally instead of considering the total 80 kilo Newton axle load we consider only one dual wheel set ignoring the other wheel set that is at the other end of the axle.

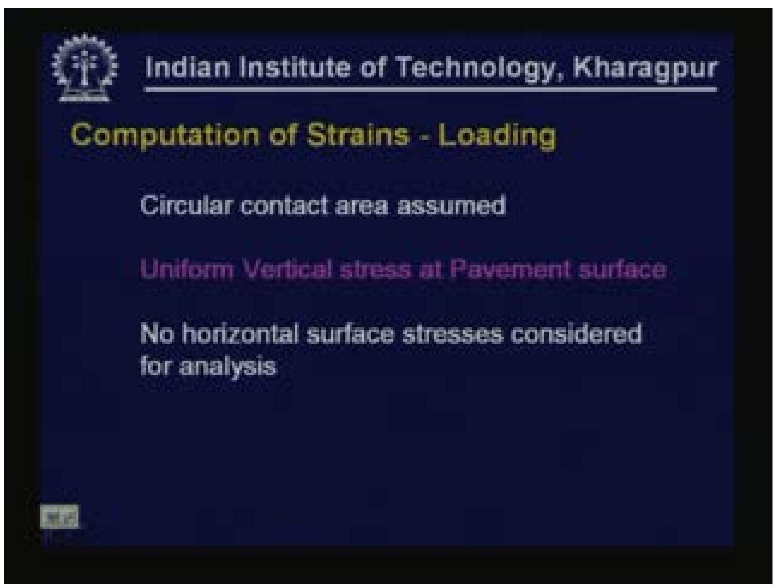
Hence, when we consider half of the axle load we have 20 kilo Newton distributed over two wheels this is the dual wheel set, 20 kilo Newton and 20 kilo Newton tire pressure of 0.56 and typically it is seen that the center to center distance between these two dual wheel loads will be about 310 mm. This is what has been observed on several measurements that have been made on typical commercial vehicles that are plying in India.

(Refer Slide Time: 00:21:55 min)



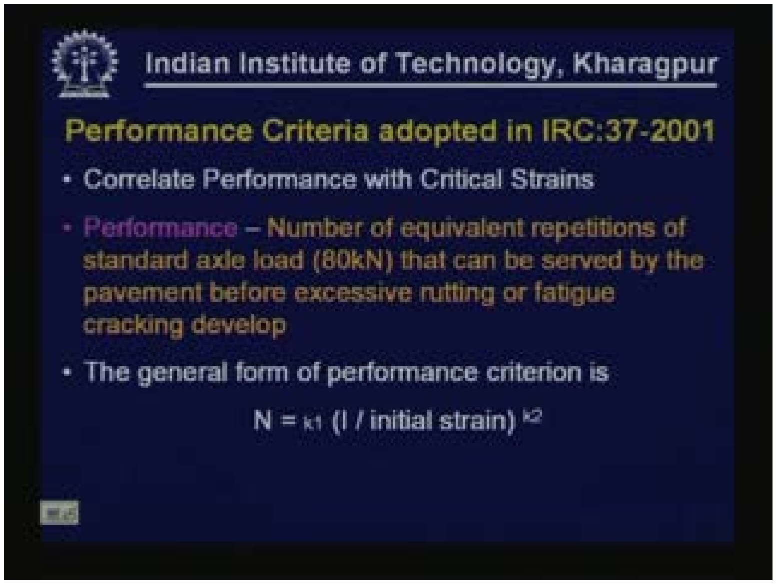
So in this system what we are going to have is for analysis standard loading is 20 kilo Newton 20 kilo Newton on each load, 0.56 MPa tire pressure and center to center spacing of 310 mm.

(Refer Slide Time: 00:22:14 min)



And for computation of these strains the loads are considered to be circular in contact area. The vertical contact pressure is considered to be uniform over the entire contact area and no horizontal surface stresses are considered. We know that there can be horizontal stresses on the surface but we consider only the vertical stresses for this analysis. Horizontal stresses can be there because of breaking acceleration and also there will be centripetal inward stresses.

(Refer Slide Time: 00:22:51 min)

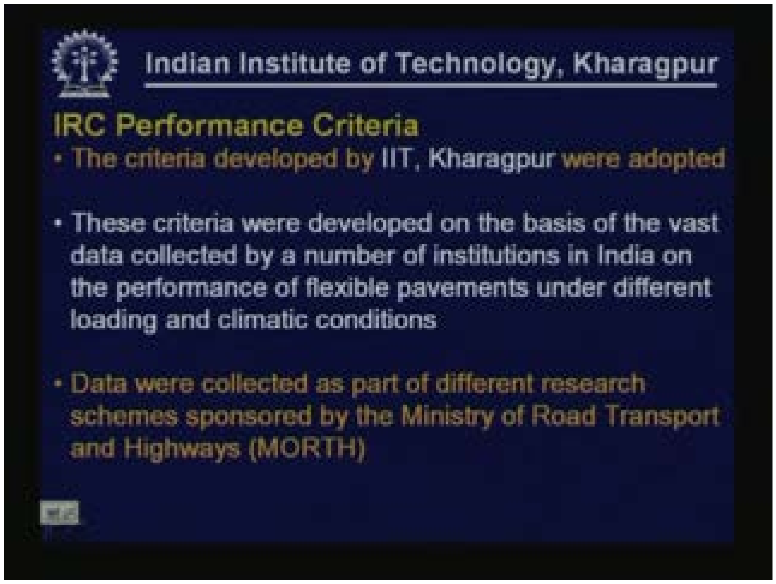


The performance criteria adopted in IRC: 37 – 2001 correlate performance with the critical parameters that were selected. There are two distances that we are interested in and there are two mechanistic parameters that were selected to explain the behavior of pavement in terms of these two distresses fatigue cracking and rutting. We recollect that the two strain mechanistic parameters that were selected are tensile strain at the bottom of bituminous layer and vertical strain on top of subgrade.

Performance is nothing but the number of equivalent repetitions of standard axle load that can be solved by the pavement before excessive rutting or fatigue cracking develops. So performance is explained in terms of number of repetitions that pavement can serve satisfactorily without excessive rutting or fatigue cracking development.

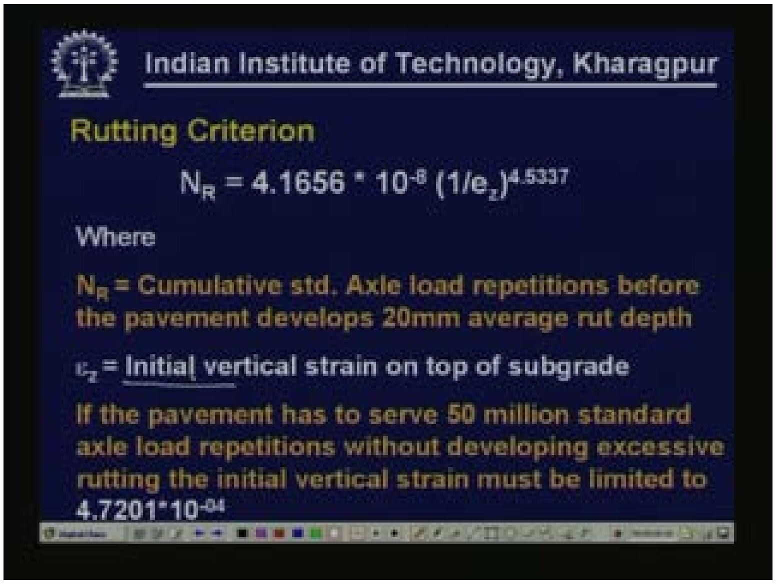
The general form of performance criterion is given as; N is the number of repetitions that will be served by the pavements satisfactorily. As a function of initial strain this may be initial tensile strain in a bituminous bound layer or initial vertical strain on top of subgrade so this is inversely related as per the general relationship. So what we need to have is the correlation coefficient constants k1 and k2.

(Refer Slide Time: 00:24:24 min)



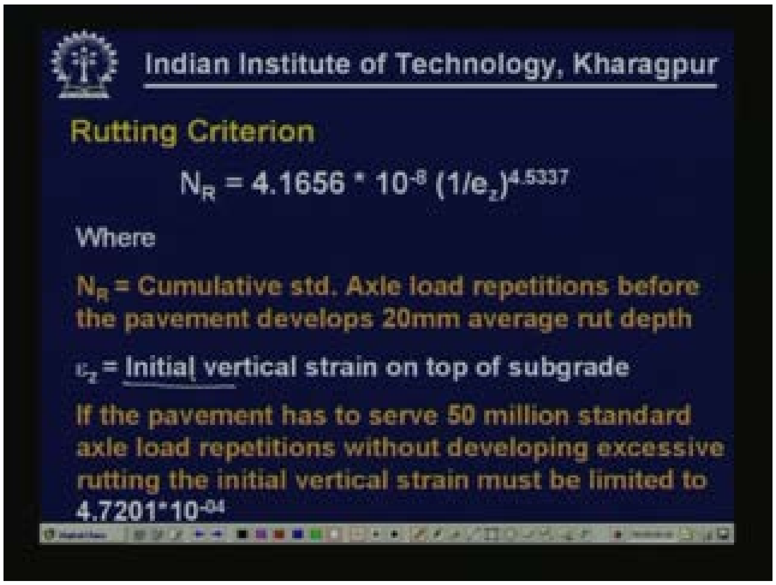
The criteria developed by Indian Institute of Technology, Kharagpur were adopted in Indian Roads Congress as performance criteria for both fatigue failure and also for rutting failure. These criteria were developed on the basis of vast data collected by IIT Kharagpur and several other institutions in India on the basis of performance data, observations of performance data of several pavements having different types of construction so all these data was pulled, analyzed and two main performance criteria were developed. And the data was collected about the performance of pavements under different loading and climatic conditions. In fact the data was collected as part of different research schemes sponsored by Ministry of Road Transport and Highways R6 and R81. These are the codes given by Ministry of Road Transport for these two main research projects.

(Refer Slide Time: 00:25:30 min)



The rutting criterion that has been adopted is NR = 4.1656 into 10 to the power – 8 into 1 by epsilon z to the power 4.5337 where NR is the cumulative standard axle load repetitions before the pavement develops 20 mm average rut depth. Epsilon z is the initial vertical strain on top of subgrade. So we are referring to the initial vertical strain. This is computed correspond to the initial condition of the pavement soon after it is constructed when it is subjected to the standard loading that we just discussed.

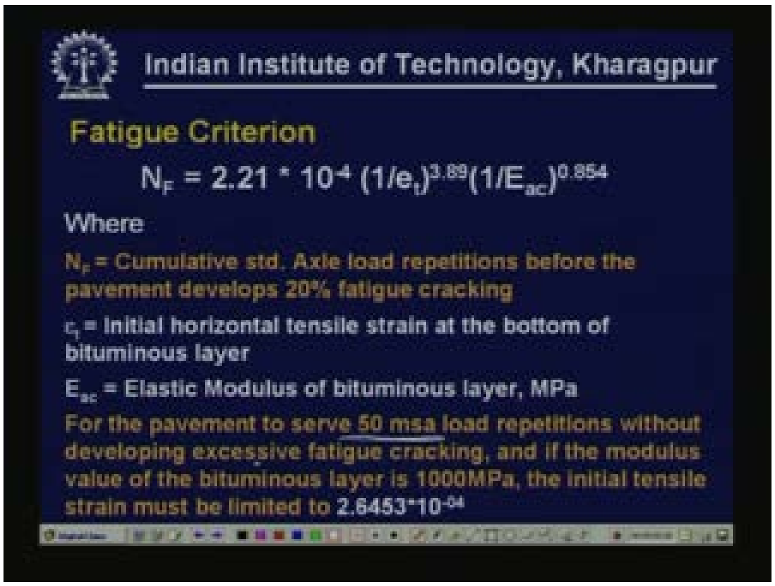
(Refer Slide Time: 00:26:14 min)



For example, if the pavement has to serve about 50 million standard axle load repetitions without developing excessive rutting that means without developing more than an average of 20 mm rutting the initial vertical strain must be limited to by substituting 50 million standard axles in the above equation we get the corresponding epsilon z value to be 4.7201 into 10 to the power of – 4. So the initial computed strain should not be more than this value.

Because standard loading is already fixed we are considering the standard loading, there is nothing to change in them but the only thing we can change is the layer thicknesses and the material that we use. These have to be carefully selected so that the initial computed strain is going to be less than 4.7201 into 10 to the power – 4 if we want the pavement to be serving at least 50 million standard axles during its service life.

(Refer Slide Time: 00:27:25 min)

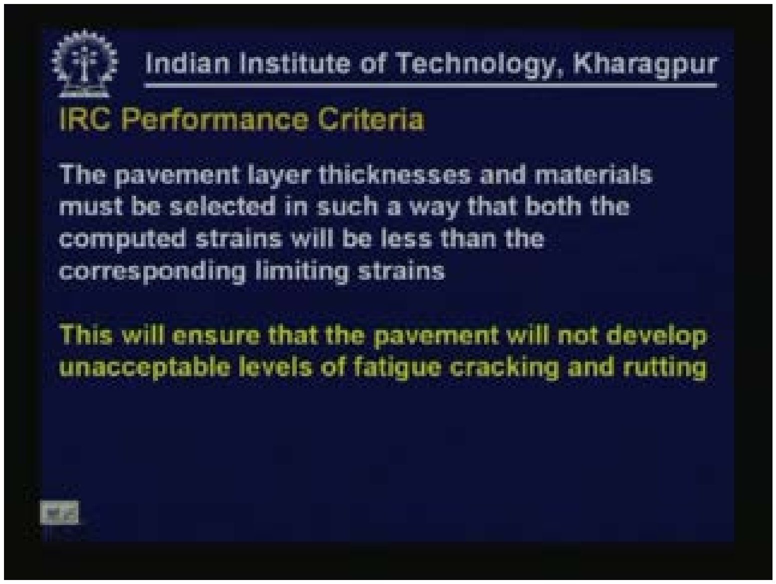


Similarly fatigue criterion NF is given as 2.21 into ten to the power – 4 into 1 by epsilon t to the power 3.89 into 1 by epsilon modulus value of epsilon concrete to the power 0.854 where NF is the cumulative standard axle load repetitions before the pavement develops 20% fatigue cracking. And epsilon t is the initial horizontal tensile strain at the bottom of bituminous layer because we have already identified epsilon t as a parameter that explains the fatigue behavior.

But another parameter is also added which is the modulus value of the bituminous layer that we are going to use because for different climatic conditions if the pavement temperature is different the modulus value will be different accordingly pavement performance is also going to be different. To account for that the modulus value of bituminous layer is also brought into the equation. So basically to estimate how many repetitions a given pavement can serve satisfactorily we have to calculate what will be the epsilon t and we should also know what is the modulus value of bituminous layer for a given condition.

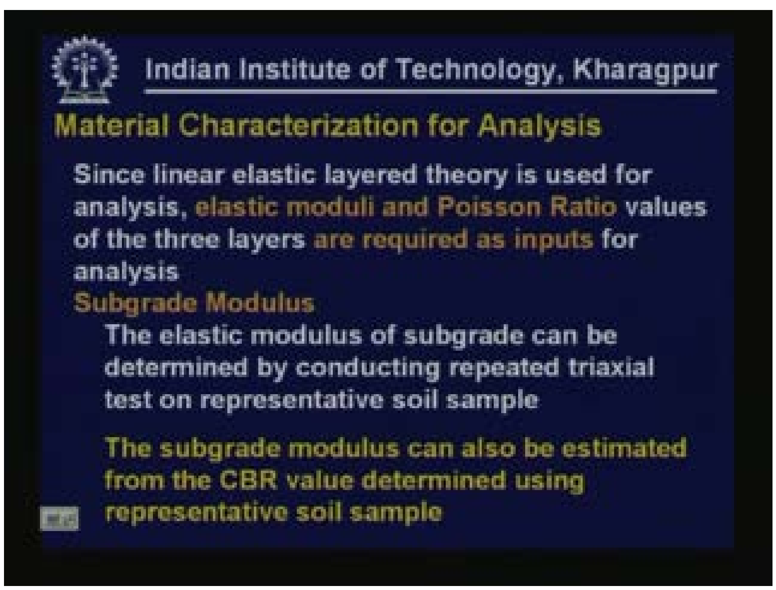
For example, for a pavement to serve 50 million standard axle (50 Msa) load repetitions without developing excessive fatigue cracking that is more than 20% of paved area in a cracked condition and if the modulus value of the bituminous layer is about 1000 MPa then the initial tensile strain must be limited to 2.6453 into 10 to the power – 4.

(Refer Slide Time: 00:29:36 min)



The pavement layer thicknesses and materials must be selected in such a way that both the computed strains will be less than the corresponding limiting strains. This is what we have been discussing. We have to select layer thicknesses and materials in such a way that the initial computed strains when this pavement is subjected to take standard loading condition will be less than the limiting strains given by the performance criteria for a given traffic loading condition. This will ensure that the pavement will not develop unacceptable levels of fatigue cracking and rutting.

(Refer Slide Time: 00:30:12 min)

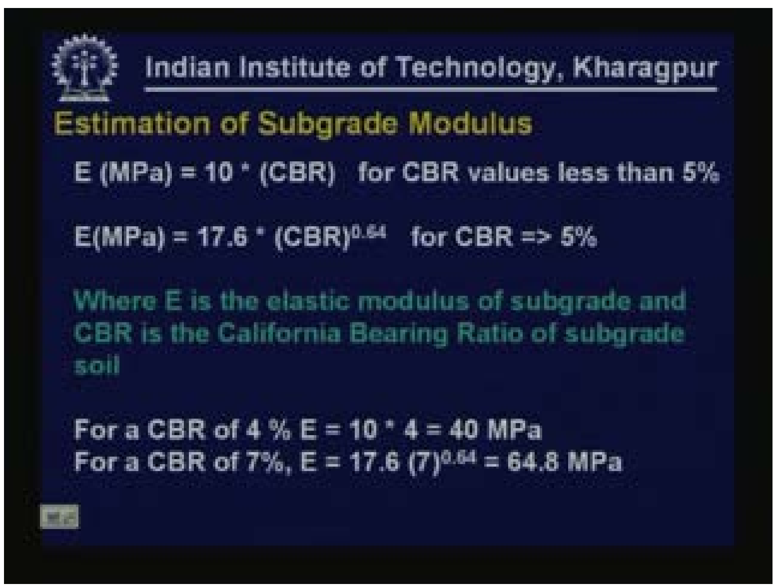


Obviously for analysis of a selected trial pavement design we need to be able to select appropriate material properties because linear elastic layered theory is used for analysis. Elastic modulus value and Poisson ratio values of the three layers as we are modeling the pavement as a three layered system as per IRC these values are required for all the three layers. Also in the trial thicknesses we have to be selecting different thicknesses for the two layers.

As far as the selection of subgrade modulus is concerned the elastic modulus of subgrade can be determined by conducting repeated traction test on representative soil sample. We had discussed about determination of elastic modulus value of different types of materials in the lesson on material characterization. So we can conduct repeated triaxial test on soil samples collected from field and then remold it on this specimen and test on appropriate conditions.

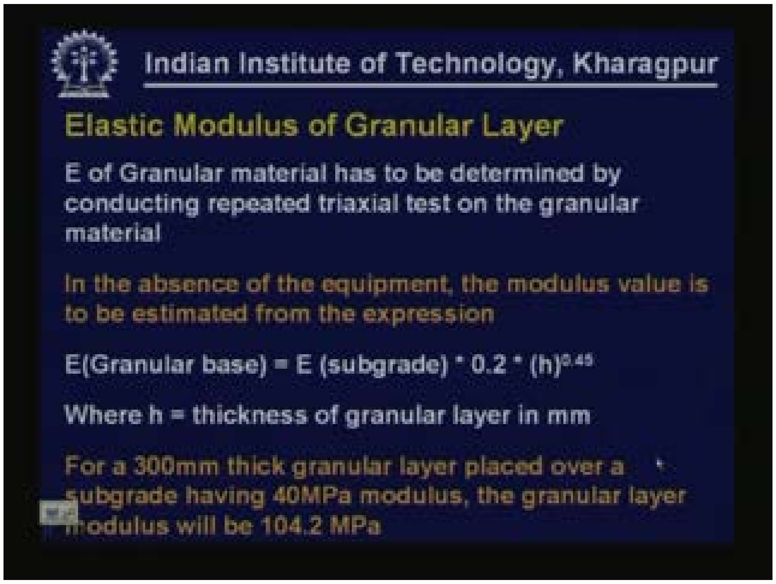
We can obtain the modulus value or the elastic modulus value for the soil. But usually it is difficult most agencies do not have this repeated triaxial test facility so normally this value is estimated from California Bearing Ratio value of the soil. Again the soil has to be collected so, that represented soil has to be used and it has to be tested under standard conditions in the laboratory and that CBR value can be used to estimate rigidity modulus value of the soil.

(Refer Slide Time: 00:31:48 min)



The expressions that are commonly used to estimate elastic modulus value or residual modulus value of subgrade soil is; elastic modulus value expressed in Mega Pascals is ten times CBR for CBR values less than 5%. For stronger subgrades represented by CBR values greater than or equal to 5% elastic modulus value can be expressed as 17.6 multiplied by CBR to the power 0.64 where E is the elastic modulus value of subgrade and CBR is the California Bearing Ratio of subgrade soil. For example, for a CBR of 4% modulus value will be 10 into four that is 40 MPa and for a CBR of 7% modulus value of subgrade will be 17.6 into 7 to the power 0.64 that will be 64.8 MPa.

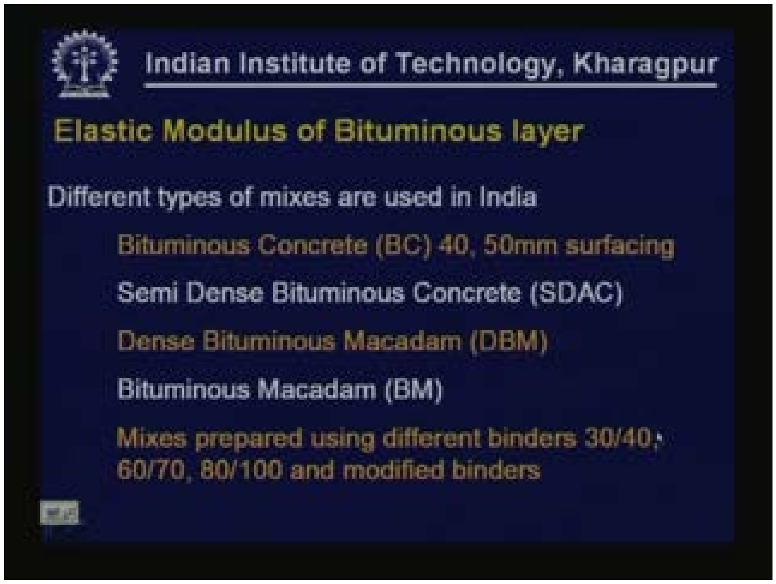
(Refer Slide Time: 00:32:46 min)



Similarly the granular layer material modulus value also has to be determined by conducting repeated triaxial test on granular material. But in the absence of equipment to conduct this test this also can be estimated from the strength of the subgrade which is represented by the modulus value of the subgrade and also from the thickness of the granular layer that we are proposing to use.

Thus in the trial thickness if we are proposing to use 300 mm thickness we are checking whether this design is okay or not so our proposal is to use 300 mm of granular. So, for that thickness and for a given subgrade strength which we have already estimated from CBR value or we have determined already by conducting triaxial test, if you know the subgrade modulus value and also if you know what is the thickness of granular layer that we are going to propose, then using these two parameters we can estimate the modulus value of the granular layer using what is known as the Shell equation given as; E granular base is a function of E of subgrade and then thickness of granular base which is in millimeters. So, for a 300 mm thick granular layer placed over a subgrade having 40 MPa modulus value the granular layer modulus value can be estimated as 104.2 MPa.

(Refer Slide Time: 00:34:17 min)

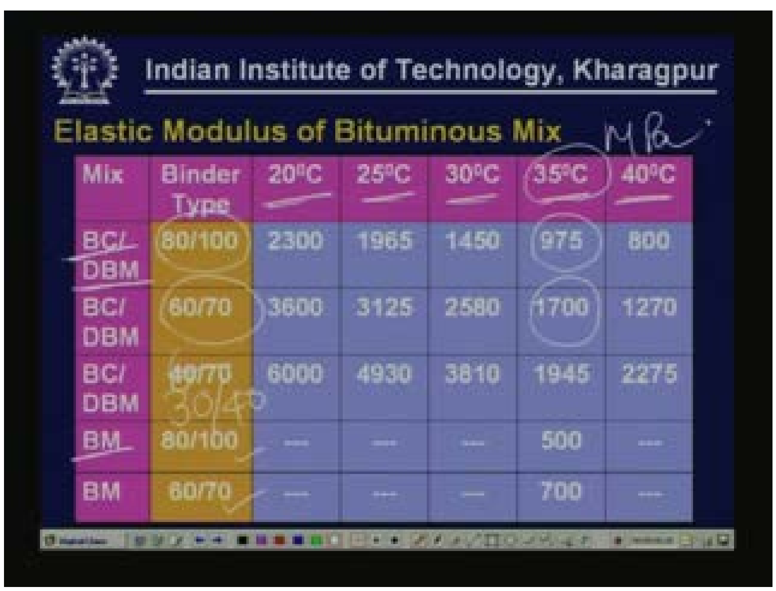


Similarly the elastic modulus value of bituminous layer can be determined in laboratory. We use different types of mixes for bituminous layers in India; bituminous concrete, semi-dense bituminous concrete, dense bituminous concrete, bituminous Macadam etc. Typically these are the materials for which elastic modulus values have been given in Indian Roads Congress IRC: 37. And also mixes are typically prepared using different types of binders; 30/40, 60/70, 80/100 penetration grade binders and also nowadays we use different types of modified binders such as polymer modified binders, crumb rubber modified binders and there are various other types of modified binders available. Normally we do not use 30/40 binder, 60/70 binder is the most commonly used binder nowadays. But however IRC gives modulus values for different type of mixes and has prepared using different types of binders not for modified binders of course.

(Refer Slide Time: 00:35:21 min)

And we know that the modulus value of bituminous mix is going to be different for different temperatures. So pavement temperature is an important parameter in selecting the modulus value of bituminous layers. The 35 degree centigrade is considered to be the average annual pavement temperature for most parts of India. We are talking about average pavement temperature and this is the average temperature at which the mix is going to be for most part of its service life so we are going to select a modulus value corresponding to 35 degrees pavement temperature. Research carried out at IIT Kharagpur and other places in India yielded typical elastic modulus values that can be selected for different average pavement temperatures applicable for different parts of India.

(Refer Slide Time: 00:36:22 min)

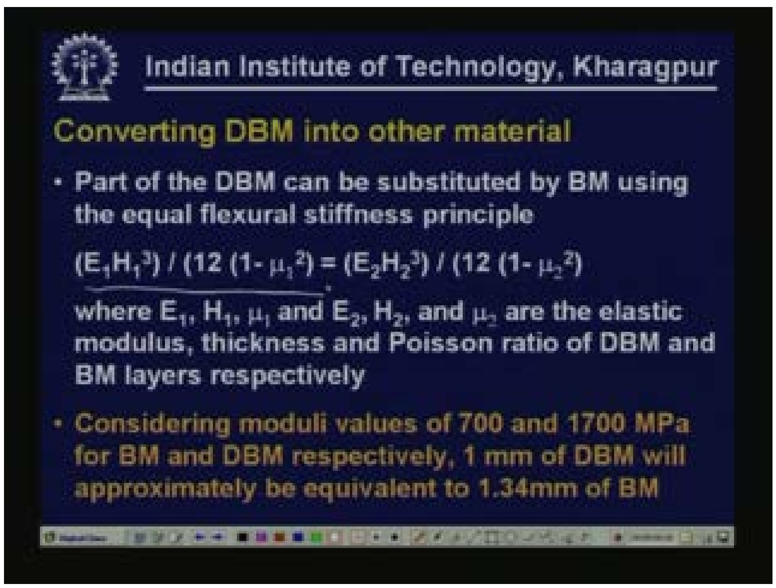


Mix	Binder Type	20°C	25°C	30°C	35°C	40°C
BC/ DBM	80/100	2300	1965	1450	975	800
BC/ DBM	60/70	3600	3125	2580	1700	1270
BC/ DBM	~~60/70~~ 30/40	6000	4930	3810	1945	2275
BM	80/100	---	---	---	500	---
BM	60/70	---	---	---	700	---

Here the represented values are typical values as recommended by Indian Roads Congress IRC: 37 are given here. For different types of mixes, bituminous concrete or dense bituminous macadam or bituminous macadam there are three types of mixes that are considered here. For different types of binders 80/100, 60/70, this is in fact 30/40 and then for BM 80/100 and for BM it is 60/70 also. So for some of these combinations modulus values are available and they are available for different values of temperature, these are pavement temperatures, average annual pavement temperature.

So, for typical or standard temperature of 35 degrees that we are considering for India a modulus value of 975 can be considered if 80/100 bitumen is used. For the same temperature if 60/70 bitumen is used a value of 1700 MPa can be used, these are all in MPa and this value increases to 1945 or 1950 if a 30/40 binder is used.

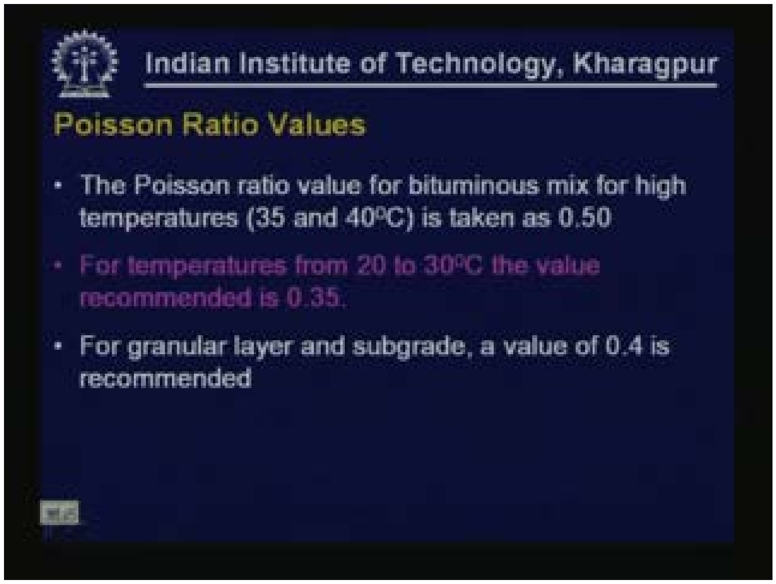
(Refer Slide Time: 00:37:57 min)



Normally part of the DBM that comes out as the requirement on the base of the analysis and on the base of the design that we do can be substituted by bituminous Macadam or one material can be substituted in terms of another material using the equal flexural stiffness principle, this is also recommended in IRC: 37. The equal flexural stiffness principle is given as E1 H1 cube divided by 12 into 1 – mu square, basically we are trying to equate EH cube by 12 into 1 – mu square of the two materials.

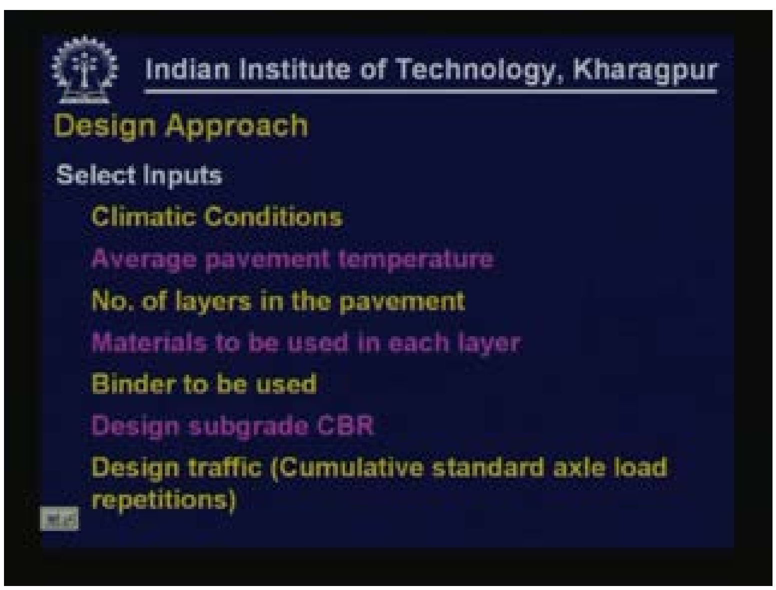
So, if you know the thickness of H1 the corresponding thickness of H_2 can be obtained provided we know E1, E2, mu1 and mu2. Considering modulus values of 700 and 1700 MPa for bituminous Macadam and DBM respectively this equivalent flexure stiffness principle yields 1 mm of DBM will be approximately equivalent to 1.34 mm of BM. That means one DBM = 1.34 BM. Similarly, we can equate DBM to any other material if we have the properties of that material available for the same temperature.

(Refer Slide Time: 00:39:27 min)



Poisson ratio values are the other important inputs that we require for analyzing the pavement system using linear elastic layered theory. The Poisson ratio value for bituminous mix for high temperature such as 35 and 40 degree centigrade is taken as 0.5. For temperatures from 20 to 30 degree centigrade the value recommended is 0.35, for granular layer and subgrade a value of 0.4 is recommended.

(Refer Slide Time: 00:40:01 min)



The general design approach includes selecting different inputs such as climatic conditions in terms of especially the average pavement temperature whether it is 20 degrees 25, 30, 40. It also includes the general condition in terms of rainfall whether it is excessive or dry will influence in selecting appropriate type of surface material, the number of layers that were going to propose in the pavement system, the material that we are proposing to use in each layer, the binder we are proposing to use, the design subgrade CBR, the material has to be tested and this value has to be obtained, and the design approach also includes the design traffic in terms of cumulative standard axle load repetitions.

(Refer Slide Time: 00:41:00 min)

So the design approach follows the next step that is to select trial designs and evaluate them. We can select various alternative designs in terms of various combinations of materials and also various combinations of thicknesses and we can evaluate each one of them and see whether they satisfy the performance criteria. You remember that there are two criteria available; one for fatigue failure and other for rutting failure.

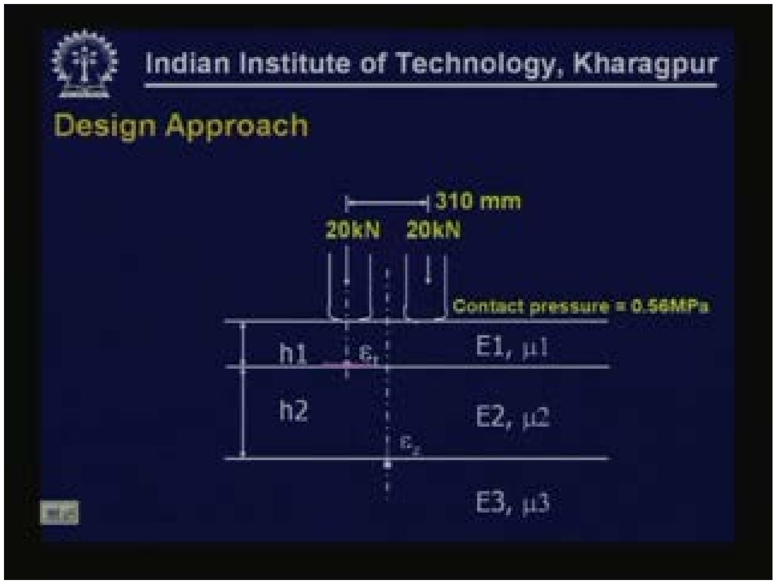
(Refer Slide Time: 00:41:30 min)

So we select trial thicknesses for different pavement layers having selected already the type of material that were going to use and we can also assign appropriate material properties to those materials. So we have already selected the materials to be, the only thing that is to be selected is the thickness of each layer.

Assign appropriate elastic moduli and Poisson ratio values for each layer. We already have the guidelines for assigning them.

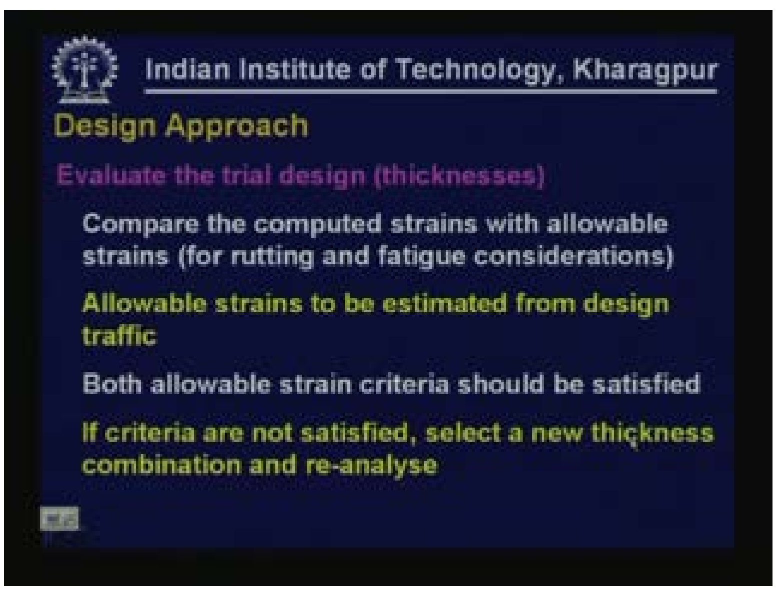
Compute critical responses: these are tensile strain at the bottom of the bituminous layer and vertical strain on the top of the subgrade using the elastic layer theory. That’s what is indicated in the next point. Use linear elastic layered theory considering standard loading conditions.

(Refer Slide Time: 00:42:16 min)



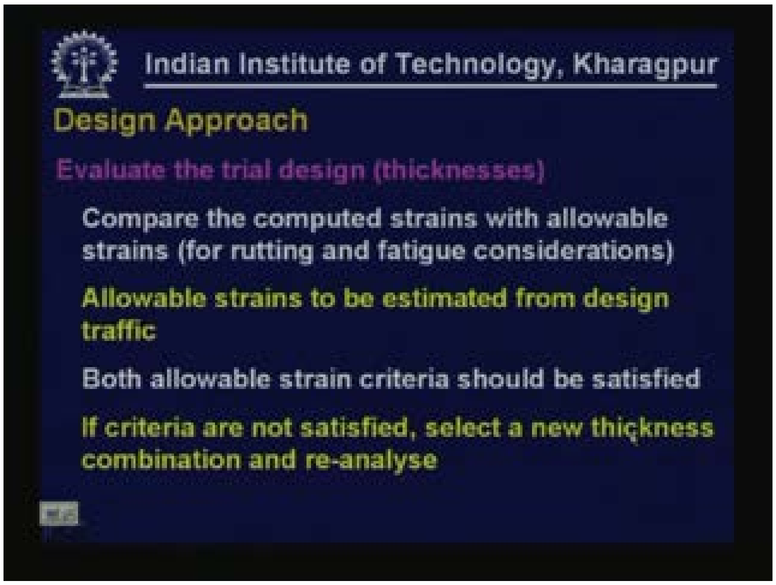
This is how we analyze the selected pavement or trial design. We have selected h1 and h2, we also selected the material properties on the basis of guidelines that are available and this is the standard loading that we are considering; 20 kilo Newton, 20 kilo Newton at a center to center spacing of 310 mm applied at a contact pressure of 0.56 we are also assuming this to be circular contact areas. So for these loading conditions for this pavement system we select a trial combination of h1 and h2 then we calculate epsilon t and epsilon z then we will compare these two values with allowable values.

(Refer Slide Time: 00:42:59 min)



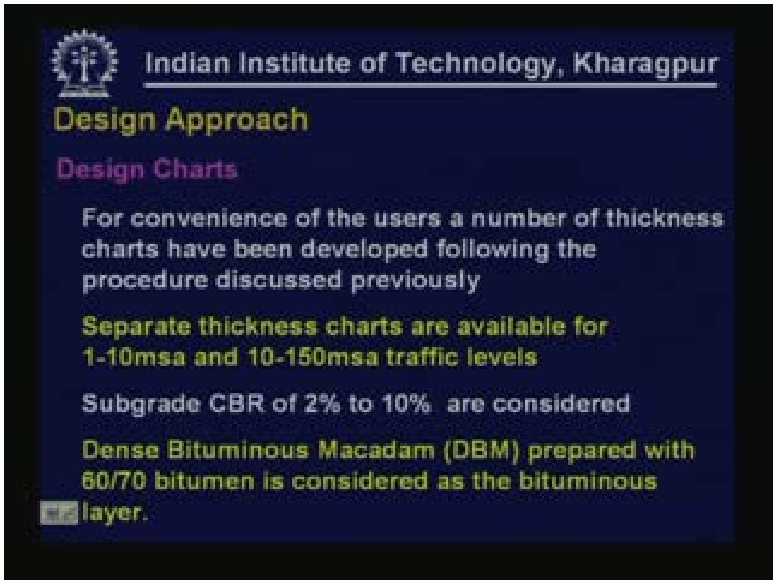
Therefore evaluating the trial techniques the next step that we do is compare the computed strains with allowable strains for rutting and fatigue considerations. Allowable strains will be estimated for the given design traffic like 50 millions, 20 millions, 100 millions depending upon the traffic intensity that is going to be there, depending on the number of years we have selected as design life period and various other traffic related parameters. We can estimate how many cumulative standard axles are going to be there in a given time period for this particular road. So using that value N and substituting that in the limiting strain equation we can get the allowable strain values. So both allowable strain criteria should be satisfied.

(Refer Slide Time: 00:43:40 min)



We are not going to just satisfy either rutting criteria or fatigue criteria both criteria have to be satisfied. If the criteria are not satisfied we select a new thickness combination and re-analyze.

(Refer Slide Time: 00:44:00 min)



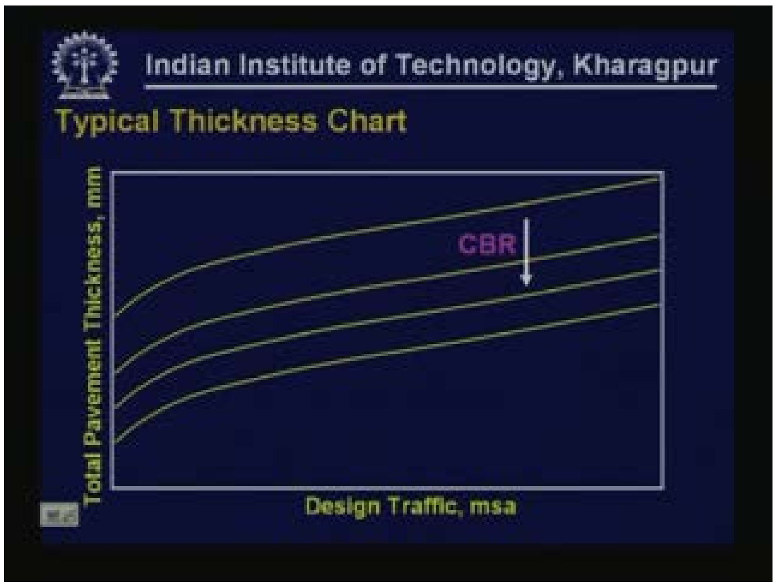
For the convenience of common users design charts have been developed and they are also presented in the Indian Roads Congress guidelines. There are separate thickness charts available for 1 to 10 million standard axles, this is a relatively low traffic volume and for 10 to 150 million standard axles these are relatively high traffic volume levels. These charts are available for subgrade CBR values of 2% to 10%, also these charts are available for dense bituminous Macadam prepared with 60/70 bitumen, this is considered to be the bituminous layer, this is the limitation of these charts. We can only get dense bituminous Macadam thickness using these charts. These are available for 2 to 10% CBR values; also these are available for 1 to 150 million standard axle repetitions.

(Refer Slide Time: 00:44:58 min)

What these charts give us will be the total thickness for a given CBR value and for a given traffic level if design charts are used. Of course if you are using a computer program using which you are capable of analyzing pavements and computing strains so there is no limitations in getting the total thickness we can select different combinations of thicknesses and check whether they are appropriate or not. But if you are using design charts given in IRC: 37 what we get is the total thickness. Obviously that has to be split into different component layers.

There are two thicknesses that we have to split this total thickness into, thickness of granular base. In fact it has to be split into thickness of granular sub-base, thickness of granular base and also thickness of surfacing. These are the three components in which we have to split the total thickness into such as granular sub-base, granular base and bituminous surfacing.

(Refer Slide Time: 00:45:59 min)

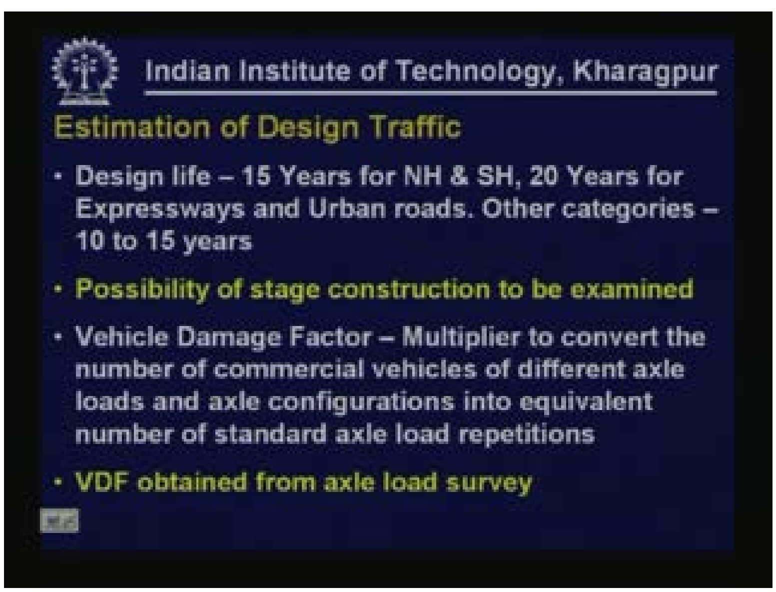


This is how a typical thickness chart looks like, this is what is given in IRC: 37 although I have not put the values here. So, for given traffic volume which can be estimated for a given design period and for a given subgrade CBR value the total thickness to be selected is given by the chart. Once we have obtained this total thickness, this is the total pavement thickness; this can be split into the component thicknesses.

(Refer slide Time: 00:46:35 min)

So the cumulative number of standard axle load coverage expected during the design life period can be estimated from, this we have briefly discussed in an earlier lesson which was exclusively dealing with traffic related parameters. We have to know the initial traffic intensity after construction in terms of commercial vehicles per day. We also should have the traffic growth rate during the design life period. We should know the design life in terms of years. We should have some knowledge of the vehicle damage factor that is likely to be there in VDF. We also have to have some lateral distribution factor to account for the lateral distribution of commercial vehicles across the carriageway. Therefore these are the parameters that we should be able to select.

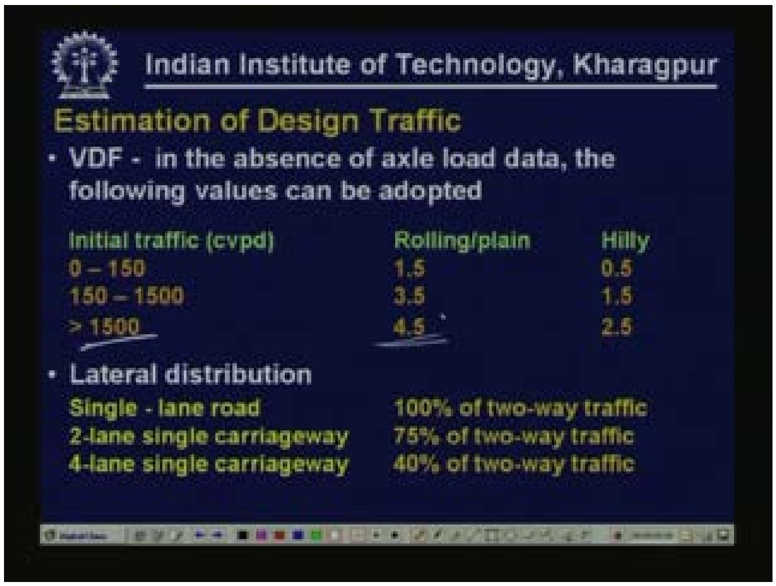
(Refer Slide Time: 00:47:21 min)



IRC gives guidelines for selecting all these parameters. Design life typically has to be selected as 15 years for high volume roads national highways and state highways, 20 years for expressways and urban roads and for other categories it can be 10 to 15 years. In selecting this design life period we should also take into consideration the possibility of constructing the pavement in different stages like stage one and stage two.

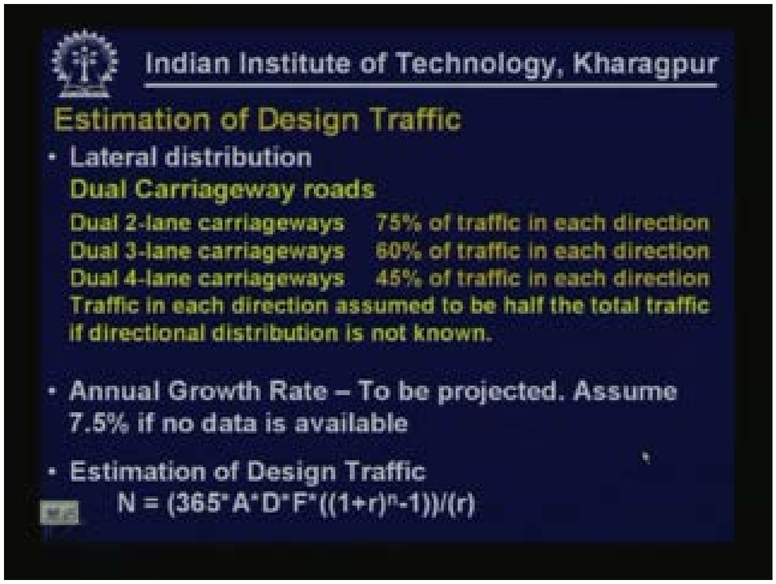
The vehicle damage factor is a multiplier to convert the number of commercial vehicles of different axle loads and axle configurations into equivalent number of standard axle load repetitions where VDF can be obtained from axle load survey.

(Refer Slide Time: 00:48:03 min)



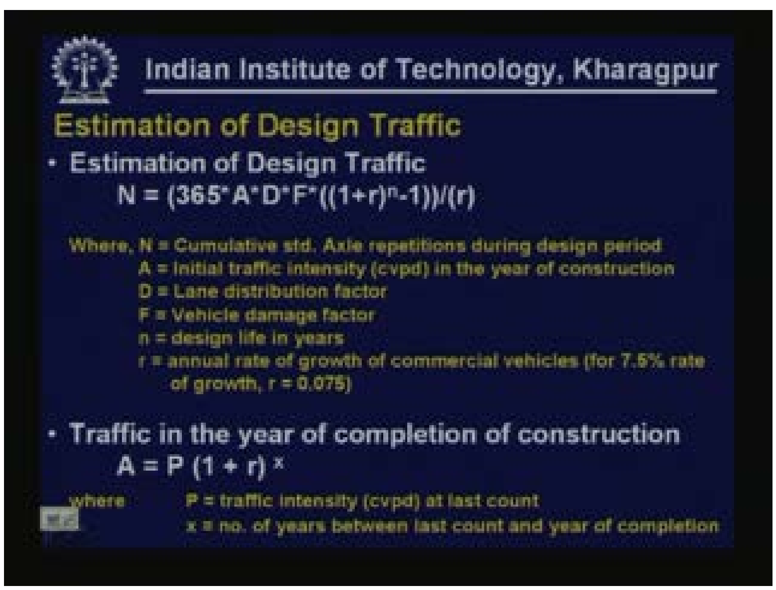
In the absence of any axle load data if we are not able to conduct axle load survey the following values can be adopted. These are the values that are recommended by Indian Roads Congress. For an initial traffic value of 0 to 150 commercial vehicle per day CVPD is commercial vehicle per day, for different terrains rolling and plain terrain, hilly terrain the recommended values are given. For example, for rolling and plain terrain for initial traffic density of more than 1500 commercial vehicles per day a value of 4.5 can be selected if it is in a rolling or plain terrain. Similarly for lateral distribution for single lane road 100% of the total 2-lane volume has to be considered, for 2-lane road single carriageway 75% of total two way traffic has to be considered, for 4-lane single carriageway 40% total two way traffic has to be considered.

(Refer Slide Time: 00:49:03 min)



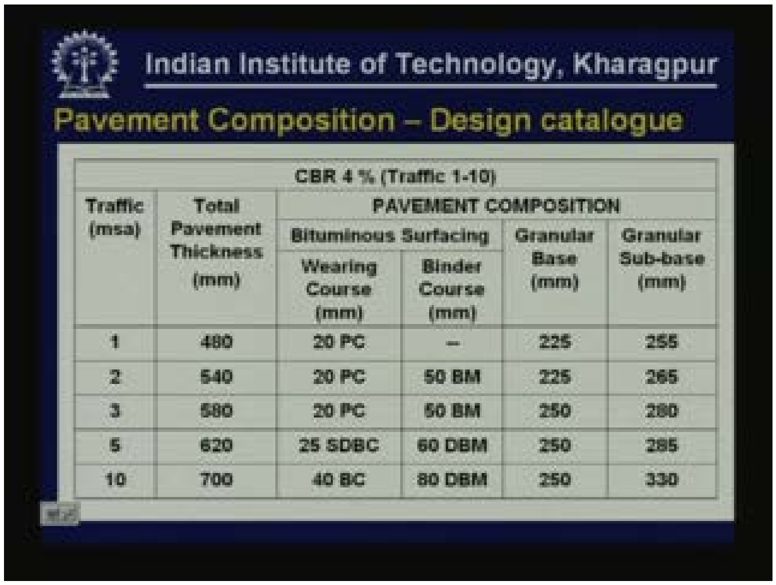
For dual 2-lane carriageway 75% of traffic in each direction has to be considered, for dual 3-lane carriage way it is 60% of traffic in each direction, for dual 4-lane carriageway it is 45% of traffic in each direction. If we do not have directional distribution of traffic we can assume that traffic in each direction is half the total traffic. And annual average growth rate of commercial traffic can be assumed to be 7.5% if no projections are available. So estimation of design traffic can be made using this expression where N = 365 into A, A is the commercial traffic volume intensity, commercial vehicles per day, we'll see the explanation of these parameters in the next slide.

(Refer Slide Time: 00:49:59 min)



D is the rather the lane distribution factor, F is the vehicle damage factor, N is the design life in years, r is the annual rate of growth of commercial vehicles assumed to be 7.5% in the options of in the data. The traffic in the year of completion of construction that is A can be estimated if you know what is the present traffic intensity, traffic intensity at the last count and also number of years between the last count and year of construction that is x using this expression.

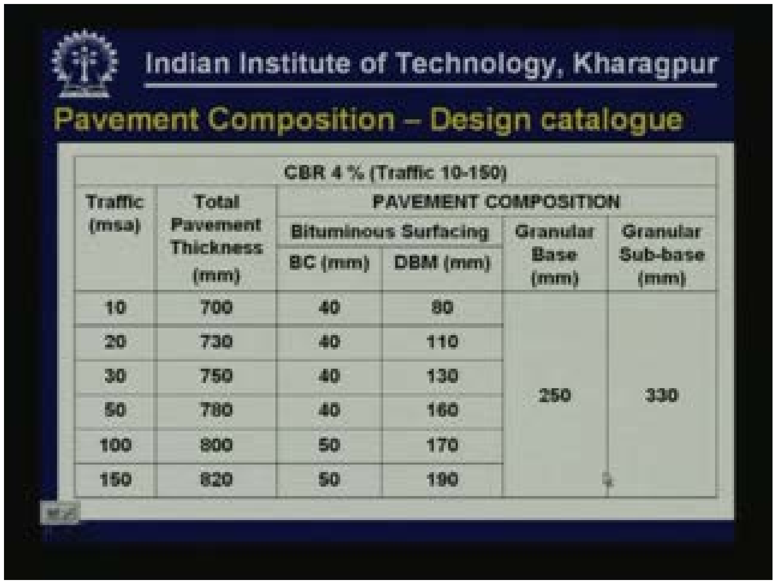
(Refer Slide Time: 00:50:30 min)



CBR 4 % (Traffic 1-10)					
Traffic (msa)	Total Pavement Thickness (mm)	PAVEMENT COMPOSITION			
		Bituminous Surfacing		Granular Base (mm)	Granular Sub-base (mm)
		Wearing Course (mm)	Binder Course (mm)		
1	480	20 PC	–	225	255
2	540	20 PC	50 BM	225	265
3	580	20 PC	50 BM	250	280
5	620	25 SDBC	60 DBM	250	285
10	700	40 BC	80 DBM	250	330

The pavement composition can be selected if we know the total pavement thickness using this catalogue or table that is given in IRC: 37. So for different subgrade CBR values and for different traffic densities of 1, 2, 3, 4, 5 and 10 million standard axles this is how the total thickness has to be split.

(Refer Slide Time: 00:51:04 min)



CBR 4 % (Traffic 10-150)					
Traffic (msa)	Total Pavement Thickness (mm)	PAVEMENT COMPOSITION			
		Bituminous Surfacing		Granular Base (mm)	Granular Sub-base (mm)
		BC (mm)	DBM (mm)		
10	700	40	80	250	330
20	730	40	110		
30	750	40	130		
50	780	40	160		
100	800	50	170		
150	820	50	190		

Similar tables are available for traffic densities, for 10 to 150 and for different subgrade CBR values. So we will have number of tables available in IRC: 37 for different traffic intensities, different subgrade values and for different types of materials.

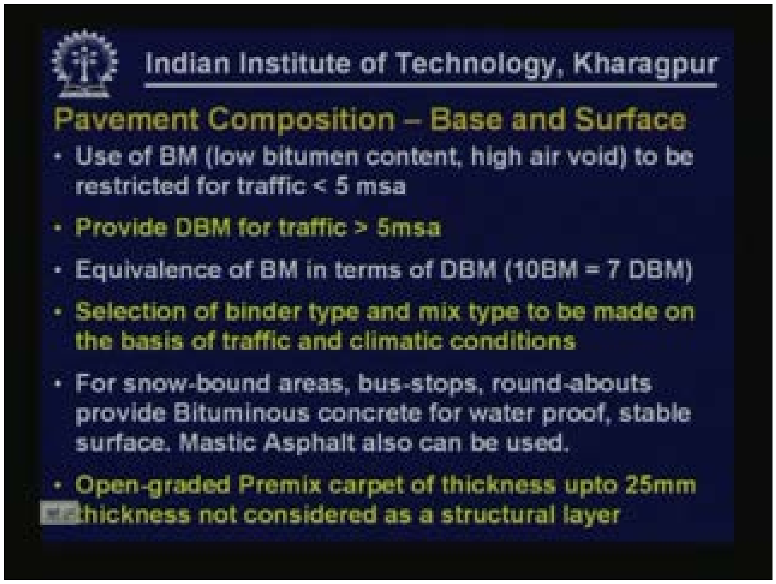
(Refer Slide Time: 00:51:19 min)

The pavement composition that has to be used must have a minimum subgrade CBR of 20% for traffic up to 2 million standard axles, it should have a minimum 30% CBR for traffic greater than 2 million standard axles, for subgrade CBR soils of low permeability the granular surface should be for full width of formation. The thickness of the extended portion should not be less than 150 mm for traffic less than 10 million standard axles and 200 mm for traffic more than 10 million standard axles. If the subgrade CBR is less than 2% design of CBR then the design should be for CBR of 2% and provide a capping layer of 150 mm thick material having a minimum of 10% CBR in addition to the sub-base.

(Refer Slide Time: 00:52:11 min)

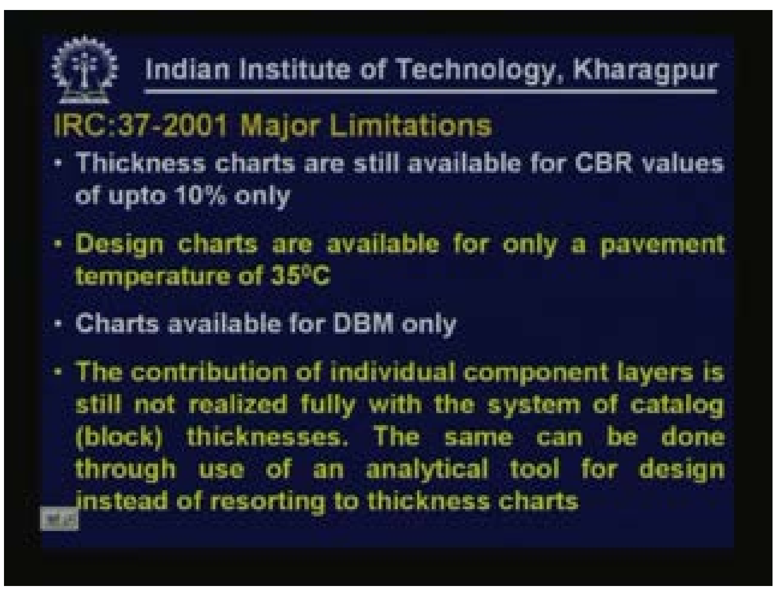
Base should be having a minimum thickness of 225 mm for traffic up to 2 million standard axles, 250 mm for traffic more than 2 million standard axles, the material should confirm to MORTH and IRC specifications. Bituminous surfacing can be a combination of wearing course plus binder course. Wearing courses typically are surface dressing, open-graded premix carpet, mix seal surfacing, cement and bituminous concrete and bituminous concrete; binder course can be bituminous Macadam and dense bituminous Macadam.

(Refer Slide Time: 00:52:40 min)



Use of bitumen typically having low bitumen content, high air void is to be restricted for traffic less than 5 million standard axles. We should normally provide DBM for traffic more than 5 million standard axles. Equivalence of BM in terms of DBM is approximately 10 BM = 7 DBM. Selection of binder type and mix type is to be made on the basis of traffic and climatic conditions. For snow-bound areas, bus-stops, roundabouts provide bituminous concrete for waterproof stable surface, mastic asphalt also can be used. Open-graded premix carpet of thickness up to 25 mm thickness is not considered as a structural layer.

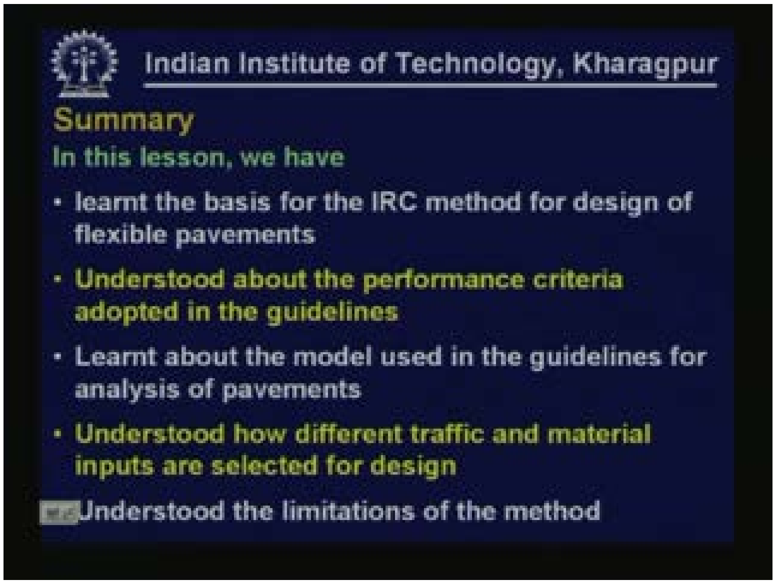
(Refer Slide Time: 00:53:25 min)



In IRC: 37 the main limitations are thickness charts are still available compared to the previous version, only for CBR up to 10% design charts are available only for pavement temperature of 35 degree centigrade. Charts are there only for DBM bituminous surface. The contribution of individual component layers is still not realized fully with the system of catalog or block thicknesses.

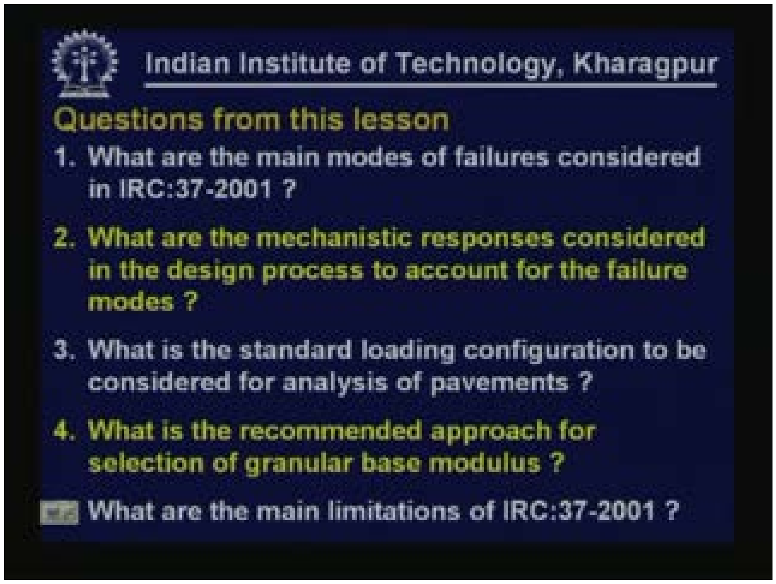
What the chart gives you is only the total thickness, how this has to be split into different component layers. If more surfacing is provided or more basic thickness is provided what would be the effect on the performance cannot be explained using these charts. Of course the same can be done through the use of an analytical tool for design instead of resorting to thickness charts.

(Refer Slide Time: 00:54:17 min)



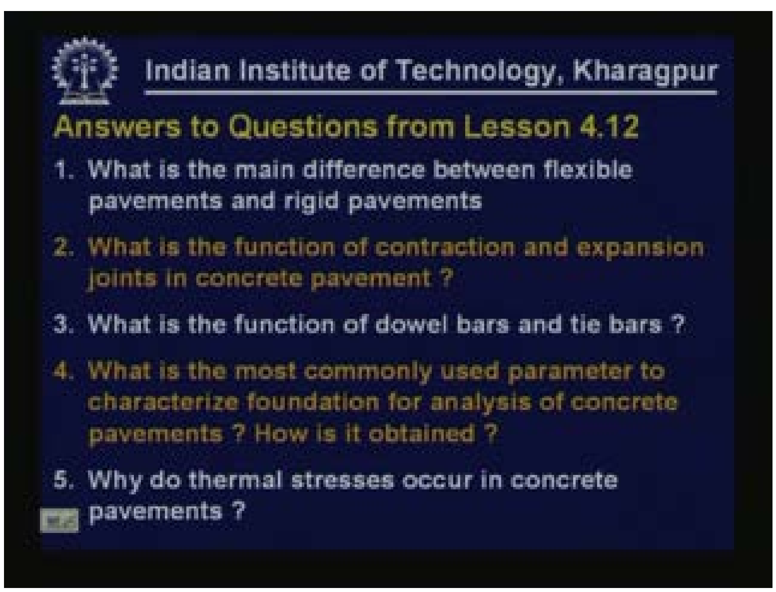
To summarize; in this lesson we have learnt the basis for the IRC method for design of flexible pavements. We also understood the performance criteria adopted in these guidelines. We have learnt about the model used in the guidelines for analysis of pavements and we also understood how different traffic and material related parameters are to be selected for designing the pavements and we also understood the limitations in IRC: 37 - 2001 in the method of designing flexible pavements.

(Refer Slide Time: 00:54:52 min)



Let us take a few questions from this lesson. Answers for these questions will be provided in the next lesson.
1) What are the main modes of failure considered in IRC: 37 - 2001?
2) What are the mechanistic responses considered in the design process to account for the failure modes?
3) What is the standard loading configuration to be considered for analysis of pavements?
4) What is the recommended approach for selection for granular base modulus?
5) What are the main limitations of IRC: 37 - 2001?

(Refer Slide Time: 00:55:24 min)



Now let us see the answers for questions that were asked in lesson 4.12.

1) What is the main difference between flexible pavements and rigid pavements?
Compared to flexible pavements rigid pavements have got a very stiff slab. The deflection is negligible compared to the deflection that flexible pavements undergo, this is the main difference. As a result the stiffness of the slab is predominant in terms of expanding the performance of the pavements compared to flexible pavements. So the foundations strength in the case of rigid pavements is not as important as it is in the case of flexible pavements. Next question is;

What is the function of contraction and expansion joints in concrete pavement?
If you construct a very long slab without any joints it is anyway going to crack because of contraction. As the temperature decreases the slab is going to contract so there is going to be some restraint that is going to be available to be provided by the foundation so as a result there are going to be tensile stresses developed it is going to crack.

To regulate the location at which the cracks are going to be forming we are going to weaken the slab at regular intervals and thereby allowing the crack to develop at that location so that's the reason we have to provide contraction joints. Whereas expansion joint is to allow for the expansion of the slabs because slab is going to expand when the temperature increases but there has to be some gap that is available between different slabs to accommodate that increase in length of the slab, that's the reason we provide expansion joints.

What is the function of dowel bars and tie bars?
Dowel bars are provided to provide low transfer mechanism from one slab to another slab. They are meant for low transfer from one slab to another slab either across the contraction joint or across the expansion joint. On the other hand tie bars are there to tie the two slabs together and see that the gap does not open and thereby the low transfer mechanism is there through granular ((57:37)).

What is the most commonly used parameter to characterize foundation for analysis of concrete pavements?
It is modulus of subgrade reaction and this can be obtained by conducting a plate load test by applying load incrementally and then observing the deflections and the load corresponding to deflection of 1.25 mm can be observed so the unit pressure corresponding 1.25 mm pressure divided by 1.25 is the value of k, this can be obtained by conducting plate load test.

Why do thermal stresses occur in concrete pavements?
Especially we are talking about curling stresses, when the top temperature and bottom temperature of the slab differ if the top temperature is more the slab will curl like this, if it is restrained from curling up like this because of its self weight or because of the restrain provided with the foundation there are going to be stresses developing. Similarly, if the bottom temperature is more than the top temperature it will curl out like this (refer Slide Time: 58:33) so because of its self weight it is restrained or the foundation also will restrain it and thereby because of the restrain curling stresses are developed, thank you.