Introduction to Transportation Engineering
Prof. K. Sudhakar Reddy
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecture - 37
Flexible Pavement Design
AASHTO Method – 1993

Welcome to lesson 14 of module IV. As you know module 4 is about pavement design. This lesson is about design of flexible pavements as per 1993 version of AASHTO method. In the previous lesson we have discussed about design of flexible pavements as per Indian Roads Congress method IRC: 37 – 2001. IRC: 37 - 2001 is the most popularly followed method in this country. However, several agencies use AASHTO method which has been developed in United States and is being used extensively by various agencies throughout the world.

Also, AASHTO method has got several very interesting concepts which have been adopted in various other design procedures also some of them having used in IRC method also. And also the AASHTO database that has originally been developed in the United States in fact form the basis for several of the design methods that have evolved especially in the United States. That's the reason why I have selected to discuss AASHTO design method also, although we have talked about IRC: 37 – 2001 which is very popular in India. As I said many agencies in India also use AASHTO design method for designing flexible pavements.

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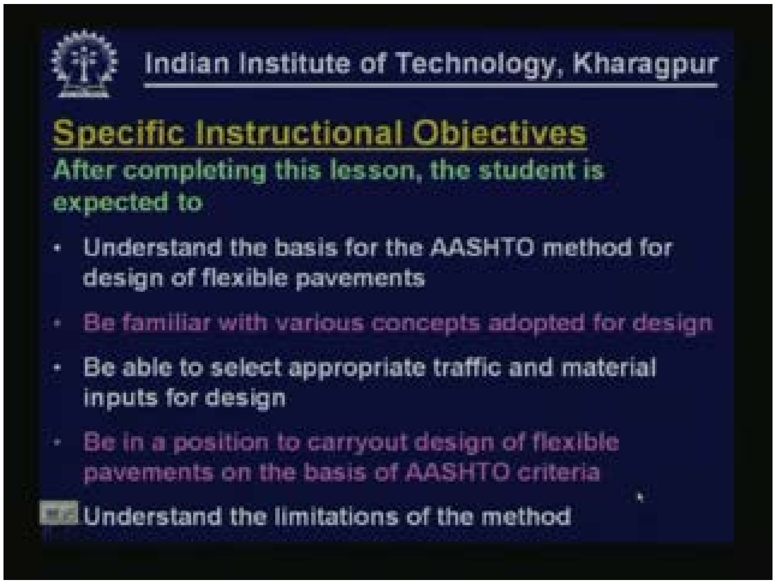

So this specific instructional objective of this lesson would be after completing this lesson the student is expected to understand the basis for AASHTO method for designing flexible pavements and be familiar with various concepts adopted for design. As I have indicated there are several interesting concepts that have evolved out of what is known as AASHO road test and the data that has been collected in the AASHO road test in fact form the basis for AASHTO pavement design method and also several other pavement design methods. So we will be specifically talking about these interesting concepts that are part of the AASHTO pavement design method. It is also expected that the students after completing this lesson would be able to select appropriate traffic and material inputs for design and also other inputs that are required for design. It is hoped that they would also be in a position to carryout design of flexible pavements on the basis of AASHTO criteria. They should also understand the limitations of the AASHTO design method for designing flexible pavements.

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In fact what we are going to discuss here is the AASHTO guidelines as per their 1993 guide. AASHTO stands for American Association of State Highway and Transport Officials. AASHTO used to be formerly known as AASHO American Association of State Highway Officials. This design method has been developed based largely on the findings from AASHO road test that I have just indicated. The AASHO road test program was conducted in the 50s. On the basis of this data an interim guide was developed in 1972 which was revised in 1981 which was again revised in 1993. The 1993 revision guidelines are what we are going to discuss here. This is of course the draft guidelines for 2002, the revision is already prepared that have been discussed, the draft copies already on the internet and it is circulated among various agencies and it has been discussed. Hence it will take some more time for this 2002 version of AASHTO revised guidelines to be available.

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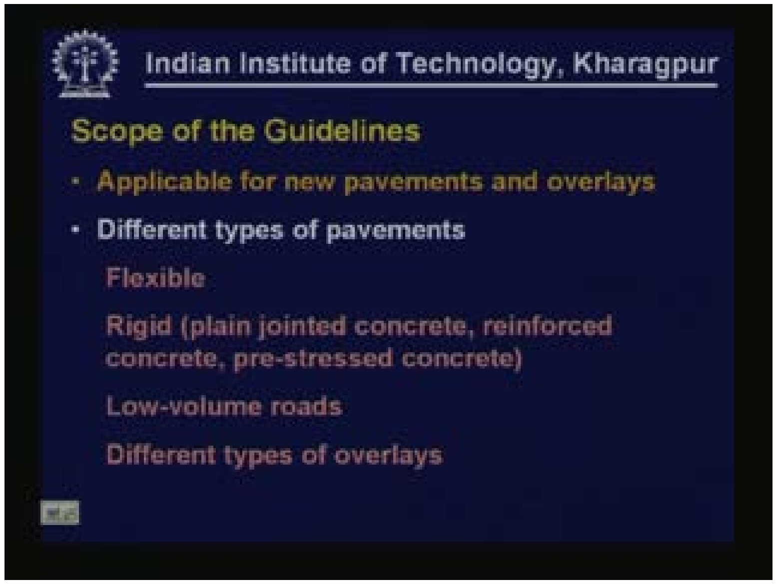

The scope of these guidelines is; these are applicable for new pavements and also overlays. Unlike in the case of IRC method of designing flexible pavements IRC: 37 as we see from its scope it is applicable only for new pavements. So AASHTO guidelines can be used for designing new pavements also for overlays. In fact this is one single set of guidelines that is available for all types of pavements such as; concrete pavements, flexible pavements, different types of flexible pavements and also different types of concrete pavements.

For example, the types of pavements that are considered in these guidelines are flexible, rigid and under rigid we have different types of pavements like plain jointed concrete, reinforced concrete, pre-stressed concrete, in fact information was available on all these types of pavements from AASHO test. Guidelines are also available in the 1993 version for low-volume roads also and also for different types of flexible overlays and different types of overlays for concrete pavements also.

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The most important features of AASHTO guidelines are; there is a concept of reliability that is built into the system built into the designed procedure so the pavements are designed for different levels of reliability. One can select what is reliability for which a particular pavement has to be designed for a given situation so the thicknesses and other properties will have to be accordingly selected. The traffic is considered in terms of equivalent axle load that is 18 kip where 18 kip is 18,000 pounds repetitions. This is similar to what we have considered for IRC: 37 – 2001 versions also. Traffic is considered in terms of 80 kilo Newton equivalent to 18 kip standard axle load repetitions.

For converting a given axle load if it is not 18 kip rather 10 kip, 24 kip or any other load because this information will be available by conducting axle load survey so obviously all the axles will not be measuring 18 kip. So if it is different from 18 kip these axle loads which are different from 18 kip are converted into equivalent number of 18 kip repetitions using equivalent axle load factors. So there are guidelines available as to how to select equivalent axle load factors using which we can convert a given traffic volume into equivalent number of standard axle load repetitions. Another concept that has evolved out of AASHO road test and has been used in AASHO pavement design guidelines is the concept of layer coefficients to represent the contribution of individual layer materials, individual components towards the performance of the pavement. Stronger materials would give more contribution to better performance accordingly it will have higher layer coefficient.

So the materials are represented in terms of their layer coefficients and not in terms of the elastic modulus value or Poisson ratio value as we are considering in the case of IRC guidelines or several other guidelines that are available for design of flexible pavements. Because in IRC we have used linear elastic layered theory for analysis of pavements so for that we needed elastic modulus value and Poisson ratio value as input but in this case there is no theoretical evaluation of pavements, it is completely on the basis of experience and how it is correlated to different pavement parameters, there is no analysis involved at least in 1993 version.

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So the layer coefficients for different types of materials on the basis of the experience gathered in AASHO road test are available in the AASHTO guidelines. A single index called as a structural number is used to represent the pavement structure. Pavement may have any number of layers; three layers, four layers or five layers so all these layers having different types of materials or having different strength are represented in terms of one single index known as structural number. Structural number gives us the strength of the pavement and the condition of the pavement at any given point of time.

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The performance in the case of AASHTO design guidelines is defined in terms of both functional as well as structural performance. The structural performance deals with; occurrence of cracking of bituminous layers, bound layers, rutting in different layers, raveling and other factors also affecting the load carrying capacity of the pavement. So we consider all those parameters that indicate the damage caused due to application of load, that indicates the structural deterioration of the pavement and also we consider different parameters that influence the structural capacity of the pavement. That way we are talking about the structural performance of the pavement also. But in general the AASHTO performance criteria at its face value would appear to be as if it is only talking about the functional performance of the pavement.

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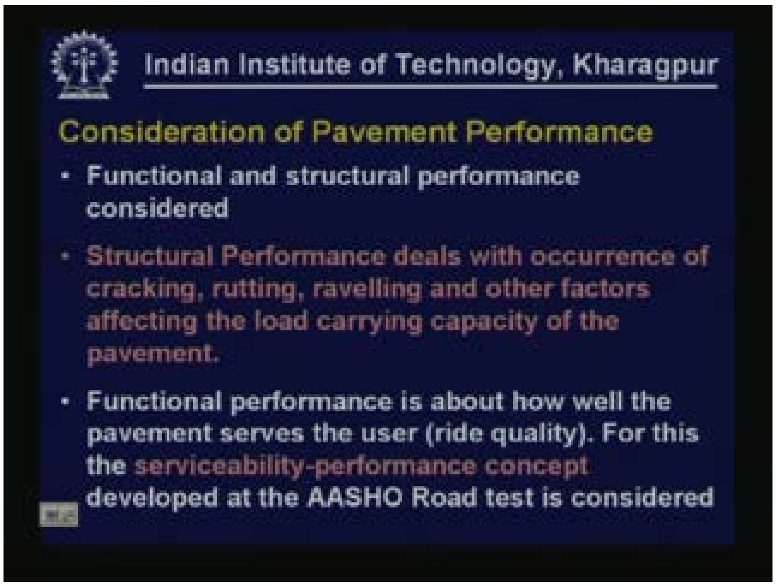

The functional performance is about how well the pavement serves the user especially the right quality. For this the serviceability performance concept is used; how well the pavement is able to serve, what is the level of serviceability available at a given point of time and so on is the concept is used in AASHO guidelines for describing the performance of the pavements. In fact this was the concept that was developed during the AASHO road test.

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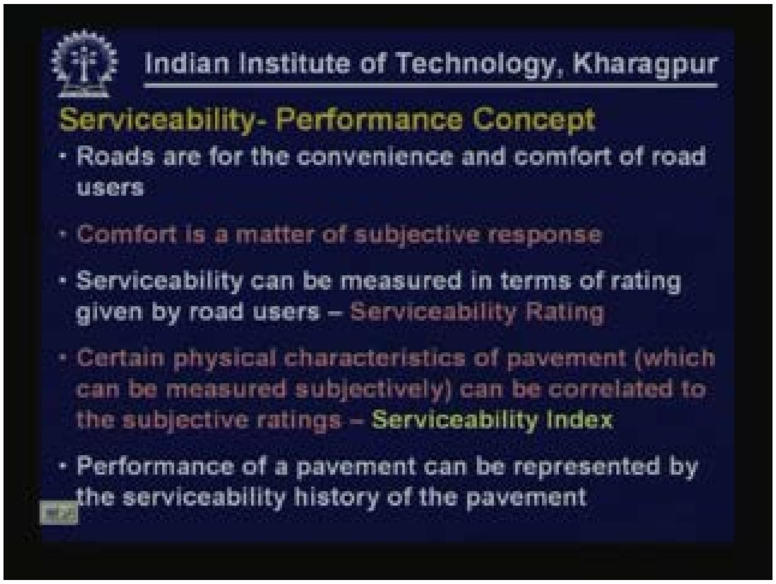

What is the serviceability performance concept?
We know that roads are for the convenience and comfort of the road users. Comfort is a matter of subject to assessment. What is comfortable to me may not be comfortable to you but when you have the collective assessment of a given road by n number of panelists or users we will get some idea about how a particular road is rated by different people and how the rating of a particular road is different from the rating given by the same panel to another road having different condition. So this way the condition or the serviceability or the functionality of a given road can be assessed in terms of parameter called as serviceability rating.

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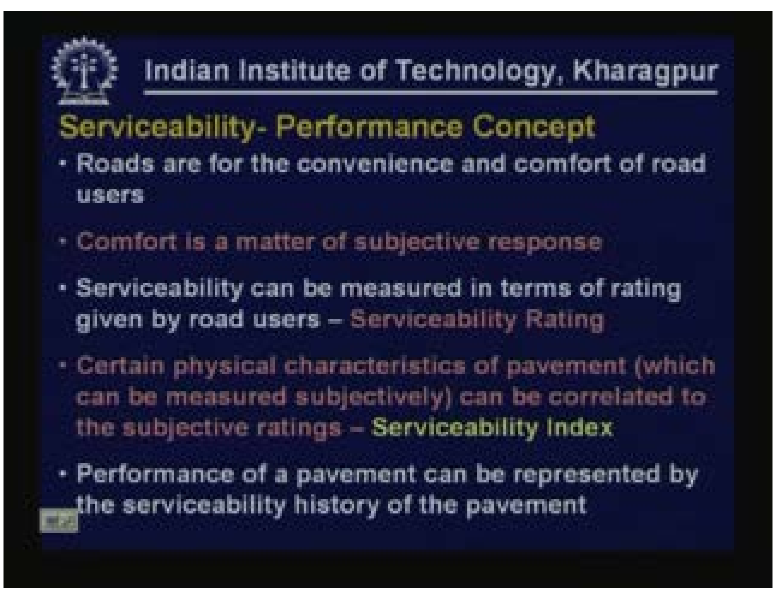

As indicated here serviceability can be measured in terms of rating given by road users known as serviceability rating. Why would the serviceability rating different from one road to another one? Obviously there must be something different in terms of its service characteristics that is affecting the ride comfort or riding quality and the comfort level that is pursued by the user. So there are some physical differences among different pavements relating to differences in different physical ratings. If these physical parameters can be quantified it is seen that they can be correlated to the rating given by these users.

For example, more the roughness of the road more will be the discomfort to the road user that should be reflected in the rating. So, if these parameters can be quantified they can be correlated to the rating given by the users. That is what they have found. Thus by correlating physical characteristics of pavement which can be measured subjectively or quantitatively these parameters can be correlated to the subjective ratings given by these users. By correlating that they have evolved an index known as serviceability index. This is nothing but the rating that would have been given by the panel if the same panel had gone to a particular road but instead of taking the panel to the road the actual service rating that would have been given by the panel is estimated on the basis of relationships that have already been developed between the serviceability rating given by the panel to different roads and the corresponding physical measurements made on those roads.

So using those correlations that is established between serviceability ratings and the physical parameters we can estimate what would have been the serviceability rating given by the panel for any given road provided we know what are the physical parameters, what is the quantifications of those physical parameters. The performance of the pavement can be represented by the serviceability history of the pavement.

Over time if no rehabilitation methods are taken or no maintenance is done after construction obviously the performance is going to gradually deteriorate, that can be represented in terms of the serviceability index value. Initially the serviceability index value will obviously be more, that will gradually start deteriorating with time with repeated application of loads so that can be represented by the serviceability index.

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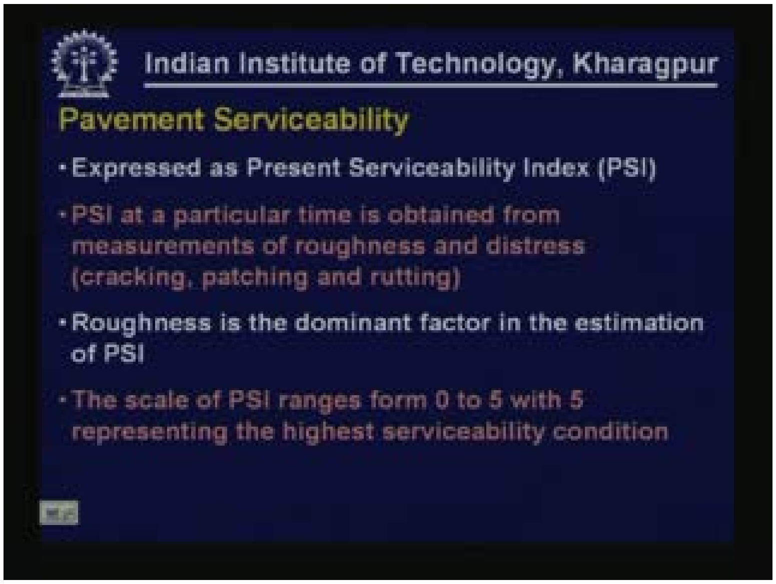

Expressed as present serviceability index the PSI at a particular time is obtained from measurement of roughness and different distress parameters. As I said there are certain physical parameters which can be correlated to the serviceability rating given by the producers which can be correlated to the comfort levels that are perceived by the road users. So these physical measures if they can be quantified they can be used to calculate what is known as present serviceability index it is called as present because these parameters are going to be changing, roughness is going to change, extent of cracking is going to change, extent of rutting is going to change so as these parameters change the corresponding PSI is going to be changing. So at a given part of time if you measure these parameters the present index corresponding to that time can be obtained.

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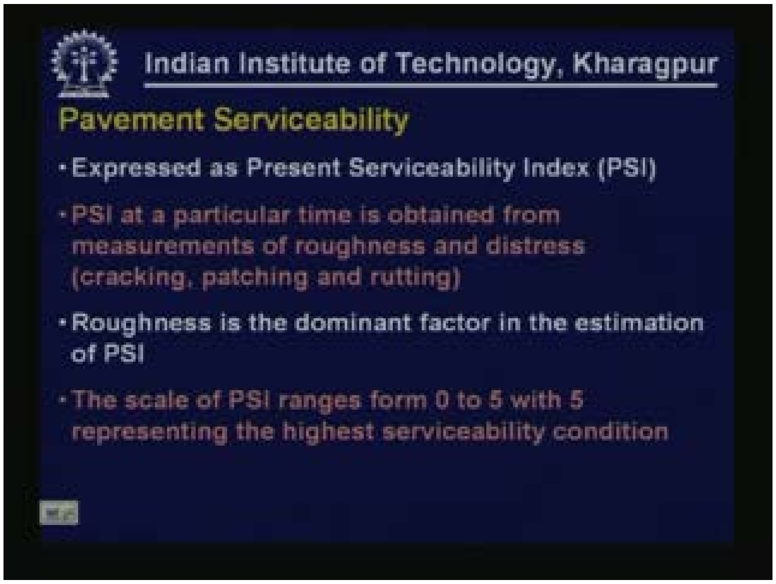

Roughness is the dominant factor in the estimation of PSI. If you see the expressions available for estimating PSI as a function of various physical parameters main parameters that are available are roughness, cracking, patching and extent of rutting. Roughness is the dominant factor in the estimation of PSI. The scale of PSI ranges from 0 to 5 with 5 representing the highest serviceability condition obviously 0 represents the worst condition that is possible.

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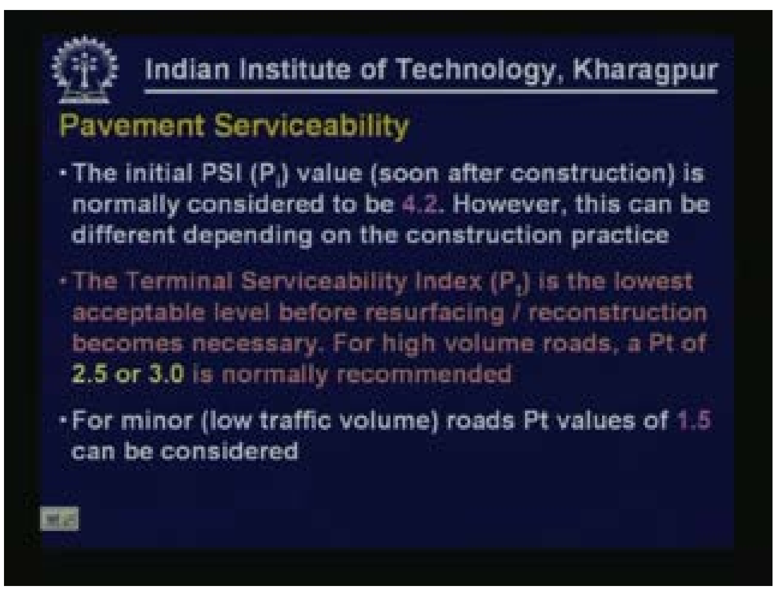

The initial PSI that is Pi this value which is seen or which is measured which can be estimated soon after construction is normally considered to be about 4.2 for flexible pavements. This can be different depending on the type of material that we use, type of construction techniques that we adopt and so on. So this is the initial roughness initial condition that we are able to attain in terms of its surface profile. So with better construction equipment obviously it would be possible to attain higher serviceability rate. But 4.2 is a typical value that is considered in the designed guidelines.

If one has a better estimate of what is the initial present serviceable index soon after the pavement is constructed one would use that value. As I said however this can be different depending on the construction practice. The terminal serviceability index represented by Pt is the lowest acceptable level before resurfacing or reconstruction becomes necessary. For high volumes Pt of two point five or three is normally recommended.

The terminal serviceability index is also a typical value that has evolved out of the service that was conducted with a panel of different road users. The road users were also asked to identify the roads that were not acceptable to them, the road that has reached the condition which is not acceptable so the serviceability index values of those roads were in the range of 2.5 and 3. So, typically 2.5 or 3 are considered to be terminal serviceability index values for high volume roads. Obviously for low volume roads one may tolerate even slightly lower serviceability index because low volume roads would be low cost roads and then they would normally expect to bear with slightly more discomforts on those roads. But if you are traveling on a high speed facility you would be expecting higher serviceability levels so the terminal serviceability values for high speed facilities high volume roads are in the order of the 2.5 to 3. For minor or low traffic volumes the Pt values can be as low as 1.5.

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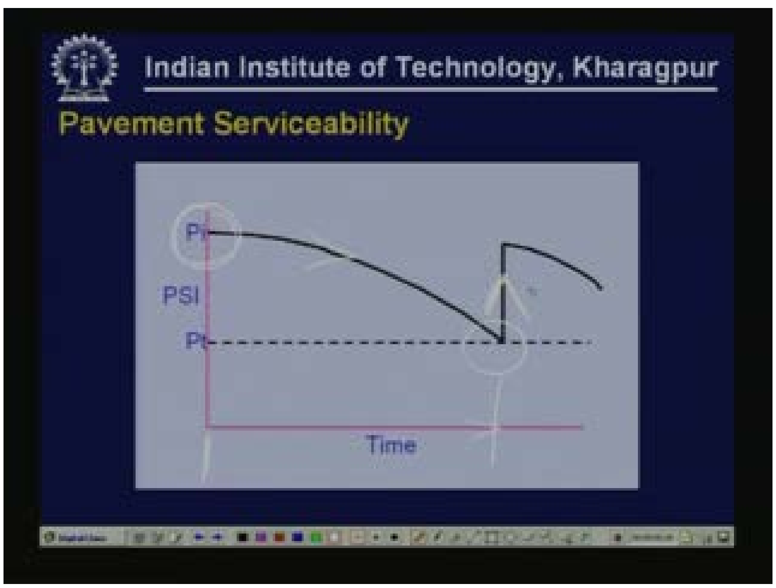

As we have indicated earlier the performance of the pavement can be represented by the serviceability index of the pavement. For example, in this chart we see the present serviceability index is going to vary with time. So soon after construction this is the serviceability index that is available but with time this is going to deteriorate. In what manner it is going to deteriorate or what shape it is going to take will be a function of the type of road, type of material that are used and also may be the type of intermediate maintenance that is carried out.

Therefore if it allowed to deteriorate to Pt let's say it reached a value of Pt after a given time period. This can be rehabilitated and its serviceability index can be improved by appropriate measures like by overlaying, by repairing and whatever measures are required to improve its present serviceability index depending on the condition in which the pavement is in when it reaches the Pt value it can be improved and then may be even brought back to an initial value of Pi.

So this goes on cyclically, the serviceability drops then it has to be repaired and rehabilitated to improve its serviceability so it goes on like this. So what we need to understand is what is the rate at which the serviceability is going to deteriorate, how much time or how many number of repetitions of load applications would be required to bring the serviceability index which is initially at Pi to an acceptable value of Pt, so below this let's say the road users would not accept the serviceability rating so in what fashion it is going to be deteriorating, what is the relationship between various pavement parameters, load applications, number of load applications and other parameters which define how the serviceability rating is going to deteriorate. This is the information that we need so that we can design pavements.

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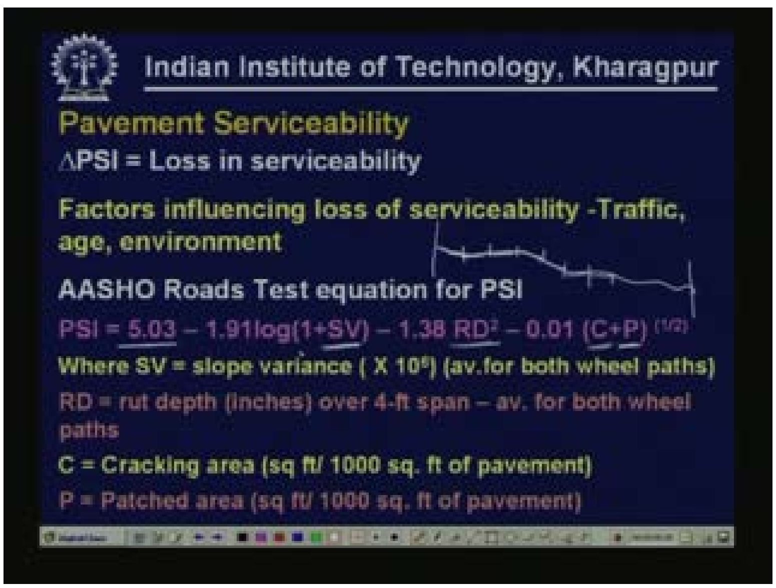

Delta PSI is what we are going to be looking at, this is the loss in serviceability. If we start with an initial serviceability of Pi with time the serviceability is going to be deteriorating. So we are going to be talking about what is the loss in serviceability that is going to be permitted over the design life period.

Factors influencing loss of serviceability:
What is the road loss serviceability?

Obviously because of repeated application of traffic loads, because of aging, because of environmental conditions the pavement layers may be saturated, there may be high temperatures leading to low strength of bituminous layers, and the climatic factors and traffic parameters are the main influencing factors that lead to the change in serviceability.

The AASHO road test equation for estimating PSI as we have indicated present PSI is an estimate for PSR in terms of physically quantifiable parameters such as roughness, rutting, cracking and other parameters. So, if you can look at this equation PSI is given as the function of 5.03 – 1.91, SV is known as slope variance, RD is the rut depth, C is the extent of cracking, P is patching done to the already cracked portion or already deteriorated portion. So the main parameters that we use in estimating PSI present serviceability index which gives us an indication of what is the present functional condition of the pavement are slope variance, rut depth, cracking and patching.

Slope variance we can define this subsequently, we have already defined this in the earlier lessons. Slope variance in fact gives us an indication of how the longitudinal slope varies. So this slope is measured over small lengths. Hence if this is a stretch that we are considering so slope is measured over small lengths and the variance of all these values is given as slope variance. Rut depth is measured over a four feet span in terms of inches. This has to be taken as average measured along both wheel paths because rutting is going to occur along wheel path. In a given lane there will be two wheel paths therefore there will be rutting here and rutting in the other wheel path also, so normally we have to consider the average of both the wheel paths, the rutting that is observed in both the wheel paths.

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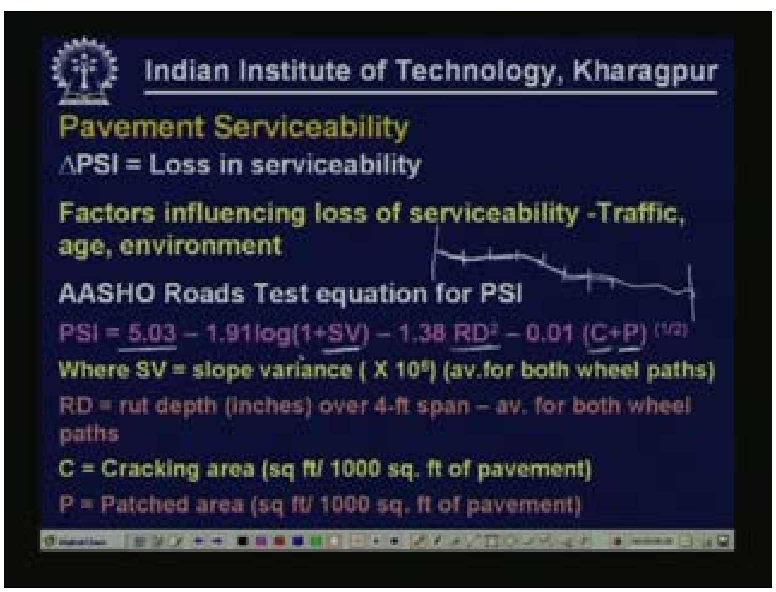

The area of cracking is expressed in terms of square feet for thousand square feet of paved area. If you observe thousand square feet of paved area out of that how many square feet has got cracked surface that is what is known as cracked area. Similarly patching is defined by how much area of the paved surface is patched per thousand square feet of pavement area.

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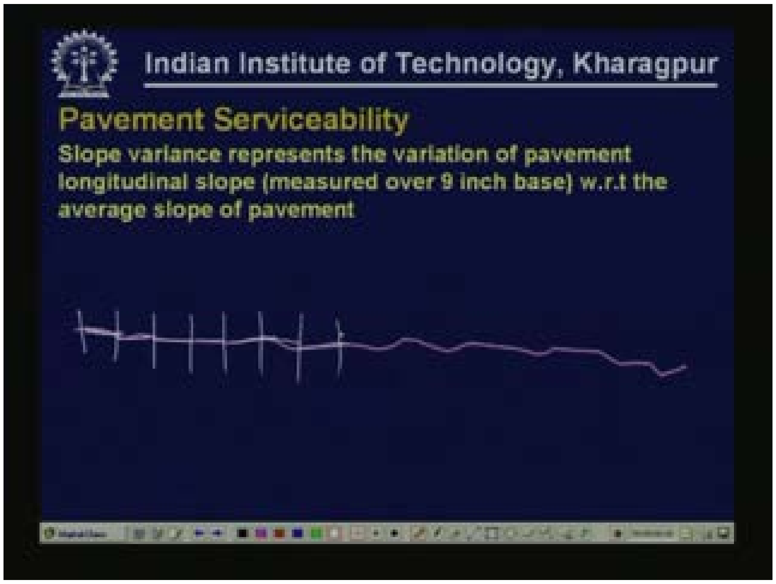

A slope variance represents the variations of pavement's longitudinal slope this is measured over 9 inch base as I have just explained in the previous slides. Thus in the 9 inch base length is considered and over this is where the slope is measured. So, if you have hundred such n values you can calculate the variance of all those n values.

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The traffic is characterized in the following manner. Traffic over the design period is estimated by assuming a suitable exponential growth rate. Analysis or design normally has to be carried out if you have high-volume urban roads for 30 to 50 years. If you have high-volume rural roads the design period can be 20 to 50 years, low-volume paved roads 15 to 25 years, low-volume aggregate surface roads which is not sealed by either bituminous surfacing or by any stabilized layer so the design period can be from 10 to 20 years.

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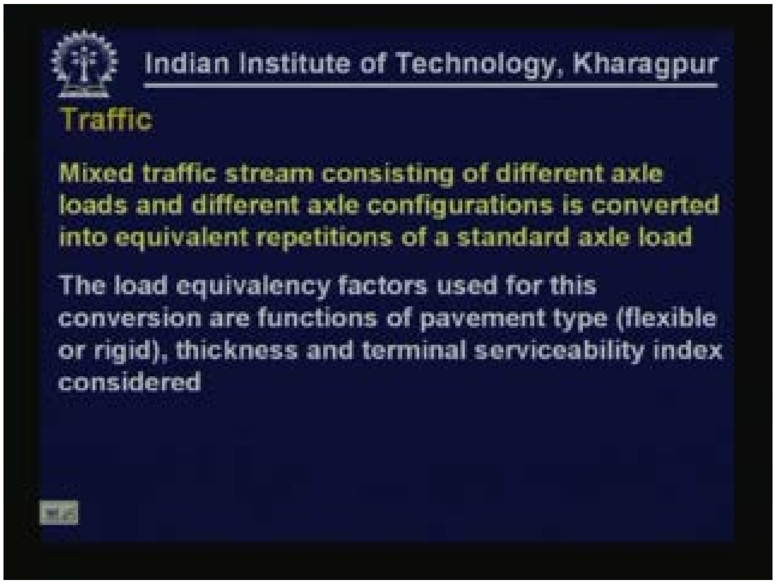

Mixed traffic stream consisting of different axle loads and different axle configurations is converted into equivalent repetitions of a standard axle load because traffic is considered in terms of repetitions of standard axle loads standard axle load being 18,000 pounds 18 kip or 18 kilo Newton load.

The load equivalency factors used for this conversion are not constant but are functions of pavement type depending upon whether it is a flexible pavement or rigid pavement, thickness of the pavement or the structural number of the pavement and the terminal serviceability index considered. So the equivalence factor converting 30 kip axle load into 18 kip axle load is not a unique phenomenon, it is not 30 by 18 into to the power 4, we have discussed a fourth power law in the lesson where we discussed about traffic considerations, it is not as simple as that.

AASHTO has given different equivalent factors for different conditions. if it is a flexible pavement a 30 kip single axle load will be having different equivalence factor, if it is a rigid pavement the equivalence factor will be different because the damage caused by 30 kip axle load to a flexible pavement will be different compared to that caused by a concrete pavement relative to the damage caused by 18 kip axle load to flexible as well as rigid pavement.

Similarly the relative damage is also a function of the strength of the pavement. For weaker pavements the relative damage is going to be different but for stronger pavements it may be different. So the strength of the pavements in the case of concrete pavements it is in terms of the thickness of the slab and in terms of flexible pavements it is in terms of structural number which we have just indicated as the single number that is used to represent the strength of the pavement. So it is a function of structural number or thickness, it is a function of type of pavement flexible or rigid, it is also function of what is the terminal serviceability index that we are referring to.

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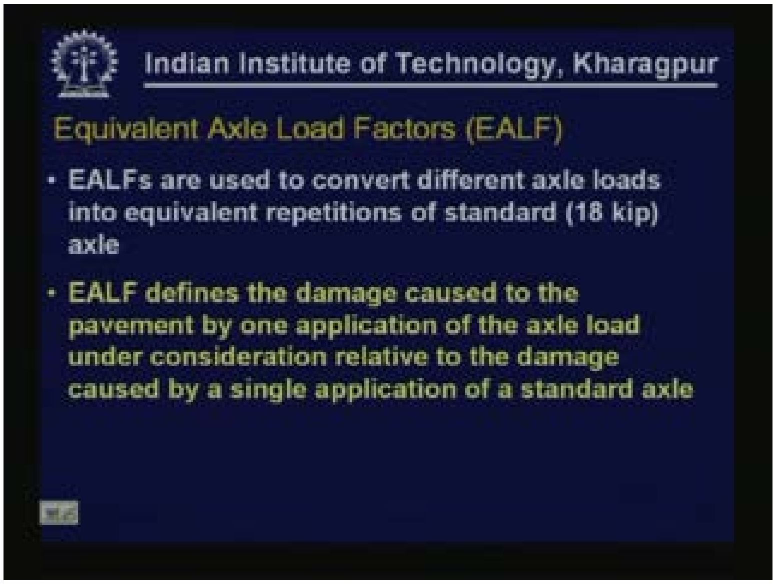

Equivalent axle load factors are used to convert different axle loads into equivalent repetitions of standard axle. Equivalent axle load factor defines the damage caused to the pavement by one application of the axle load under consideration relative to the damage caused by a single application of a standard axle. This concept we have discussed in the previous lessons. But let us see once again, equivalent axle load factor gives us an idea of relative damage caused by a specific load in comparison to the damage caused by the standard axle load which is 18 kip axle.

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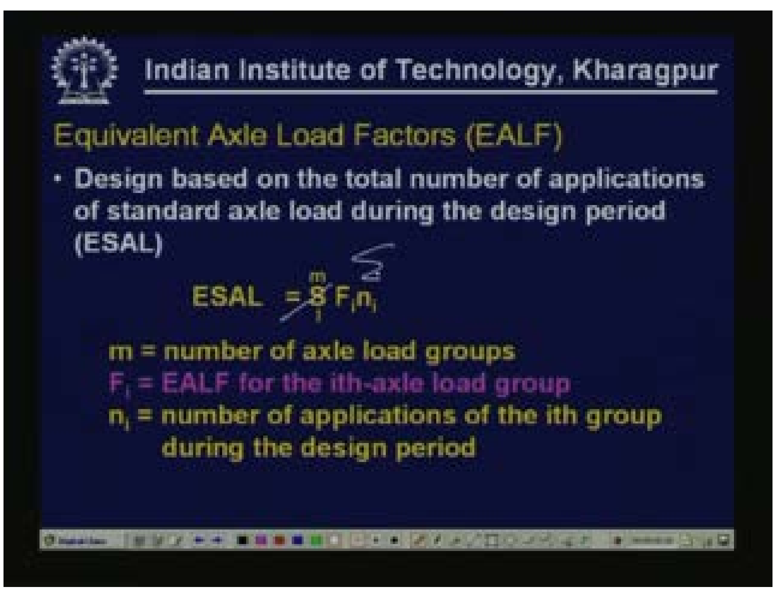

So the total number of equivalent standard axle load repetitions can be obtained using this expression (Refer Slide Time: 29:56). In fact the design based on the total number of applications of standard axle load during the design period can be obtained as, this is the summation term; sum of F and n. If you consider there are n categories or m categories of axle loads as different groups and having the corresponding factor representative of that group and the number of repetitions of different groups we can work it out, let’s say group 1 there are thousand repetitions, the equivalent number is F so the total number of equivalent axle load factors can be Fn summation where m is the number of axle load groups, Fi is the equivalent axle load factor for the ith-axle load group, ni is the number of applications of the ith group during the design period.

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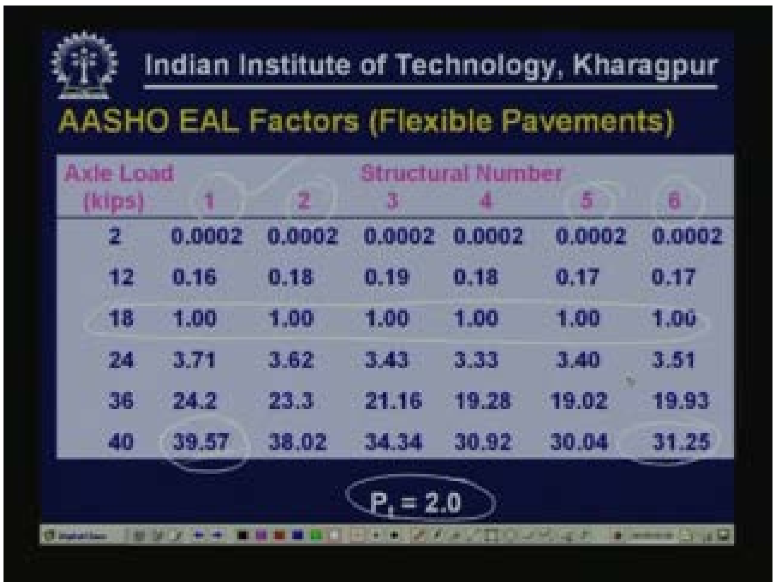

Axle Load (kips)	Structural Number 1	2	3	4	5	6
2	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
12	0.16	0.18	0.19	0.18	0.17	0.17
18	1.00	1.00	1.00	1.00	1.00	1.00
24	3.71	3.62	3.43	3.33	3.40	3.51
36	24.2	23.3	21.16	19.28	19.02	19.93
40	39.57	38.02	34.34	30.92	30.04	31.25

These are the typical values of axle load factors or equivalent axle load factors that are given for flexible pavements. As you can see there are different values of equivalent axle load factors available for different structural numbers. This table is used for a terminal serviceability value Pt of 2.0. We’ll have similar tables available in AASHTO guidelines for different serviceability indices rather different terminal serviceability values of 2.5, 3, 1.5 etc.

So, as you can see here obviously for 18 kip axle load irrespective of structural number of the pavement the structural number of the pavement indicates the strength of the pavement so obviously the equivalent axle load factor is 1 because we are comparing with 18 kip axle load.
If you look at 40 kip axle load that compared to an 18 kip axle load for a weak pavement, one structural number indicates weak pavement so the equivalent factor is about 39.57 that means one 40 kip axle load is approximately equal to about 40 standard axle load for a pavement having structural number of 1 if the terminal serviceability index that is considered is about 2.

Same axle load if you consider a stronger pavement the corresponding equivalence factor is significantly reduced. We will have several other tables which give us equivalence factor for concrete pavement and also flexible pavement for different terminal serviceability values, for different structural numbers and also for different thicknesses of concrete slab in the case of concrete pavement.

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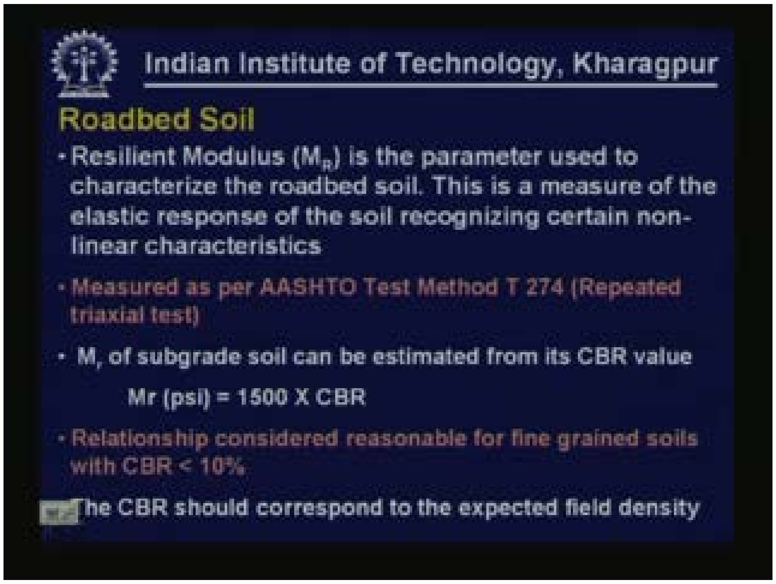

The roadbed soil that is the foundation or subgrade is represented by the resilient modulus value of the soil. The resilient modulus value is a measure of the elastic response of the soil recognizing certain non-linear characteristics. We have already discussed earlier a few times in the preceding lessons that resilient modulus value can be obtained by conducting repeated triaxial test on the soil sample. The test has to be conducted under certain specified stress conditions of deviator stress and confining stress.

Therefore AASHTO suggests things like what are the stress conditions to be adapted, how the test has to be performed for evaluating the resilient modulus value of the parameter of the subgrade soil. So this can be measured as per AASHTO test method T 274 repeated triaxial test procedure. Alternatively Mr of the subgrade soil can be estimated from its CBR value. This is what has been suggested by IRC: 37 – 2001 also.

If repeated triaxial test cannot be done the modulus value can be estimated from subgrade CBR value as 10 CBR or 17.6 CBR, 3 power 0.64 so this is what we had seen in the previous lesson. We have a similar expression here where resilient modulus value or subgrade soil can be estimated from its CBR value given as Mr in terms of psi = 1500 multiplied by CBR. This is exactly the same equation as Mr = 10 CBR where Mr is an Mpa.

As described in AASHTO guideline the relationship is considered reasonable for fine grained soils with CBR less than 10%. The CBR should correspond to the expected field density. The specimen should not be prepared to any density or it should not be standard density, this is the density that can be expected in the field. If it is an existing pavement the specimen should be prepared corresponding to the density that exists in the field. Or if it is a new pavement also then taking into consideration the tolerances that are there like whatever density that can be attained or whatever density that is permitted that is the lowest value this specimen has to be prepared corresponding to that density.

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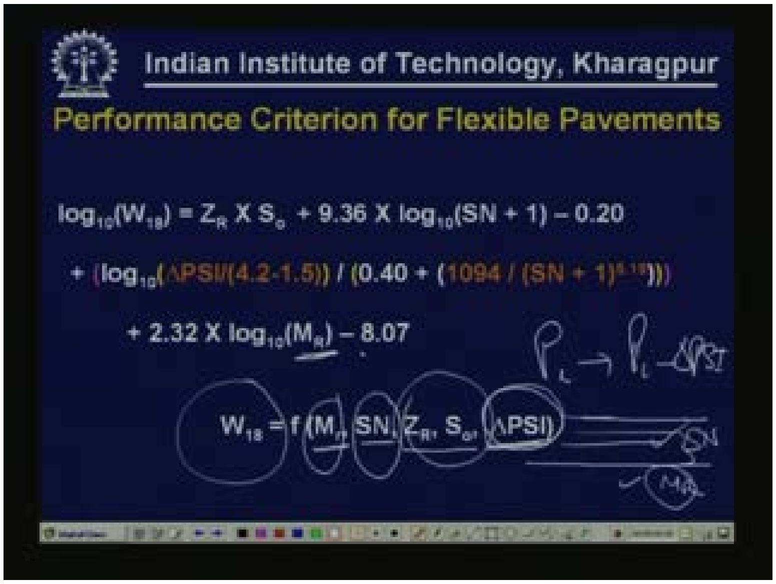

This is the performance criteria used in AASHTO flexible pavement design.

This is the equation that correlates log W_{18} to various pavement parameters and other parameters, we'll discuss these parameters. W_{18} is the numbers of repetitions of load that a given pavement is capable of serving satisfactorily during its service life period provided the pavements specified in terms as given here is provided.

W_{18} is a function of, as you can see here the resilient modulus value of the subgrade structural number is the strength of the pavement that is provided. So number of repetitions a given payment can handle is obviously a function of the subgrade strength and the structural number which represents the strength of this pavement, and Z_R and S_o are two parameters that take into consideration the reliability levels that are required, take into consideration the variability that is going to be there in the materials that we use, in the estimation of different parameters and also in the uncertainty that is built into the equation in terms of how well we are able to predict the performance if you know all the other parameters. So the variability that is going to be there in terms of traffic estimation, in terms of material availability, in terms of variations and construction practices to take into account all those things and to provide designs on the basis of reliability that is required these two parameters are built into the system.

W_{18} is the number of repetitions that will be handled by the pavement having this Mr and the structural number with these reliability parameters. So the serviceability will be reduced from an initial value of Pi to a value given as (Refer Slide Time: 38:41). So this is the magnitude of loss in serviceability when the pavement is subjected to W_{18} repetitions of standard axle load, when the pavement is built over a subgrade having Mr strength and when the pavement itself has got a strength represented by SN. Therefore for a given pavement the pavement is completely described by the Mr value of the foundation and the structural number of the pavement and this is the loss in serviceability that is going to be there so W_{18} is the corresponding number of load repetitions that can be handled by the pavement satisfactorily.

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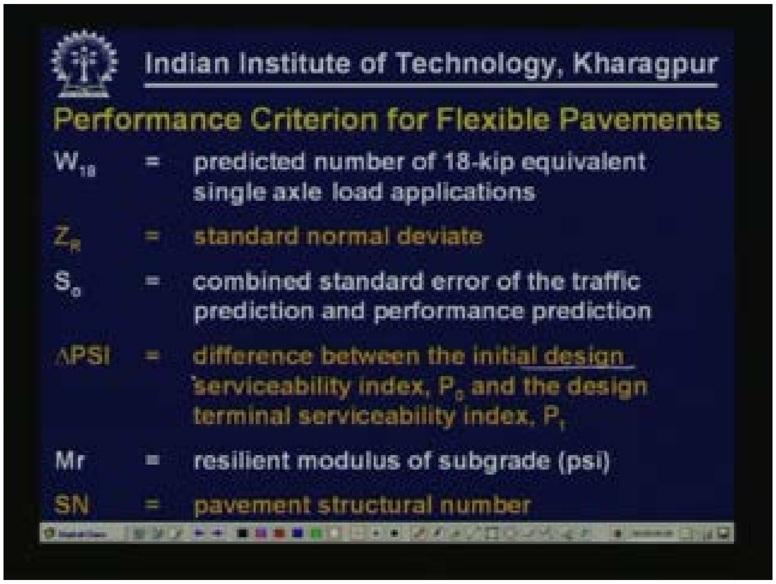

To describe briefly the parameters that are used W_{18} is the predicted number of 18 kip equivalent single axle load repetitions. This is the number of repetitions for which the pavement is being designed. Z_R is a standard normal deviate. We can select the value of the standard normal deviate correspondent to the level of reliability that we want to have like 99%, 95%, 85% these are the standard values and the corresponding standard normal deviate can be selected. And S_o is the combined standard error of estimation of the traffic prediction and performance prediction. It is because there is variability in predicting the traffic accurately in W_{18} itself and also in predicting the performance.

Once we have the parameters how well we can predict the performance, there is variability in that, there is uncertainty in that and so on. Therefore to represent the combined variability or uncertainty in the estimation of both these parameters Sy is the term that is used**.** Thus reliability concepts have to be used in estimating S_o value for a given set of system, for a type of construction the quality control measures that are there like how variability is and it also depends upon what is the extent of the data that we have on the basis of which we have estimated W_{18}, what is the level of data that we have and so on.

Thus taking into consideration all these parameters S_o can be estimated however AASHTO provides us typical values of S_o for use. Delta PSI is the difference between the initial design serviceability index P original or you can call it as P initial Pi and the design terminal serviceability index. We are calling both these terms as design because this is what we expect when we follow certain new materials and follow certain construction practice. We expect that the initial serviceability index is going to be 4.2, 4.3 depending on the practices that we adopt.

Similarly we are designing the pavement so that its terminal serviceability index at the end of 10 years at the end of 50 million standard axles, 60 million standard axles is going to be either 2.5 to we are selecting them, that’s why it is a design terminal serviceability index.

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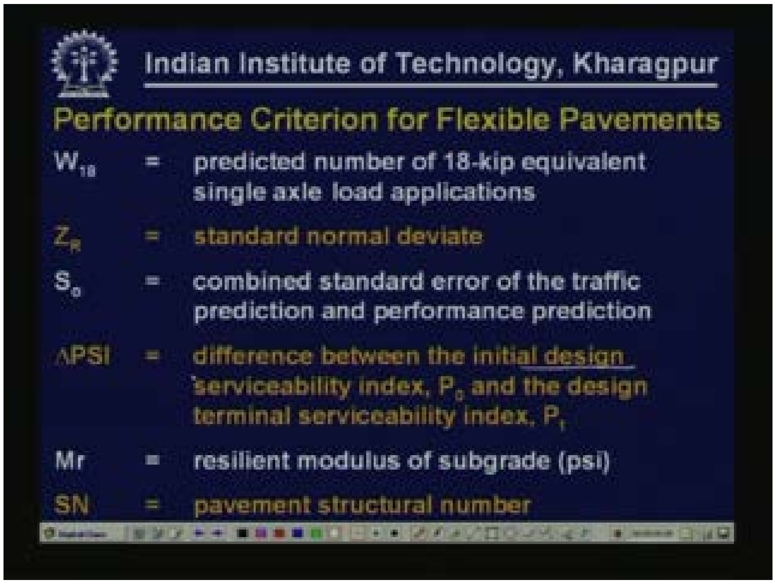

Similarly the other parameters that are used in the performance equation is Mr which is the resilient modulus value of the subgrade and the structural number SN which is the pavement structural number.

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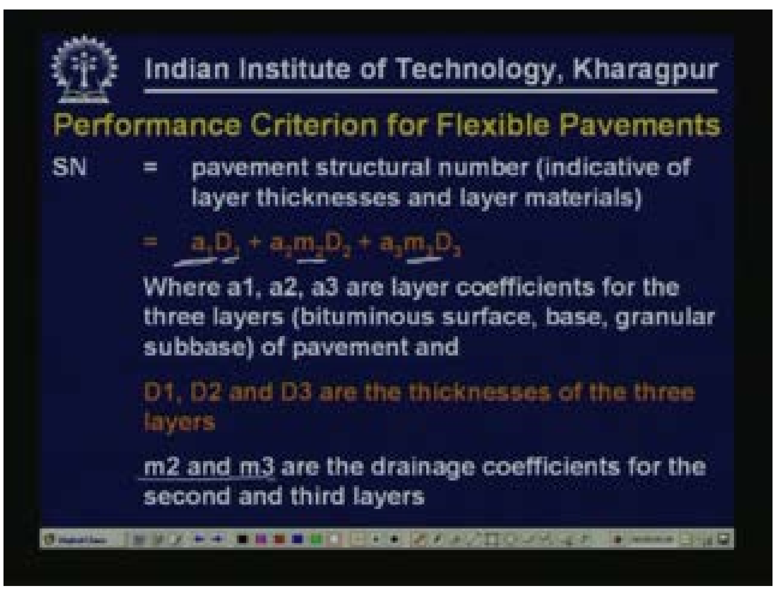

As I mentioned earlier SN is a single index that indicates the strength of the pavement. We know pavement consists of number of layers and what we are representing as pavement represents all those layers that are above the foundation. There can be three layers or four layers, it can be having different kinds of materials and these materials may be affected by different climatic conditions in a different manner so taking into consideration all those things one single parameter or one single value has to be evolved to represent all these layers. So pavement structural number is indicative of the layer thicknesses and also the materials that are used in the layers. This is given as the summation of the layer coefficient and thickness of each layer.

That is, if you consider a typical three layered system rather four layered system the fourth layer being the subgrade so above the subgrade if you consider that there are three layers with top layer being typically bituminous surface layer, second layer and third layers being granular base, granular subbase so if you have granular base and granular subbase and bituminous surfacing layer typically this is how we estimate structural number; SN = a1 d1 + a2 m2 d2 + a3 m3 D3. Here A1 A2 A3 are layer coefficients which represent the material that is used which represent the contribution of the individual layers to the pavement performance. D1, D2, D3 are the thicknesses of the three layers that is the top layer, next layer and next layer. We see there are m2, m3 parameters build into the system only for the second and third layer if it is granular base and granular subbase.

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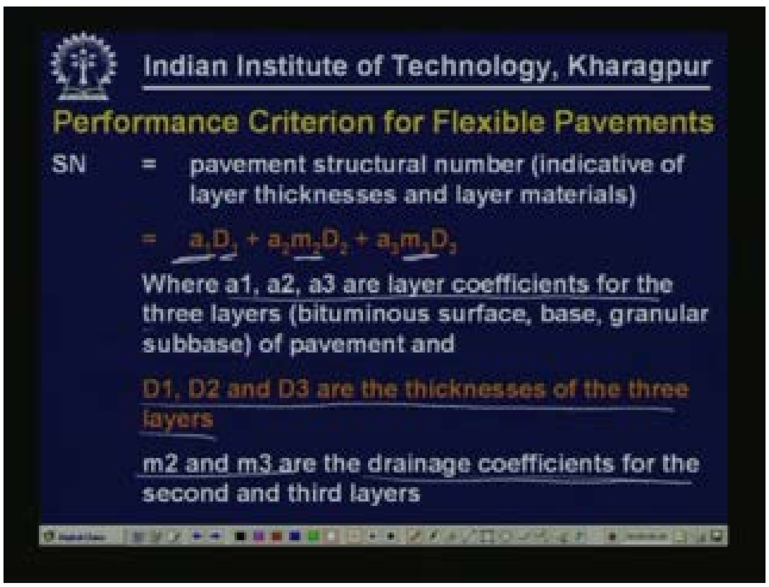

You can have a look at this equation; so granular base and granular subbase has got m2 and m3 parameters. As shown here these are drainage coefficients for the second and third layers. D1, D2, D3 are the thickness of the three layers, a1, a2, a3 are layer coefficients for the three layers namely bituminous surface, base, granular subbase of the pavement. So to assess what is the structural number of the pavement we should be able to select D1, D2, D3 thicknesses we should also be able to select the layer coefficients for the materials that we are using a1, a2, a3 and we should also be able to select the drainage coefficients m2 and m3.

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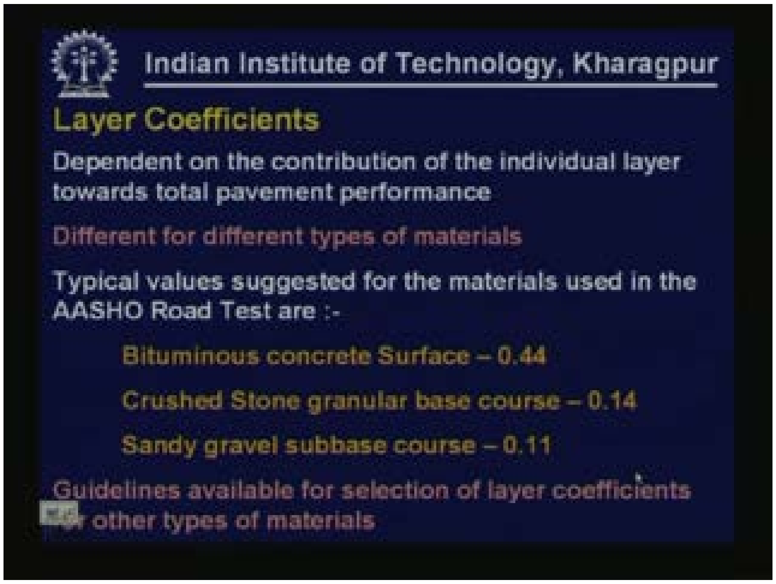

The layer coefficients depend on the contribution of the individual layer towards total pavement performance. They will be different for different types of materials. Typical values suggested for materials used in the AASHO road test in the early 1950s are bituminous concrete 0.44, crushed stone granular base 0.14, sandy gravel subbase course 0.11. There are guidelines available for selection of layer coefficients for other types of materials also.

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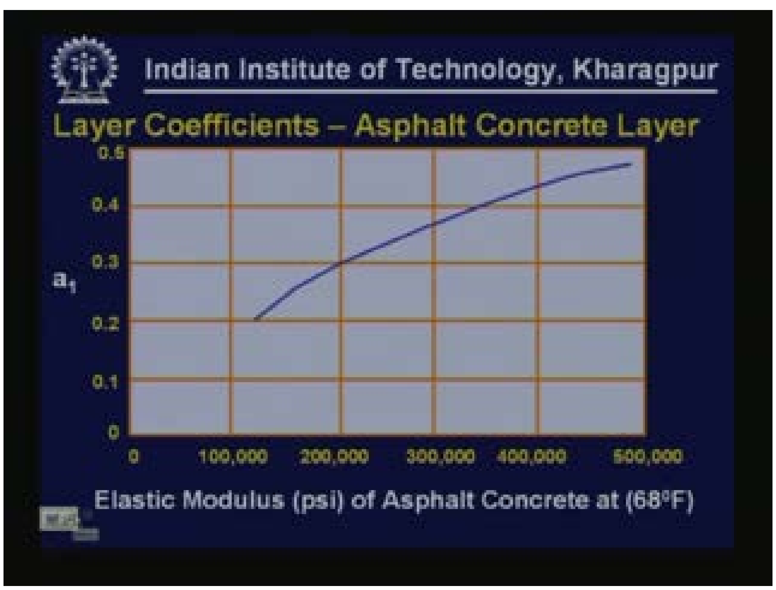

For example, if we are trying to select layer coefficient for the Asphalt concrete layer if you know the modulus value of Asphalt concrete at 68 degrees Fahrenheit temperature we can select the corresponding layer coefficient for this. So what we need to know is the elastic modulus value at 68 degrees Fahrenheit temperature.

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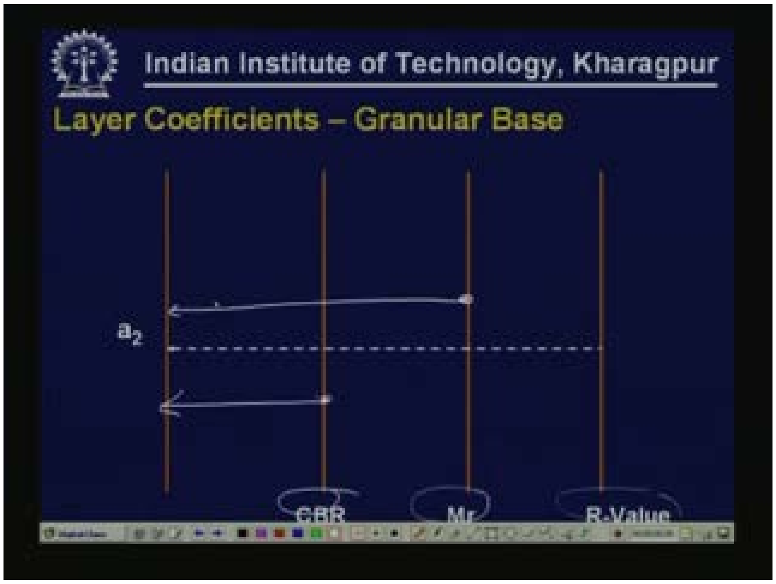

Similarly for a2 if you know any of these parameters like the granular base that is CBR resilient modulus value or any other parameter like R value or any other parameter then we can estimate the corresponding; for a given CBR value we can find out what is a2, for a given Mr value what is a2 so the material has to be tested first for either Mr or CBR or other parameters using which we can estimate a2. So these are nomograph that are available using which we can estimate the layer coefficients for different types of materials.

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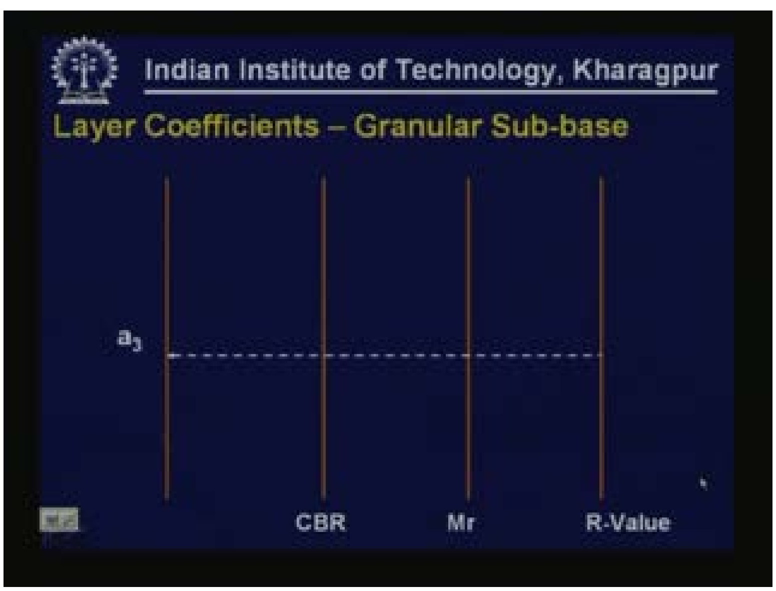

This nomograph indicates how one can estimate layer coefficient for granular surface again on the basis of CBR, Mr and R value.

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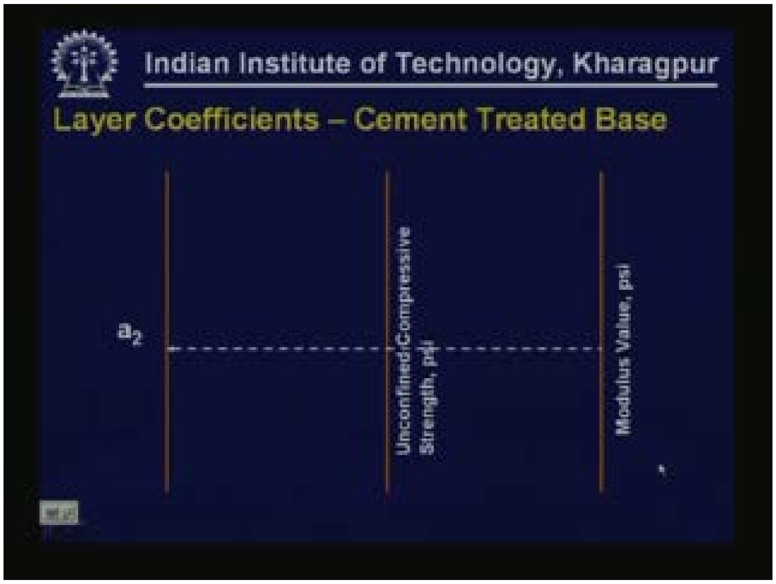

Similarly layer coefficients estimation can be done on the basis of unconfined compressive strength or the modulus value of cement treated base.

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For bitumen treated base if you know the Marshal Stability you can estimate a2 or if you know the modulus value then we can estimate a2.

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The drainage coefficient depend on the quality of drainage facility and also the percentage of time during the year the pavement structure would normally be exposed to moisture levels approaching saturation which depends on average rainfall and prevailing drainage conditions. While selecting drainage coefficients what we are normally concerned about is the effect of moisture on granular subbase and granular base, how long these subbases and bases are going to be under saturated conditions and how good is the drainage in general, whether the water is going to be immediately removed or is it going to be there for about 20% of time or 30% of time so if you know about these conditions we can select the drainage coefficients.

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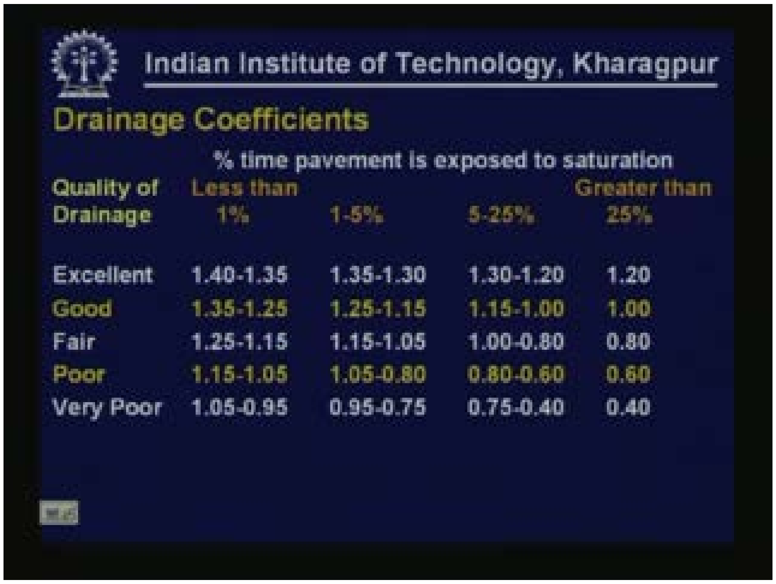

As given from these guidelines you can see; if we rate the quality of drainage, very good drainage facilities are provided, excellent drainage facilities are available, the water that goes into the pavement system can be removed quickly so depending on the measures that we take we can rate this as excellent, good, fair, poor, and so on.

And also on the basis of time for which the pavement is likely to be saturated where the granular base and granular subbases are likely to be saturated the corresponding drainage coefficients can be selected. So we have to have some idea of about what is the quality of drainage facility that is going to be provided and how long these layers are likely to be under saturated condition during the year.

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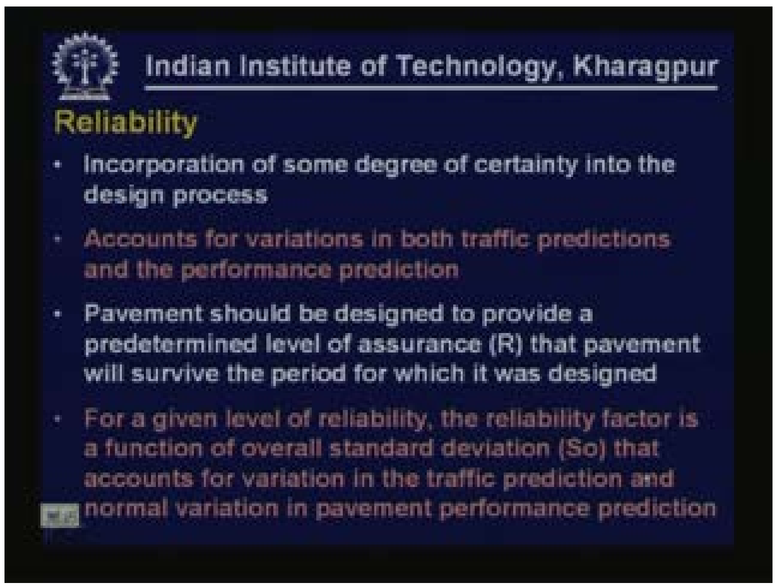

Reliability is another concept that is incorporated to have some degree of certainty into the design process. This accounts for variations in both traffic predictions and the performance predictions, this we discussed earlier.

The pavement should be designed to provide a predetermined level of assurance (R) reliability and that pavement will survive the period for which it was designed. So before designing itself we are going to state that I am going to design this pavement so that with 95% confidence we can say that this pavement is going to last. For a given level of reliability the reliability factor is a function of overall standard deviation S_o that accounts for variation in the traffic production and normal variation in pavement performance prediction.

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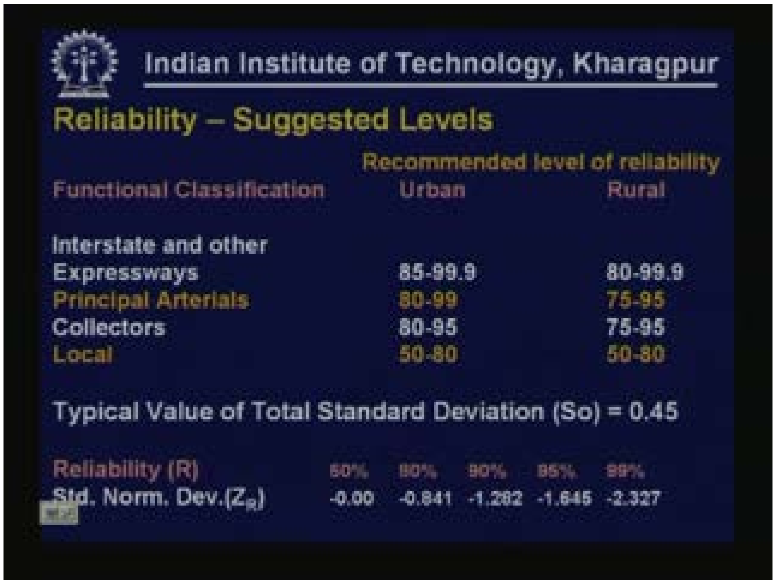

Normal reliability levels that are suggested are; depending on the type of pavement different levels of reliability are suggested. Obviously for express ways high levels are reliability, for local roads low levels are reliability. The standard normal deviates that are used for different levels of reliability are; for 99% it is – 2.327, for 95% it is – 1.645 so these are standard values depending on normal distribution.

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So the design inputs that are used for designing pavements are; we have to have information on traffic, we have to select the reliability level, we have to estimate or take the values from the guidelines about total standard deviation, we also have to select an initial PSI depending on the type of construction, type of materials, we also have to select terminal PSI value depending on the high volume road low volume road so accordingly we will have to select the terminal serviceability index value Pt 1.5 to 2.5, we also have to select pavement layer type and material properties, drainage conditions and have knowledge about resilient modulus value of subgrade and then we have to solve the performance equation of structural number.

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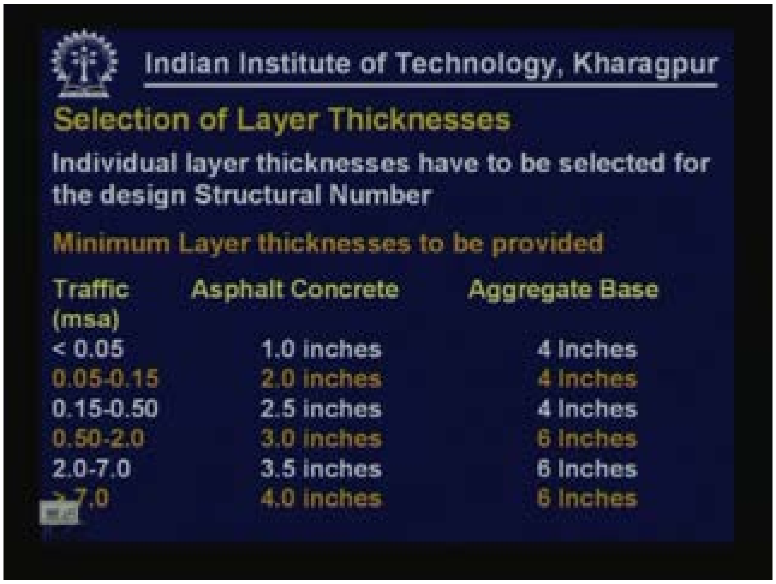

We have to put all these inputs in the performance equation W_{18} equal to as a function of all the parameters that were given earlier and putting all these parameter there we can work out the structural number from that equation. So what we get is the structural number from that equation and that has to be split into different layer thicknesses and different material properties.

Therefore individual layer thicknesses have to be selected for the designed structural number. minimum layer thicknesses to be provided are; for different traffic levels the corresponding minimum thicknesses to be provided would be, if you are providing Asphalt concrete surfacing and aggregate base then for Asphalt concrete what are the minimum thicknesses for different traffic levels and for aggregate base what is the minimum thickness for different types for different levels of traffic are indicated here.

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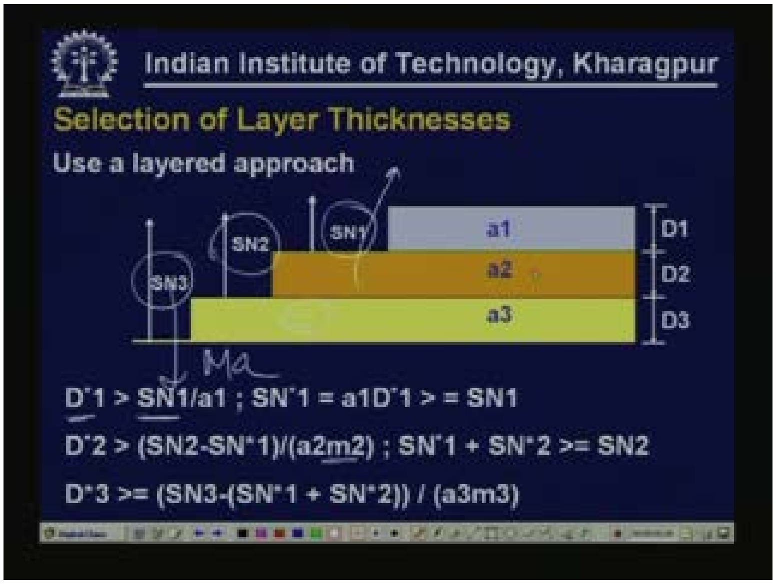

We can use the layered approach to determine what should be the thickness of each individual layer. What is shown here is if you can estimate the structural number required above subgrade this can be estimated by knowing the Mr value of the subgrade. Similarly if you can assign elastic modulus value to the subbase so putting that value in the equation we can get SN2.

Similarly if you can get some modulus value to the base layer also putting that again in the equation you can get the structural number SN1. So if you have already selected layer coefficients for the material that we have used a1 a2 a3 then D1 can be estimated as SN1, SN1 is the structural number to be provided on layer two so SN1 divided by a1 can be obtained, SN1 actually provided is a1 into D star 1 so this should be greater than or equal to SN1.

Similarly D2 star has to be greater than SN2 – SN1 that is already provided divided by a2 the layer coefficient for second layer and we may use drainage coefficient for the second layer also. So SN1 star + SN2 star that is actually provided has to be greater than SN2 that is required. Similarly D star 3 also can be obtained as greater than or equal to SN3 – SN1 star + SN2 star that is already provided divided by a3 m3.

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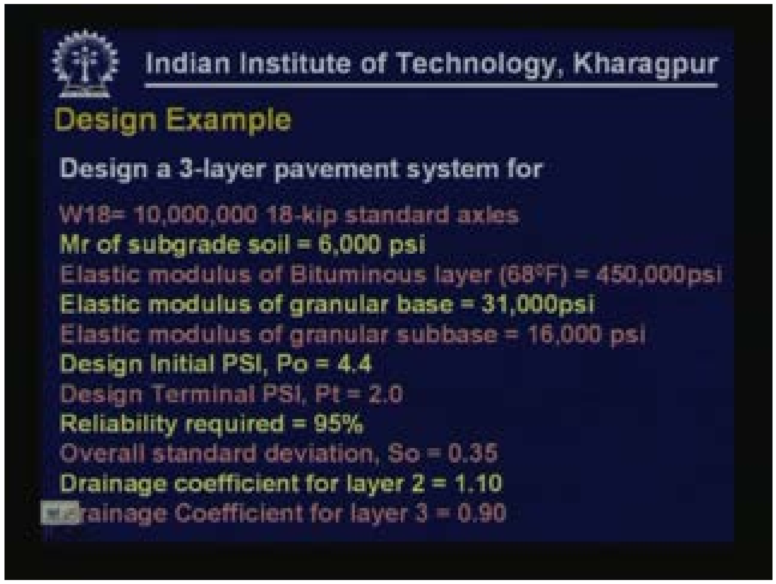

I have given a design example here, you can see this data here; W_{18} is 10 million standard axles, we are trying to design a three-layered pavement, Mr is 6000 psi, elastic modulus of bituminous layer at 68 degree Fahrenheit is 450,000 psi, elastic modulus value of granular base is 31,000, subbase 16,000, design initial PSI is 4.4, design terminal PSI is 2, reliability required is 95%, overall standard deviation is 0.35, drainage coefficient for layer two is 1.1, and drainage coefficient for layer three is 0.90.

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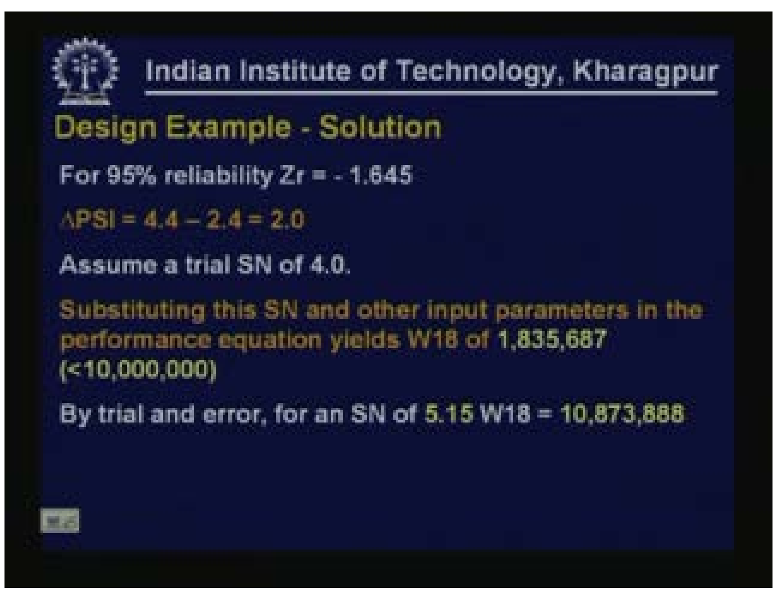

For 95% reliability Z_R value is 1.645, delta PSI is 4.4 – 2.4 = 2. Assuming a trail structural number of 4 substituting this in the performance equation W_{18} left hand side works out to be about 1 million which is much less than 10 million. So by trial and error by varying the structural number value the structural number of 5.15 gives a W_{18} value of about 10.874 millions. So we consider this to be approximately satisfactory for our condition so we are going to provide a structural number of 5.15.

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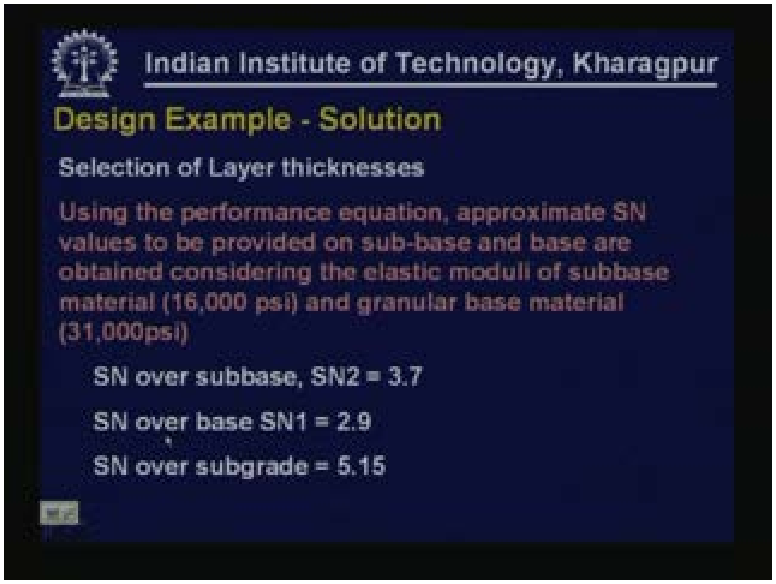

So the structural number corresponding to each individual layer can also be selected by using the appropriate modulus values for each layer. We have already done the subgrade and the structural number required is 5.15. By selecting the modulus value for subbase putting that in the equation you can get the structural number required that is 3.7. Similarly by putting the modulus value of granular base in the equation you can get the structural number of 2.9 as indicated here.

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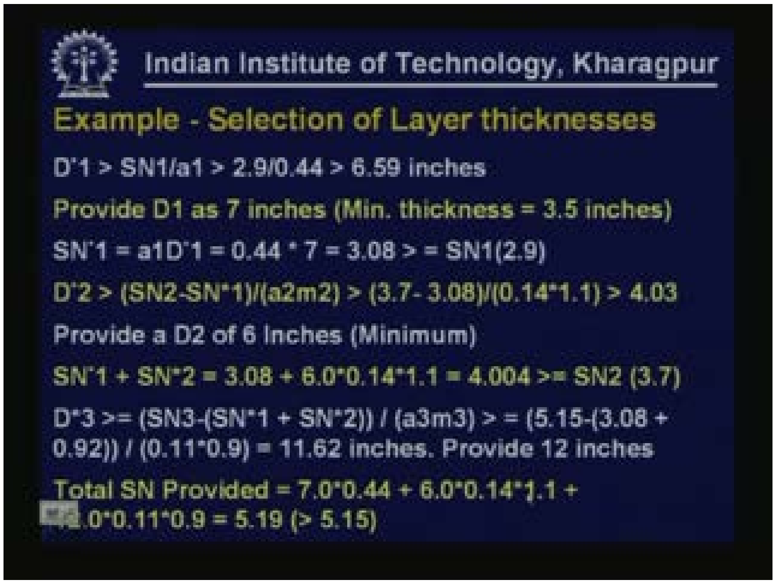

So this is how we can work out individual layer thicknesses as we have explained in the procedure in the previous slide. You can see the calculations here.

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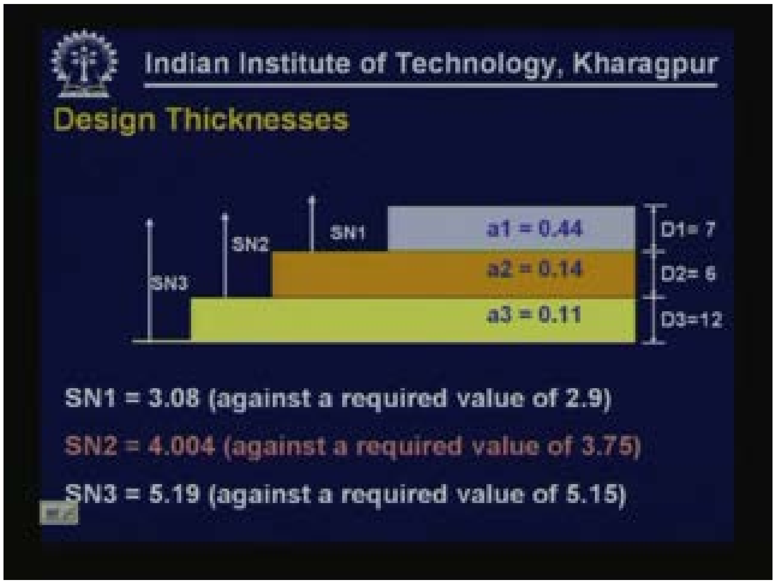

These are the final thicknesses that were obtained for each layer. Top layer works out to be seven inches, second layer six inches, third layer twelve inches and the layer coefficients for the modulus values that we have; a1 is 0.44, a2 is 0.14, a3 is 0.11. We can check this structural number that is provided; SN1 is 3.08 that is 0.44 into 7 against a required value of 2.9, SN2 is 4.004.14 into 6 + 0.44 into 7 against a required value of 3.75, SN3 is 5.19 0.44 into 7 + 0.14 into 6 into m2 + 0.11 into 12 into m3 this is against a required value of 0.15.

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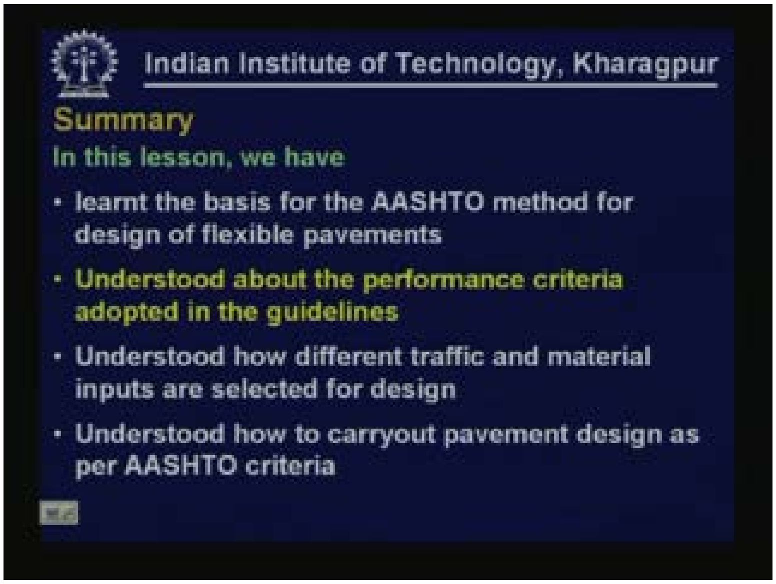

To summarize; in this lesson we have learnt the basis of AASHTO method for design of flexible pavements. We understood about the performance criteria adopted in AASHTO guidelines. We also understood how different traffic and material inputs are selected for design. We have understood how to carryout pavement designs as per AASHTO criteria.

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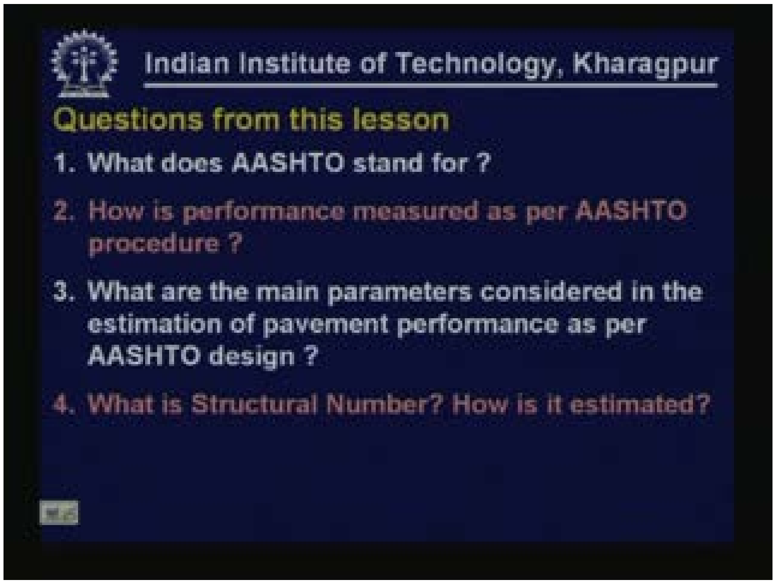

These are the questions from this lesson. Answers for these questions will be provided in the next lesson.

1) What does AASHTO stand for?

2) How is performance measured as per AASHTO Procedure?
3) What are the main parameters considered in the estimation of pavement performance as per AASHTO Design?
4) What is structural number how is it estimated?

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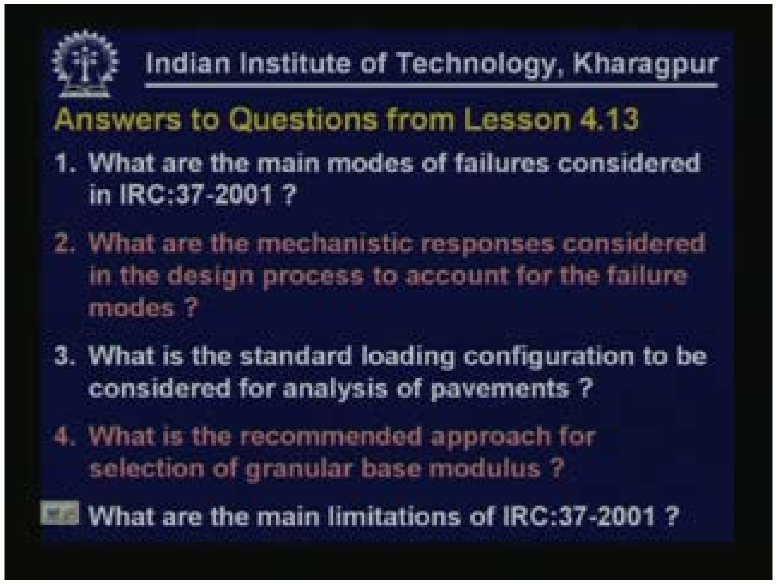

Let us see the answers for the questions that were asked in lesson 4.13.

1) What are the main modes of failures considered in IRC: 37 – 2001?
In fact three modes of failures are considered. One is rutting due to permanent deformation occurring in subgrade, rutting due to permanent deformation occurring in bituminous layer and fatigue cracking occurring in bituminous layer. However, there are only two criteria provided for rutting occurring due to permanent deformation subgrade and fatigue cracking of bituminous layers.

What are the mechanistic responses considered in the design process to account for the failure modes?
There are two important failure modes; fatigue cracking and rutting. for fatigue cracking horizontal tensile strain in the bituminous layer is considered to be the important parameter to explain fatigue cracking. Vertical compressive strain on top of subgrade is considered to be important for explaining fatigue behavior.

What is the standard loading configuration to be considered for analysis of pavements?
We have to apply standard axle load that is 18 kip 18 kilo Newton load at 0.56 tire pressure circular contact areas but we normally consider only one set of dual wheels so
20 Kilo Newton 20 Kilo Newton with center to center spacing of 310 mm, 0.56 Mpa and then circular contact area.

What is the recommended approach for selection of granular base modulus?

Granular base modulus value can be estimated using the Shell equation which is given as granular base modulus value equivalent to subgrade modulus value into 0.2 times h to the power 0.45 where h is the thickness of the granular base expressed in millimeters and granular base modulus value is expressed in terms of Mpa.

The next question is what are the main limitations of IRC: 37 – 2001?
The main limitations of IRC: 37 are in terms of the use of the charge which is meant for only 35 degree centigrade, which will give you thickness in terms of DBM only which will also give you only thicknesses for 60/70 binder and limited CBR range and also limited traffic range, thank you.