Introduction to Transportation Engineering
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Lecture - 40
Pavement Evaluation and Rehabilitation

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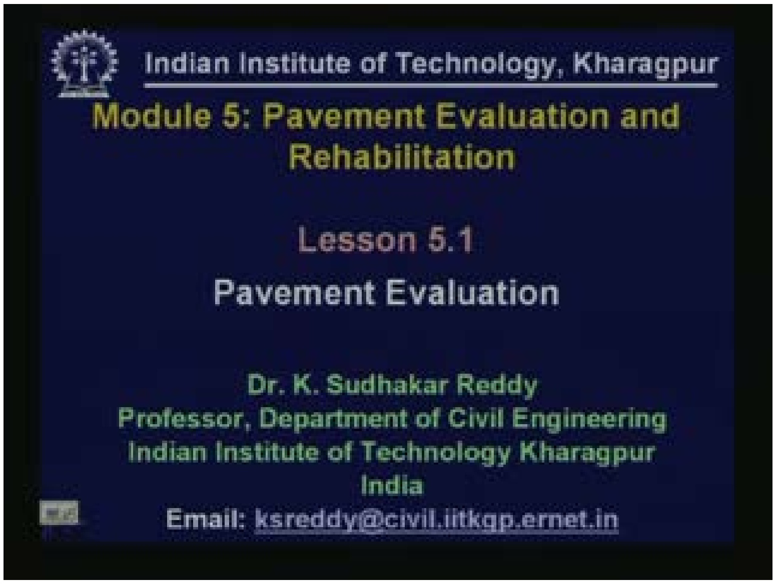

Hello viewers with this lesson we are starting a new module, module V which is on pavement evaluation and rehabilitation. This module will be very short and will comprise only two lessons. The first lesson 5.1 is on pavement evaluation.

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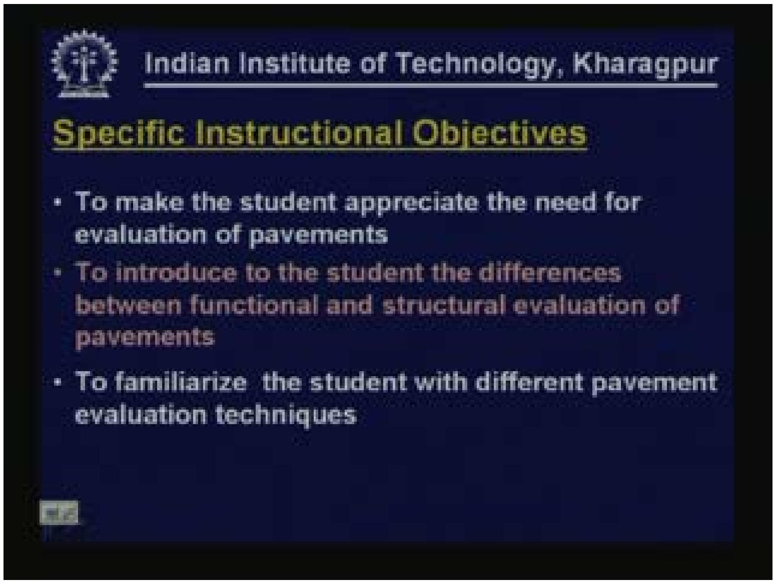

The specific objectives of this lesson will be to make the student appreciate the need for evaluation of pavements and to introduce to the students the differences between functional and structural evaluation of pavements and also to familiarize the student with different pavement evaluation techniques.

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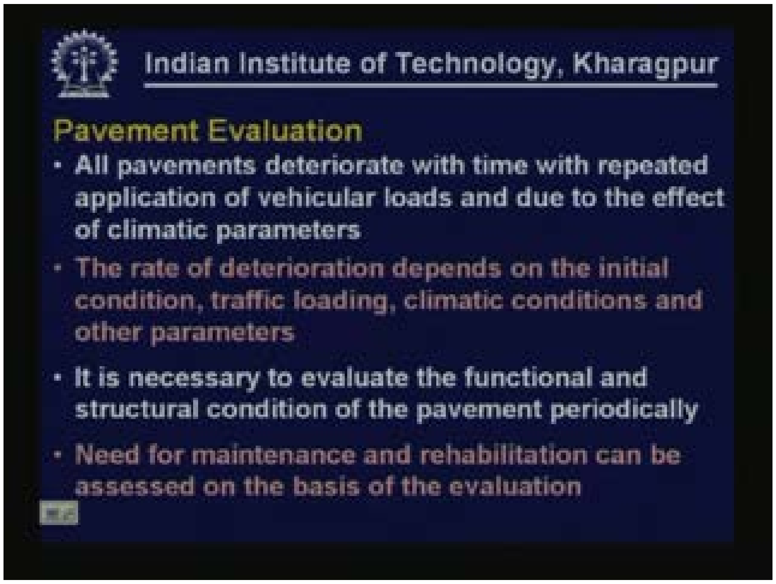

Any structure that is built will deteriorate with time when it is subjected to loads and various climatic factors so all structures including pavements will deteriorate with time. So it is necessary that these structures for example in our case pavements have to be evaluated occasionally, periodically to assess their structural condition and also to assess the remaining life of the pavement and how much more time the pavement can serve the users satisfactorily. So for that one should have appropriate tools to evaluate existing pavements collect some data, collect some information and one should be able to interpret the data that is obtained and make right decisions in terms of the condition of the existence pavement and what is to be done with the existing pavement if its life has to be extended by a given number of years.

As you can see here all pavements deteriorate with time with repeated application of vehicular loads and due to the effect of climatic parameters. The rate of deterioration depends on the initial condition of the pavement, the rate of traffic loading, the magnitude of traffic loading, climatic conditions and various other parameters.

In fact the rate of deterioration would depend if you recollect the AASHTO equation either for concrete pavements or for flexible pavement you can see the number of load repetitions a pavement can satisfactorily serve is a function of various parameters like pavement related, reliability related, structure related and various other factors. So to properly explain the performance of a pavement like how long it's going to last, what is going to be the condition of the pavement after certain number of years at a given part of time, if it starts with an initial condition then it requires lot of input.

It is also necessary to evaluate the functional and structural condition of the pavement periodically. As I just indicated we should be able to assess the structural condition and functional condition of the pavement periodically and decide whether the pavements require any maintenance, major rehabilitation or even reconstruction. Need for maintenance and rehabilitation can be assessed on the basis of the evaluation that we carry out.

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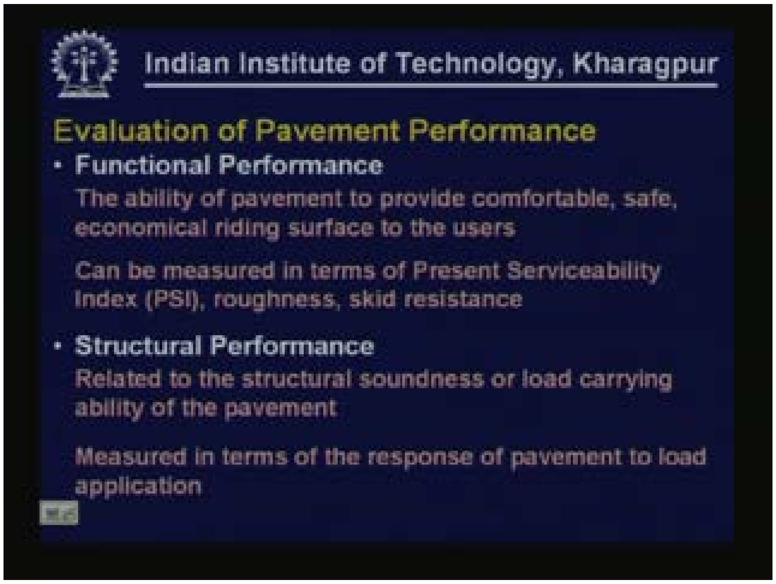

Pavements are evaluated typically for two types of performance; one is functional performance and the other one is structural performance.

Functional performance is the ability of the pavement to provide comfortable, safe, economical riding surface to the users. That basically is a function of the pavement as far as the user is concerned, user requires safe and comfortable ride. As long as the pavement is in a position to give satisfactory service to the road user in terms of safe comfortable ride the pavement continues to be in a functionally acceptable condition.

The functional performance can be expressed or measured or quantified in terms of either the present serviceability index, the index that we discussed in the case of AASHTO pavement design or in terms of roughness or in terms of skid resistance or any other parameter that is related to the surface that could be related to the safety and comfort of the road users. On the other hand structural performance is related to the structural soundness of the structure or the load carrying ability of the structure. This can be measured normally in terms of the response of the pavement when it is subjected to a load. Normally structural performance will be expressed in terms of structural response of the pavement.

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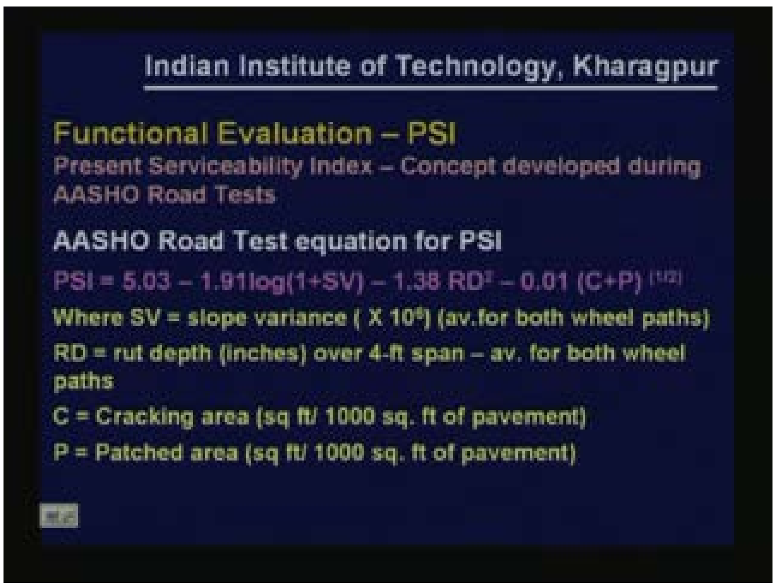

As we already discussed in the previous lessons functional evaluation can be done in terms of present serviceability index. This is one of the commonly used parameters though not commonly used in India because AASHTO is not that extensively used in India. So, for evaluation of functional performance of the pavement present serviceability index is the parameter that is normally evaluated. We also know that this is a concept that has been developed during the AASHTO road test.

The AASHO test equation for present serviceability index correlates the present serviceability index with the surface characteristics of the pavement such as slope variance which gives an indication of the variance of the surface profile in the longitudinal direction and rut depth for a flexible pavement and for concrete pavement both for cracking area and patched area expressed in terms of square feet for thousand square feet of paved area.

Similarly patching also is expressed in terms of square feet per thousand square feet of paved area. thus as we can see in the case of flexible pavements present serviceability index is mainly in terms of what can be measured in terms of the surface characteristics like surface profile, rut depth, cracking and patching is what you can observe on the pavement surface.

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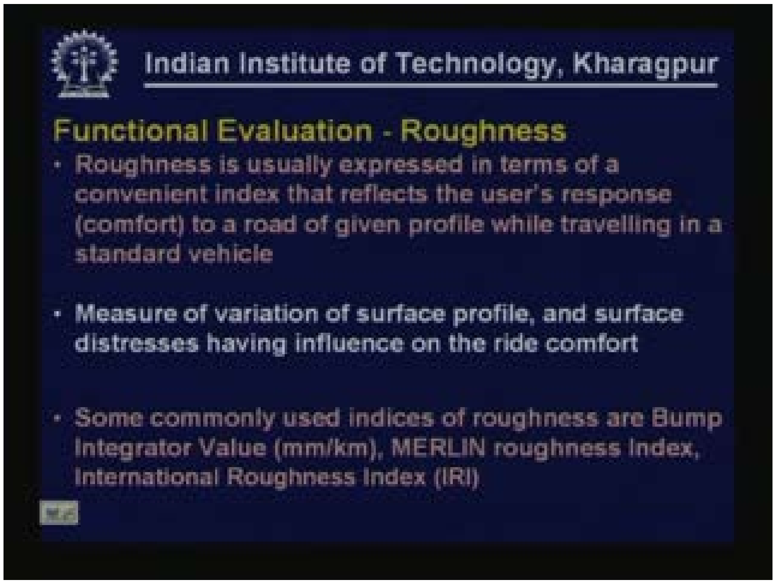

Another parameter that is most commonly used to evaluate the functional performance is the roughness, how rough the road is. Roughness is usually expressed in terms of the convenient index. In fact various types of indices are used to express roughness. So this is a convenient index that reflects the user's response to a road of a given profile while traveling in a standard vehicle. That means how the user perceives the comfort level that is offered by a given road having certain profile characteristics and various other surface conditions so that is expressed in terms of roughness index. All the roughness indices that are used by various agencies are developed in such a way that they are sensitive to the road user and the users perception to the surface conditions in terms of the comfort that the road user is getting.

Roughness is the measure of variation of surface profile and other surface distresses that may have some influence on the ride comfort. Hence roughness will be influenced by all those surface parameters that have some influence on the ride comfort. Some commonly used indices for roughness are bump integrator value, MERLIN roughness index and international roughness index, we will discuss them in detail later. We will basically be talking about these three main roughness parameters; bump integrator value, MERLIN roughness index and international roughness index.

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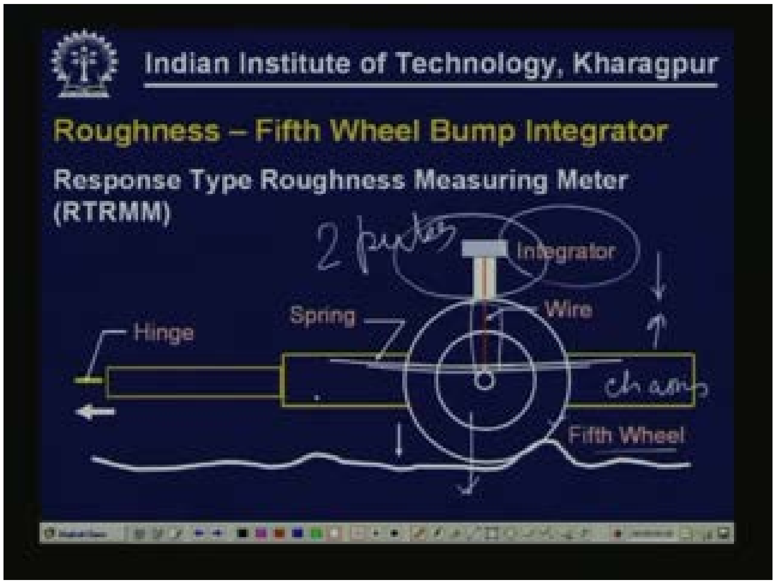

The roughness in terms of bump integrator value is normally measured using equipment called as fifth wheel bump integrator. This comes under the class of roughness meters known as response type roughness measuring meters. The roughness of the road can be obtained in terms of the surface profile.

One can measure the surface profile by taking levels by rod and level procedure and there are other equipments which give us indices that say something about the profile of the road. These indices also are expected to be giving some idea about the comfort that the road users get. But response type roughness measuring meters are those equipments which measure the response of a given mechanical system to a road having certain profile. So when this response equipment travels along a given road the equipment responds to the variations in the surface profile. This response is measured accumulated over distance and given as an index.

For example, in a fifth wheel bump integrator this is called as the fifth wheel because we have one single wheel here and having an arrangement of chassis and hinge arrangement so this has to be towed by another vehicle. So we will have another vehicle towing this fifth wheel and this is a single wheel so this vehicle will be towed by another vehicle whether the fifth wheel will be towed by another vehicle so that’s why this is called as a fifth wheel.

What we see here is basically this wheel known as fifth wheel and there is a chassis which is basically a heavy mass over which there is an integrator that is attached to this, (Refer Slide Time: 12:04) there are springs here, there will be suspension system, and what we actually measure is as the wheel moves along this road it goes up and down along the variation in the profile. So as this moves up and down the vertical stroke of the suspension system of this arrangement is measured. So as the suspension system gets the stroke by certain magnitude that triggers some pulses in this integrator. So a downward movement of let’s say 2 inches will trigger say two pulses in this integrator. That means if you see two pulses in this integrator it means that the bump integrator at this location has gone down by about 2 inches. So if it encounters another bump after some distance of 1 inch magnitude then it will add one more index to the counter. therefore this counter gets accumulated depending on the number of bumps of different magnitude that are encountered over some distance so all those bumps in terms of 1 inch multiples will be accumulated so over 5 km stretch or 10 km stretch we will find out how many total inches of bumps are there. But this has to be pulled at some constant speed and we also should be able to measure what is the distance covered by this bump integrator.

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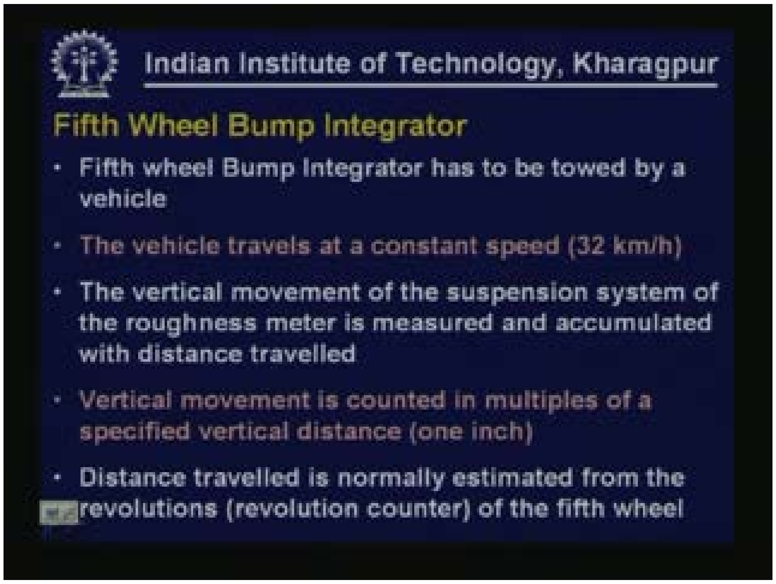

Therefore the fifth wheel bump integrator has to be towed by a vehicle so that's the reason why it is a fifth wheel. the vehicle travels at a constant speed typically the recommended speed is 32 km per hour because in the first slide I talked about the comfort level that is perceived by the user traveling in a standard vehicle. The vertical movement of the suspension system of the roughness meter is measured and accumulated with the distance traveled. So, what we are trying to measure is the accumulated vertical movement of the suspension system as the vehicle is traveling forward. The vertical movement is counted in multiples of a specified vertical distance. Typically the counters that are used in the fifth wheel bump integrator get triggered the value changes whenever there is at least 1 inch of downward movement. If there is a downward movement of 2 inches or three inches then the corresponding change in the counter reading will be 2 or 3. The distance traveled is normally estimated from the revolutions of the fifth wheel, there will be another counter normally to count how many revolutions the fifth wheel is rotating.

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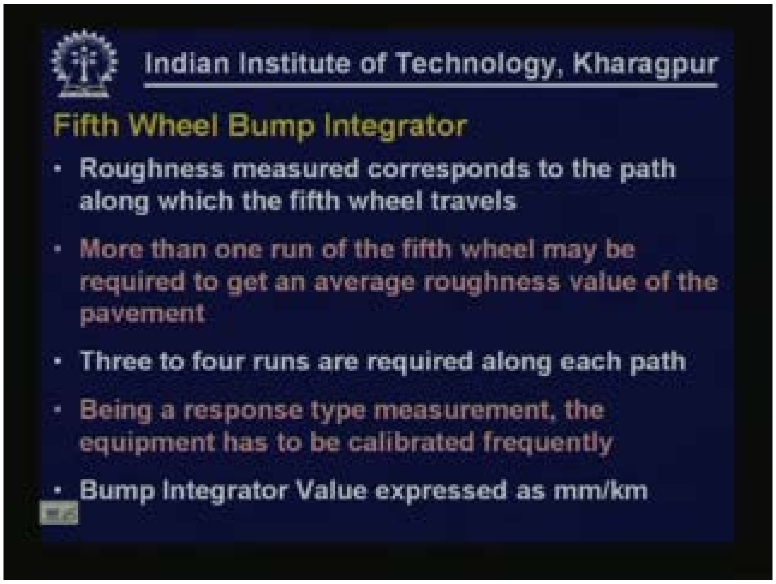

Roughness corresponds to the path along which the fifth wheel travels. The fifth wheel will be made to travel along one line. Obviously it cannot be represented to have the entire pavement section. Normally we try to make this fifth wheel travel along the wheel path. If you are interested in finding out the average roughness of the pavement we may have to make the fifth wheel travel along different longitudinal lines and take average of all those values. Along a given line also you may have to make the fifth wheel run, make a number of runs. For example three to four runs are normally required along each path and what we normally represent is the average of this three to four runs.

Being a response type measurement the equipment has to be calibrated frequently. Because if the vehicle is changed there will be parameters of the suspension system that are going to be changed so the value may be changing. Even if the vehicle is operated again you may get a different value, over time also even if the roughness of the road doesn't change the value may change.

If you use another similar response type equipment another fifth wheel bump integrator it may give you a different value. So it is necessary to calibrate the value that is obtained from a roughness measuring machine such as fifth wheel bump integrator which is a response type equipment this has to be calibrated so that we know what is the corresponding standard value that we are going to refer to. Bump integrator value is normally expressed as millimeters per kilometer. Millimeter is the vertical cumulative stroke of the suspension system of the fifth wheel bump integrator and kilo is expressed in terms of the total distance that is covered.

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Another simple equipment that we normally use for measuring roughness is the MERLIN equipment. MERLIN stands for Machine for Evaluating Roughness using Low cost Instrumentation MERLI and N also has to be there so it is IN. This is a very low cost equipment compared to all the other equipments that we use for measuring roughness such as the fifth wheel bump integrator and other equipments. It is simple to operate and this gives an index of the variation of the profile of the road along the path considered. That is what any roughness machine is trying to measure. This is slow so it is not suitable for evaluating long stretches. If you are trying to measure the roughness of a 100 km stretch obviously MERLIN is not the right equipment for that. We should be able to operate at higher speeds so we have to use something similar to the fifth wheel bump integrator which can be operated at some speed. Even 30 km is a slow speed but it is much faster than what we can achieve by a MERLIN machine.

However, this is often used for calibrating response type roughness measuring machines because the roughness that we measure using a MERLIN machine is not a response type. It is somewhat like an optional parameter. So this can be considered to be a standard measure of roughness for a given road which doesn't change so significantly with time if the same equipment is used as long as the machine is kept in a standard form format and then standard conditions are maintained so we are likely to get a more or less similar roughness value. That's why it is normally used to calibrate response type equipments.

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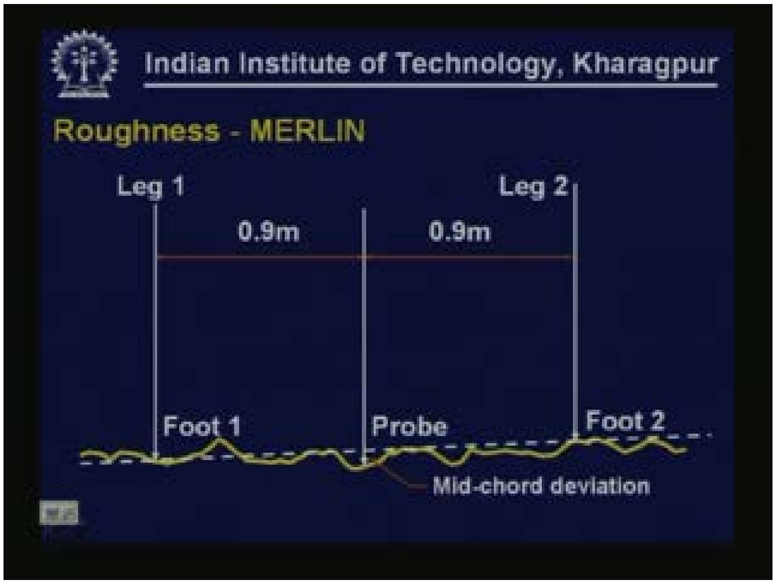

The principle of MERLIN is in this the MERLIN will have two legs; front leg and the rear leg resting their foot on the pavement surface. So, foot 1 and foot 2 will be resting on the pavement surface. There will be another probe which is placed in the middle which will also be resting on the pavement surface. If you connect the two points at which the foot one and foot two are resting on the pavement with reference to that the position of probe gives us what is known as mid chord deviation. Thus, if the midpoint is either above or below then accordingly we will get a mid chord deviation. If it is also exactly on the line correcting foot one and foot two points then there will not be any mid chord deviation. So the machine will be made to move along a given stretch of road at different positions. This particular diagram represents a particular position of the MERLIN on the given road. Hence for a given position we can get one mid chord deviation then for another position the mid chord deviation may be above the line or below the line. So accordingly we can get some idea about the variation with reference to these two points above the midpoint.

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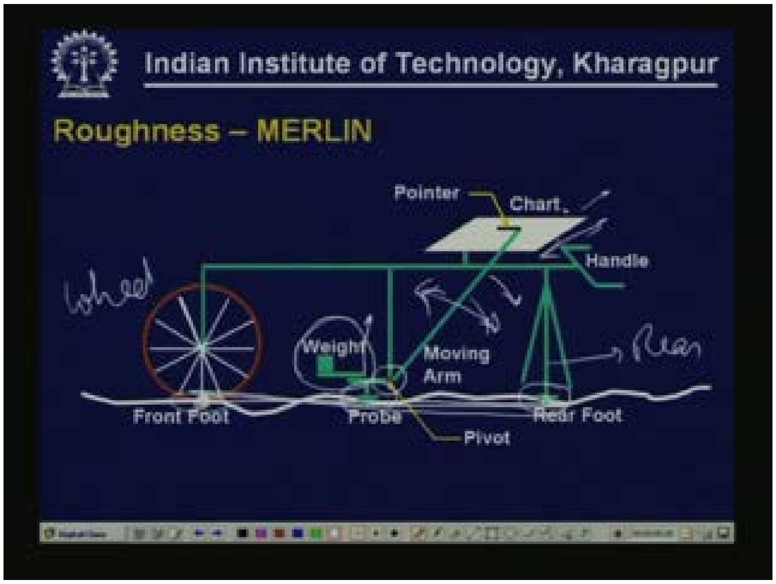

This is a diagrammatic arrangement of presentation of the MERLIN equipment. (Refer Slide Time: 20:46) this has got a wheel in the front and rear leg, this is the rear foot and the location at which it touches the pavement surface can be considered to be the front foot. So if you connect this point to this point so with reference to this the probe point is going to be somewhere here. There is a moving arm because there is a pivot here and hinge here and there is a counterbalancing weight arranged on the other side.

So at any given position this makes this probe touch the pavement surface. Thus along with this the moving arm also moves in this direction. At a given position the probe touches the pavement surface and that position is represented by the pointer which moves on the chart in this direction. If the probe goes out then this will be moving in this direction so corresponding to that the pointer will move in one direction. So depending up on the relative position of the probe with reference to this line the pointer is going to move on the chart. Therefore what is done is for each position of the MERLIN on the pavement the position of the pointer on the chart is noted. When the MERLIN is moved to a new position again the position of the probe and the corresponding position of the pointer on the chart is noted by marking a cross on the chart. This is what is done at each position of the MERLIN movement.

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This is a photograph of a MERLIN machine. As you can see this is a very simple apparatus. You can see the front wheel, you can see the rear leg, you can also see the counter weight here, this is the hinge part, you can see the counter here though it may not be very clear and this is the moving arm.

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As I said the MERLIN machine has to be shifted along the road and the position of the pointer is noted on the graph sheet. This position corresponds to the mid chord deviation at that particular location. About 200 such measurements or 200 such noting on the graph sheet has to be made at regular intervals. So, for these 200 positions there will be 200 markings that are made on the graph sheet. The distribution of the marks on the chart represents the roughness of the road.

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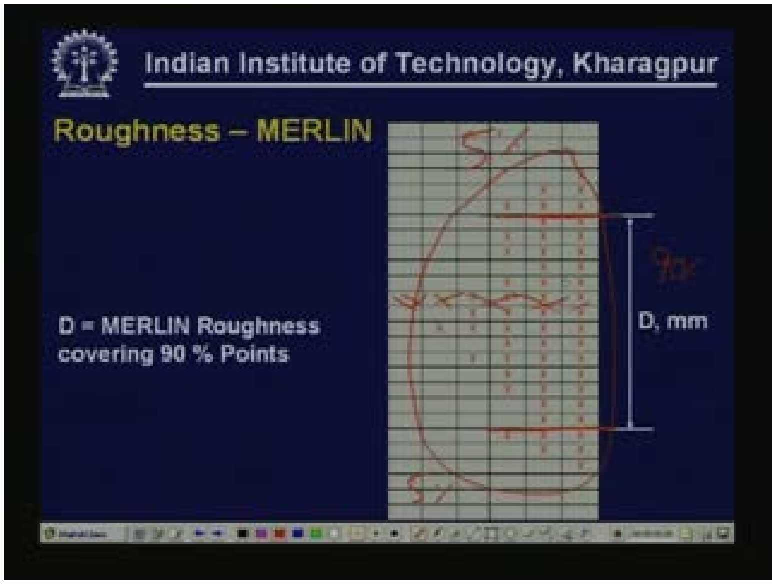

Typically this is how a completed graph sheet will look like. Obviously this should have 200 points I have not put all those 200 points here. Therefore depending upon the movement of the pointer on the graph sheet the points are going to be scattered along the graph sheet. A particular block may have more points and other blocks away from the center may have lesser points depending upon the variation in the surface profile of the road. What is done is once we get this scatter in terms of all these points we will consider the spread of these points for 90% of the points, what we do is we eliminate 5% on either end and consider 90% of the points so the distance within which 90% of the points are covered is represented as the MERLIN roughness that is D expressed in terms of millimeter as we measure on the graph sheet.

What it indicates is if the road were to be having constant longitudinal slope so there will not be any mid chord deviation with reference to these two points so the probe will be on the same line so we will continue to be getting the points along one line only, all the lines will be along the middle of the graph sheet but as the roughness increases somewhere it is above the mid chord, somewhere it is below the mid chord the points get scattered all over the graph sheet. Hence that scatter represents the variation in the profile. The distance within which 90% of the points would be lying will be more, if it has got more or less a constant slope and there is not much variation in the longitudinal slope then most of the points would be lying close to the center so 90% of the points could be covered within a smaller distance so the roughness will be lesser.

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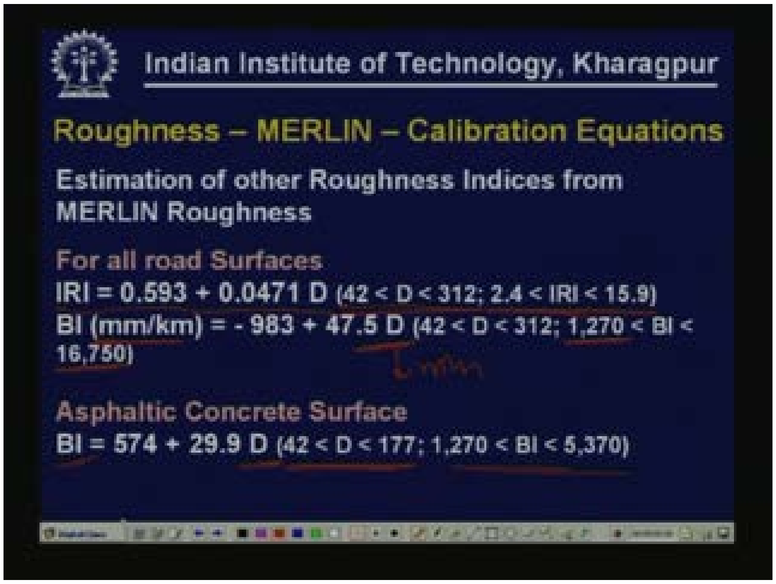

Using the MERLIN roughness value other roughness parameters can be estimated. For example, international roughness index can be estimated as a function of MERLIN roughness. Good correlation is found between these two parameters. For the same road if you measure MERLIN roughness and also if you compute international roughness index you can find good correlation between them. We will discuss about the international roughness index after a few slides. For all types of road surfaces IRI is given as 0.593 + 0.047 multiplied by D. we have to understand that this is for a range of D ranging from 42 to 312 mm and the corresponding IRI range that we are talking about is about 2.4 to 15.9.

We can also estimate the bump integrator value because correlations have already been established on the basis of experiments conducted earlier. Bump integrator value for all types of surface has a general equation. It can be expressed in terms of millimeter per kilometer, can be estimated from the D value expressed in millimeters, D is the MERLIN roughness as – 983 + 47.5 times D this is again valid for the same range of D and bump integrator value range of 1270 mm per kilometer to 16750 mm per kilometer. But if you look at the equation that is applicable for only asphalt concrete surface the bump integrator value is correlated to the D value with this equation. This is the range of D values and range of BI values for in which this equation is applicable.

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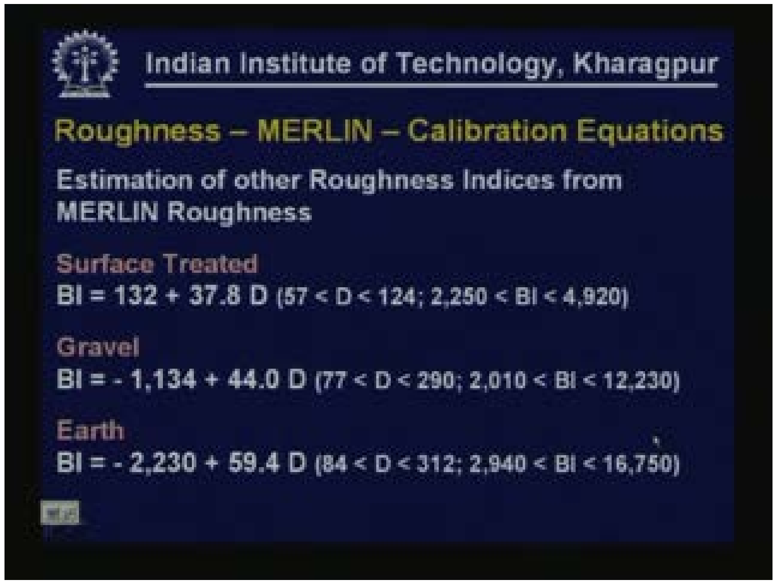

Similarly for surfaces that are treated the BI can be estimated from MERLIN using this equation, for gravel, for earth surface also different correlations are available as you can see here. We should also note the range of D values and the range of BI values for which these equations are applicable.

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The next and most commonly used roughness index worldwide is the international roughness index. This is a very interesting concept in terms of expressing roughness of a given road. IRI is the International Roughness Index. This is an ideal roughness index developed to calibrate response type roughness indices. Basically IRI concept has been evolved to calibrate various response type roughness equipments because as we discussed the measures that we obtained from roughness type response machines will vary over time and with different machines for the same road we will get different values. So there was a need to bring all these parameters that are obtained over time with different equipment may be for the same road having same characteristics to the same platform and then standardize all of them. It is obvious that each one of these machines are going to different values but what is the correct value or what is the standard value that has to be expressed for the given road, but again it is the same road.

Respond type system of measuring roughness in millimeter per kilometer though popular is found to have some difficulties. The same roughness values are not obtained if different vehicles are used. Even with the same vehicle similar roughness values are not obtained over time. This is what I have been saying.

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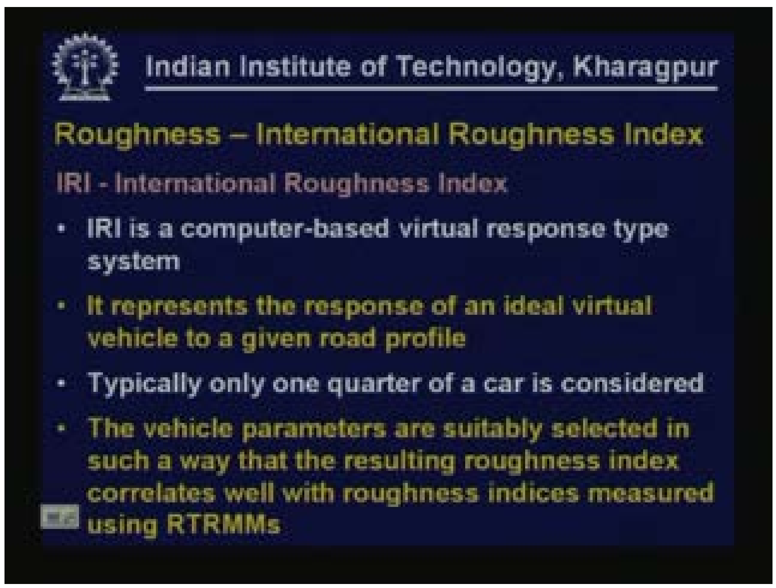

IRI is a computer-based virtual response type system. This is not something that we are going to measure. We cannot measure IRI but we can compute from some given inputs. So whatever value we measure it's a standard value. There are no physical practical parameters that are going to influence this parameter this is a theoretically computed value.

It represents the response of an ideal virtual vehicle to a given road profile. So this also is response type in some way but this is the response of an ideal vehicle theoretical vehicle and not the actual vehicle. So since this is a theoretical vehicle its coefficient, its suspension system and other parameters are not going to change over time or any time. So it represents the response of a theoretical vehicle to a given profile.

Typically only one quarter of the vehicle is concerned. We will not consider the full vehicle because the analysis becomes more complex and most of the time we are only interested in analyzing the roughness along the given profile. So taking the entire vehicle does not really mean much if you are considering only one profile but if you want to have a represented value for a given use the entire vehicle and find out its response to the given profile then you can express it as IRI. But basically it is for a given profile that the IRI is calculated and the given profile will be along one line.

The vehicle parameters are suitably selected in such a way that the resulting roughness index correlates well with roughness indices measured with using RTRMMs. This is Response Type Roughness Measuring Machines. So the golden car or quarter car its parameters are selected in such a way that the resulting IRI that we are getting correlates well for a given road.

For example, for a given road we measure the profile by let's say rod and level method we get the exact profile of the road. For the same road when we conduct a survey using a roughness meter let's say fifth wheel bump integrator we know what is the fifth wheel bump integrator value that we get so that value can be correlated with the IRI that is calculated. For calculating IRI we have to select some parameters of the vehicle.

So normally what is done is that for calculating this IRI the vehicle parameters are selected fine tuned in such a way that there is good correlation between the computed IRI and the measured roughness value using RTRMMs.

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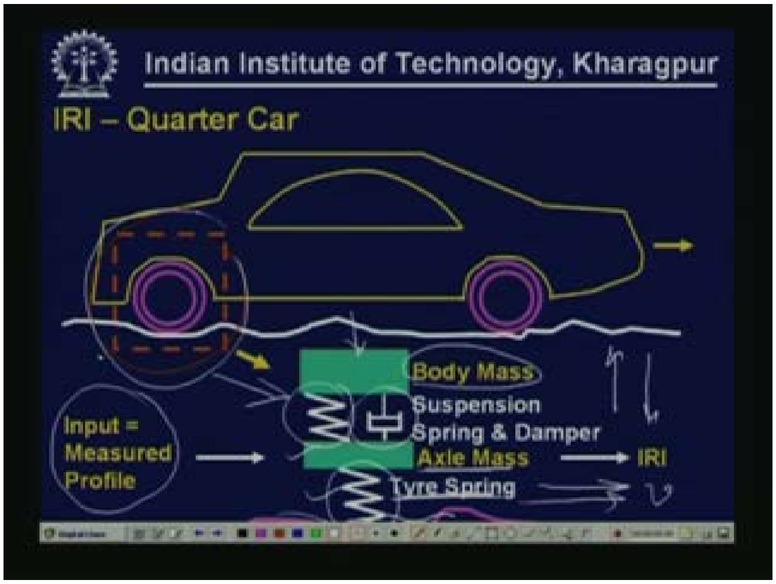

This is the quarter car that we are referring to. So we consider just only one quarter of this vehicle given by one wheel system. So here we have the wheel and also the part of the load that is coming and various suspension systems. So this can be represented by this mechanical model. if this is the road profile this represents the stiffness of the tire, this is the tire spring tire being represented by a spring here then this is the mass of the axle then the suspension system is represented by a spring and a dash board over which the mass of the body is going to come on to this particular vehicle.

Hence we have to have all these parameters, we have to select what is the body mass that is coming on this vehicle on this wheel then the spring and the suspension system corresponding to the suspension system that is used in this vehicle then the mass of the axle and we have to have a spring representing the tire. So input to this system, this is a theoretical system so when it is subjected to variation in this profile when this vehicle is made to move over this profile and it is made to move at some speed then using some theories we can compute theoretically the vertical stroke of the suspension system.

So as it moves along this profile the cumulative vertical movement of the suspension system can theoretically be calculated. So for this system we have to give the measured profile as input. The measured profile can be in terms of discrete values, levels at different locations, and may be every 0.5 m, 1 m, 5 m depending upon how closely we are able to collect the data so that profile can be fed to the system. Then there is a mechanical dynamic system that is going to be used and then the output that is going to be available from the system will be the accumulated stroke of the suspension system with distance.

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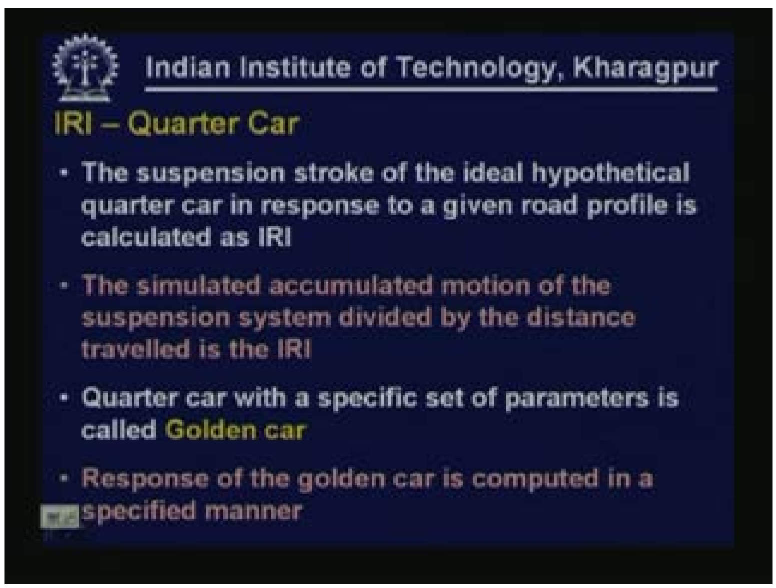

The suspension stroke of the ideal hypothetical quarter car in response to a given road profile as it is made to move over a road having different characteristics so the quarter car response the suspension system of the quarter car response the suspension stroke is calculated as IRI.

The stimulated accumulated motion of the suspension system divided by the distance traveled is the IRI. Quarter car with a specific set of parameters is called as golden car. because as we have seen here there are certain parameters that we have to select; the body mass, axle mass, the suspension system, spring and the dash board parameters and the spring representing the tire. So all these parameters have to be selected and then put it in the dynamic system so that we can calculate the suspension system or vertical movement of the suspension. The response of the golden car is computed in a specified manner like how the profile has to be processed, how the suspension system movement has to be calculated and so on so there is a set of steps that are involved in computing the IRI.

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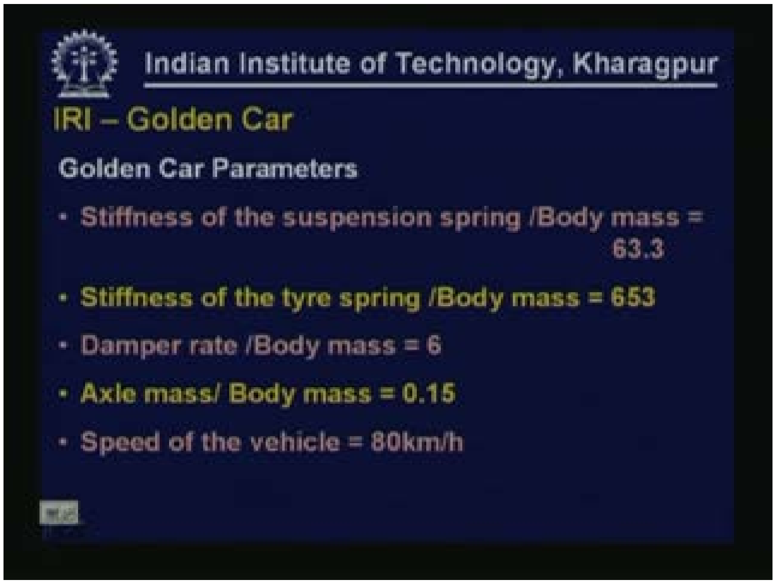

These are the golden car parameters that are used. stiffness of the suspension system by body mass is taken as 63.3, stiffness of the tire spring by body mass is taken as 653, the damper rate by body mass is taken as 6, axle mass by body mass is taken as 0.15 and the speed at which the vehicle is made to move in the theoretical model is 80 km per hour.

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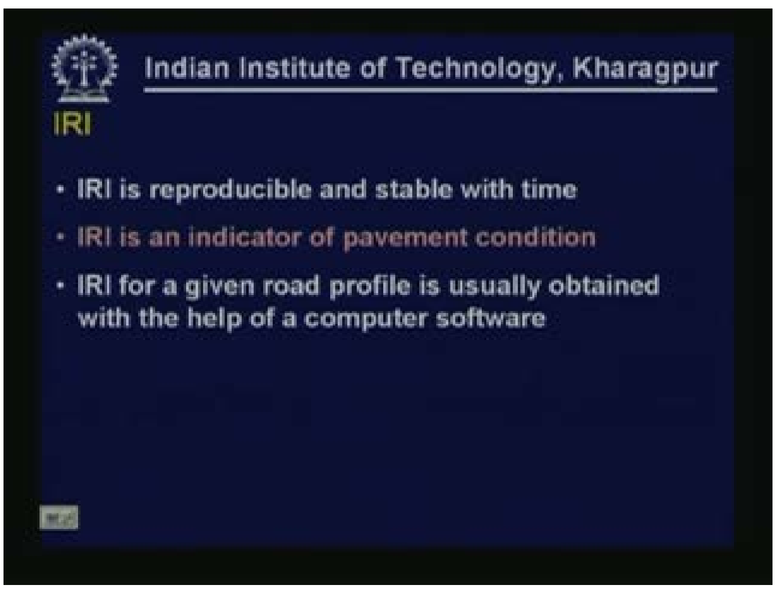

The advantage with IRI is IRI is reproducible and stable with time because it is a theoretical value for a given profile which can be fed to the system. There is nothing that is going to change as long as do not change the model parameters, parameters of the golden car IRI is not going to change. So for a given profile any time you calculate as per the same procedure you get the same IRI value so this becomes sort of standard for a given profile. IRI obviously is an indicator of the pavement because it represents an index which represents the profile of the given road. So we are using the profile of a given road and coming out with a index and obviously it represents the condition of the pavement. IRI for a given road profile is usually obtained with the help of computer software. Normally we cannot do hand calculations for computing IRI because there will be lot of data that has to be processed in terms of the profile and lot of calculations that have been made in computing the suspension system stroke.

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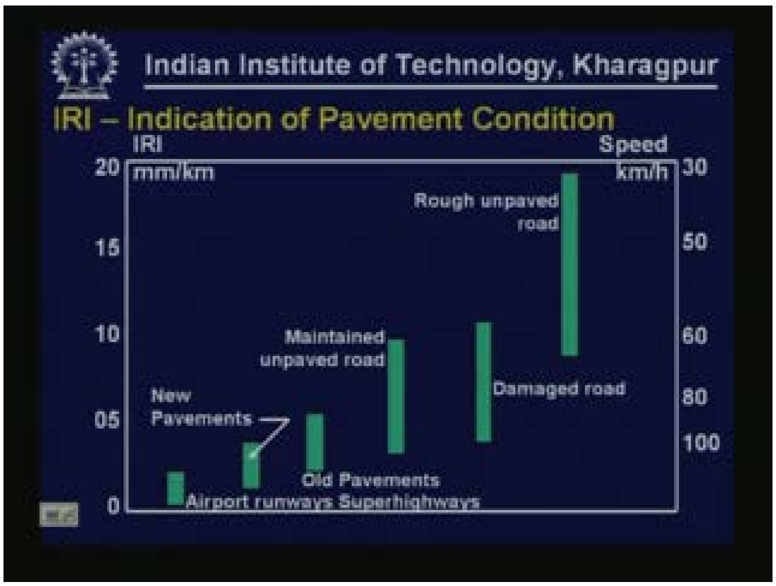

Typically IRI's value would be ranging from 0 to 20, 20 would be for the almost worst kind of a road. This picture here illustrates the typical ranges of IRIs that one can expect for different types of facilities. for example for airport runways and super highways the IRIs could be in the range of may be 0 to 2 very good surface condition for typical new highway pavements it can be in the range of may be 1 to 3.5 or 4. Similarly for very rough unpaved road the IRI could be in the range of say 7 to 18. This is just an indicative idea about what could be expected in terms of IRI for different types of facilities and also in terms of the condition at which the pavement is designed. On the right hand side we also have the speed. if the IRI indicated on the left hand side exists for a given road or computed for a given road what is the speed that can be expected on that road.

For example, if you are talking about IRI of 20 the corresponding speed that we can refer to will be about 30. If the IRI value is say only as small as let's say 2 or 3 we can talk in terms of speeds as high as 100 km per hour.

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That was about functional evaluation. For functional evaluation we talked about assessing function evaluation in terms of present serviceability index which can be estimated by measuring physical parameters such as roughness, cracking, and longitudinal slope variance and so on. We also talked about various roughness indices like fifth wheel bump integrator, MERLIN and IRI. There can be is various other ways of evaluating functional performance of the pavement.

Now we will talk about structural evaluation of pavements which is required to assess the structural soundness of the pavement at a given point of time, which is also required for estimating the remaining life of the pavement and to determine the requirement of rehabilitation that is to calculate overlay thickness if it is required.

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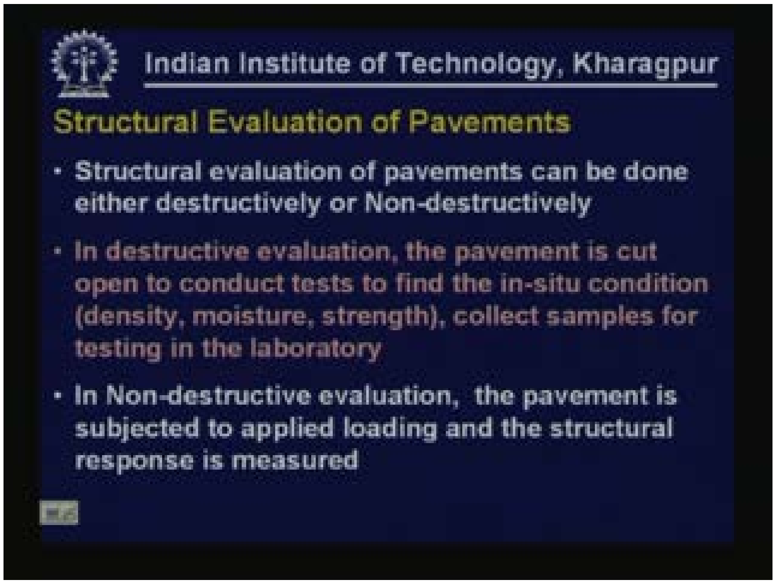

Structural evaluation of pavements can be done either destructively or non-destructively. In destructive evaluation what we do is the pavement is cut open or we take cores from the pavement, we collect samples from the pavement and then bring them to the laboratory test them under representative conditions like conditions in which these materials were there in the field in terms of their density, in terms of the gradation whatever conditions we have to stimulate for a given material as they are in the field has to be stimulated in the laboratory and the material properties have to be evaluated. The material properties that we evaluate will have to correspond to the design methodology that we have.

For example, we have a design methodology in which CBR is the only parameter that we are using; we will evaluate the CBR value of the material. Or if we are using the elastic modulus value of a particular material in your design procedure and analysis then you have to determine the elastic modulus value of the material that you have collected from the field. Again we have to use representative materials and the conditions at which we are testing the materials also will have to be representative of the conditions that we have found in the field. Therefore normally for destructive testing we can cut open the pavement and then remove all the materials.

For example, if you are trying to find out the existing density of the sub-grade then cut open the pavement, find out the density, find out the moisture content, may be possibly you can do the CBR test also. We can also do what is known as dynamic cone penetrometer test and then from the penetration value that is obtained we can get the estimate of other parameters. So in destructive evaluation the pavement is cut open to conduct test to find the in-situ condition that is density, moisture and strength if possible. They normally collect samples for testing in the laboratory. On the other hand in non-destructive evaluation the pavement is subjected to some applied load and the structural response is measured.

The destructive testing is normally very difficult. You have to cut open the pavement at number of locations; you cannot go on excavating the pavement. Of course if you do not have any equipment capable of carrying out non-destructive evaluation that is the only thing that we may be doing so maybe you will only carry out destructive evaluation. But if possible one should go for non-destructive evaluation in which we apply load and measure the structural response of the pavement.

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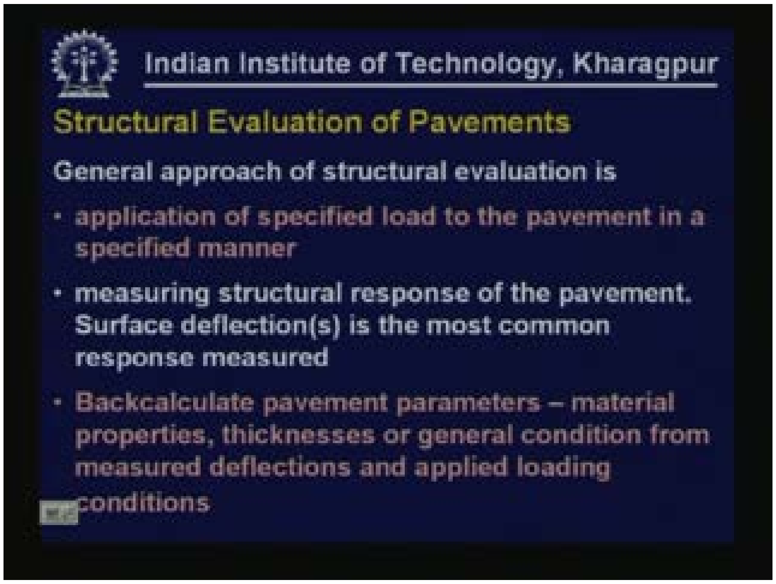

The general approach of a structural evaluation method will be to apply a specified load to the pavement in a specified manner. The load applied and the manner in which it is applied has to correspond to the theoretical model that we are using or the model that we are using in making interpretations about the pavement condition.

Measure structural response of the pavement: after you apply the load then measure the response of the pavement. Surface deflection is the most common response that is measured because it is very easy to measure the surface deflection. And on the basis of the surface deflections that we measure back calculate the material parameters.

It could be thicknesses and if you would not know about the thicknesses you have some information in terms of the structural response you can back calculate the thicknesses, you can back calculate the material properties or we can back calculate some parameters that tells us about the strength of the pavement. So we can back calculate pavement parameters such as material properties thicknesses or general conditions from measured deflections and applied loading conditions.

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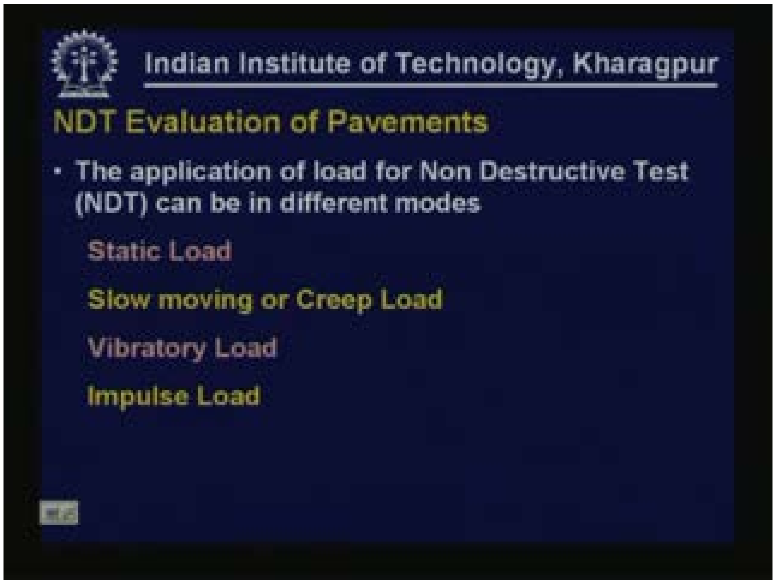

The application of load for NDT testing can be done in different modes. It can be a static load, it can be slow moving or creep load it can be vibratory load, it can be impulse road.

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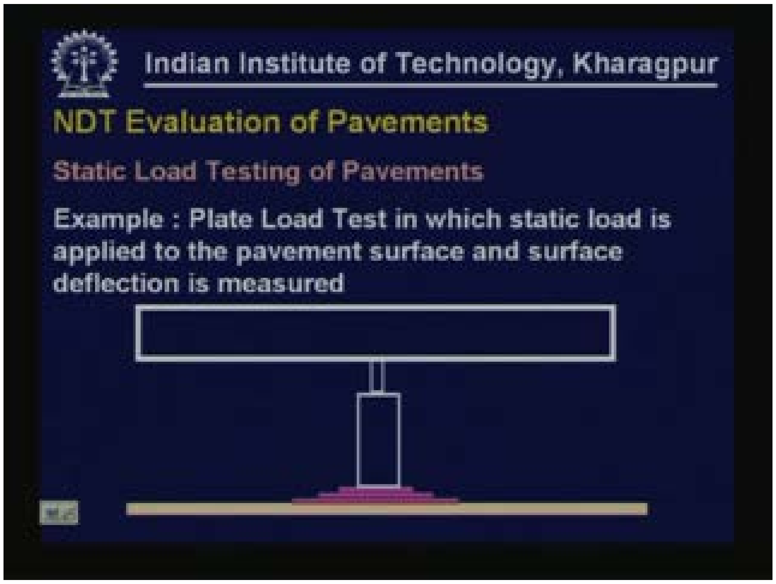

In a static load the simplest of static load testing could be conductive plate load test. If you are interested in determining the modulus of sub-grade reaction this is one method of conducting plate load test. You are applying static load and then measuring the deflection so from deflection and the load applied you are finding some parameter about the sub-grade or any layer on which we are conducting test. So we may be getting information about the modulus values or we may be getting information about the modulus of sub-grade reaction if you are using this as a foundation of concrete pavement. So plate load test is one static load arrangement testing that we can do on pavements.

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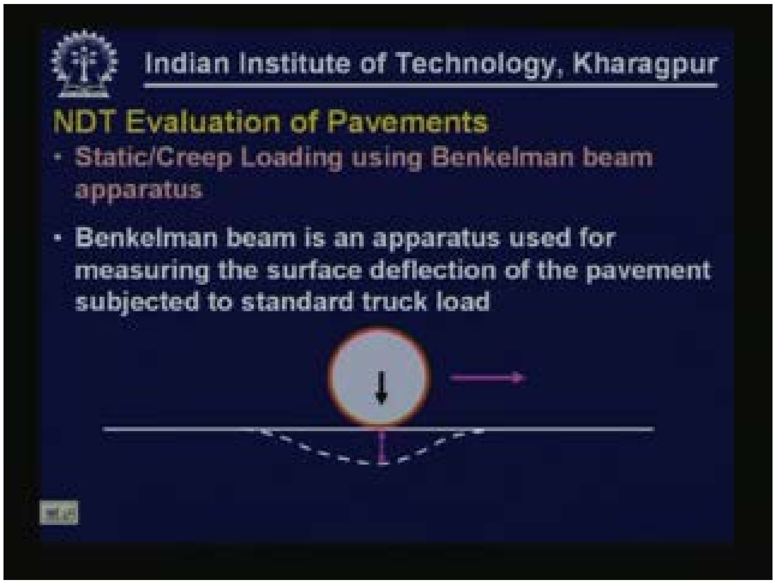

The other most commonly used method is the Benkelman beam apparatus. This can be done either in static load or creep loading condition. We will not go into the complete details about the Benkelman beam procedure because we will be covering this in the next lesson when we talk about design of overlays using Benkelman beam apparatus.

The Benkelman beam is an apparatus used for measuring the surface deflection of the pavements subjected to a standard truck load. We use a standard truck to apply load to the pavement surface then we measure the pavement surface deflection. So the load that is applied is standard truck and then we measure one single surface deflection which is the maximum deflection which we are going to measure. So as you see here when the pavement is loaded by one wheel of a standard truck the pavement deflects so we are going to measure the maximum deflection.

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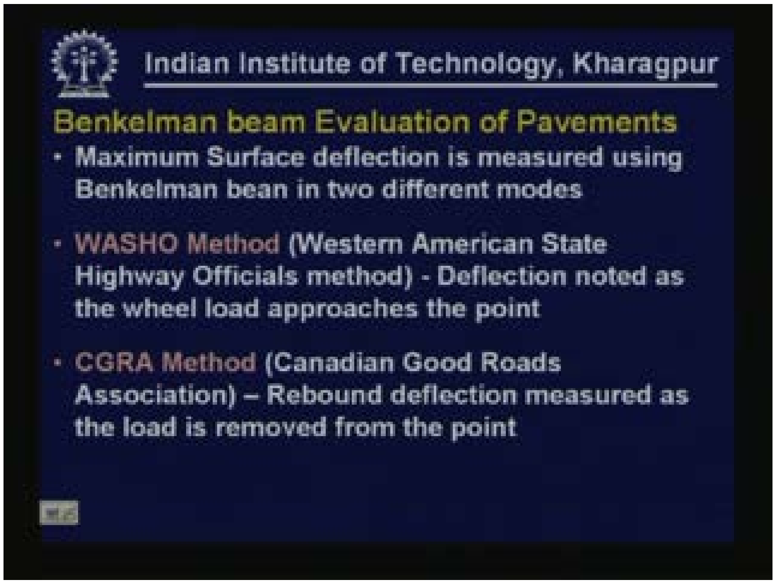

Maximum surface deflection is measured using Benkelman beam in two different modes. There are two different procedures using which we can measure the maximum deflection. One is WASHO procedure Western American State Highway Officials method in which the deflection is noted as the wheel approaches the point. The wheel will initially be away from the point and then as it approaches the point we measure the deflection and when the wheel load is right on the point the maximum deflection will be observed.

In the other procedure initially the wheel will be at the point and then we note down the initial deflection reading then as the wheel load moves away from the point we see the difference observed as what is known as rebound deflection. So this is the CGRA procedure Canadian Good Roads Association procedure in which we measure the rebound deflection as a load is removed from the point.

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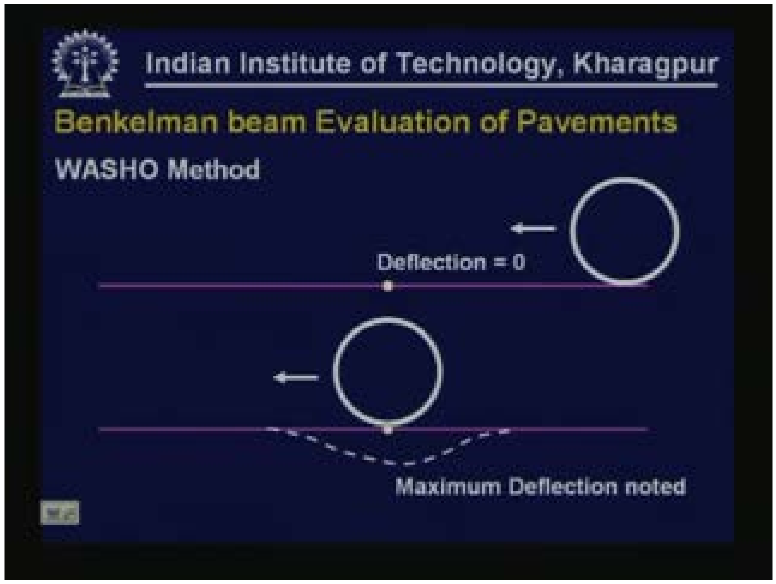

The WASHO procedure is depicted here. In the WASHO procedure initially the load is away from the point so deflection is 0 and as it approaches and is right over the point we observe the maximum deflection.

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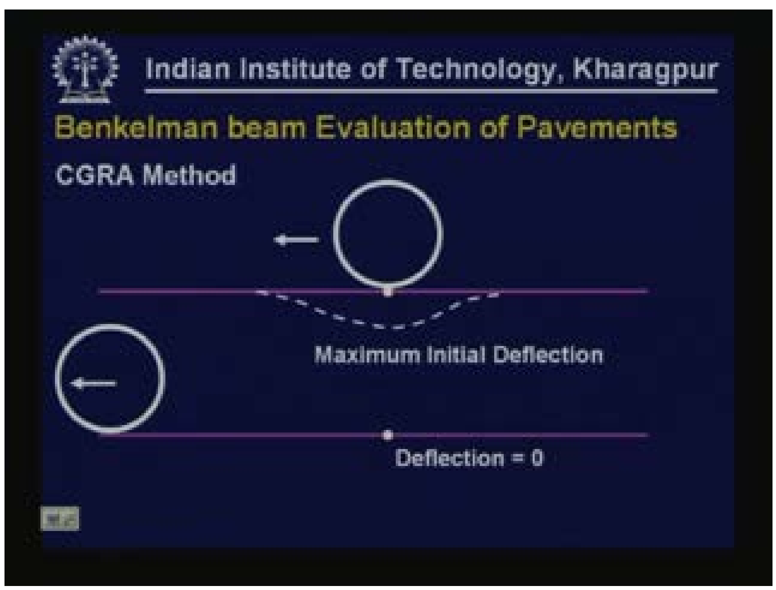

In the other procedure CGRA initially the load is on the point itself so you already have the maximum initial deflection so when you remove the load away from the point deflection theoretically has to become 0 then the difference is the rebound deflection.

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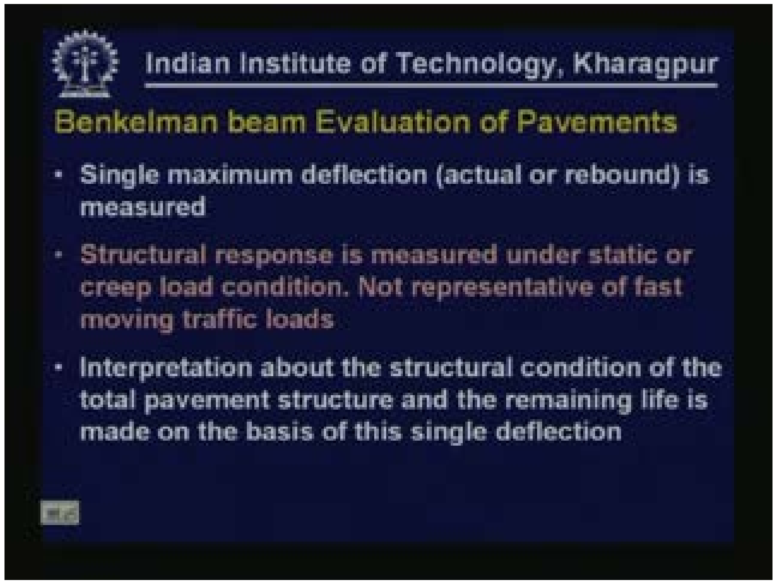

What we get from Benkelman beam evaluation of pavements say is one single maximum deflection. It is either the actual deflection in the case of WASHO procedure or the rebound deflection in the case of CGRA procedure. Such structural response is measured under static and creep load conditions this is the problem. Because actual loading condition that is applied on pavements is by fast moving vehicles, the loading time is very short so the loading that we apply using a Benkelman beam procedure is not very realistic. The interpretation about the structural condition of the total pavement structure and the remaining life is made on the basis of one single deflection. We have only one deflection that is available and on the basis of this we have to interpret the complete pavement structure.

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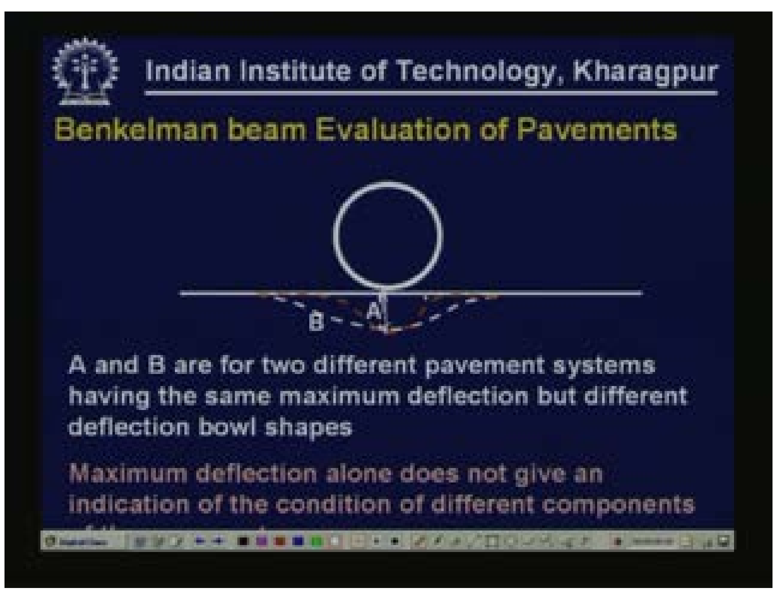

The problem with this we can be explained using this diagram. For example we have two different pavement structures having the same maximum deflection. But as you can see the deflection bowl shape is different; one is widely spread and the other one is very narrow for the same loading. Obviously these two pavements are not similar, there must be something different between these two pavements but if we are measuring only the maximum deflection you tend to think that both the pavements are similar this is the main difficulty with Benkelman deflection or the main difficulty in interpreting the pavement condition on the basis of one single deflection. The maximum deflection alone does not give an indication of the condition of different components of the pavement. That's the reason why most commonly structural evaluation is carried out using falling weight deflectometer.

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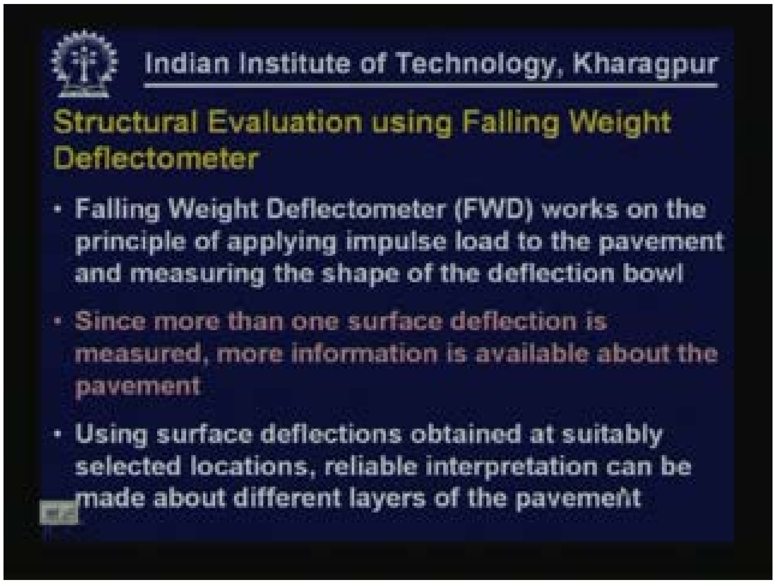

Falling Weight Deflectometer are popularly known as FWD works on the principle of applying impulse load to the pavement and measuring the shape of the deflection bowl. That means we do not measure one single deflection but we measure more than one deflection, typically five, six, seven deflections are measured and the load applied is also not a very static or slow moving load. It is impulse load. The load duration will be of such magnitude and duration which simulates to the load that are actually applied by moving traffic vehicles.

Since more than one surface deflection is measured more information is available about the pavement. Using surface deflection obtained at suitably selected locations reliable interpretations can be made about different layers of the pavement. Because we have more deflections more information is available so we can interpret better about the pavement condition, better about different layers of the pavement.

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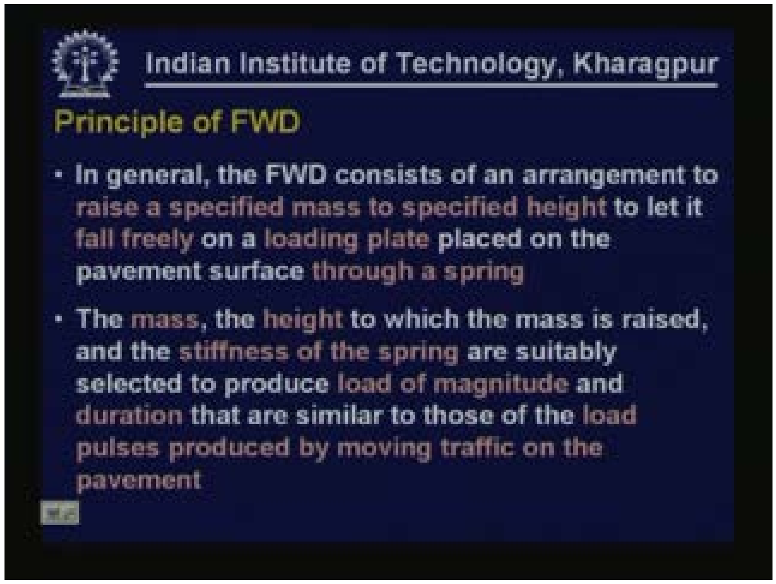

In general FWD consists of an arrangement to raise a specified mass to specified height and to let it fall freely on a loading plate placed on the pavement surface through a spring. The mass, the height to which the mass is raised and the stiffness of the spring are suitably selected to produce a load of magnitude and duration that are similar to those of the load pulses produced by moving traffic on the pavement.

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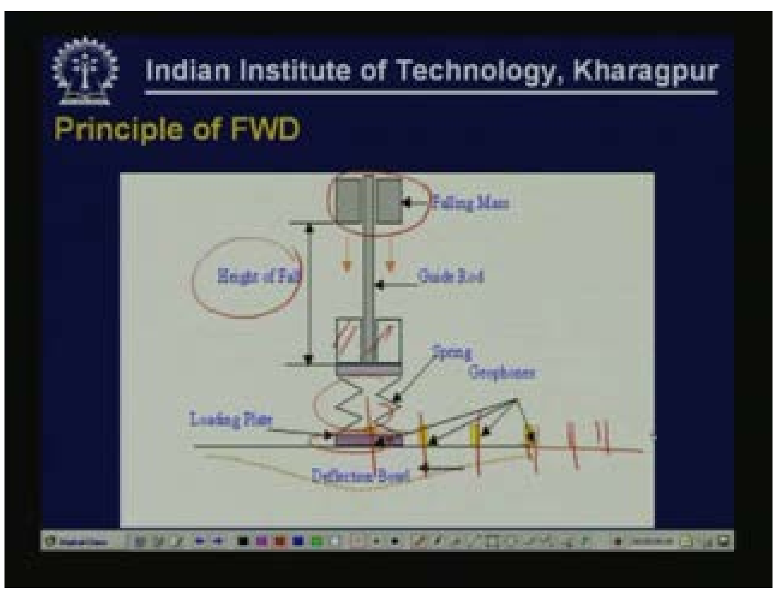

This sketch here explains the principle of a Falling Deflectometer. As you can see there is a falling mass raised to certain height and there is a loading plate here and there is a spring arrangement so the mass is made to fall on the spring which in turn transmits the load to the pavement surface. There are a number of geophones and sensors that can be used to measure deflection placed at different radial distances from the center of the wheel load so we can measure the shape of the deflection bowl once the load is dropped.

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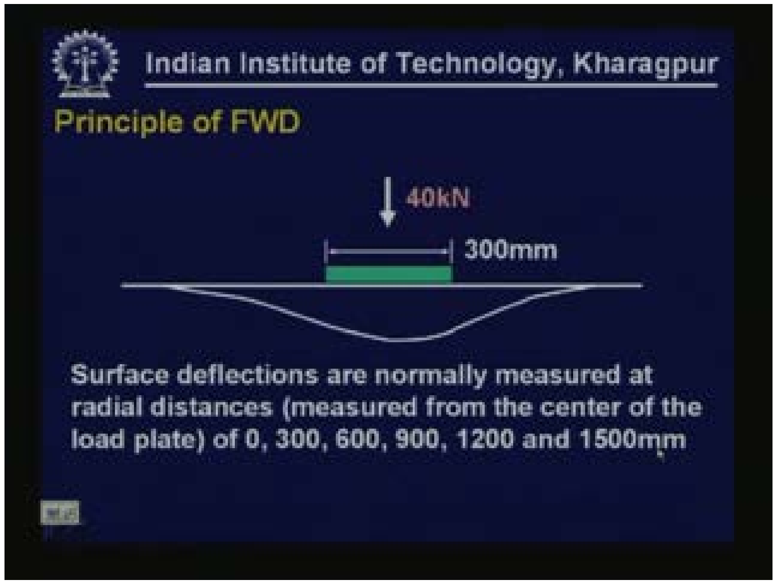

Typically this is the loading that is adopted; 40 kilo Newton load is applied this is half the standard axle load and this is applied over 300 mm dia loading plate because 300 mm also would give us a pressure of about 0.56 MPa that is the contact pressure we would get for 40 kilo Newton and 300 mm diameter. Surface deflections are normally measured at radial distances measured from the center of the load plate of 0, 300, 600, 900, 1200 and 1500 mm. In many cases the deflections are measured at regular intervals also wherever required.

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a number of falling weight deflectometers are commercially available. However, these are very costly for most of the agencies in India to purchase and they are even difficult to maintain also. IIT Kharagpur has developed indigenous falling weight deflectometer and has been using them for the last ten years. There are two models; one is trailer mounted other one is in-vehicle were pretty well developed.

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The next photograph shows the two models that were developed at IIT Kharagpur and this is the trailer mounted model, a very simple one.

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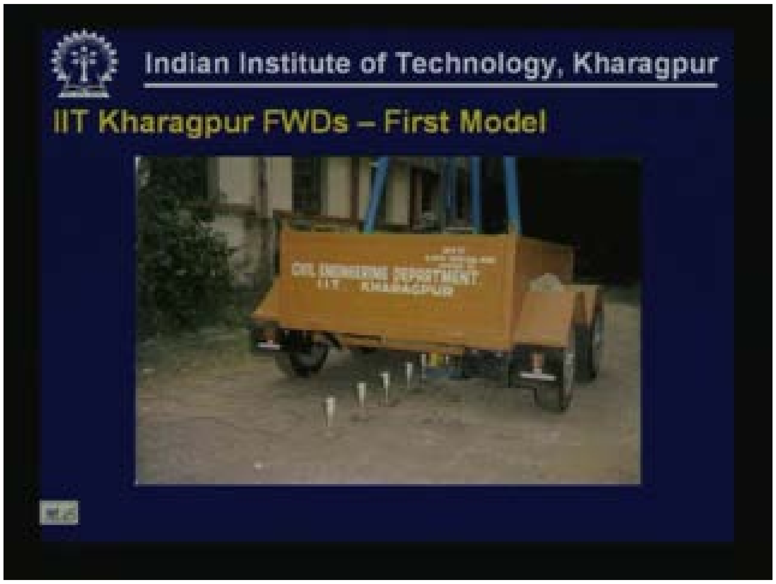

We can see the mass spring system, we can also see the geophones placed behind the trailer to measure the deflections.

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This is the photograph showing the pavement evaluation of national highway 6 using the trailer mounted falling weight deflectometer.

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This is an in-vehicle falling weight deflectometer developed for the ministry of surface transport under the six scheme R81, the complete arrangement is placed inside the vehicle.

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You can see the details of the falling weight deflectometer here. What you see on the right hand side and the left hand side is the extendable foldable geophone placing arrangement.

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National highway 6 is being evaluated using the falling weight deflectometer in-vehicle.

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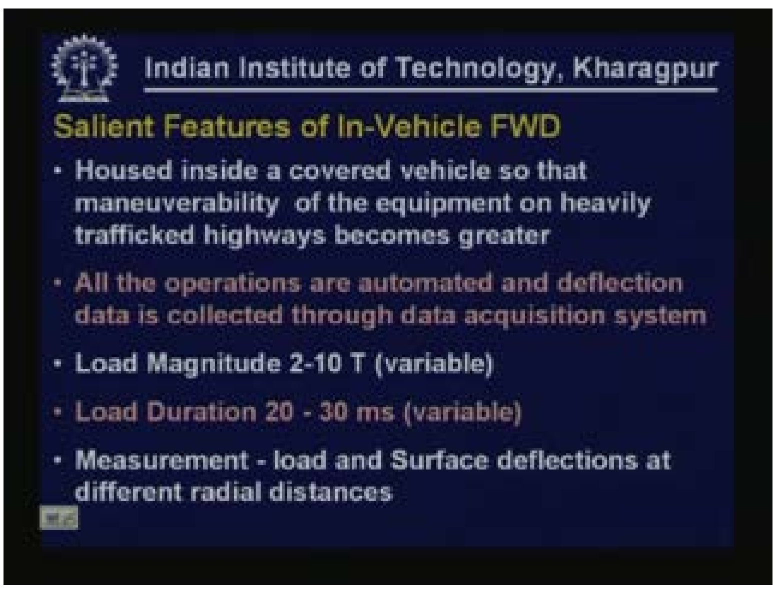

The salient features of the in-vehicle falling weight deflectometer are it is housed inside a covered vehicle so that maneuverability of the equipment on heavily trafficked highways becomes greater. All the operations are automated and deflection data is collected through data acquisition system. Load magnitudes in the range of two to ten tones can be applied this can be varied. Load duration of twenty to thirty milliseconds can be applied again this can be varied. Measurement that is done is load and surface deflections at different radial distances. The load applied and the surface deflections at different radial distances can be measured.

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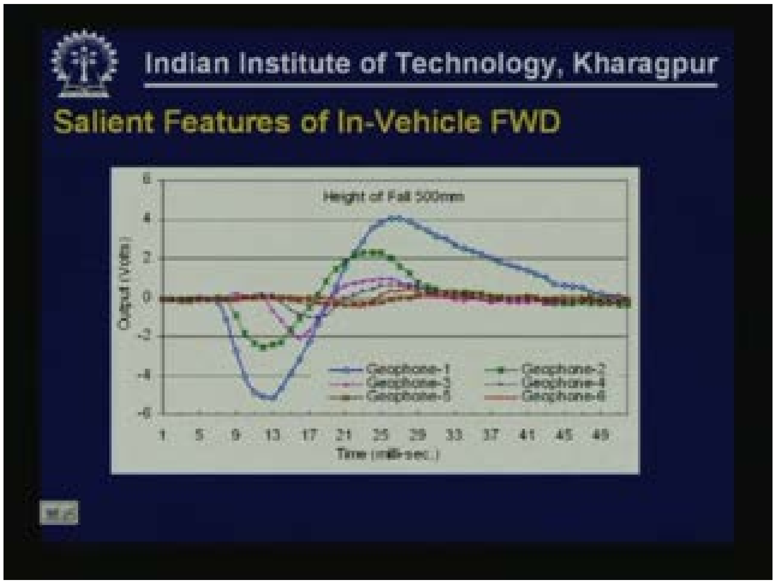

This diagram show shows a typical output obtained from the geophones. Each one of these lines represents different deflections measured in different locations.

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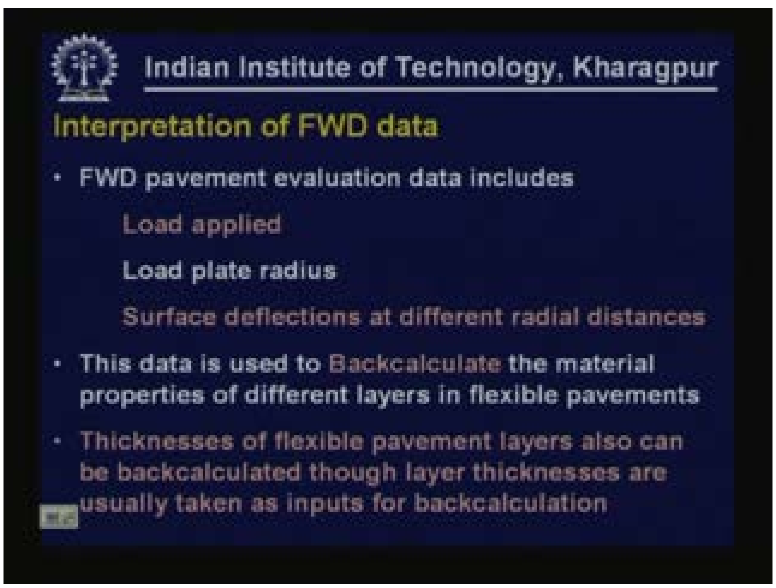

Interpreting falling weight deflectometer data:

We get load applied, load plate radius, surface deflections at different radial distances from the FWD testing procedure.

This data can be used to back calculate the material properties of different layers in flexible pavements. Thicknesses of flexible pavement layers also can be back calculated, although layer thicknesses are taken as inputs for back calculation.

We can back calculate the material properties we can also back calculate the thickness also. But normally either from construction history or from indirect testing procedure also we can get the layer thicknesses; we normally use them as inputs. But there are procedures with which we can back calculate the layer thickness also along with the layer material properties.

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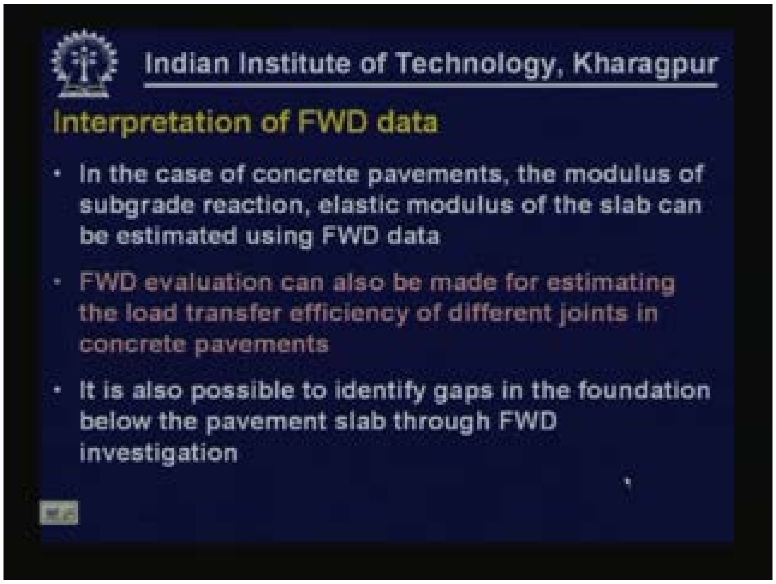

In the case of concrete pavements the modulus of sub-grade reaction, elastic modulus value of slab can also be estimated, FWD evaluation can be used to estimate the load transfer efficiency of joints in the concrete pavements, and it can also be used to identify gaps below the pavement.

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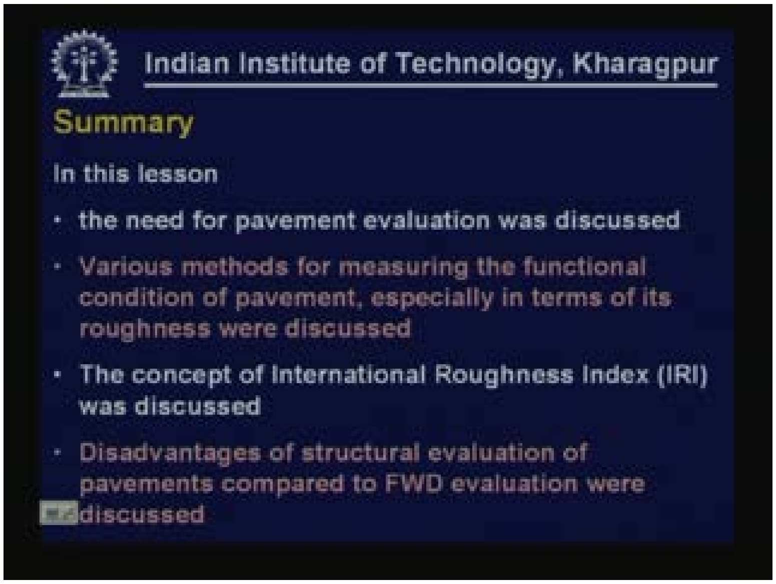

To summarize; in this lesson we have discussed about the need for pavement evaluation. We have also discussed about various methods for measuring the functional condition of the pavement especially in terms of different roughness indices. We have also discussed about the concept of international roughness index and we have also discussed about the disadvantages of structural evaluation of pavements or different types of structural evaluation of pavements compared to FWD evaluation of pavements.

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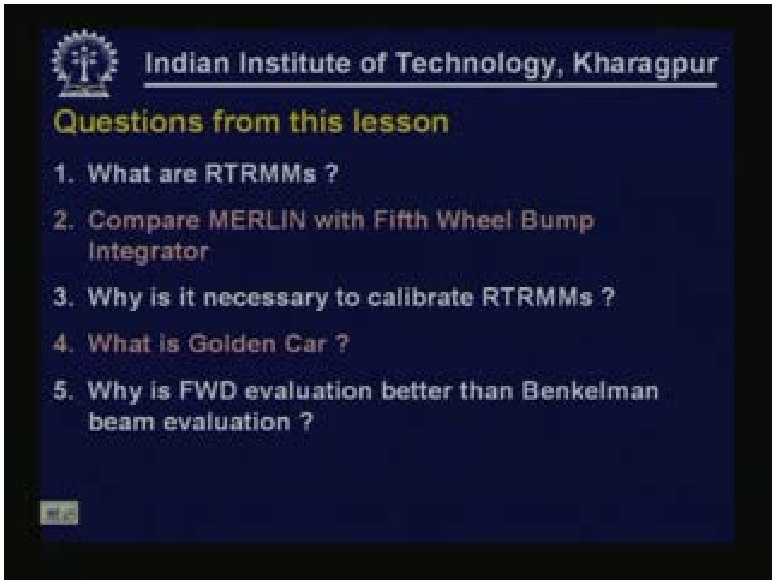

The questions from this lesson are:

1) What are RTRMMs?
2) Compare MERLIN with fifth wheel bump integrator
3) Why is it necessary to calibrate RTRMMs?
4) What is a golden car?
5) Why is FWD evaluation better than Benkelman beam evaluation?

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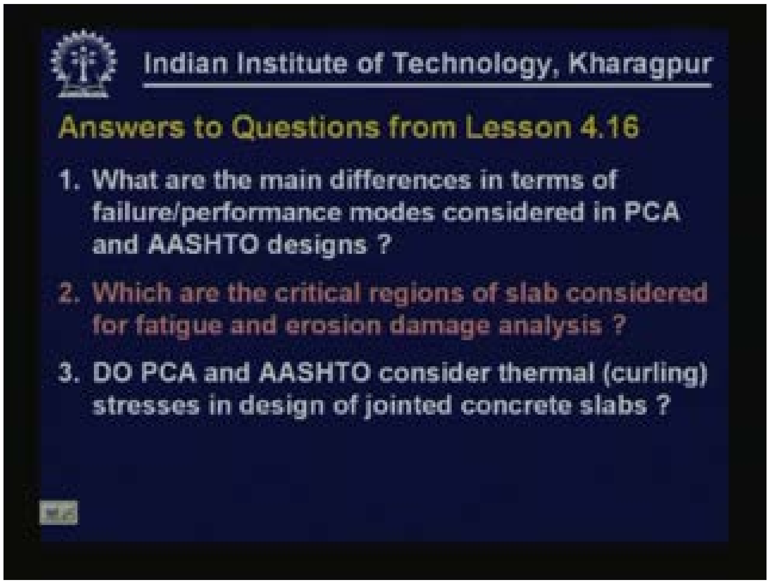

We will now have answers to the questions that we asked in lesson 4.16. Lesson 4.16 was the lesson on concrete pavement design using PCA procedure and AASHTO procedure.

1) What are the main differences in terms of the failure and performance modes considered in PCA and AASHTO designs?
There is a significant difference or vast difference between PCA procedure and AASHTO procedure. AASHTO performance is defined in terms of PSI Present Serviceability Index which only takes into consideration terms of the surface characteristics, longitudinal slope variance, cracking and rutting whereas PCA procedure is in terms of theoretical evaluation of the pavements so fatigue criterion is there and erosion criterion also is there.

2) Which are the critical regions of slab considered for fatigue and erosion damage?
Especially we are referring to PCA because in AASHTO there is no such analysis available. For fatigue analysis edge region is considered to be critical and for erosion analysis since deflection is more important the corner region is considered to be important.

3) Do PCA and AASHTO consider thermal curling stresses in design of jointed concrete slabs?
AASHTO doesn’t take into account the thermal stress at all. PCA also doesn’t take into account the thermal stresses. it is not considering fatigue analysis because of the reason of the combination of thermal stresses and wheel load stresses throughout the season is not going to be additive so that’s the reason thermal stresses or the curling stresses are not considered in the PCA design, thank you.