Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture 41
Evaluation of Pavement

Hello friends, welcome to the NPTEL Online Certification Course, Retrofitting and Rehabilitation of Civil Infrastructure. Today we will discuss module F. The topic for Module F is Concrete Overlay for Pavement Rehabilitation.

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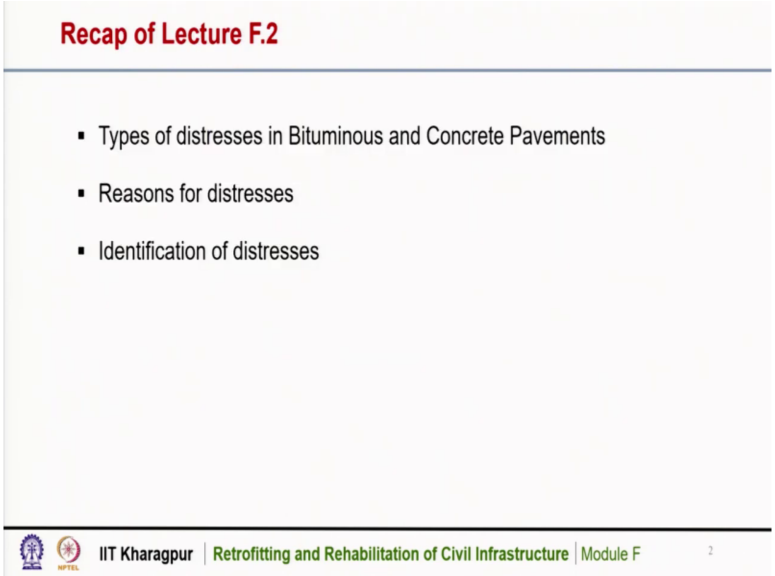

In the previous lecture, we have discussed the types of distresses in bituminous and concrete pavements. There are different reasons for distresses of pavements that we have discussed and also how to identify these distresses both in bituminous pavement and concrete pavement that were discussed in the previous lecture.

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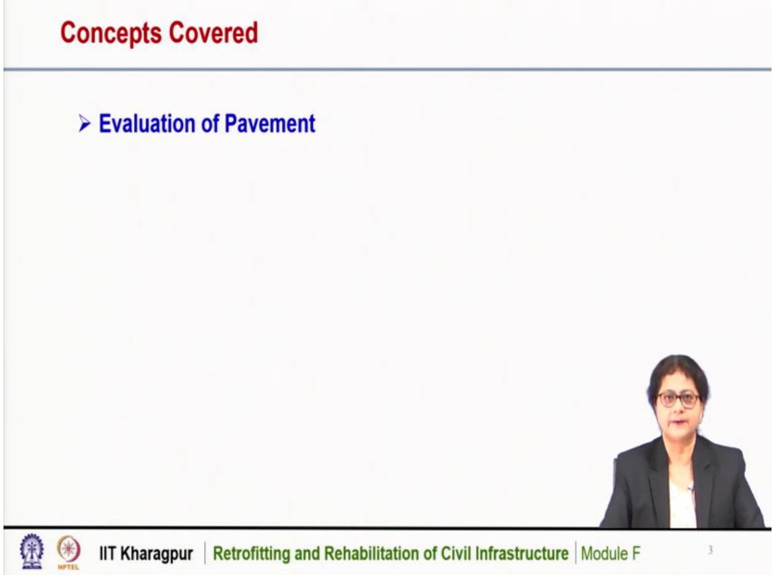

Today, we will discuss the evaluation of pavement.

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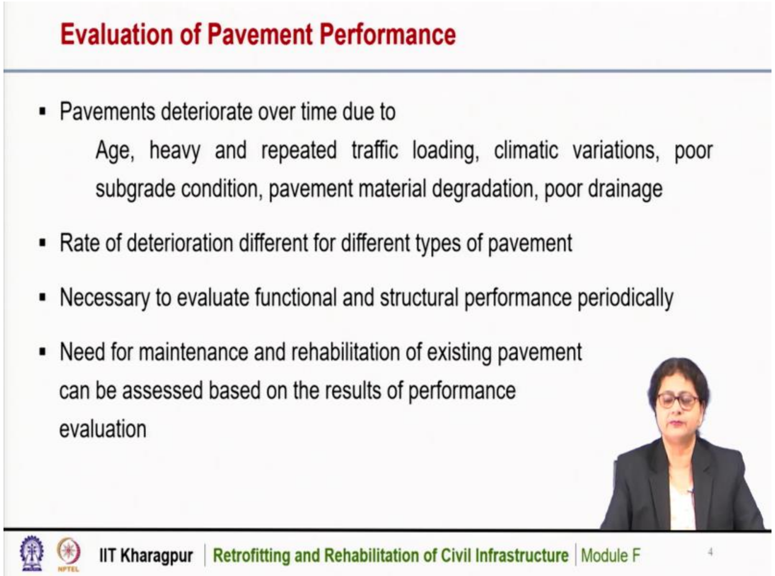

Pavements may deteriorate over time due to aging, due to heavy and repeated traffic loading. The main load coming on the pavement is the traffic loading and overloading is one of the major problems on Indian highways. So, that may affect the performance of the pavement. Due to repeated traffic loading the pavement may get deteriorated over time. The pavement is exposed to environment. So the climatic variations, the seasonal temperature changes, the moisture variation that may affect the performance of the pavement.

The subgrade condition is an important consideration for pavement performance; the pavement is supported on compacted subgrade. So, the subgrade should be sufficiently strong so that it can take the load coming on the pavement. There may be material degradation that may affect the performance of pavement.

And poor drainage is also one of the reasons for pavement deterioration. The water that is coming on the pavement that is the surface water should be properly drained off for the pavement and if the water is not properly drained off, it may accumulate that may damage the surface material, it will also percolate through some cracks or joints to the inner layers and that may further damage the pavement.

So, there are different reasons for the pavement deterioration and the rate of deterioration is different for different types of pavement. Generally, bitumen is more susceptible to temperature and moisture as compared to concrete. So, the deterioration of Bituminous pavement is more frequent as compared to concrete pavement. Therefore, it is necessary to evaluate the performance of the pavement on a regular basis.

And both the functional performance and structural performance need to be assessed periodically. And by evaluating the performance of the pavement, we can assess the need for maintenance and rehabilitation of an existing pavement. So, based on the results of the performance evaluation, both functional performance and structural performance, the need for maintenance and for the rehabilitation of the existing pavement can be assessed.

So, it is important to properly evaluate the performance of existing pavement, so that if there is any maintenance requirement or strengthening requirement that can be timely addressed, and the pavement can perform in a better way and serve for longer duration.

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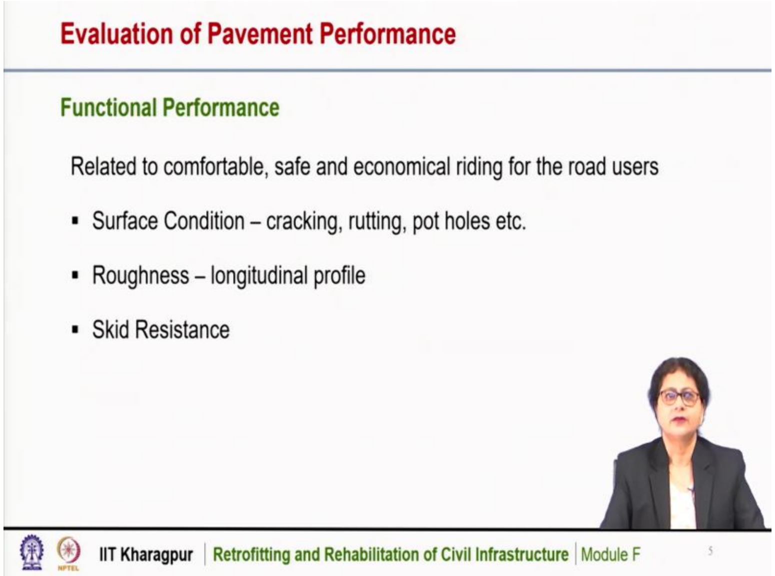

For the functional performance, this is related to the comfortable, safe and economical riding for the road users. So, the main function of the pavement is to carry the vehicular load safely and comfortably. So, the functional performance of pavement relates to the comfortable, safe and economical riding for the road users. Therefore, it is important to assess the surface condition, the roughness and the skid resistance of the pavement.

The surface condition includes the amount of cracking, rutting, pot holes etcetera on the pavement. Surface roughness means the longitudinal profile of the pavement and skid resistance is also important because for moving vehicle, there should be sufficient friction on the surface otherwise, the vehicle may suffer skidding. So, for a safe ride of the vehicles, it is important that there should be sufficient friction or skid resistance on the surface.

The surface should be properly uniform and there should not be too much of undulations or cracking or rutting. All these may cause uncomfortable ride to the road users. So, functional performance includes the assessment of the surface condition, the longitudinal profile and the skid resistance of the pavement.

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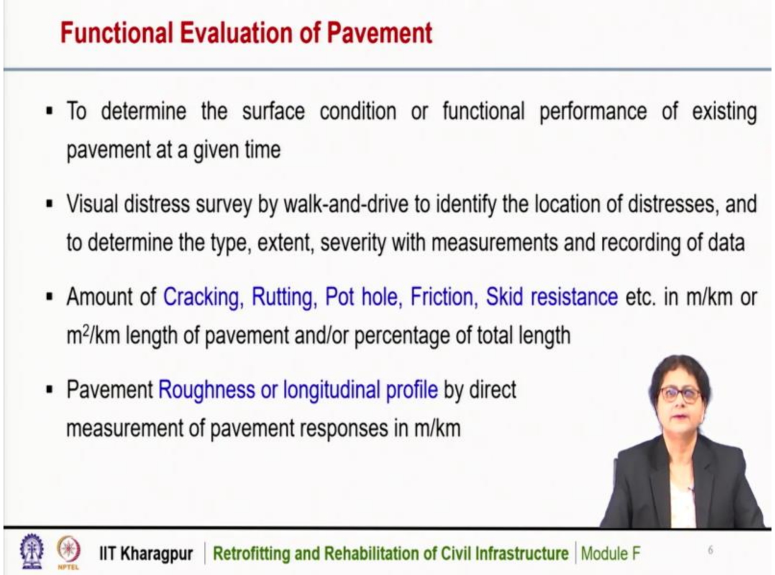

To determine the surface condition or functional performance of existing pavement at a given time, is therefore important for the functional evaluation of pavement. Visual distress survey can be carried out by walk and drive to identify the location of distresses on the pavement and then to determine the type, extent and severity of the damage with measurements and recording of the data.

So, we can carry out a visual distress survey and that can be done by walking or by a car to identify the locations of distresses and how much damage has been occurred on the pavement if it is cracking, rutting or pot hole, how much is the amount of damage that can be determined from this survey.

So, the amount of cracking, rutting, pot hole or amount of friction, skid resistance etcetera can be determined from this type of condition survey and they can be determined in meter per kilometer or meter squared per kilometer length of the pavement or in terms of percentage of the total length of the pavement. So, we can determine the extent of damage per kilometer length of the pavement or the damage could be in terms of meter square of area per kilometer length of pavement or in terms of percentage of the total length.

So, that way we can determine the amount of damage on the pavement. Pavement roughness or longitudinal profile can be measured by direct measurement of the pavement responses in meter per kilometer. So, this is the longitudinal profile of the pavement or the roughness that we can measure by the response of the pavement in meter per kilometer.

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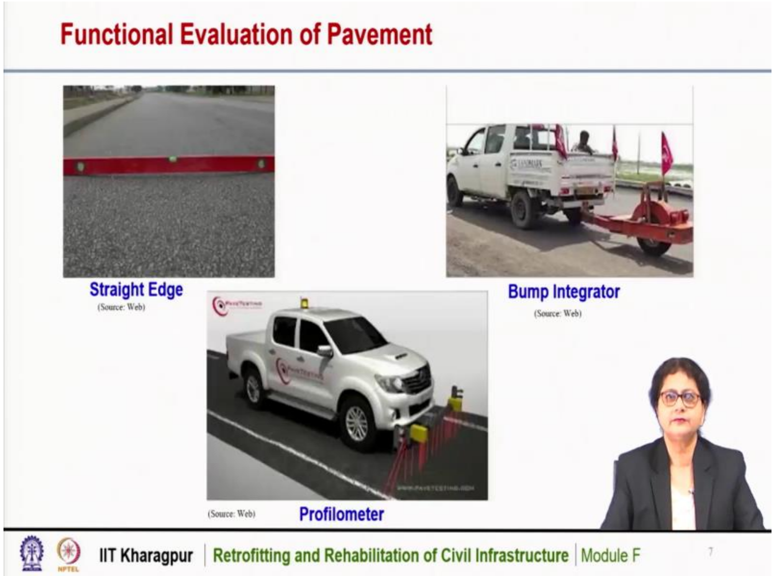

There are several equipments that can be used for the functional evaluation of pavement. Here are few of the equipment shown here. So, this is a straight edge, with the straight edge we can measure the undulations or the amount of rutting on the pavement. So, here we can see that there is the depression on the surface.

So, this straight edge can tell us the amount of depression, how much is the depression we can measure and that can be determined in per kilometer length of the pavement, how much is the depression. This is a bump integrator; with this we can determine the longitudinal profile of the pavement. So, this is a bump integrator or sometimes called fifth wheel bump integrator, by which we can measure the roughness of the pavement.

This is an advanced equipment laser profilometer. Here with this equipment, we can measure the longitudinal profile of the pavement and also the amount of cracking or rutting or pot holes that can be measured with this type of profilometer. So, these are the additional arrangement has been made on this vehicle.

And through this laser technology, the amount of depression or the undulations can be accurately measured by this profilometer. So, there are several other equipment available and with that we can evaluate the surface condition of the pavement, which is a measure of its functional performance.

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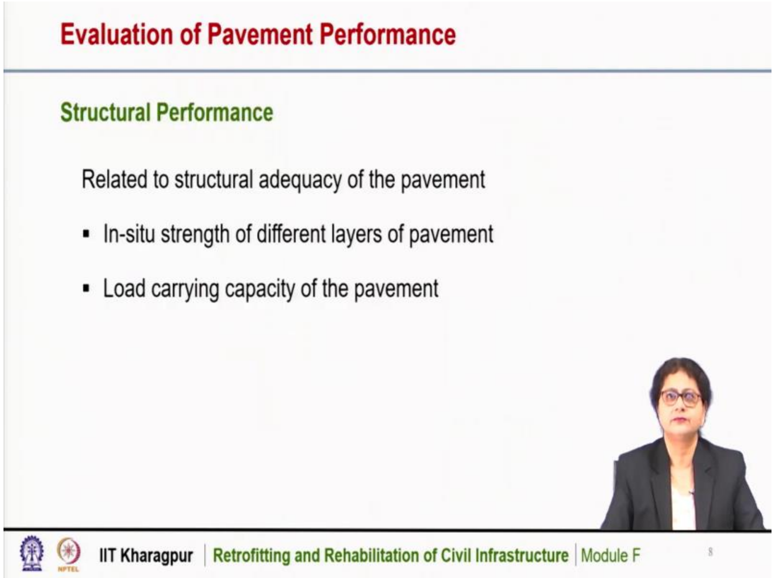

Now, for the structural performance of pavement, this is related to the structural adequacy of the pavement. Here the in-situ strength of the different layers of pavement is estimated and also the load carrying capacity of the pavement is estimated. So, the structural performance is related to the structural adequacy of the pavement. What is the in-situ strength of the different layers of the pavement and what is the load carrying capacity of the pavement?

So, to evaluate the structural performance of the pavement, it is important to estimate the in-situ strength of the different layers and the overall load carrying capacity of the pavement. For evaluating the performance of pavement, it is necessary to estimate the functional performance as well as the structural performance. A pavement may be structurally strong, but it may happen that its functional performance is poor that means the surface condition is poor.

So, it will not provide comfortable and smooth journey to the road users. And if a pavement is structurally weak, it is unable to carry the traffic it is intended for, then it requires further treatment or maintenance or rehabilitation. So, for functional inadequacy as well, a pavement may require maintenance and rehabilitation and also for the structural, if it is inadequate, then proper treatment and strengthening or rehabilitation is necessary.

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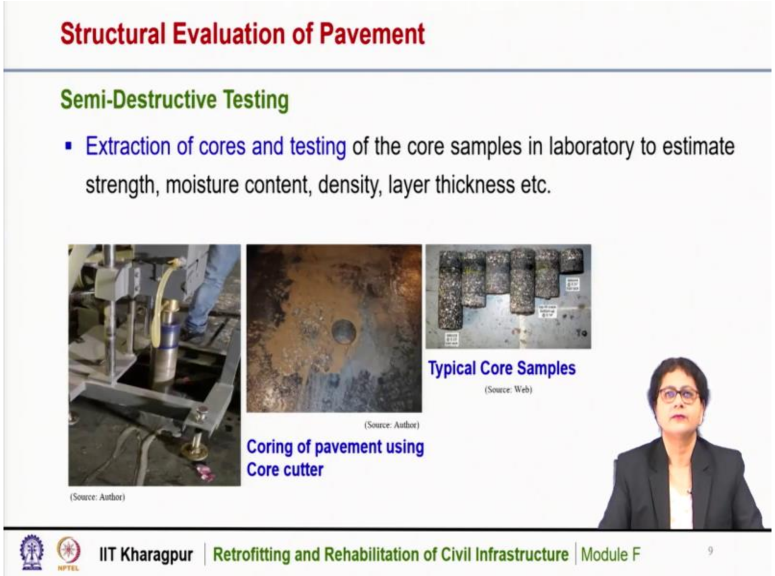

For structural evaluation of pavement, there may be different ways we can evaluate the performance of the pavement. One is semi destructive testing, semi destructive testing is the extraction of cores, and testing of the core samples in laboratory to estimate the strength, moisture content, density or layer thickness etcetera.

So, like in other structures, we can extract cores, from the pavement and those cores can be tested in the laboratory and we can estimate the strength of the pavement material, the moisture content, the density or the layer thickness and many other properties as well. There is a picture of core cutting on the pavement using core cutter, as you can see this is an existing pavement and the core cutter is placed here for the extraction of cores.

And once the core is extracted, the pavement surface looks like this. So, coring of the pavement using the core cutter and this is a picture of typical core samples for the testing. So, we can see here that the different layers can also be seen in this picture. So, we can estimate the layer thicknesses as well. So, this is from work done in Kolkata and the pavement was evaluated.

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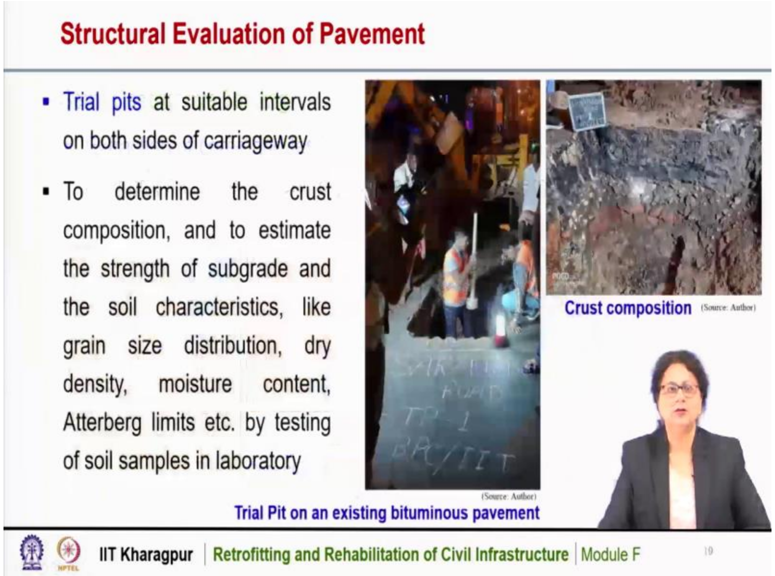

Along with extraction of course, trial pits can also be dug and this is prepared to estimate the strength of the soil. So, trial pits are dug at suitable intervals on both sides of the carriageway to determine the crust composition and several properties of the soil, like the strength of the subgrade and soil characteristics like grain size distribution, dry density, moisture content, Atterberg limits etcetera by testing the soil samples in the laboratory.

So, we can take the soil samples from the trial pit and test it in the laboratory to determine the strength of the subgrade and several characteristics of the soil like grain size distribution or Atterberg limits like liquid limit, plastic limit, etcetera, the dry density, moisture content and also the physical characteristics of the soil.

So, here are some pictures of the trial pit, that is being made on an existing bituminous pavement in Kolkata that is one of our projects, the pavement was evaluated and the trial pit was done. And this picture shows a part of the trial pit and from here we can see the crust composition. So, all the different layers which are present for the existing pavement, the composition of the different layers and their thicknesses are obtained from this trial pit.

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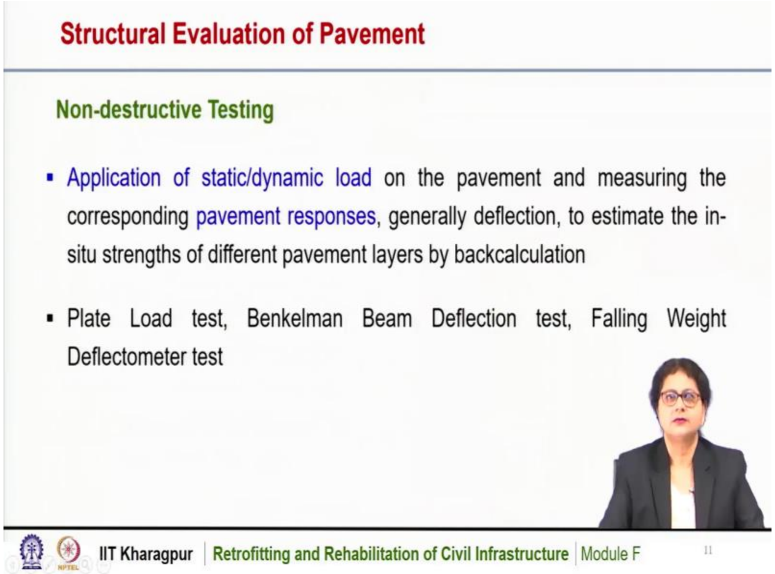

Non-destructive testing can be used for the structural evaluation of pavement. In non-destructive testing, there is an application of static or dynamic load on the pavement and then the measuring of the corresponding pavement responses is done. The pavement responses maybe deflection or strain and that we can measure using some sensors to estimate the in-situ strength of different pavement layers by back calculation.

So, in non-destructive testing, we apply a static load or a dynamic load on the pavement and by measuring the pavement responses, we can estimate the in-situ strength of the different pavement layers by back calculation. There may be different tests for non-destructive type of evaluation. Plate load test, Benkelman Beam Deflection test, Falling Weight Deflectometer tests are the most common NDT tests on pavement. Plate load test is widely used for determination of the subgrade strength.

And in this test, the static load is applied. Benkelman Beam Deflection test or BBD test is also used for bituminous pavement evaluation and in this test also static loading is applied. Falling Weight Deflectometer test is an advanced NDT test and this test is now widely used for structural evaluation of pavement both Bituminous pavement and concrete pavement. This equipment is very useful for estimating the structural strength of pavement and that is why its used is wide in recent years.

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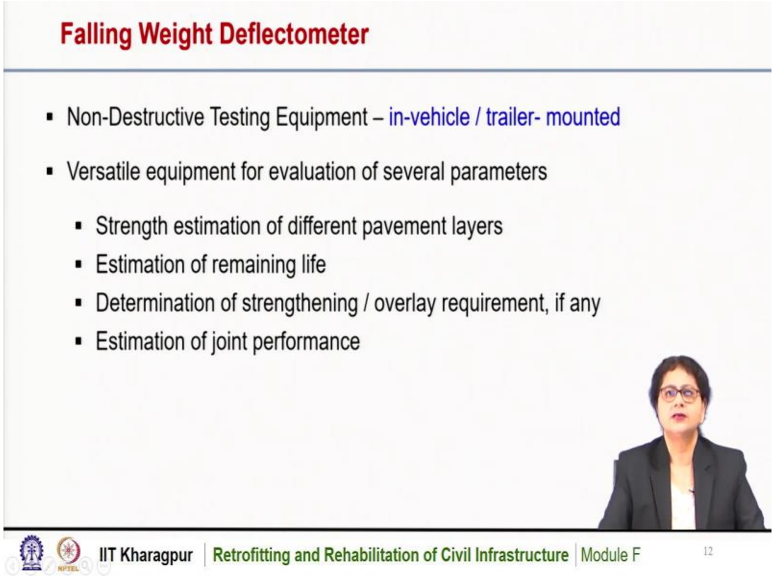

So, we will discuss the structural evaluation of pavement using falling weight deflectometer. It is a non-destructive testing equipment and the equipment maybe in vehicle or trailer mounted. This is a versatile equipment for evaluation of several parameters of the pavement performance. We can carry out strength estimation of the different pavement layers, estimation of remaining life of the pavement, determination of strengthening or overlay requirements for an existing pavement that can be determined from FWD testing.

And estimation of joint performance can also be done using FWD testing for concrete pavement. So, there are different evaluation techniques by which we can assess the strength of the different pavement layers, we can estimate the remaining life or the strengthening requirements or the joint performance, the load transfer efficiency or the detection of voids etcetera below the pavement slab. So, these can be evaluated using falling weight deflectometer or FWD.

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There are several commercial models available for falling weight deflectometer and in IIT Kharagpur also we have developed two different models, actually three different models were developed. So, this is the second model which is an in-vehicle falling weight deflectometer model and this is a trailer mounted falling weight deflectometer model, these are all IIT KGP model. And a lot of works have been done on pavement, on highways to evaluate the structural performance using these falling weight deflectometer equipment.

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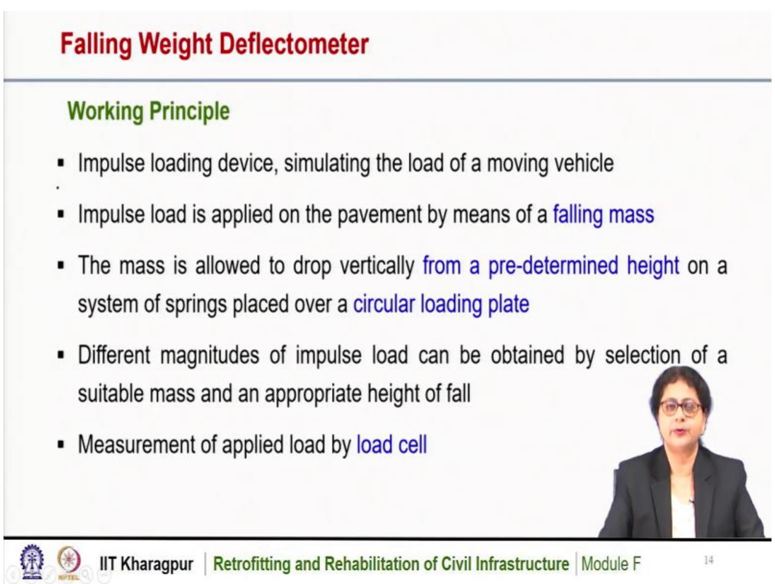

So, we will discuss the working principle of falling weight deflectometer. This is an impulse loading device that simulates the load of a moving vehicle. So, this is more realistic as compared to BBD test because there the load is applied static loading and here it simulates the load of a moving vehicle. The impulse load is applied on the pavement by means of a falling mass.

The mass is allowed to drop vertically from a predetermined height on a system of springs placed over a circular loading plate. Different magnitudes of impulse load can be obtained by selection of a suitable mass and an appropriate height of fall. And we can measure the applied load by a load cell. So, the load can be adjusted, we can apply different amount of load by adjusting the height of fall and the amount of mass that is to be dropped.

So, different magnitudes of impulse load can be applied on the pavement by selecting the suitable mass and an appropriate height of fall.

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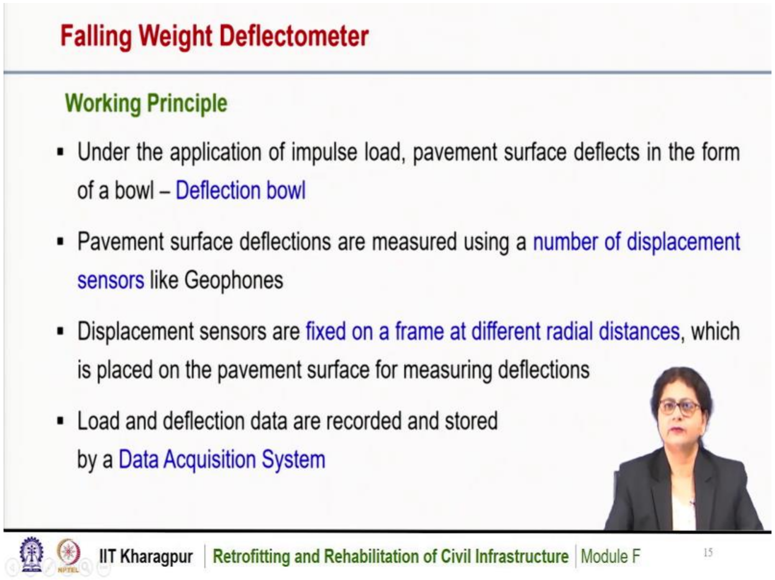

Under the application of the impulse load, the pavement surface deflects in the form of a bowl and we call it deflection bowl. So, the maximum deflection occurs just below the loading plate and as we go farther the deflection reduces. So, if we can take the several deflections, it takes the form of a bowl or saucer, so we call it a deflection bowl.

So, under the application of the impulse load on the pavement, the pavement surface deflects in the form of a bowl. And this is commonly termed as deflection bowl. The pavement surface deflects and the deflections are measured using a number of displacement sensors and geophone is a default displacement sensor that is used for measuring the surface deflections.

The displacement sensors are fixed on a frame at different radial distances, which is placed on the pavement surface for measuring the deflections. The load and the deflection data are recorded and stored by a data acquisition system. So, the data acquisition system is inbuilt into the equipment and we can record the load data as well as the deflection data.

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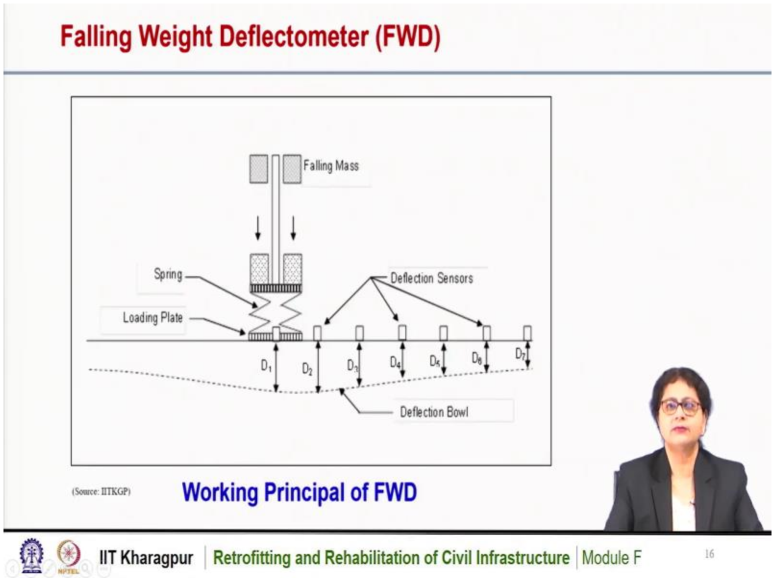

So, this is the schematic diagram of the working principle of falling weight deflectometer. This is the pavement surface and this is the schematic diagram of the equipment, this is the loading plate that is to be placed on the pavement surface. So, this is the loading plate and these are the springs. This is the falling mass and this has to be dropped from a certain height to this plate.

And this is placed on springs and there are rubber pads through which this falling mass is dropped from the height and is placed on this plate and through this spring system it is applied to this loading plate. And there is a sensor which measures the load that is the load cell is attached here.

So, we can measure the applied loading and these are the locations of the displacement sensors. So, these are the sensors which can measure the deflection at different points. So, one sensor is placed just below the load and then at some specific distance apart the displacement sensors are placed.

So, when the load is applied on the pavement, the pavement surface deflects in the form of a bowl. So, maximum deflection will be there just below the load and when we go farther away from the load point the deflection is reduced. So, D2 is less than D1. Similarly, D3 is less than D2 and these Di are the displacements of the pavement surface. So, there are a number of sensors to measure these deflections.

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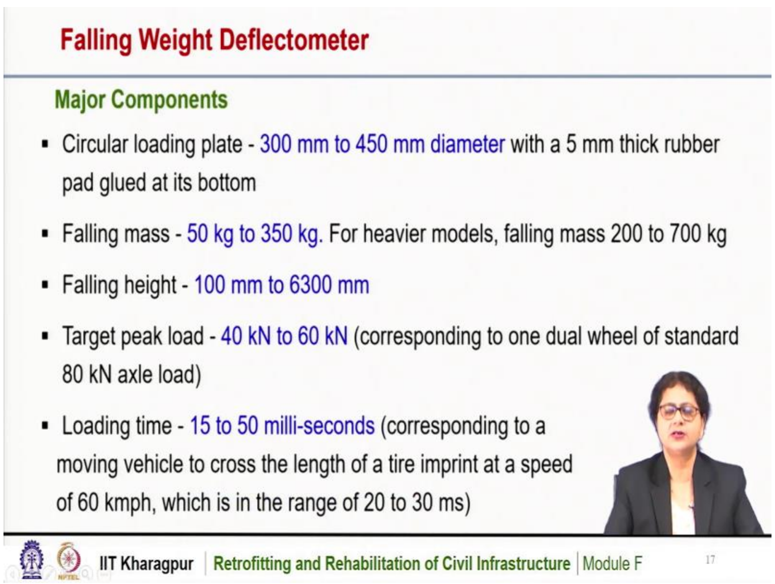

So, the major components of falling weight deflectometer are a circular loading plate, which is to be placed on the pavement surface and that is 300 millimeter to 450 millimeter diameter with a 5 millimeter thick rubber pad glued at its bottom. The falling mass that needs to be dropped and the amount of this falling mass is 50 kg to 350 kg, for heavier models falling mass maybe higher may range from 200 to 700 kg. Falling height, we can adjust that falling height it may be from 100 millimeter to 6300 millimeter.

So, there is a significant height and by adjusting the height we can drop the mass, the target peak load is 40 kN to 60 kN. This corresponds to one dual wheel of standard 80 kN axial load. So, we are trying to put the load in such a way that the applied load is 40 kN or 60 kN. The loading time is 15 to 50 milliseconds.

This corresponds to a moving vehicle to cross the length of a tire imprint at a speed of 60 kilometer per hour which is in the range of 20 to 30 milliseconds. So, the load is applied that is a sinusoidal load is applied and the loading time is ranging from 15 to 50 milliseconds. So, in case of a moving vehicle when it is traveling at a speed of 60 kilometer per hour to cross the length of a tiring print, it generally takes the time of 20 to 30 milliseconds. So, considering that, here also the load is applied, such that the loading time varies from 15 to 50 milliseconds.

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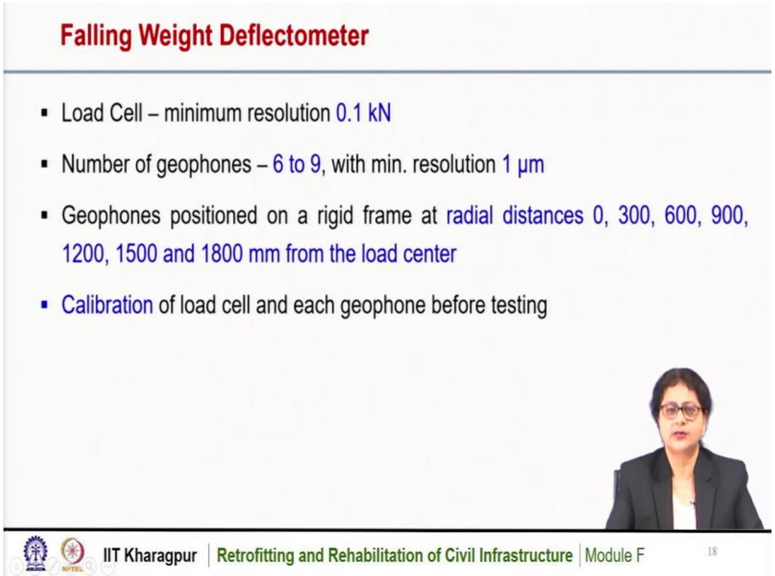

There is a load cell for measuring the applied load and the minimum resolution should be 0.1 kilo Newton. A number of geophones are required that is the displacement sensor. So, for different types of FWD, a number of geophones may be there and the number of geophones may vary from 6 to 9 and these geophones also have minimum resolution of 1 μm.

So, a number of geophones maybe they are and these geophones are positioned on a rigid frame at radial distances 0, 300 millimeter, 600 millimeter, 900 millimeter, like that up to 1800 millimeter, if there are seven geophones from the load center. So, one geophone is there for measuring the central deflection just below the load. And at equal intervals, we have to place these geophones, generally it is kept as 300 millimeter.

So, for 5, 6 or 7 or 9 geophones accordingly the frame is to be arranged and the geophones need to be attached on the frame. Before the testing all the geophones and the load cell need to be calibrated. So, this is important for all the testing, all the geophones and the load cells need to be calibrated.

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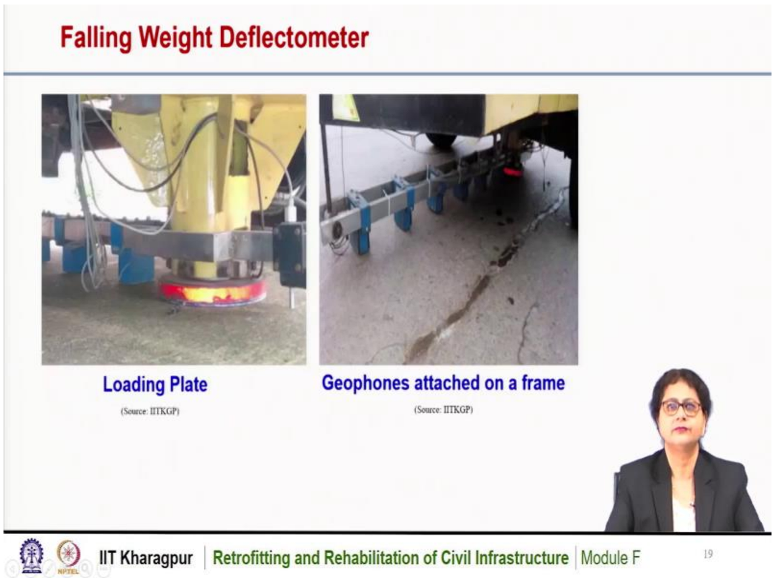

This is the picture of the loading plate of the FWD. So, this is the loading plate through which the load is applied and this is the rigid frame on which the geophones are attached. So, here we can see that they are placed on the pavement surface before testing. So, these are the geophones which are attached on this rigid frame and this is the loading plate.

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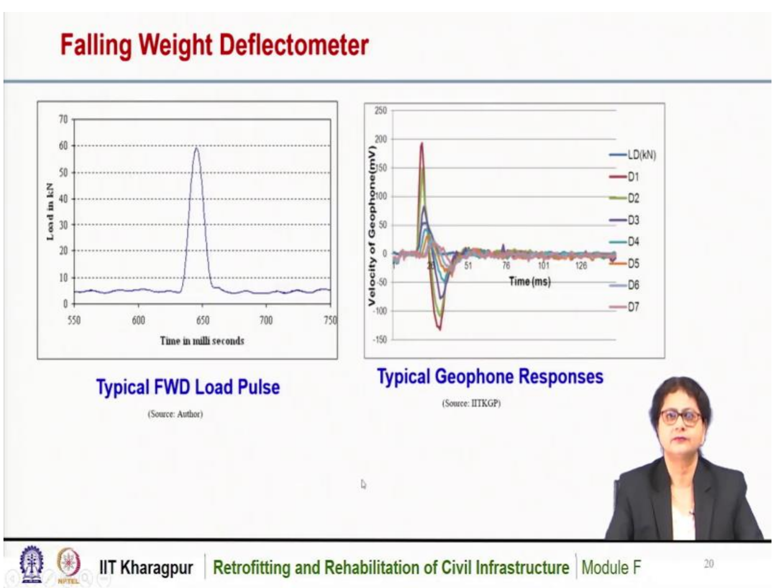

This is a typical FWD loading impulse. So, here we can see that it is applied for a very short duration and this is a typical load impulse. And this picture shows a typical geophone response. So, there are seven geophones in this FWD and the responses of the geophones are also sinusoidal here as you can see that the maximum deflection is measured from the central deflection sensor and as we go farther the deflection reduces. So, this can be seen from these plots.

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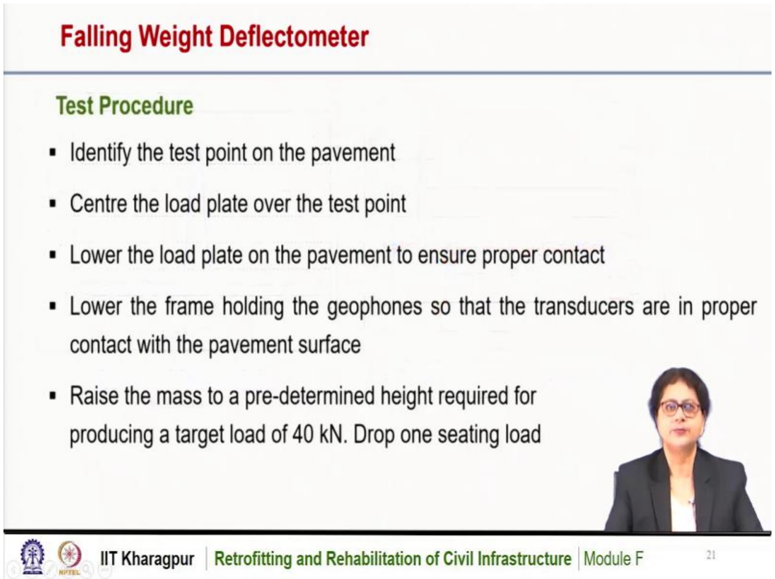

Now, the test procedure for FWD is first we need to identify the test point on the pavement, then we need to place the load plate center over the test point. Now, we need to lower the load plate on the pavement to ensure proper contact. So, the load plate is to be placed properly on the load point and we have to ensure that there is proper contact between the load plate and the pavement surface. There should not be any gap and we should avoid the location where there are undulations.

So, the entire load plate area should be in contact with the pavement surface and there should not be any water or any grease material on the pavement and that we have to check before testing. Now, we need to lower the load plate so that the proper contact is maintained. Then we need to lower the frame holding the geophones so that the transducers are in proper contact with the pavement surface.

So, once the load plate is placed, and in proper contact with the pavement surface we need to place the frame, that is the frame which connects the geophones. We need to lower the frame, holding the geophones so that all the geophones are in contact with the pavement surface. So, they are placed in such a way that the geophones are in contact with the pavement surface.

Now, we need to apply the load. So, raise the mass to a predetermined height, required for producing a target load of 40 kilo Newton then we drop one seating load. So, this is just for the initial checking, we may not record this seating load. So, we target that the applied load should be 40 kilo Newton.

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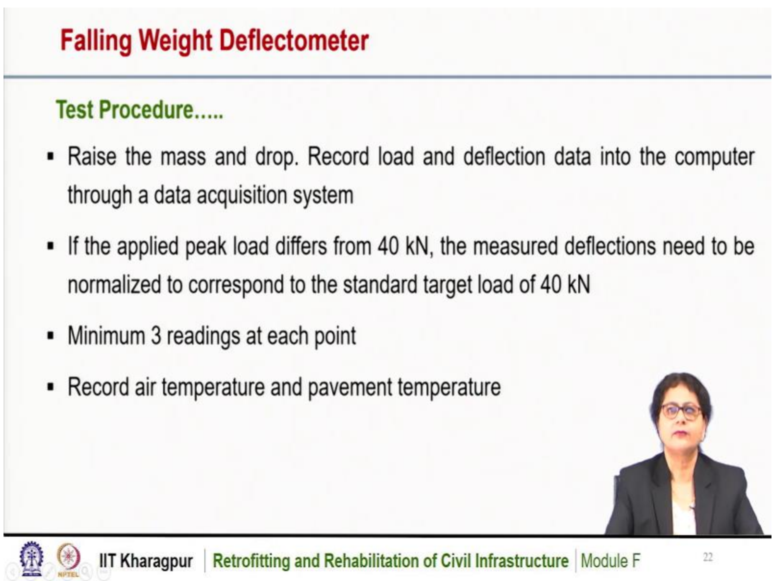

Now, we need to raise the mass and drop from the desired height. So, the load is applied. Now, we need to record the load and the deflection data into the computer through the data acquisition system which is there in the equipment. So, the mass is dropped and as it drops, the load is recorded and the paper deflects and all the deflection data from the sensors are recorded through this data acquisition system.

If the applied peak load differs from 40 kN, the measured deflections need to be normalized to correspond to the standard target load of 40 kN. Sometimes it is difficult to maintain 40 kN for the application of load. So, we may apply load which may be different from the standard load. So, in that case we can normalize the deflections correspond to the standard target load of 40 kN.

And at each point, we need to take at least three ratings. We also need to record air temperature and pavement temperature, because temperature may affect the deflection of the pavement. Because there may be curling effect due to temperature. So, we need to record the temperature of the pavement as well as the air temperature. Generally, the pavement temperature is higher as compared to the air temperature.

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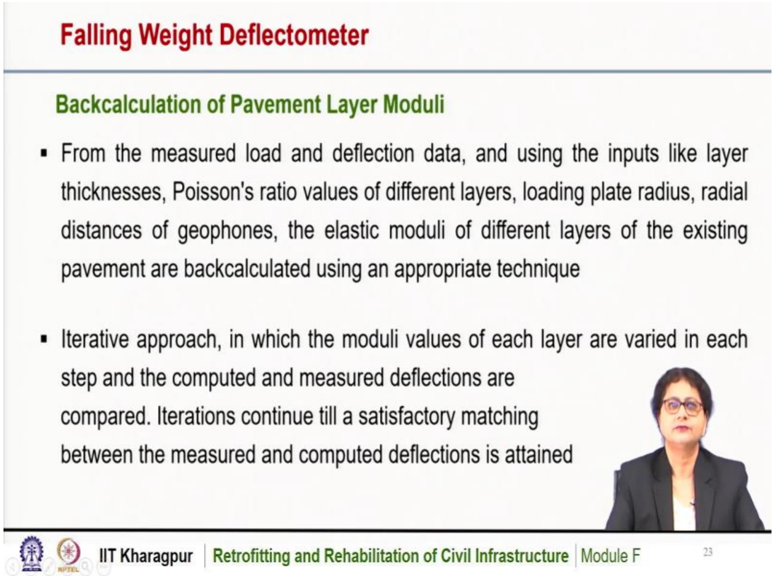

Now, we need to analyze the data. So, here we need to back calculate the pavement layer moduli. So, from the measured load and deflection data and using the inputs like the layer thicknesses, the Poisson's ratio values of different layers, loading plate radius, radial distances of the geophones, the elastic modulus of different layers of the existing pavement are back calculated using an appropriate technique.

So, here we have other inputs like what are the layer thicknesses, what are the Poisson's ratio of different layers and we also know the loading plate radius, the radial distances of the geophones etcetera. So, from this and we also have the applied load and the deflection of the pavement at different points with 7 or 9 geophones.

So, now, we back calculate the elastic moduli of the different layers, that means, which elastic moduli will produce this type of deflections on the pavement surface that we want to find out. So, we back calculate the elastic modulus of the different layers from the load and deflection data and the inputs from the pavement geometry. So, this is an iterative approach in which the moduli values of each layer are varied in each step and the computed and the measure deflections are compared.

So, iterations continue till a satisfactory matching between the measured and the computer deflections is attained. So, first we assume some elastic modulus for the different layers, the top layers and the base, sub base as well as the subgrade and then we analyze it and check that whether our computer deflections and the major deflections are matching or not.

So, if it does not match, we can make another trial. So, it is an iterative process by which we can estimate the moduli values and this iteration continues till the matching is satisfactory. So, this way we can back calculate the pavement layer moduli.

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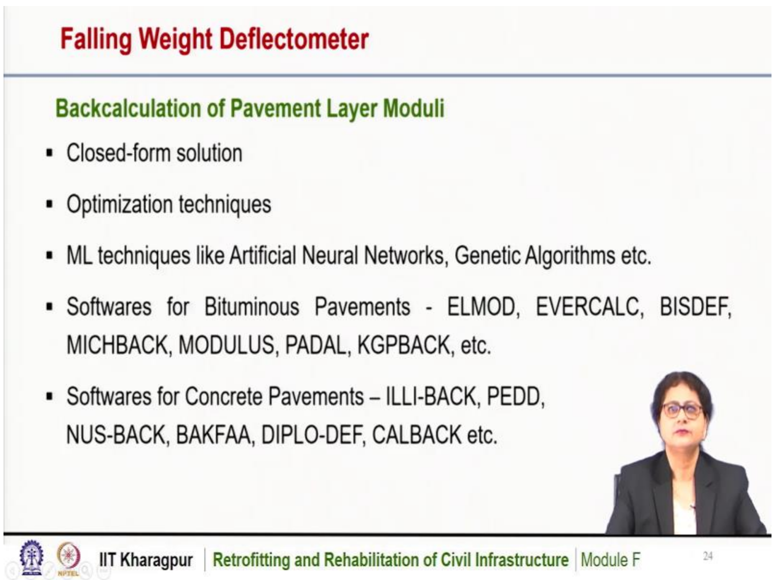

So, there are different techniques for back calculation as found in the literature. It may be closed-form solution, there is several optimization techniques that are used for back calculation of the pavement layer module, there are machine learning techniques that are also used in recent years, artificial neural networks or genetic algorithms, etcetera.

And these are developed to back calculate the pavement layer moduli so that we can assess the in-situ strength of the different layers. So, by back calculation of the pavement layer modulus we can find out the in-situ moduli, that tells us the strength of the different layers. So, we can assess the condition of the pavement in situ. So, there are several software that have been developed for this type of back calculation technique.

For bituminous pavements a number of softwares have been developed by researchers like ELMOD, EVERCALC, etcetera, KGPBACK has been developed by IIT Kharagpur and that is used in India for the back calculation of different layers moduli in bituminous pavement. A number of softwares are also available for concrete pavement and these are ILLI-BACK, NUS-BACK, etcetera.

And these softwares have been developed based on several road testing using falling weight deflectometer. So, these softwares can give us the back calculated elastic modulus of different layers. And by assessing these back calculated elastic modulus value we can determine the in-situ condition of the pavement layers and the strength of the pavement.

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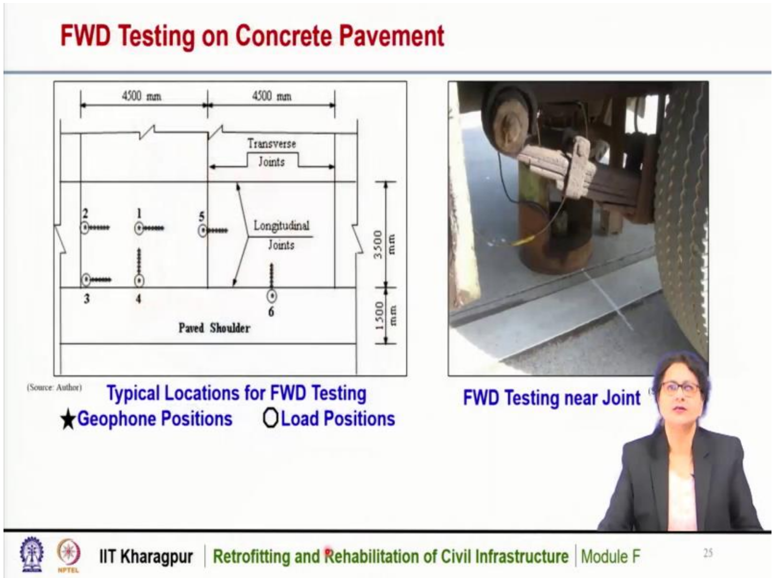

These are the pictures and schematic diagrams of the FWD testing on a concrete pavement. This is a part of a national highway where we have carried out the FWD testing. This diagram shows the panels of the concrete pavement, these are the two panels separated by joints, this is the transverse joint spaced at 4.5 meter and these are the longitudinal joints and there is paved shoulder. So, the panel size was 4.5 × 3.5 meter with a 1.5-meter paved shoulder.

And the joints were provided with dowel bars. The transverse joints were provided with dowel bars and longitudinal joints were provided with tie bars. And these are the locations of the FWD testing on the pavement. So, this circle represents the load plate position and these stars are the geophone positions. So, in this FWD, this is IIT KGP FWD model, it has seven geophones and one geophone is just below the loading plate to measure the deflection below the load point and on a frame the other six geophones are attached.

So, this shows that the location of the geophone frame. And all the geophones are attached to that frame and this is shown here schematically. So, these are the locations of the FWD testing, it was tested at the interior of the panel, then at the age of the panel, at the longitudinal of the panel or at the corners, etcetera.

And this picture shows the FWD testing near the joint, this is at a load position 4 we can see here, this is the longitudinal joint and the load plate is placed just next to the joint. So, the test was carried out on different locations and the layer moduli were back calculated. So, a finite element model of the existing pavement was developed.

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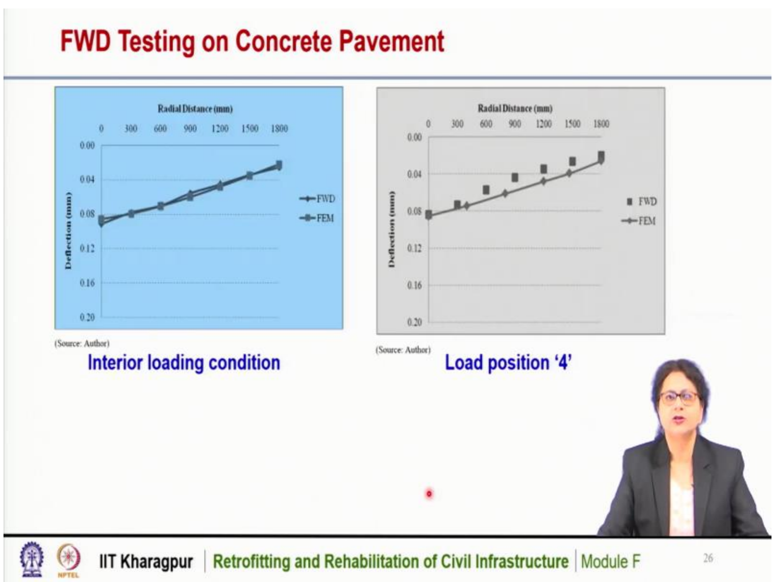

And we have carried out an iterative process to determine the deflections under the load and this load simulated the FWD loading. So, from the FWD testing, we have applied the loading on the pavement and that load is simulated in the finite element model. Then, using an iterative process we have done and then the deflections at different locations of the pavement were obtained.

So, from the deflection bowl we got the deflections at different locations and then we have compared the measured deflections with the model deflections. So, after several iterations, a fairly good match was obtained as we can see here, this is for the comparison of the interior loading condition, comparison of the deflections for interior loading conditions that is load position 1 here and the other one is for load position 4 where the load plate was placed near the joint. So, these are the points from the FWD testing.

So, these are the major deflections and these are the deflections from the model. So, similarly, for this case also, these points are the major deflections and these are the model deflections. So, we got a fairly good comparison and from that the layer moduli were obtained. So, using this falling weight deflectometer, we can obtain the elastic moduli of different layers and this is an effective method or effective testing for assessing the condition of the existing pavement.

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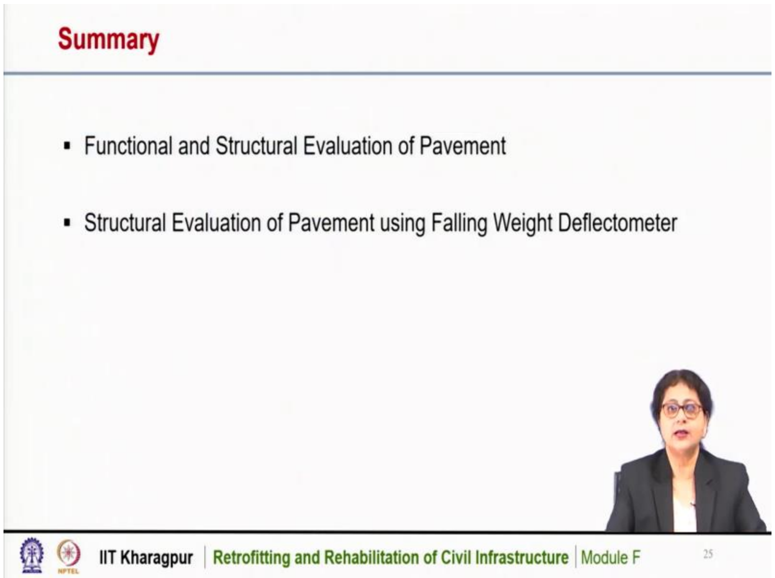

So, to summarize, we have discussed the functional and structural evaluation of pavement and we have discussed the structural evaluation of pavement using falling weight deflectometer.

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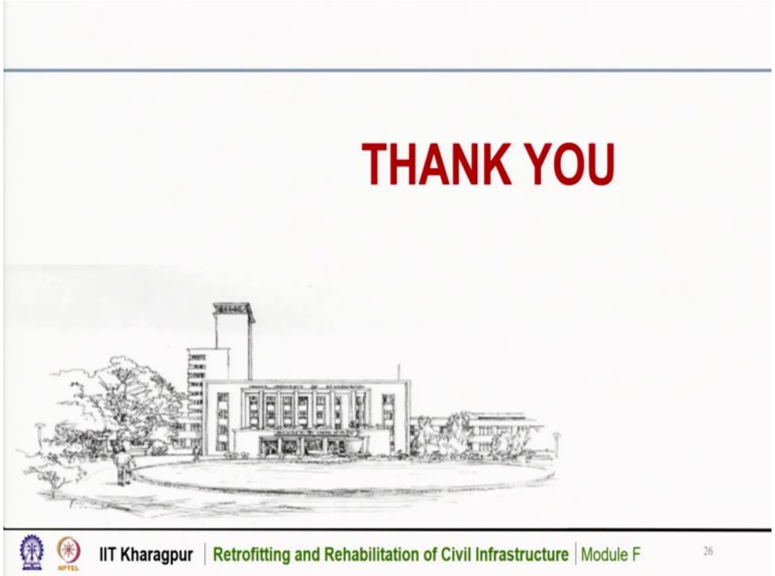

Thank you.