Introduction to Transportation Engineering
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Lecture - 26
Traffic Loading – II

Welcome to lesson 4.3 traffic loading part II. This is third lecture in pavement design module.

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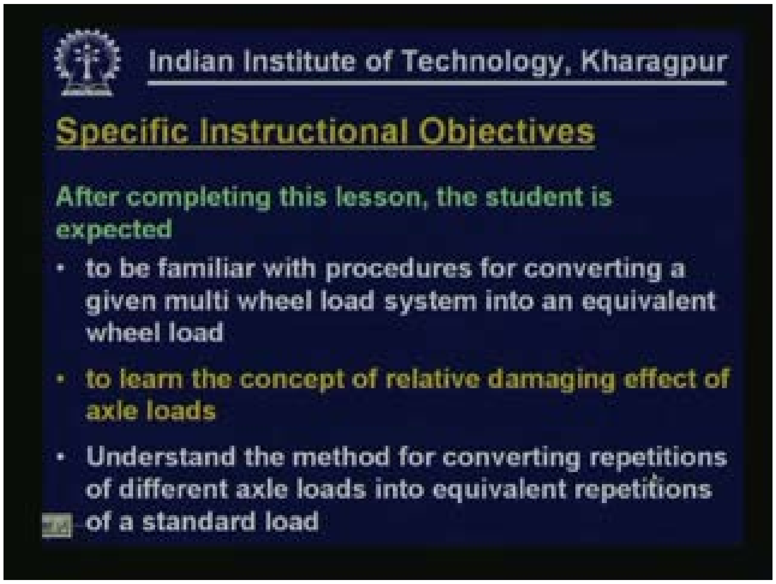

In the last lesson which was on traffic loading part one we have discussed various parameters of traffic loading that need to be considered for pavement design which included the loading which also included the transfers distribution of wheel loads, we also discussed about various types of vehicles that we have to consider like big vehicles, small vehicles which carry heavier loads and small loads and other features of traffic loading parameters we discussed.

In the last class we did not specifically discuss about certain aspects like how to take into account the different loads that are carried by vehicles. Besides this we will also consider certain other aspects that are very important for pavement design. the specific instructional objectives of this lesson would be; after completing this lesson the student is expected to be familiar with the procedures for converting a given multi-wheel load system, multi wheel load system means consisting of two wheels, more than two wheels, number of axles so the student must know how to convert all those number of wheels into an Equivalent Single Wheel Load. We'll also try to learn the concept of the relative damaging effect of axle loads and using this concept how different number of repetitions of different magnitudes or loads can be converted into an equivalent number of a standard load.

So we would be discussing about two different concepts mostly in this; that is how to convert a given wheel load configuration into an equivalent wheel load, single wheel load or how to convert different number of repetitions of different load magnitudes into an equivalent number of repetitions of a standard load. We'll also be discussing about the approaches that are normally adopted taking into account the traffic design and pavement design, there are three or four approaches so we will also be discussing those approaches.

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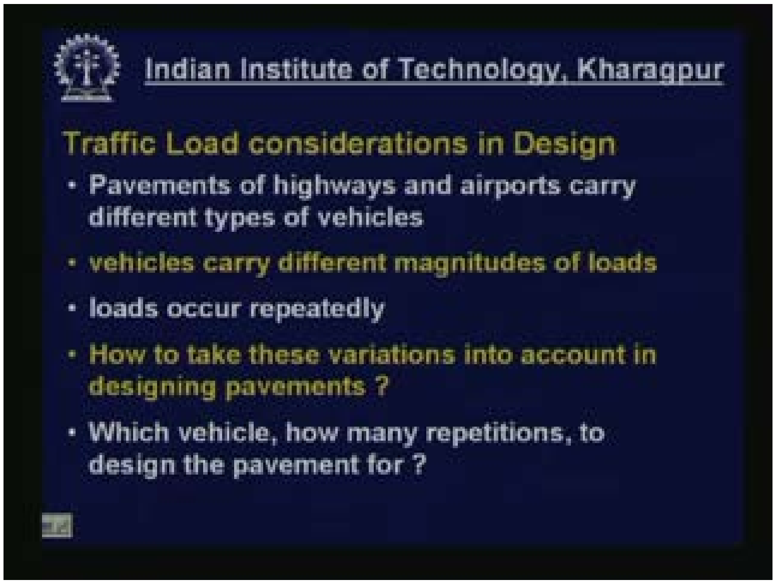

Normally traffic load is considered in design in different ways. We understand that pavements of highways or airports or other types of roads carry different types of vehicles, this we discussed in the previous lesson and these vehicles which are different in shape and size carry different magnitudes of loads and these loads occur repeatedly. Some facilities carry more number of repetitions during its service life period, some carry lesser number of loads, some of these facilities carry very high wheel loads, some carry loads of lesser magnitudes so how do we take these variations into account while designing pavements. We understand that there are going to be repetitions of loads, we also understand that the loads are of different magnitudes, so how do we account for all these things and come out with one single number and one single load which can be used as an input in pavement design? Which vehicle has to be designed or how many number of repetitions of a standard load we have to design the pavement for are the issues that we are going to discuss in this lesson.

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Load consideration pavement design are usually adopted as per three different approaches; first one is fixed traffic approach, then we have fixed vehicle approach, then the third approach is variable traffic, variable vehicle approach. Let us take up each one of these approaches one by one and discuss them.

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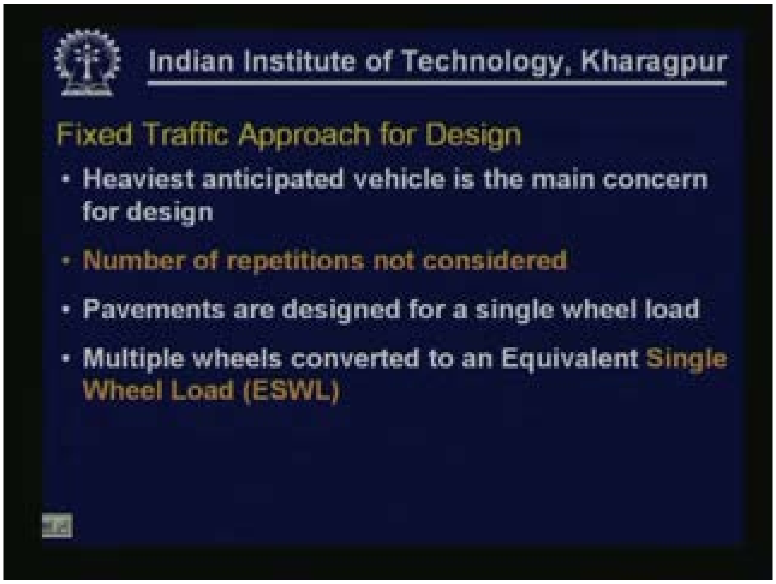

In the fixed traffic approach the heaviest anticipated vehicle is of importance for us, this is our main concern. The number of repetitions that a given facility gets is of not that significance compare to the load that the heaviest vehicle is going to carry. We are very seriously concerned about the load that the biggest vehicle or the heaviest vehicle is going to be applying on the pavement. Naturally these are facilities where the number of repetitions is not that significantly high. For example when we talk about airport pavements airports can have vehicles whose magnitudes of loads would be varying very significantly, there can be very heavy vehicles, there can be smaller vehicles, the number of repetitions are not of the order of millions like you have in the case of heavier pavements so the numbers of repetitions are not very significant but the load is very significant in this case. Therefore the pavements are designed for a single wheel load.

We are not going to take the entire configuration because the heaviest vehicle will have certain configuration in terms of the number of axles it is going to have and in terms of the number of wheels it is going to have on each axle. All these configurations whatever be the configurations number of axels, number of wheels will have to be converted into equivalent single load equivalent being that it would produce similar damaging effect on the pavement as it would be produced by the total vehicle. Hence we will be talking about an Equivalent Single Wheel Load and that is the input parameter that we will use for designing pavements for these facilities where heaviest vehicle is of concern for us.

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As I indicated multiple wheels that a vehicle has got of different configurations will be converted into an Equivalent Single Wheel Load ESWL. This is commonly used for design of airport pavements and for highway pavements on the other roads which would carry very heavy loads but it will have less traffic volume. Now-a-days this is not a very commonly used approach.

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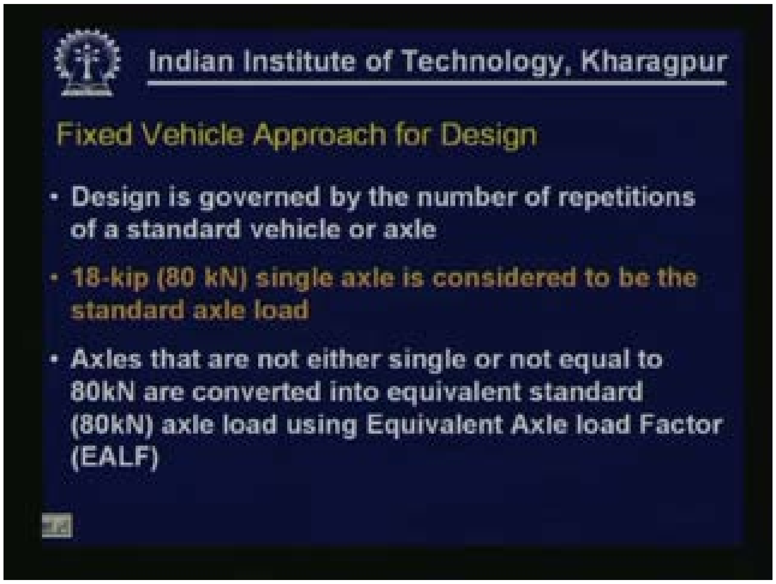

On the other hand in the fixed vehicle approach for design of pavements the design is governed by the number of repetitions of a standard vehicle. Here we will talk about the standard vehicle and then how many repetitions of a standard vehicle the pavement is supposed to carry that number is going to be the input parameter for pavement design. But we understand that there are going to be different magnitude of loads different types of vehicles and each type of vehicle may have different repetitions during the service life period during the twenty years of life period or fifteen years of life period of a given pavement.

The 10 ton axles may be of a certain number, the 8 ton axles may be of a different number, 6 ton axle may be a different number. All these weights all these numbers will have to be converted into an equivalent number of repetitions of a standard note. The most commonly used or rather the standard load that is considered is a 18-kip 18000 pound single axle load that is 80 Kilo Newton load, single axle load is considered to be the standard axle load. all the vehicles, all the axle loads that a pavement is expected to carry expected to receive during its design life period will be converted into equivalent repetitions of 80 Kilo Newton single load axle repetition.

Axles that are neither single nor equal to 80 Kilo Newton will be converted into equivalent standard axle loads using Equivalent Axle Load Factors. These are the conversion factors that were used to convert a given load into equivalent repetitions of the standard load which is 80 kilo Newton.

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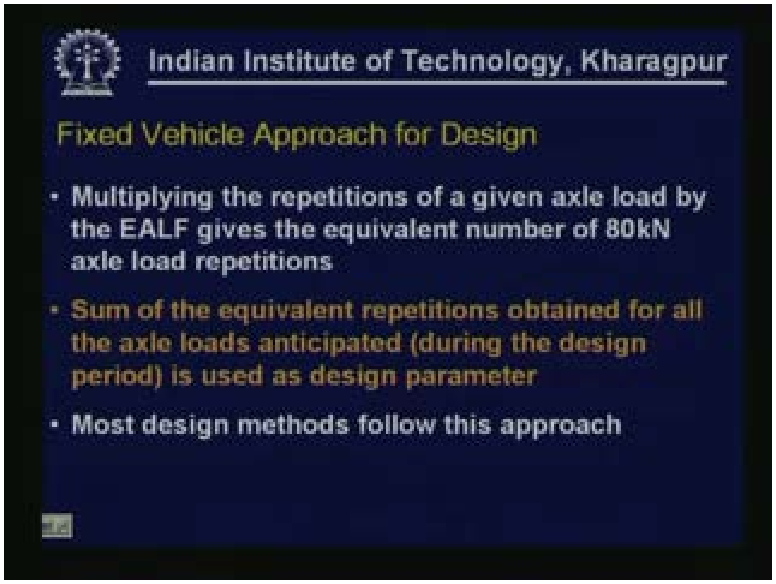

In this we multiply the repetitions of a given axle load by the equivalent axle load factor corresponding to that particular load and this will give us the equivalent number of 80 Kilo Newton axle load repetitions. but we have to have some information about what is the equivalent load factor that we have to use or equivalent axle load factor that we have to use to convert a given load into equivalent repetitions of a standard load. The sum of all equivalent repetitions obtained for all the axle loads is anticipated to be coming during the designed life period and is used as the design life period. This number of equivalent standard axles is the input for design.

Most of the design approaches follow this method of considering traffic in pavement design. We can also have an approach which is called as variable vehicle variable traffic approach in which we will not talk about a fixed vehicle, we will not talk about the standard load, will not talk about standard traffic level also rather whatever be the load whatever be the number of corresponding repetitions we will take into account all of that.

If we have ten thousand repetitions to ten ton axle we will find out what is the damage caused by ten thousand repetitions of ten ton axles and certain other repetitions of eight ten axle and then may be another thirty thousand repetitions of six ten axle. We will take into account all the loads and all the corresponding repetitions, we will not talk about anything fixed here.

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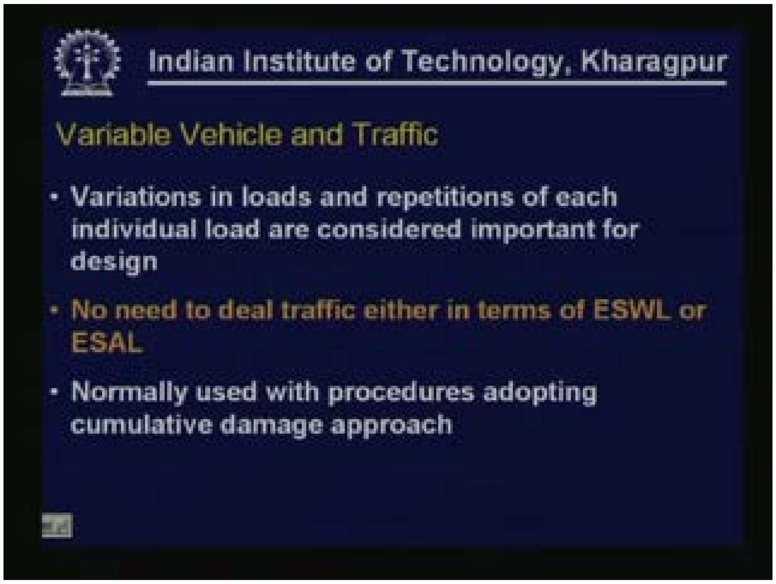

So there is no need to deal with traffic either in terms of equivalent standard wheel load or equivalent standard axle load. Such an approach is normally used with procedures where we calculate the cumulative damage of the pavement caused by individual loads and corresponding numbers such as design approaches where we are trying calculate cumulative fatigue damage or accumulated permanent deformation, for such approaches we can use this but still this is also not a very common approach.

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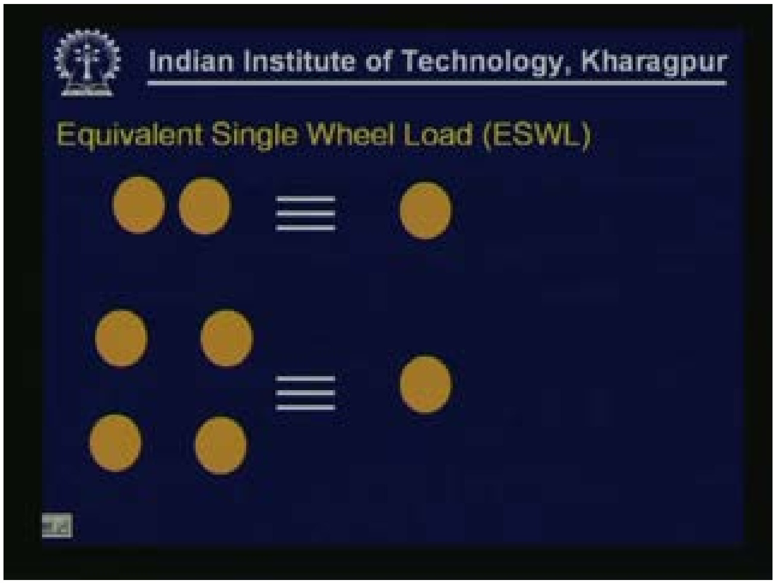

Coming to the fixed traffic approach where we have to convert a given vehicle into an Equivalent Single Wheel Load you may have two wheels, you may be talking about a dual wheel set which needs to be converted into an Equivalent Single Wheel Load or we may be talking about four different wheel loads which has to be converted into an Equivalent Single Wheel Load so there has to be some definition of what is equivalence and how that has to be calculated so there are various approaches that are to be followed.

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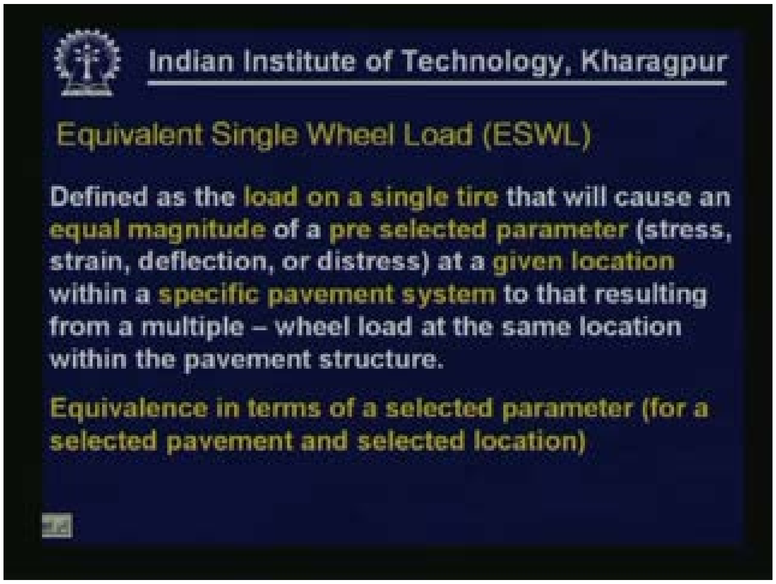

Equivalent Single Wheel Load is defined as the load on a single tire or a single wheel, that will cause an equal magnitude and that's where the equivalence is coming to picture of a pre-selected parameter, equivalence in terms of a pre-selected parameter; either stress, strain, deflection or some other distress at a given location within a specified pavement system to that resulting from a multiple wheel load at the same location within the same pavement system. So we are trying to compare two different situations. we have the effect produced by single wheel load that is Equivalent Single Wheel Load in a given pavement system, at a given location, the equivalent effect is in terms of the deflection that is produced, the stress that is produced or it can be strain so we'll have to select one of these parameters. Different agencies select different parameters.

We are also talking about a particular pavement system and the parameter is calculated at a particular location of the pavement so these are all fixed. So individual agencies define Equivalent Single Wheel Load using different framework of what is the pavement system that is considered, at which location this parameter is calculated and what is the parameter that we are calculating. Thus equivalence is in terms of a selected parameter for a selected pavement at a selected location.

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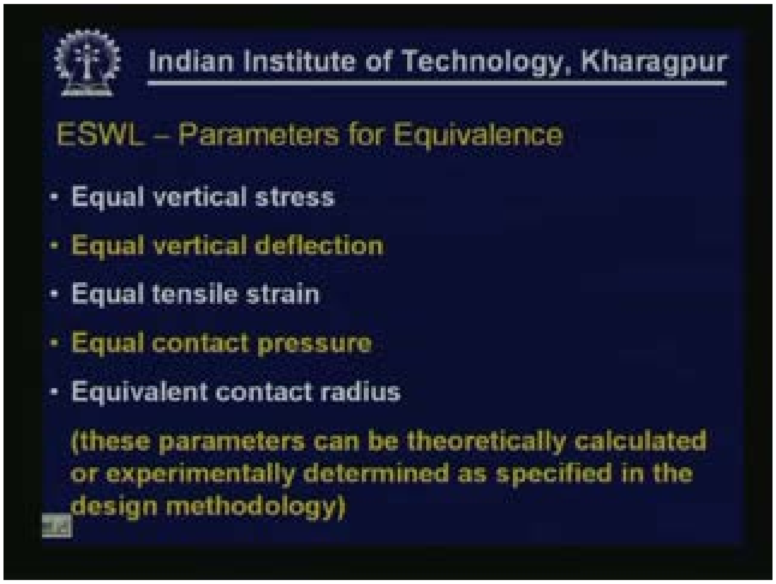

The parameters of equivalence can be equal vertical stress, equivalence single wheel load will have to produce same magnitude of vertical stress as would be produced by a set of wheel loads, it maybe in terms of equal vertical reflection it can be in terms of equal tensile strain, equal contact pressure, equal contact radius etc. These parameters can be theoretically calculated using appropriate theory or they can be experimentally determined as specified by the design methodology. So any design methodology which uses an Equivalent Single Wheel Load approach has to specify how this Equivalent Single Wheel Load has to be determined whether it has been determined by an exponential approach and if it is an exponential approach what sort of an exponent has to be conducted, how exactly this has to be done and if it is theoretical one which theory is to be used, at what location, which parameter has to be calculated etc so a complete framework has to be specified by the agency which is using the Equivalent Single Wheel Load approach.

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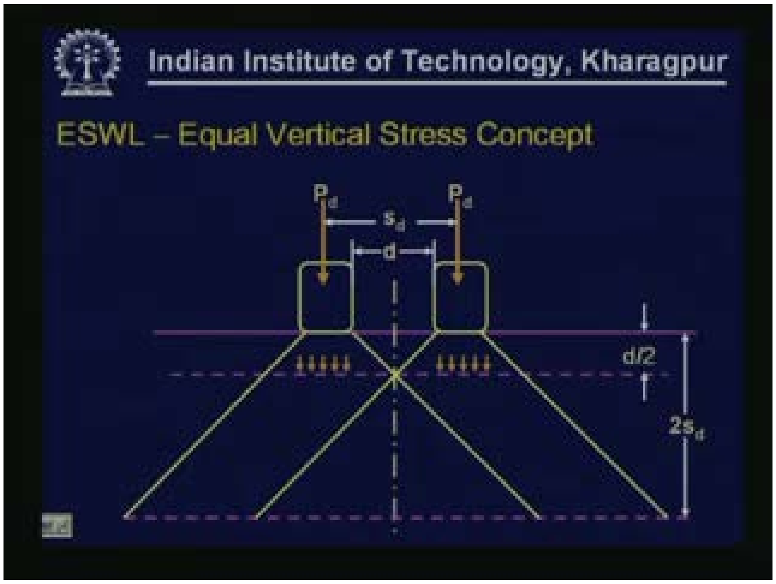

The first concept that we'll use to determine equivalent single load is equal vertical stress concept. here we are referring to equal vertical stress that is produced by, right now we are saying it is a dual wheel set, a two wheel load supplied on pavement system and each wheel load carries Pd as the load and the clear spacing between these two wheels is d and the centre to centre spacing between these two wheels is Sd.

If you see from this diagram if you make some simplification about the load distribution through this pavement stress distribution to the pavement the at a depth of d/2 these two envelopes just start getting overlapped, the stress envelopes produced by the two individual wheel loads they just start getting overlapped. And then at a significantly larger depth which is approximately equal to $2S_d$ the suffix d is normally used because we normally refer to dual wheel sets and its conversion into Equivalent Single Wheel Load but that's not exactly required so at a depth of two Sd or beyond the overlap is of such significant magnitude to such an extent. We can consider the stress produced at any given location within this overlapped zone will be equal to the stress that is produced by P_d where the left side and right side wheel are combined together.
Let us see how this concept is used to compute Equivalent Single Wheel Load.

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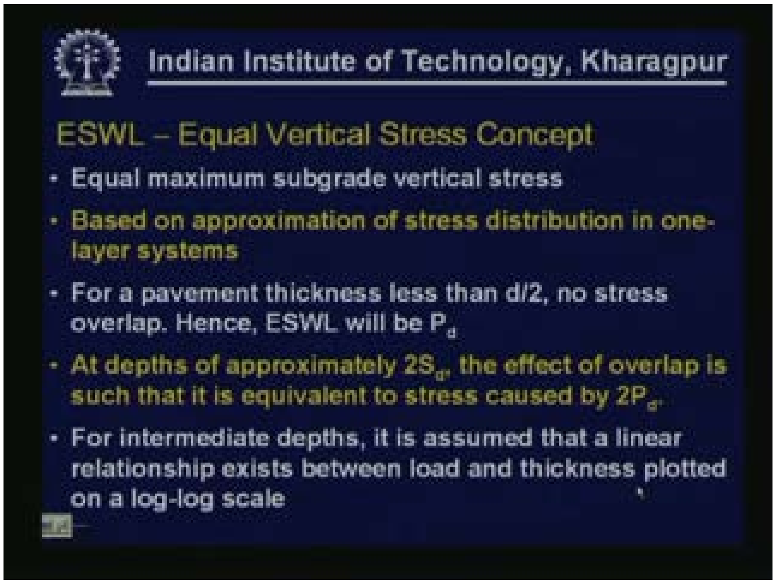

We are referring to equal maximum sub grade vertical stress. If you have a two layer system we are talking about the vertical stress on top of sub grade. If you have single layer system where there is no pavement but only subgrade that we are talking about so normally such systems are not of much importance to us but still we are referring to a single layer system, we are referring to vertical stress at a specified depth. This is based on the approximation of stress distribution in the layer system or single layer system.

For a pavement thickness less than d/2, if you have a pavement of thickness less than d/2 then there is no overlap as we have seen in the previous slide hence the Equivalent Single Wheel Load will be P_d that is equal to one single wheel load. The other wheel load is not coming to picture, its influence not to be seen at smaller depths. For a depth of approximately $2S_d$ or greater the effect of overlap is such that it is equivalent to the stress caused by $2P_d$ twice the magnitude of each one of these wheel loads. But for intermediate depths linear interpolation is made between the load and thickness plotted on a log-log scale. Let us see this in the next slide.

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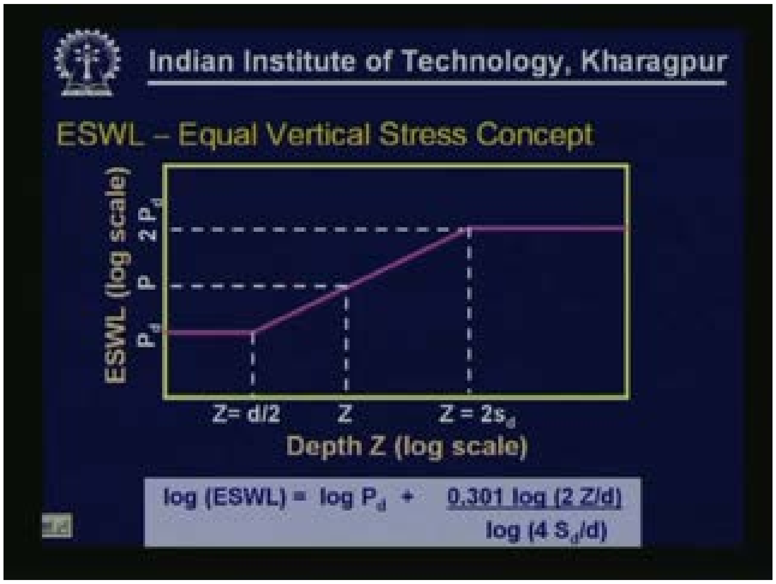

This concept is presented pictorially hep. On the x axis we have thickness plotted on a log scale and on the y axis the corresponding Equivalent Single Wheel Load is plotted. as you can see here for depths less than d/2 to the Equivalent Single Wheel Load will be P_d and for depths more than or equal to $2S_d$ the Equivalent Single Wheel Load would be two P_d and for any wheel load P can be obtained by interpolation. The expression for this is given here; log Equivalent Single Wheel Load is equal to log P_d this is one single wheel load of the dual wheel system plus 0.301 log twice depth divided by d small d is the clear distance between the wheel loads divided by log of $4S_d$ where S is the centre to centre spacing between the wheel loads divided by the clear spacing between the wheel loads.

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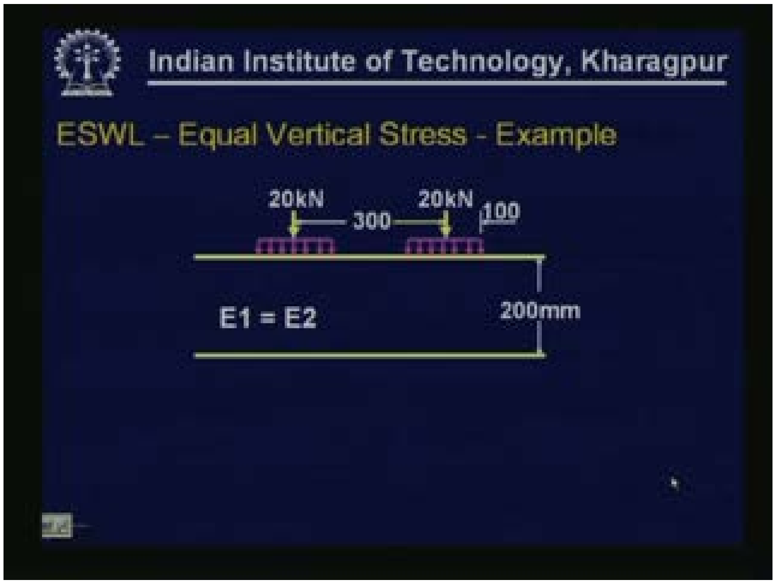

Let us take an example and calculate the Equivalent Single Wheel Load. What we have here is a dual wheel system each wheel carrying 20 kilo Newton. the centre to centre spacing between these two wheels is 300 mm and the radius of contact area assuming that these are circular contact areas is 100 mm so this will give us Pd = 20 kilo Newton, Sd = 300 mm and then d = 300 – 100 – 100 that will be hundred millimeters and the depth that was specifying is 200 mm so z = 200. Now let's see the calculations.

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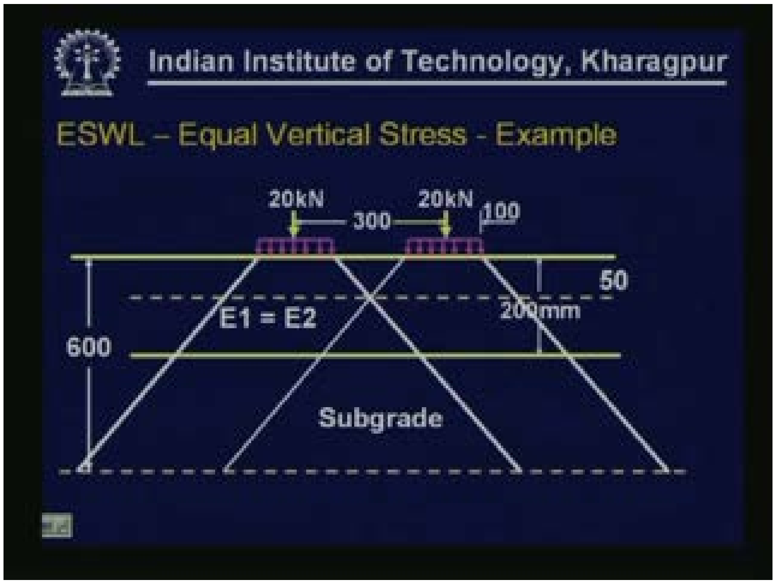

This is how we assume this stress distribution is going to be. So, at a depth of less than 50 mm that is d/2 there is no overlap so the Equivalent Single Wheel Load is going to be 20 kilo Newton, and at a depth of 600 mm that is twice Sd that is 2 into 300 there is going to be complete overlap so within this region the Equivalent Single Wheel Load will have to be 2 into 20 kilo Newton that will be 40 kilo Newton but in between at a depth of 200 mm at which we are interested in the Equivalent Single Wheel Load has to be somewhere between 20 kilo Newton and 40 kilo Newton and this we can see from this plot.

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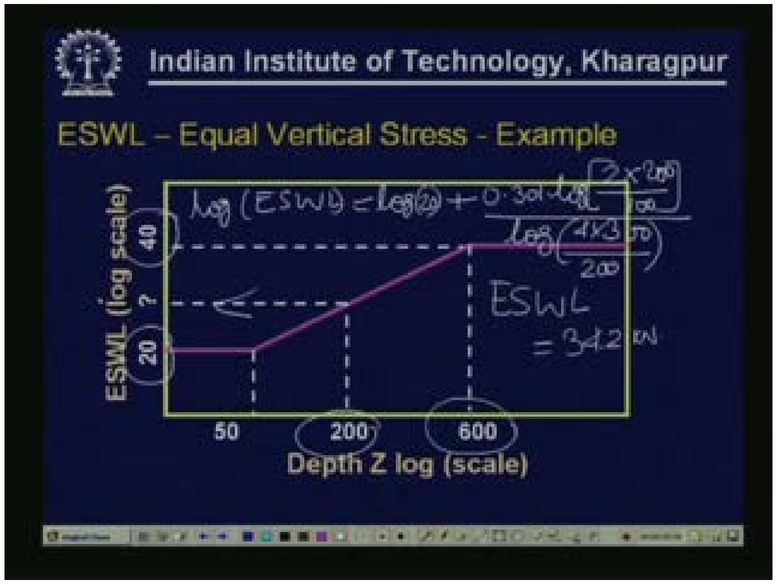

For 50 km depth 20 is the Equivalent Single Wheel Load, for 600 mm depth 40 is the Equivalent Single Wheel Load, for a 200 mm depth plotted in log-log scale we can directly obtain this thickness. Let us see if we can calculate this. Log of Equivalent Single Wheel Load will be equal to log 20 is in the expression that were given in the previous slide plus 0.301 log 2 into 200/100 where 200 is the depth by log 4 into 300/200. Solving this we will get an Equivalent Single Wheel Load of 34.2 kilo Newton. This could have been obtained graphically also.

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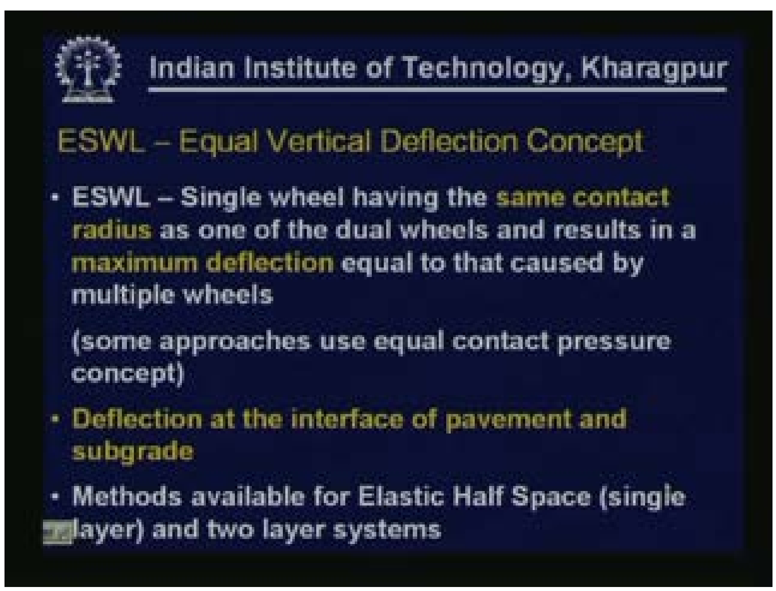

We can also adopt equal vertical deflection concept. In this approach a single wheel has the same contact radius as one of the dual wheels or as one of the multiple wheels that are there and is resulting in a maximum deflection equal to that caused by multiple wheels. So we are trying to equate the deflection we are trying to equate the maximum deflection produced by Equivalent Single Wheel Load and produced by a given set of wheel loads.

Some approaches also use equal contact pressure. Here we are trying to keep the contact radius or contact area of the Equivalent Single Wheel Load equal to that of one single wheel load of the given loading system. Normally we calculate the deflection at the interface of a pavement or at a specified depth in the pavement system if it is only a single layer system. So, if it is single layer system we calculate the deflection at a specified depth, if it is a pavement and subgrade a two layer system then the deflection will be calculated at the interface.

There are number of methods available for working out this parameter. If it is a single layer system we will use what is known as an elastic half space analysis. We will be discussing these things in greater detail when we talk about analysis of pavements. But at this stage we will just use some charts of some methods that is available for calculating these things. And we also have two layer systems for which we can calculate inter layer deflections, standard charts are available. If you have computer programs you can calculate any of these things.

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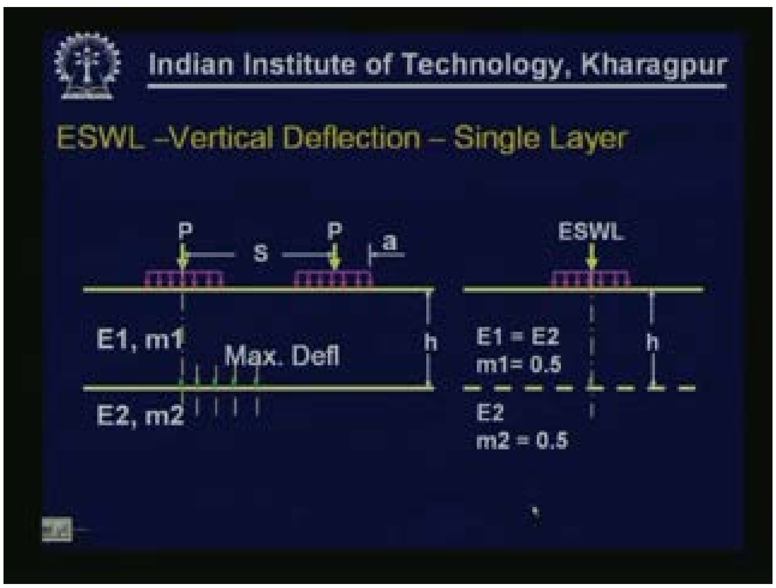

This is depicted here. We have a two wheel system here separated by a spacing S and each load being P and load rates being small 'a'. This is a two layer system which is characterized by its Poisson's ratio value and the modulus value. Modulus values are E1, E2 for the two layers, m1 and m2 represent the Poisson ratio value for the both the layers. so what we are trying to identify for the given loading system which is given on the left hand side is to find out where the maximum deflection would be at the interface which is at the depth of h. so maximum deflection on the interface we have to explore different locations. Obviously it has to be somewhere from the centre line of one of the wheel loads and at the access of symmetry of both the wheel loads. So we explore different points, calculate the deflection, find out where the maximum deflection is going to be and similarly to obtain the Equivalent Single Wheel Load we will keep the radius of this equivalent single load constant or equal to that of the radius of contact of one of these wheel loads we keep the same parameters and at this depth obviously the maximum deflection is going to be along the axis of symmetry at the interface.

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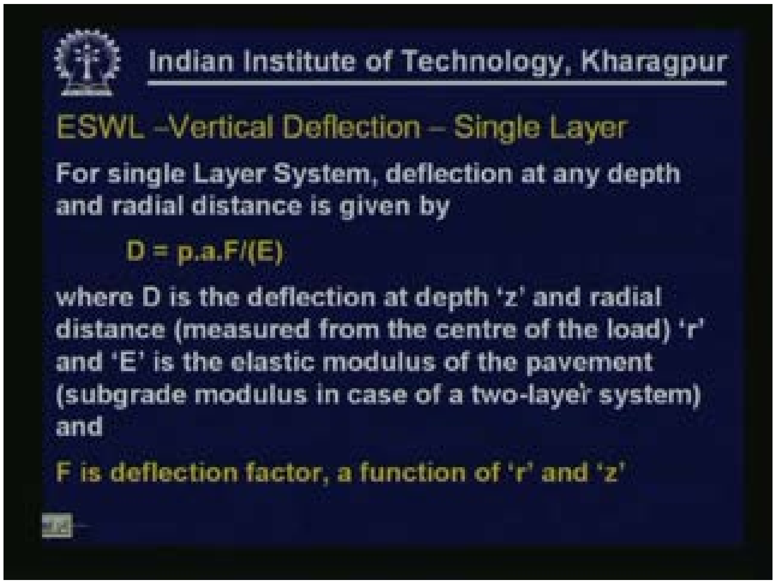

So we will try to calculate this and we will try to work out where the maximum deflection is going to be for the system that is there on the left hand side then the wheel load that will produce the same amount of maximum deflection corresponding to the left hand side system will be the Equivalent Single Wheel Load. For a single layer system the deflection is usually a function of the contact stress, radius of contact area and a function of the modulus value of the system multiplied by a factor f which is called as deflection factor where D is the deflection at depth z, radial distance R is measured from the centre of the load, E is the elastic modulus value of the pavement and subgrade modulus value in case of a two layer system and F is the deflection factor which is a function of the position of the wheel position of the point at which we are trying to calculate the deflection, z is measured from the pavement surface.

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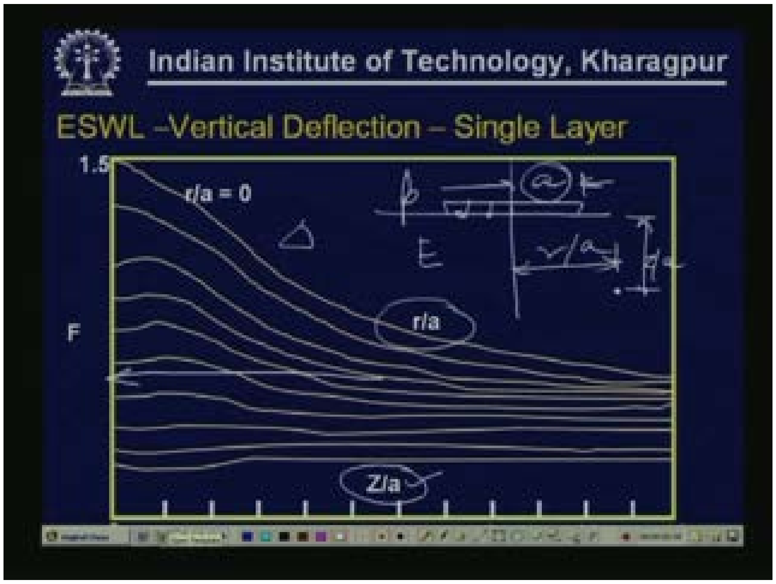

We have charts of this type available for computing vertical deflection factors as a function of depth expressed as a ratio of z by this is the radius of load contact area and also as a function of radial distance. If this is a location at which we are trying to calculate the deflection then we are referring to this radial distance and this depth expressed as r /a and z/a where 'a' is the radius of load contact area. So if you know the location we know r, we know z expressed as r/a and z/a then for a given z/a and r/a we can get the corresponding F value. Once we get the F value we can substitute this in the previous expression if you know modulus value of this material if you know p the pressure and then 'a' we can calculate the deflection.

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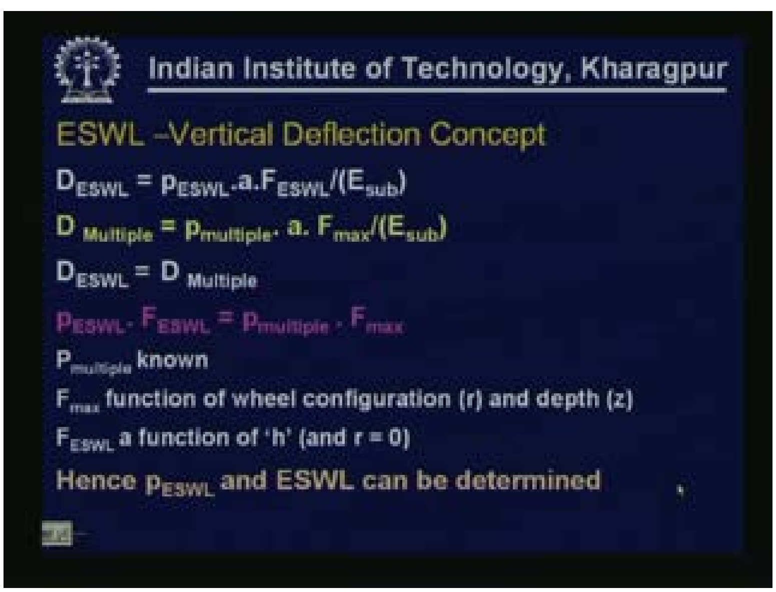

Hence as you can see here deflection produced by an Equivalent Single Wheel Load is equal to the pressure of the Equivalent Single Wheel Load, load radius that is Pa which is nothing but equal to the load radius of any one of those loads that are there in the given system and then deflection factor that is applicable for the Equivalent Single Wheel Load and then modulus value of the subgrade.

For the multiple system we have to get the tire pressure corresponding to the multiple system. This is given, this is known to us and we also know the radius of the contact area. We have to obtain what is the maximum deflection factor for the number of loads that we have and also where the maximum deflection is going to be, this is what we have to obtain and this is also known. So, for equivalence concept this has to be equal to this, the deflection produced by Equivalent Single Wheel Load has to equal deflection produced by multiple wheel loads. That means pressure for Equivalent Single Wheel Load multiplied by the load deflection factor for Equivalent Single Wheel Load will be equal to pressure corresponding to multiple wheel load and then maximum deflection factor which correspond to the maximum deflection produced by the given load system.

This is known (Refer Slide Time: 30:51) P multiple is known, F maximum is a function of the wheel load configuration that is with reference to any one single wheel load where the R and Z are the points at which we are exploring to find out the maximum deflection, F Equivalent Single Wheel Load is a function of h and obviously we are referring to r = 0 because maximum deflection is going to be produced along the axis of symmetry so r = 0 but we have to see what is the depth at which we are referring to then the corresponding factor has to be selected. So this way P Equivalent Single Wheel Load and corresponding Equivalent Single Wheel Load can be obtained. Once we get this, from this and the load contact area we can calculate Equivalent Single Wheel Load.

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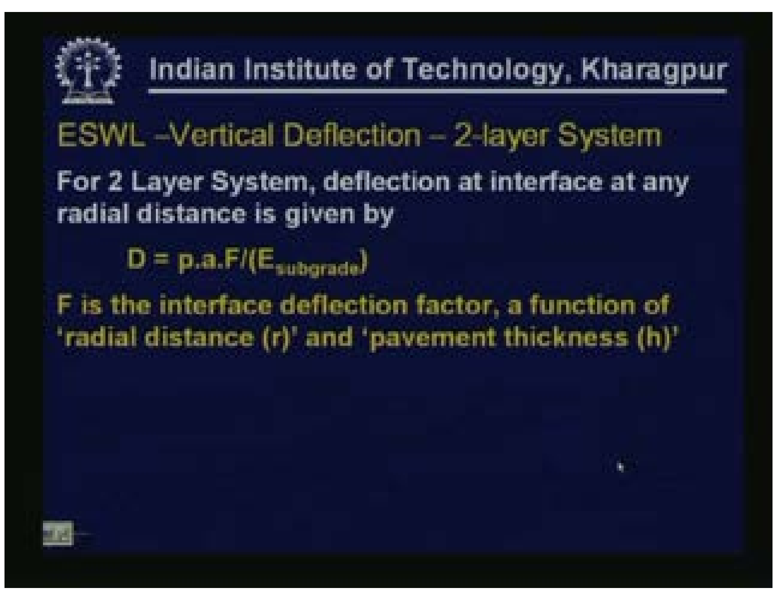

For a two layer system also we can adopt a similar concept. here also we use this same approach, the deflection is a function of pressure, load contact area rather the radius load contact area, deflection factor and the subgrade modulus value where F is the interface deflection because if it is a two layer system we are interested in the deflection that occurs at interface. F is the interface deflection factor which is a function of the radial distance and pavement thickness which difference the location of the interface like in the previous case.

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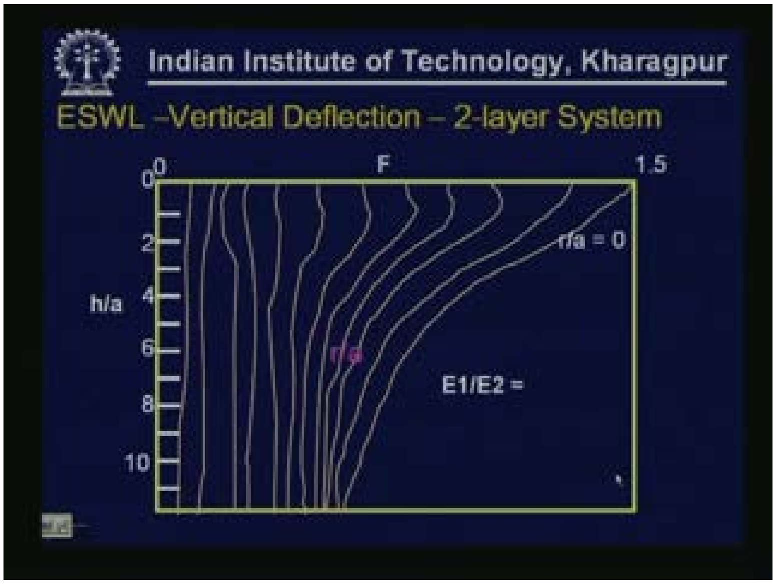

So we have a similar chart available for interface deflection factor given by F which is a function of the radial distance r and the thickness of the payment which defends the interface location. You normally get standard charts and standard literature for various charts available for different module ratios where E1 is the modulus value of the upper layer, E2 is modulus lower layer and for any given ratio you can get a set of chart for this. Therefore once you identify the chart that has to be used you know the radius at which this has to be calculated and also the thickness of the pavement which defines the interface location you can identify the interface deflection factor.

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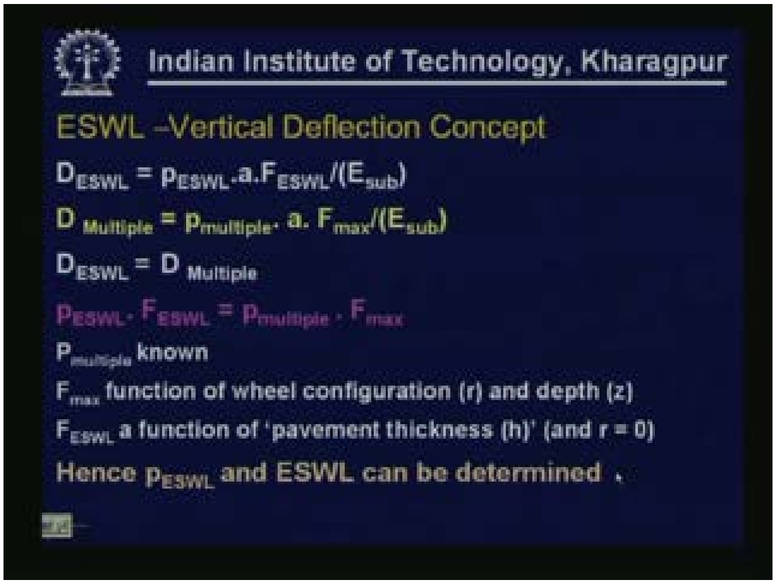

Thus following the same approach that we used earlier Equivalent Single Wheel Load is P Equivalent Single Wheel Load 'a' deflection factor for Equivalent Single Wheel Load and then modulus value D multiple deflection produced by multiple wheel load is pressure multiple, radius of load contact area, the deflection factor that corresponds to maximum deflection produced by all those wheel loads, modulus value of the subgrade equating these two you will get this pressure multiplied by deflection factor for both the systems. Like in the earlier case we know multiple system P, F maximum has to be evaluated for the given configuration, F Equivalent Single Wheel Load is a function of thickness since r = 0 and once we get this value we can calculate the corresponding Equivalent Single Wheel Load.

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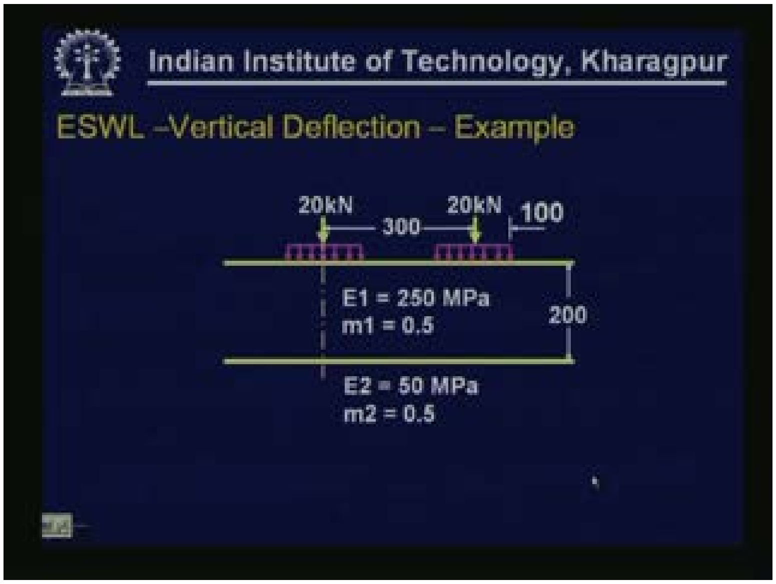

Here is an example; we are trying to work out Equivalent Single Wheel Load for a dual wheel load system 20 kilo Newton each separated by 300 mm centre to centre spacing, ‘a’ is 100 mm, the modulus value of the first layer is 250 mega Pascal, modulus value of the second layer is 50, Poisson ratio values of both the layers is taken as 0.5, interface is at a depth of 200 mm that is thickness of the pavement is 200 mm.

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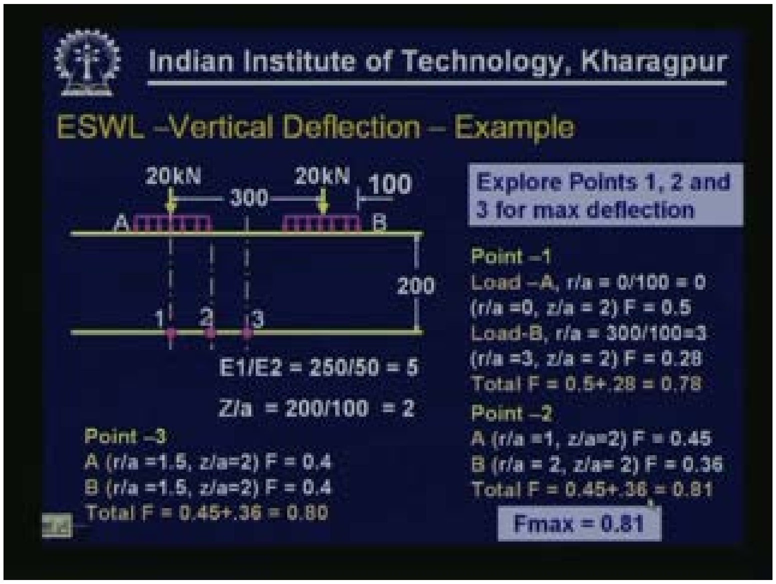

For this how we proceed is for the given loading system we explore different locations starting from 0.01, 0.02, 0.03 and we can explore more points also so find out the what is the deflection at this location, what is the deflection at this location or alternative we will try to find out what is the deflection factor because once you know deflection factor Pa deflection factor divided by modulus value of the subgrade and other things being constant deflection is basically a function of f. So, for load ‘a’ radius is 0 so r/a0, z/a = 2 that is 200/200 = 2 so the deflection factor corresponding to this load at this point can be obtained using the chart we know r/a, z/a.

Similarly the deflection that is produced at this location by load B can also be worked out by the corresponding radial distance and the depth. For this point and for this load the radial distance is 300 mm so that is 300/300 = 3. And z/a is the same ratio as you have here so for this the deflection factor is 0.28 as seen from the previous chart and in this case it was 0.5 so the total deflection factor which is influenced by both these wheel loads at this point is 0.5 + 0.28 = 0.78. Similarly, for 0.2 r/a = 1, z/a = 2 because the radial distance is 100, a = 100 so r/a = 1, z = 200, a = 100, z/a = 2 so this deflection factor is 0.45, the deflection factor due to B can also be similarly obtained; r/a = 2, z/a = 2, deflection point is 36 so the total deflection factor is 0.45 +| 36 = 0.81.

We can also similarly explore point three. Thus for both load A and B the deflection factor can be obtained as point four because of symmetry the total factor here is 0.3 so out of the three locations that were explored to identify where the maximum deflection is going to be on the interface you can see 0.2 gives a deflection factor of 0.81. Possibly there could have been another point where if you can explore it further which would have been slightly larger than this

0.81 value. Anyway assuming that this is the location where maximum deflection is going to be we’ll find out the corresponding Equivalent Single Wheel Load to produce similar deflection at that location.

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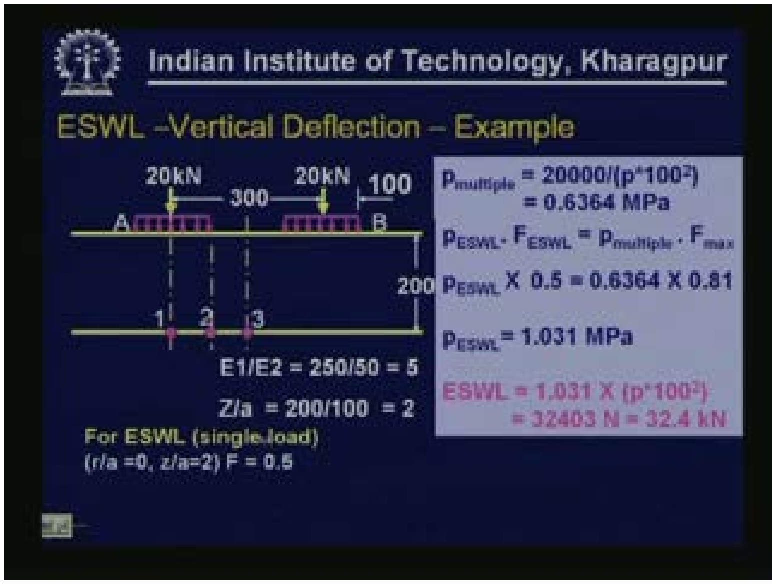

So P multiple is given as 20000 by, this is the radius so this is the pressure for the given system 20 kilo Newton is there and radius of contact is given so we can calculate the tire pressure so P Equivalent Single Wheel Load multiplied by factor of Equivalent Single Wheel Load is equal to P multiple into F maximum, F maximum we already worked out as 0.81, pressure is point six three six four that we have calculated, F Equivalent Single Wheel Load will be for a given single wheel load r = 0, z/a = 2, for this F will be 0.5 (Refer Slide Time: 38:50) so this also determined so we only need to determine what is the tire pressure corresponding to Equivalent Single Wheel Load so from this expression you can calculate it as 1.031. Once we have the tire pressure corresponding to Equivalent Single Wheel Load you can calculate the Equivalent Single Wheel Load tire pressure multiplied with the area of contact, load contact area since we know the radius of the load contact so this gives us 32.4 kilo Newton.

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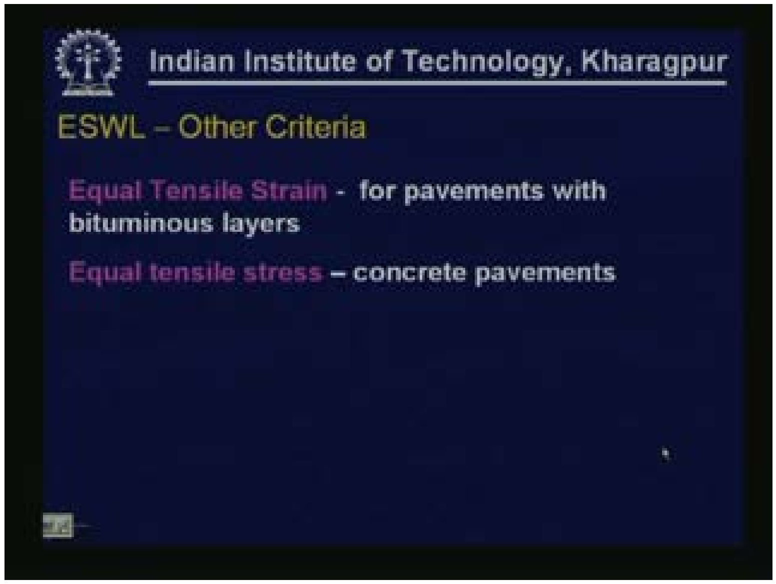

There are various other concepts also that can be utilized for working out Equivalent Single Wheel Load. We have seen equal vertical stress, we have also seen equal vertical deflection at a certain depth or at the interface we can also use equal tensile strain, equal tensile stress and other concepts also can be used.

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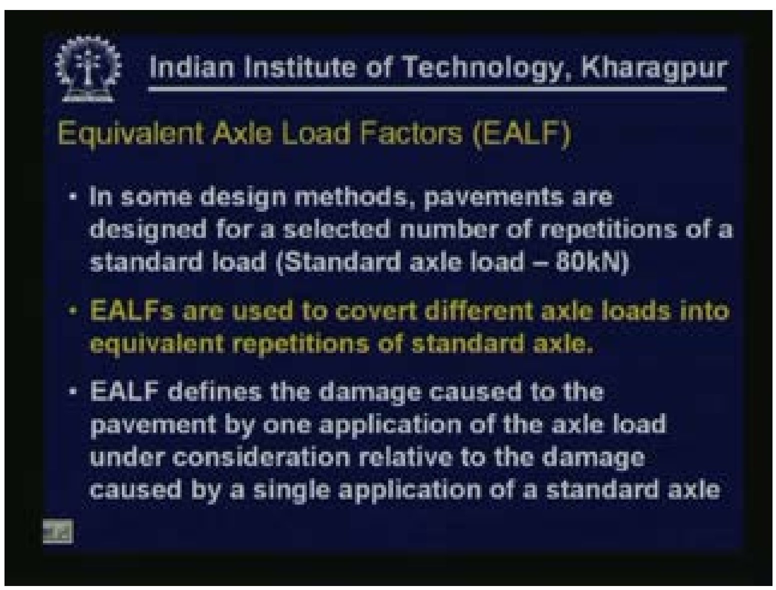

If we are using fixed vehicle concept wherein we are talking about a fixed vehicle and converting the repetitions of all other vehicles into an equivalent number of repetitions of the fixed vehicle we are going to make use of Equivalent Axle Load Factors. In some design methods pavements are designed for selected number of repetitions as we discussed earlier. The standard load that is considered is 80 kilo Newton. Equivalent Axle Load Factors are used to convert different axle loads into equivalent repetitions of standard axle. Equivalent Axle Load Factor defines the damage caused to the pavement by one application of the axle load under consideration 100 kilo Newton or 120 kilo Newton relative to the damage caused by a single application of a standard axle which is 80 kilo Newton. So the damage caused to the pavement by different axle loads are compared and Equivalent Axle Load Factors are worked out.

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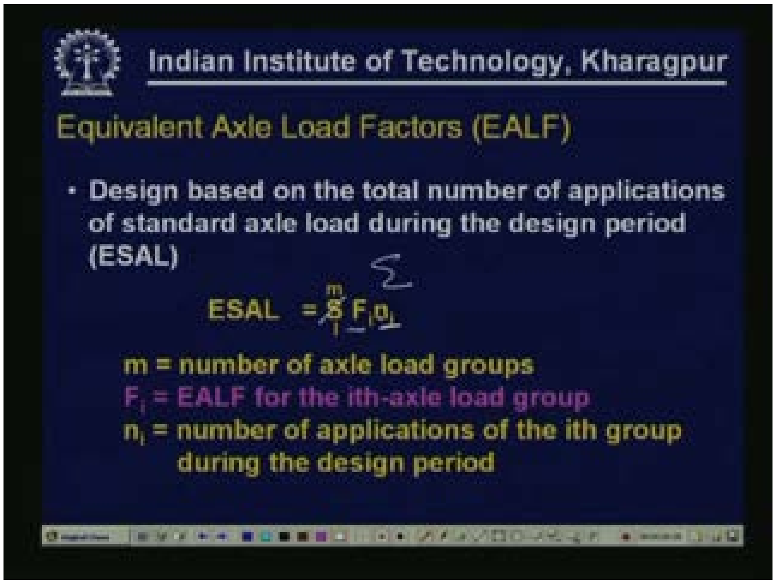

If you know the Equivalent Axle Load Factors for different load groups if you have that information then the design would be based on the total number of applications of standard axle load during the design period given as total number of equivalent standard axle load will be sum of equivalent axle load factor corresponding to ith load group and then number of repetitions of the ith load group.

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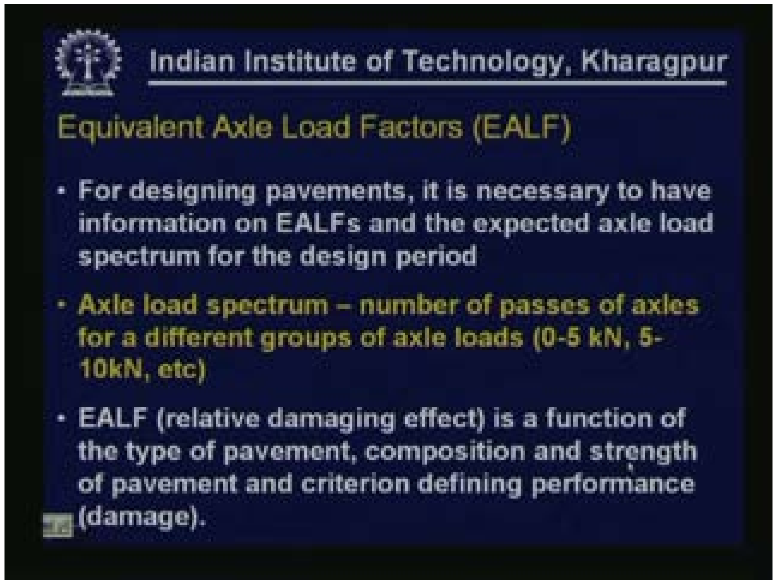

For designing pavements it is necessary to have information on the equivalent load factors for any particular load group that we want to convert into equivalent standard axles and we also need to have the expected axle load spectrum. Over the next twenty years or fifteen years how many repetitions of certain load groups will occur for example, 0 to 5 kilo Newton how many repetitions, 5 to 10 kilo Newton how many repetitions, 10 to 15 how many and so on so this information is required, somebody has to make projections about this and we also need to have equivalent load factors so that we can convert each one of these load groups into equivalent standard axle load repetitions.

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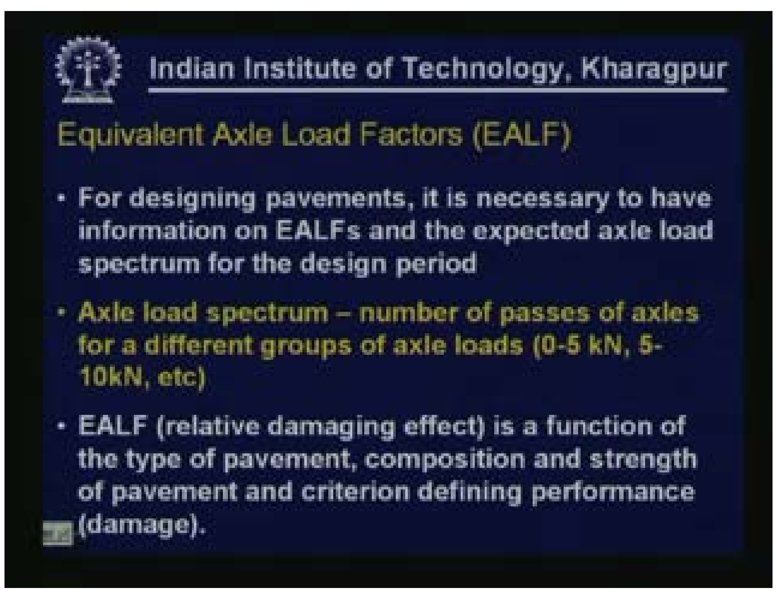

The axle load spectrum is nothing but the number of passes of axle for different load groups. And equivalent axle load factor is a function of, we cannot have the same equivalent load factor for a given load. For example, if you are talking about hundred kilo Newton we will not have exactly the same equivalent load factor for all situations, it is a function of the type of pavement that we are referring to, its composition, strength and also the criteria that we are using to define the performance of the pavement.

Equivalent Axle Load Factors are usually determined by conducting axle load surveys in the field or rather by observing the relative damage caused by different axle load groups to a given specified pavement system.

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The equivalent factors obtained from AASHO road test are most commonly used by almost all the agencies. AASHO road test we have referred to this earlier which was conducted in the 1950s and sixties. so this was one of the concept that has evolved out of AASHO road test. Equivalent Axle Load Factors can also be obtained from theoretical exercise using appropriate mechanistic criteria. Equivalent Axle Load Factors are different for different types of pavement as I have indicated in the previous slide. Equivalent Axle Load Factors are a function of pavement type, the approach that we use for defining performance.

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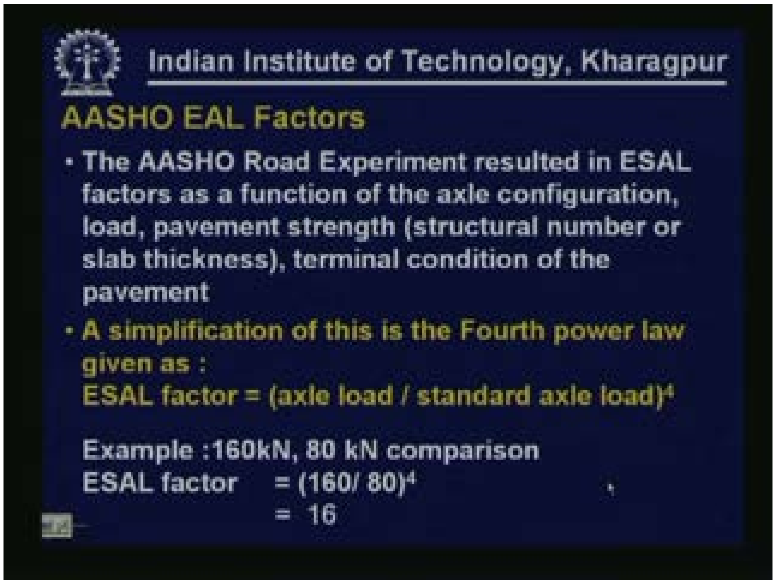

The AASHO equivalent load factors have been derived out of large number of experiments that were conducted on different types of pavements by loading these pavements with different load magnitudes and by observing the performance of the pavements the damage that is caused to these pavements by different load magnitudes. These are usually found in tabulated form for different types of pavements, different load magnitudes different equivalent standard axle load factors are available but a simplification of this is what is known as the Fourth power law which is given as; Equivalent Standard Axle Load factor is axle load under consideration divided by the standard axle load which is 80 kilo Newton to the power 4 that's why it's called as Fourth power law this is an approximate one.

For example, if we are referring to 160 kilo Newton load and we are trying to convert that into equivalent number of 80 kilo Newton standard axle so the conversion factor will be rather the equivalent standard axle load will be 160/80 to the power 4 = 16. This means that 160 kilo Newton axle is capable of producing about sixteen times more damage compared to 80 kilo Newton axle. So this way you can obtain equivalent standard axle load factors for different load groups but only we have to use the Fourth power law.

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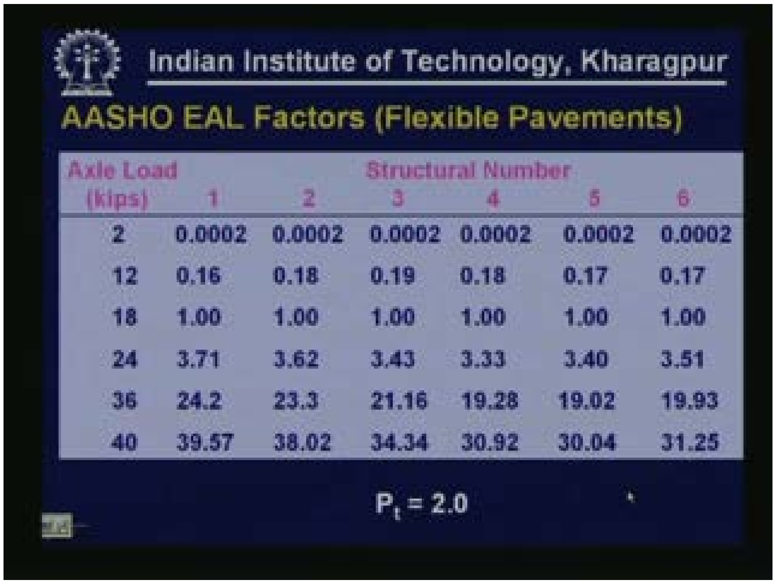

Axle Load (kips)	Structural Number 1	2	3	4	5	6
2	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
12	0.16	0.18	0.19	0.18	0.17	0.17
18	1.00	1.00	1.00	1.00	1.00	1.00
24	3.71	3.62	3.43	3.33	3.40	3.51
36	24.2	23.3	21.16	19.28	19.02	19.93
40	39.57	38.02	34.34	30.92	30.04	31.25

The AASHO Equivalent Axle Load Factors as you can see in various standard literature are given as for different axle load groups each axle group is given in terms of kips thousand pounds. For example 18 kilo Newton 18000 pounds is the standard axle. So corresponding to these we will have equivalent factors to be 1.

If you consider 40000 pounds axle load then this should approximately correspond to 40/18 to the power four so this would be approximately equal to 39.57 but this is a more precise value as obtained in the AASHO road test. This is for a pavement whose terminal condition is defined in terms of a terminal serviceability index value of 2, we will not discuss this right now. But this is for a specified definition of serviceability and for different types of pavements defined by what is known as structural number more the structural number strong receipt pavement so for different types of structural numbers you have different equivalent standard axle load factors so for all types of pavements and for all types of performance definitions we cannot have the same equivalent axle load factor.

We’ll have similar factors available for concrete pavements. In this case instead structural number the strength of the pavement is represented in terms of the slab thickness, in terms of inches 6, 7, 8, 9, 10 and so on. Again this is specified for a particular terminal condition of the pavement defined as Pt = 2. Similar tables are available for different other terminal serviceability values 2.5, 3 and so on.

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In order to be able to convert given axle load spectrum into equivalent number of standard axles we need to have information about the axle load spectrum that is going to be there during the design life period. For this we have to carry out axle load survey. Axle load survey is nothing but measurement of axle loads on a sample basis of all the commercial vehicles or rather a sample of commercial vehicles that are plying on a given facility.

If there is a new route we cannot naturally collect samples on this particular road so we will collect data on similar facility which can be considered to be applicable to this facility also when it is constructed and this data is collected using portable weigh pads because we cannot expect the vehicles to be taken to a weigh bridge at a fixed location so what we have to use or portable weigh pads which can be placed on the road and you can stop the vehicles measure each wheel and from that you can collect axle load information.

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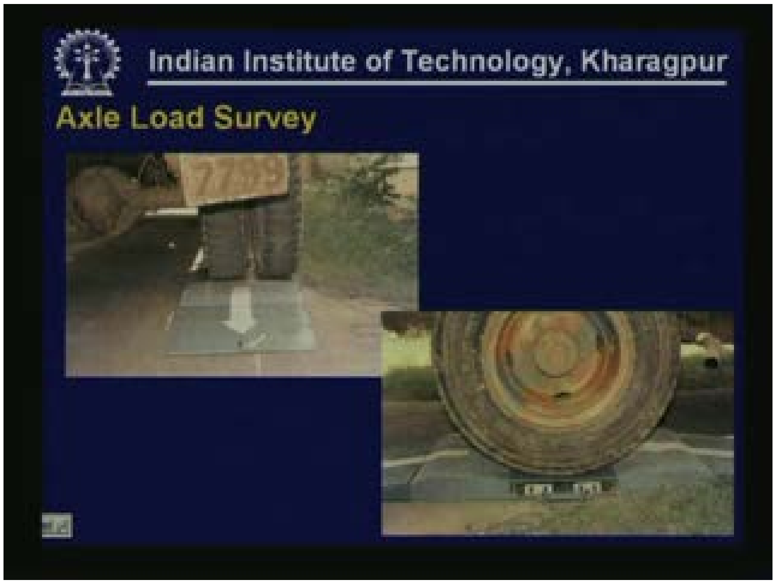

This photograph here shows a portable weigh pad that was developed by IIT Kharagpur. An improved version of this is presently available in a commercial form. We can see the wheel load placed on the weigh pad on either side you have wooden ramps facilitating the vehicles to climb on that. What we do in this survey is we select a sample, we will not normally stop all the commercial vehicles, we are only trying to take the weights of commercial vehicles, this we have discussed in the previous lesson. As far as the pavement design is concerned we are interested only in commercial vehicles because other smaller vehicles will not be able to produce significant dimensions to the pavement.

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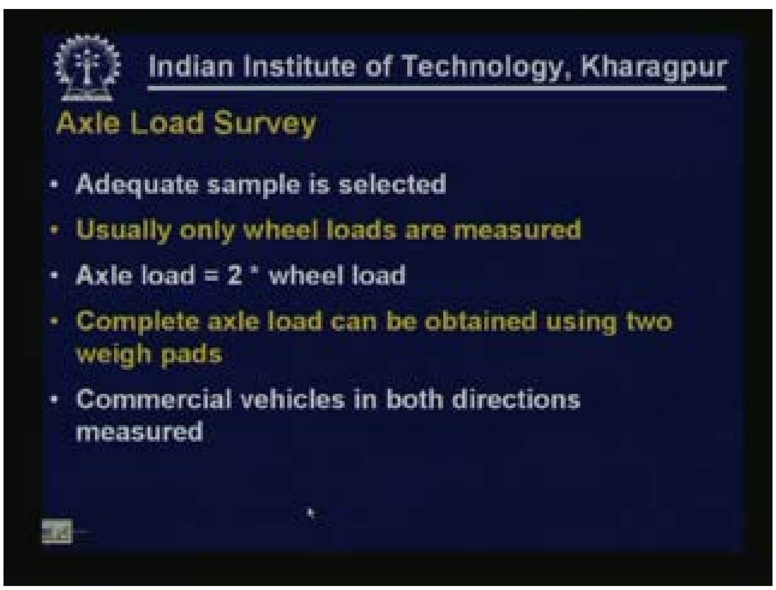

Adequate sample has to be selected. Usually only wheel loads are measured and normally complete axle is not measured but if you put two pads on either side you can measure the complete axle simultaneously. If you are measuring only wheel load we assume the axle load to be approximately equal to twice the wheel load that is measured and commercial axles normally in both the directions are monitored.

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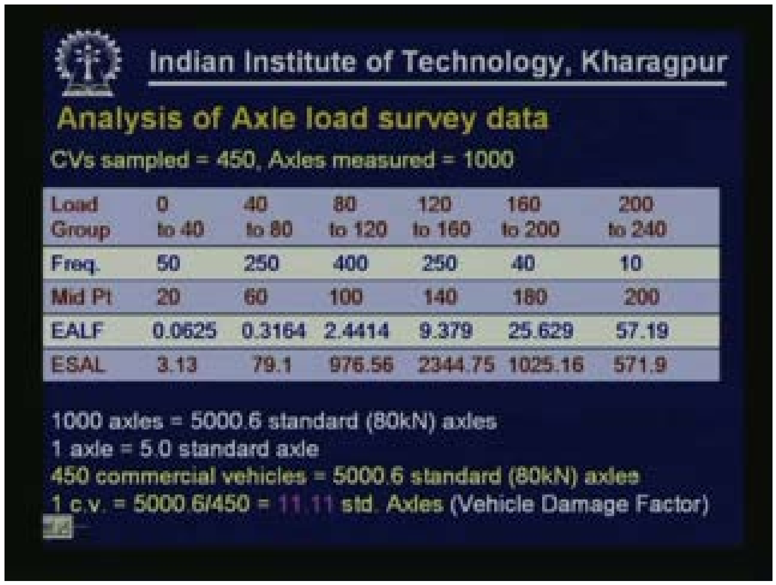

So, if you have data collected like this having load group of 0 to 40 kilo Newton this is the frequency, 40 to 80 kilo Newton this is the frequency, 80 to 120 this is the frequency and the midpoint of this is 20, this is the equivalent axle load factor 20 divided by 80 to the power 4, then equivalent number of standard axles if you have 50 axles ranging from 0 to 40 kilo Newton these 50 axles would be equivalent to 3.13 numbers of 80 kilo Newton axles. Similarly, 160 to 200 load range group if you have 40 axles the midpoint of this will be 180, equivalent axle load factor will be 25.629 180/80 to the power of 4 and this multiplied by 40, this is the equivalent number of 80 kilo Newton standard axle loads so that's equivalent of 40 numbers of load ranging between 160 to 200.

Similarly, we can work out equivalent standard axles for each one of these load groups knowing the frequency for each load group. As you can see the total of these axles that have been measured is about thousand so these thousand axles are equivalent to if you take a sum of these they is equivalent to 5000.6 standard axles. That means one axle is equal to approximately about 5 standard axles.

We have measured about 450 commercial vehicles they had about thousand axles because some of the vehicles had more than two axles. So, 450 commercial vehicles are equal to 5000 standard axles. That means 1 commercial vehicle is equivalent to 5000/450 that is 11.11. This is called as vehicle damage factor which is a representative parameter that will give us one commercial vehicle is approximately equal to so many standard axles. That means if you have vehicle damage factor this information will give you, for a given road this is the vehicle damage factor to be adopted then if you know what are the commercial vehicles that are going to be there that multiplied by this vehicle damage factor will give us equivalent number of standard axles so this is how we can obtain the vehicle damaged factor by conducting axle load survey, by knowing the number of commercial vehicles that were sampled by converting all of them into equivalent number of standard axles.

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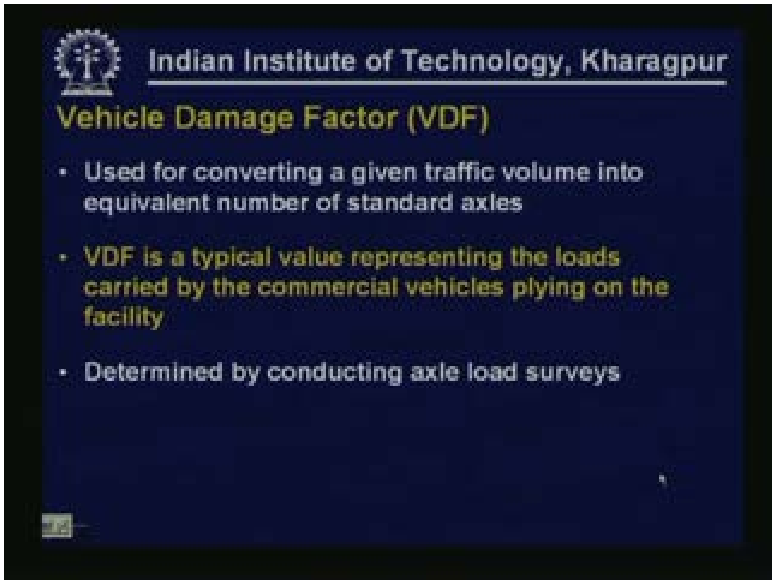

This we have discussed. If you can get information on vehicle damage factor which can be determined by conducting axle load surveys we can convert the commercial vehicles into equivalent number of standard axles.

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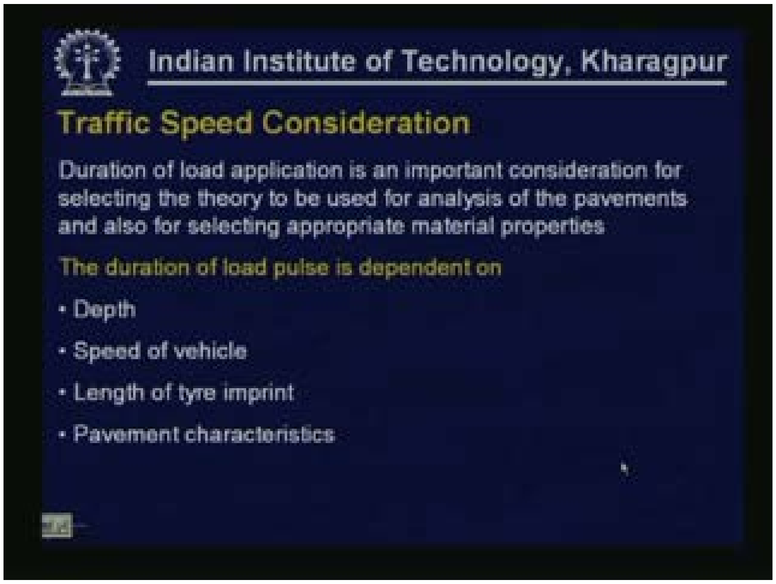

We have also taken into account speed. This is important for selecting appropriate material properties.

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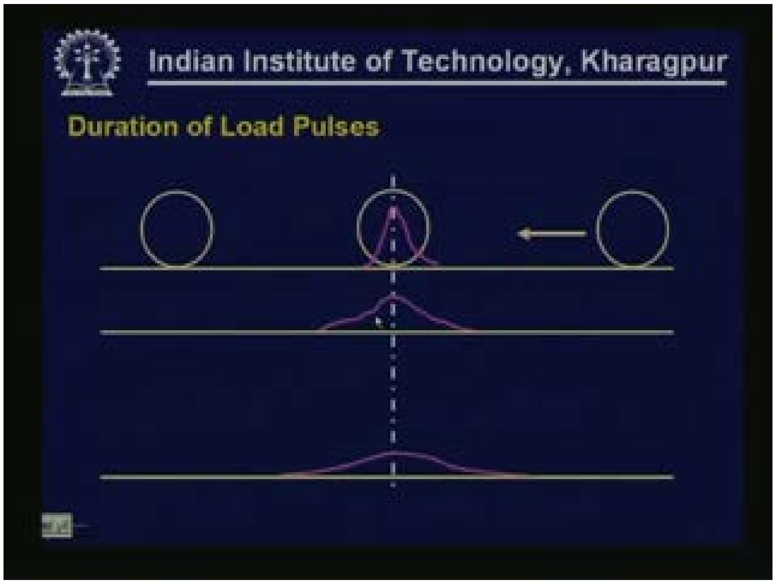

At any given location on the pavement if the load is away the stress is 0. As the load approaches this location stress builds up, reaches a maximum and as the load moves away stress become 0 again so this is how the stress builds up. So the points that are closer to the surface will have high stresses but smaller loading time whereas the points that are at lower depth will have much larger loading time but smaller magnitude of stress. This concept again we will discuss when we talk about characterization of pavement materials.

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Estimating design traffic, we have discussed this partly in the previous lecture. We need to start with the initial traffic, we have to have information on vehicle damage factor, we also have to have lateral placement characteristics, using this information we can calculate what will be the total number of standard axles that are expected during the design life period of twenty fifteen twenty five years.

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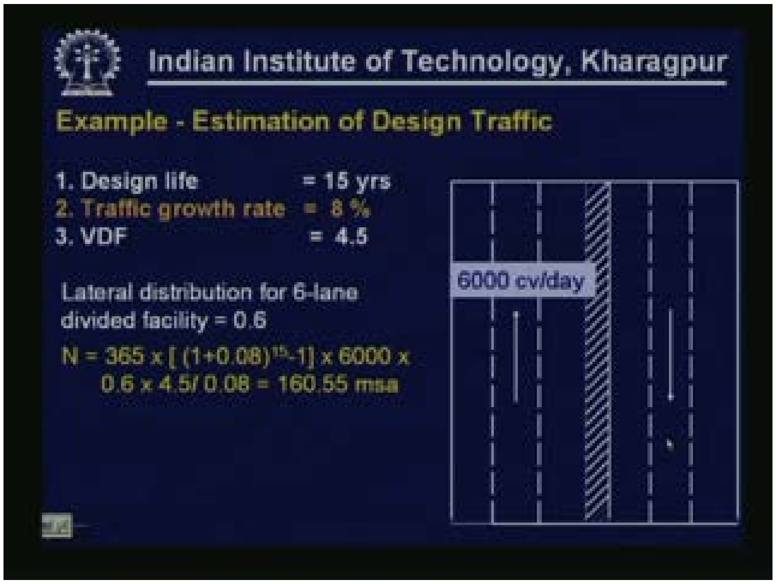

For example, if you take a design life of fifteen years and it traffic growth rate of 8%, VDF of 4.5 and if it is a six lane road divided facility as you have seen in the earlier case we are using a distribution factor of 0.6 so we can work out the number of equivalence standard axle load repetitions as 160.55. In this case we have also used a vehicle damage factor of 4.5.

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To summarize, in this lesson we have discussed about fixed vehicle, fixed traffic, variable traffic and variable vehicle approaches. We have also learnt about computations of Equivalent Single Wheel Load from different consideration. We also discussed about equivalent standard axle load factors for converting the repetitions of a given axle load into equivalent repetitions of standard axle and also learnt about vehicle damage factor and how that can be used to convert a given volume of commercial traffic into equivalent cumulative standard axle load repetitions.

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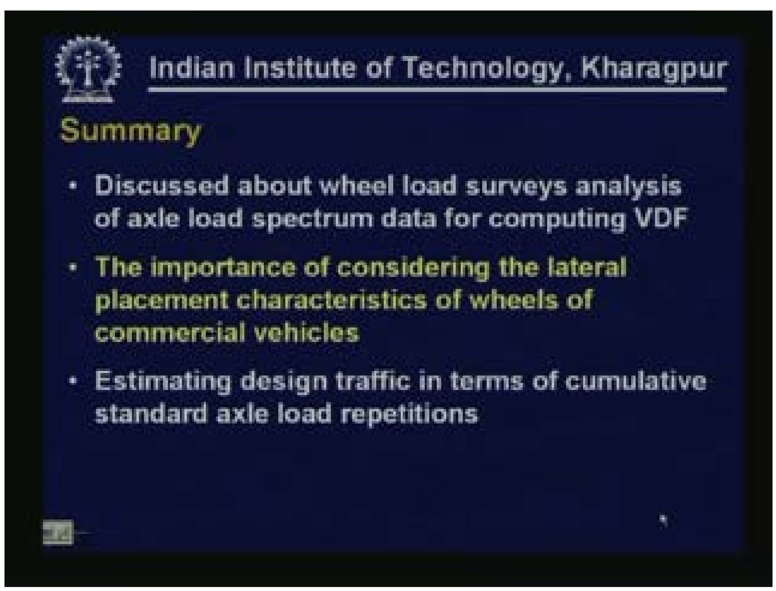

We also discussed about axle load surveys or wheel load surveys that can be conducted and also about the importance of considering lateral placement characteristics of wheel loads of commercial vehicles and we have seen how using all these information equivalent number standard axle loads can be estimated for a design life period.

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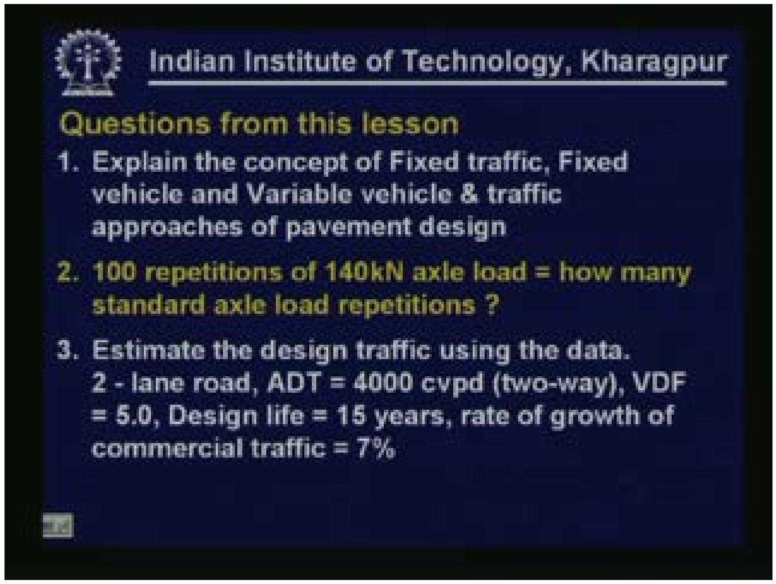

Let us see some questions that we would like to answer, we will provide the answers in the next class.

Explain the concept of fixed traffic, fixed vehicle and variable vehicle, variable traffic approaches for pavement design.

Hundred repetitions of 140 kilo Newton axle load is equivalent to how many standard axle load repetitions?

Estimate the design traffic using the following data: There is a two lane road average daily traffic is 4000, commercial vehicles per day two way traffic, vehicle damage factor is 5 design life is 15 years and the rate of growth of commercial traffic is 7%.

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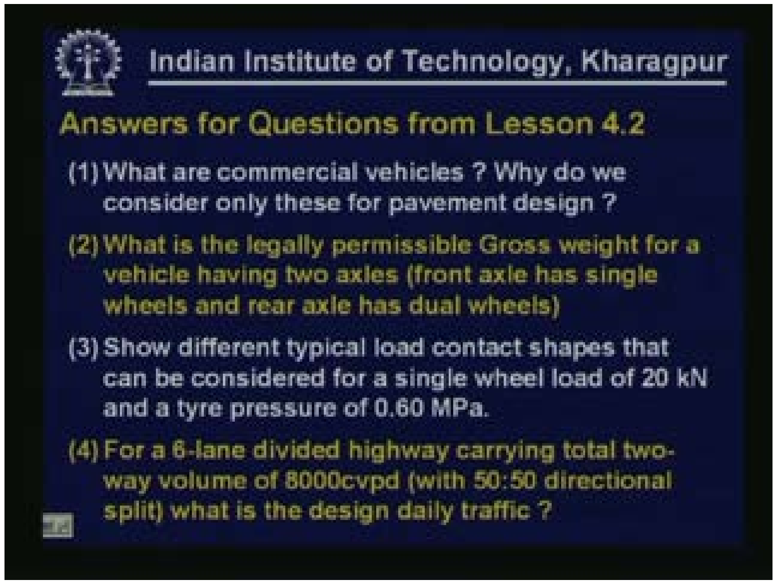

Answers for questions that we have asked in the previous lesson;

What are commercial vehicles? Why do we consider only these for pavement design?

Commercial vehicles are those which have laden weight of more than 3 tons because smaller vehicles which carry smaller loads do not produce significant amount of stresses so as to cause significant damage to the pavement that's why we would not consider other than commercial vehicles.

What is the legally permissible gross weight for a vehicle having two axles? Front axle has single wheel and rear axle has got dual wheels?

As you have seen in the previous lesson if an axle has got single wheel on either ends permissible wheel limit is 6 tons and if an axle has got dual wheel set on either ends permissible limit is 10.2 ton therefore in this case 6 + 10.2 = 16.2 tons so 16.2 tons is the permissible unit.

Next is show the different typical load contact shapes that can be considered for a single wheel load of 20 kilo Newton and a tire pressure of 0.6.

I am sure you will be in a position to calculate this, you have the load given, you have the contact pressure given, if it is assumed to be circular contact area 20000/0.6 would give you the area and you can calculate the load radius. Similarly you can calculate other shapes that we have discussed in the earlier step.

For a six lane divided highway carrying total two-way volume of 8000 commercial vehicles per day with 50:50 directional speed what is the design daily traffic?

So we have a divided carriage way, it is a 50:50 directional split so in one direction we will have 4000 commercial vehicles per day. Since you have three lanes in each direction if you refer to the previous lesson we have said 60% of the traffic in this direction has to be taken if it is a three lane separate carriage way that we have so this becomes 4000 into 0.6 = 2400 commercial vehicles per day that is a traffic that we have to consider in this direction.

Of course that we have to adjust this for using the appropriate vehicle damage factor and then convert this into equivalent standard axle load repetitions, that in fact is the input that were going to use for pavement design. With this we come to the close of this lesson, so thank you.