Introduction to Transportation Engineering
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Lecture - 38
Concrete Pavement Design Indian Roads Congress Method

Hello students welcome to lesson 15 of module IV. As you know module IV is on pavement design. In this lesson we will be discussing about how to design concrete pavements as per Indian Roads Congress guidelines.

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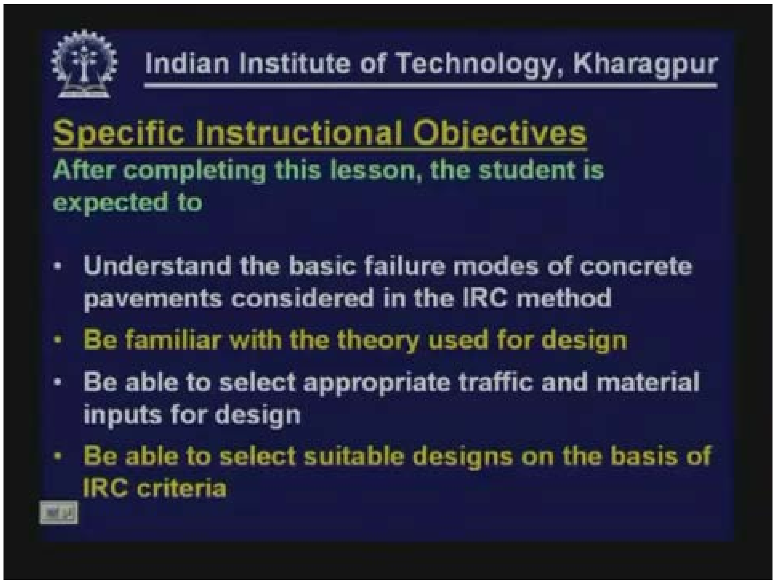

The specific instructional objectives of this lesson are after this lesson it is expected that the student would understand the basic failures modes of concrete pavements considered in the Indian Roads Congress method of designing concrete pavements. He would also be familiar with the theory used for analysis of this concrete slabs and as a result use for design of concrete pavements. He would also be able to select appropriate traffic and material inputs required for designing concrete pavements as per Indian Roads Congress guidelines and the student would also be able to select suitable designs that are he would be able to design concrete pavements as per Indian Roads Congress guidelines.

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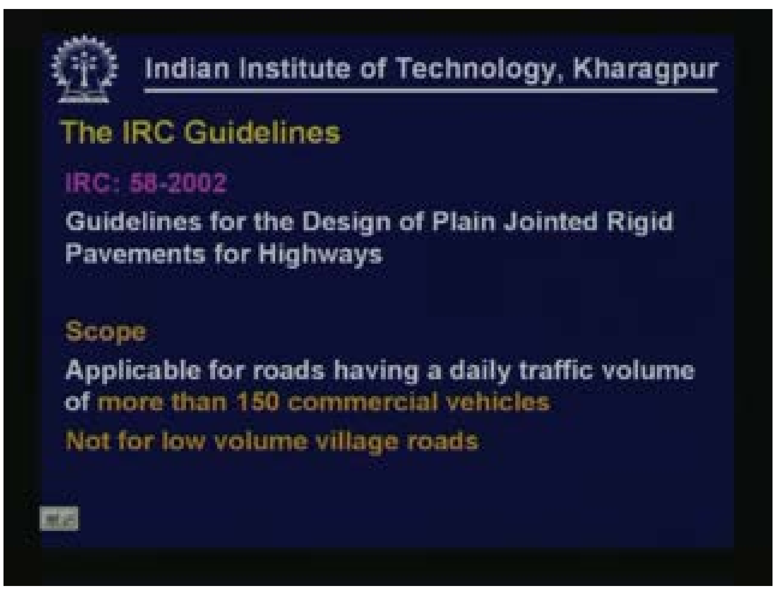

The IRC guidelines or in IRC: 58 in its 2002 version it is titled as guidelines for the design of plain jointed rigid pavements for highways. We know that there are different types of pavements; concrete pavements, jointed pavements, there can be continuous pavements also without any joints, you can have prestressed concrete also so various types of concrete pavements can be there but these guidelines cover plain cement concrete not reinforced concrete or prestressed concrete and jointed slabs. The scope of these guidelines is that they are applicable for roads having a daily traffic volume of more than 150 commercial vehicles per day. Obviously these guidelines are not applicable for low volume village roads. We understand what a commercial vehicle is. We are referring to trucks and other commercial vehicle which carries commercial goods, buses also can come into this category. So, if the traffic density per day is more than 150 then the design thickness that is given by these guidelines will be applicable only for those types of roads.

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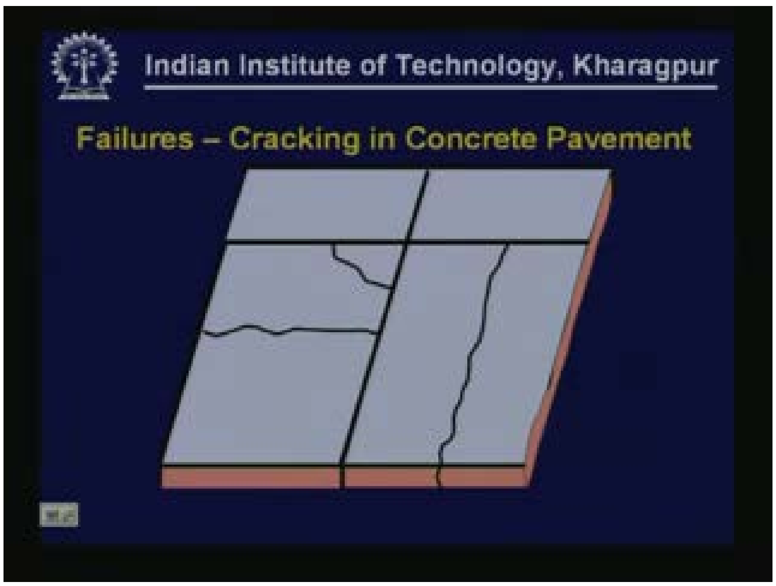

Concrete pavements fail in different modes. This being a bound material cement concrete obviously cracking is the main mode of failure. Cracks can occur in different regions in different directions, and in different locations of the slab. This can occur because of various seasons such as load related, temperature related etc.

Cracking is something that is brought about by variation change in volume of whether the slab or the other layers in the pavement system base or subgrade or foundation so we can have different types of cracks developing in the concrete pavement because of various reasons and they also occur in different regions of the slab. As you can see there are corner slabs, there are transverse cracks and also there are longitudinal cracks.

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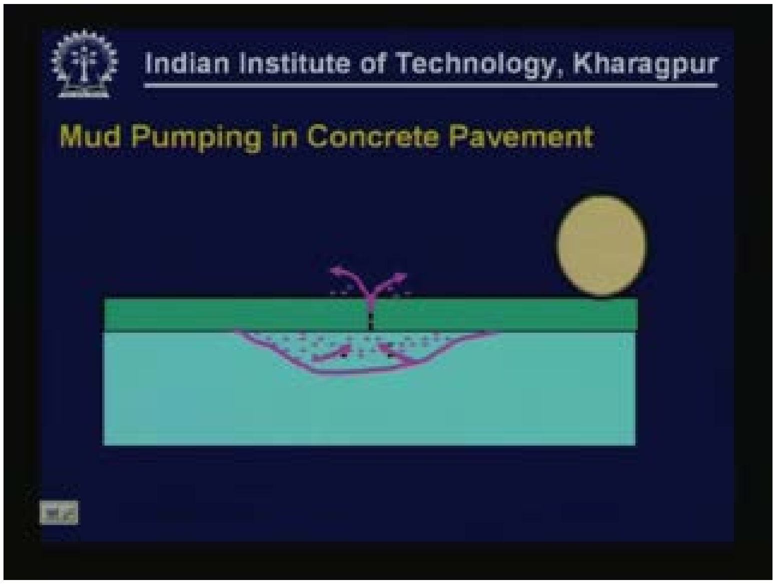

Another main type of failure that is very common in concrete pavements but very difficult to understand and model is mud pumping in pavements. Mud pumping is the phenomena due to which if there is a fine grain material below the slab as the wheel passes over this and the slab at the joint deflects it pumps out the fines from below especially when it is in the saturated condition so gradually each application of load at the joint are near the corner, the slab deflects and then pumps out the fines. So after sometime if you have a base which is of erodible material then there is going to be void forming here which results in loss of support to the slab and then leading to cracking of the slab. This is the phenomenon that is also known as erosion of base or popularly known as mud pumping, erosion is a result of mud pumping.

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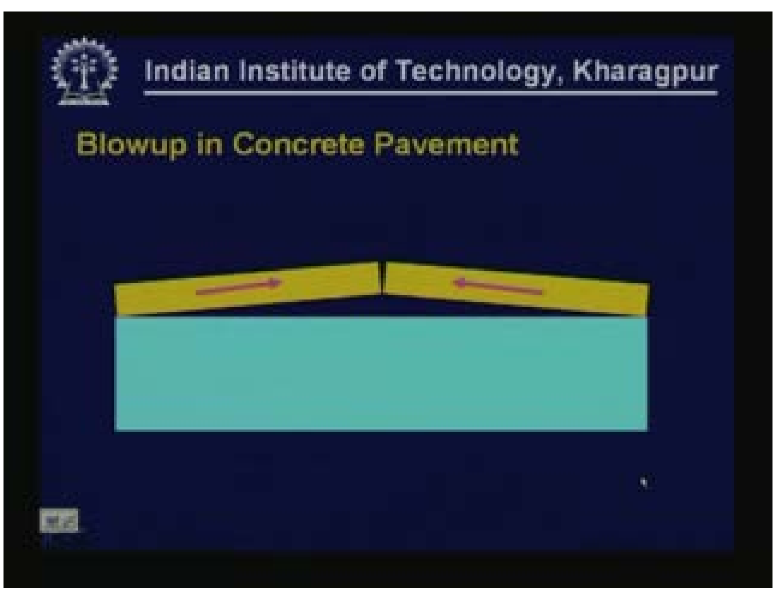

There can also be blowups occurring in concrete pavement especially. Because of increase in temperature the slabs try to expand and if there is no provision for the expansion of the slab it may buckle up and it may lead to crushing of this portion at this joint. So as we have discussed in the previous lessons there has to be sufficient provision made along the length of the slab to accommodate increase in length of the slab because of increase in temperature.

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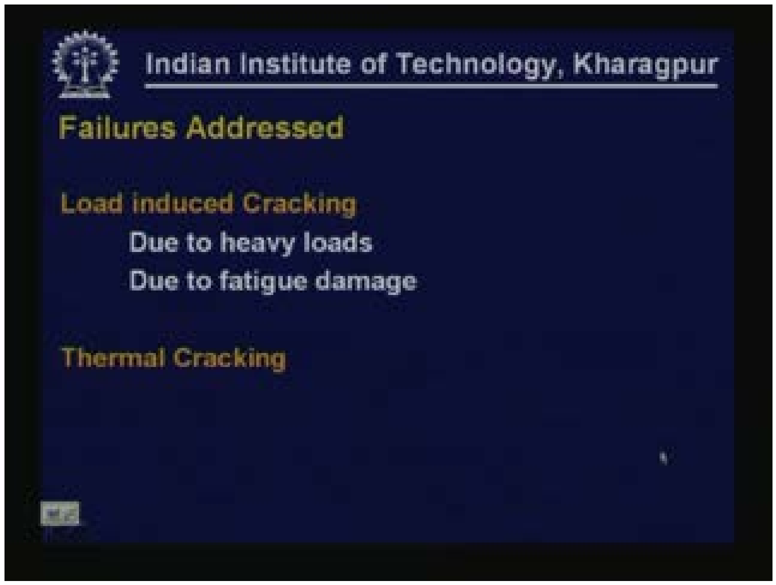

Now let us see what are the failures that have been addressed in IRC: 58 - 2002 version. Load induced cracking: because of the application of very heavy loads cracking can be because of two main reasons; a very heavy load is applied which induces tensile strength which is more than the strength of the concrete so, that single load itself can lead to cracking of the slab. On the other hand if you apply loads of lesser magnitude repeatedly they also can produce cracking in the slab because of what is known as fatigue problem. So there are two types of damages that we are concerned about. One is damage caused by heavy loads and also fatigue damage caused by loads of lesser magnitude but applied repeatedly.

Obviously for a highway pavement there will be number of wheel loads that are going to be applied, vehicular loads that are going to be applied these are going to be applied repeatedly, and magnitudes are going to be different. It is not very common that we are going to be having very heavy load which alone is going to produce damage to the entire pavement. It is usually the repeated application of these wheel loads that is going to be causing cumulative damage which ultimately leads to the failure of the pavement. These are wheel load associated failures either due to heavy load or due to repeated application of loads.

The other type of cracking that can occur is the thermal cracking either because of curling up or curling down of slabs, because of variation in temperature within the slab or also because of contraction and the restraint provided to contraction by foundation, this we have discussed in the analysis of concrete pavements. The thermal stresses also can lead to cracking of the slab.

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For analysis concrete pavement it is modeled as a slab on Winkler foundation. We have discussed about Winkler foundation in the previous lessons. Winkler foundation can be modeled as a set of springs. So this is a slab on the spring foundation. This is the model adopted by IRC: 58 - 2002 for analysis of concrete pavements. The foundation is represented by its spring constant known as modulus of subgrade reaction k. The analysis of concrete pavements or the solution of these problems is based on Westergaard analysis and the works done by Picket and Rays.

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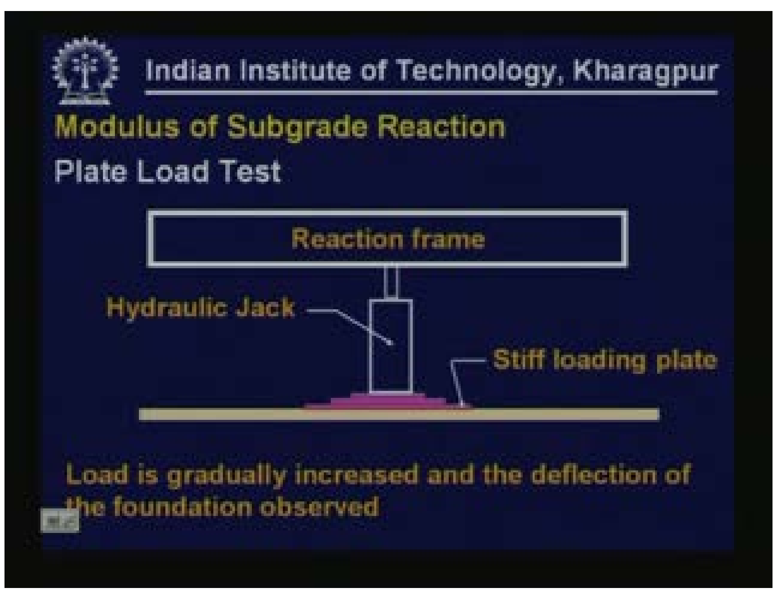

We just mentioned that modulus of subgrade reaction is the parameter used to describe the foundation for concrete slabs. So the modulus of subgrade reaction as we have discussed in earlier lessons can be obtained by conducting a plate load test on the foundation. If already the foundation is laid or tile section of a foundation is laid then the plate load test can be conducted on that and by using that we can plot load versus deflection diagram so the slope of this line curve at a specified deflection gives you the modulus of subgrade reaction. So the load is gradually increased and the deflection of the foundation is observed.

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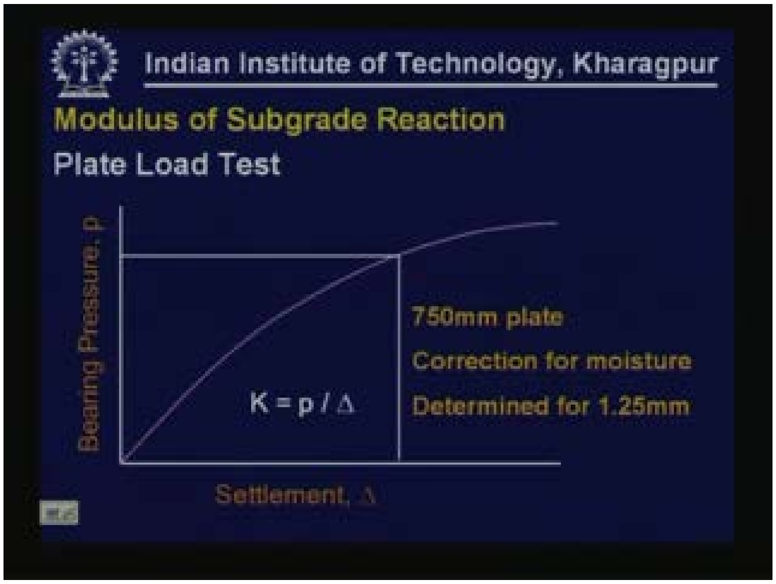

So the ratio of pressure to the settlement corresponding to 1.25 mm deflection gives the modulus of subgrade reaction. What is to be noted is the test has to be conducted using 750 mm dia plate. Also, this test typically has to be conducted when the foundation is in its worst condition which would naturally be soon after monsoon when it is in a saturated condition or in terms of the moisture condition it is going to be in its worst condition. Therefore that is the condition we have to simulate that is the worst condition that the pavement can have. So we have to use a 750 mm dia plate, we also have to conduct the test corresponding to worst moisture condition.

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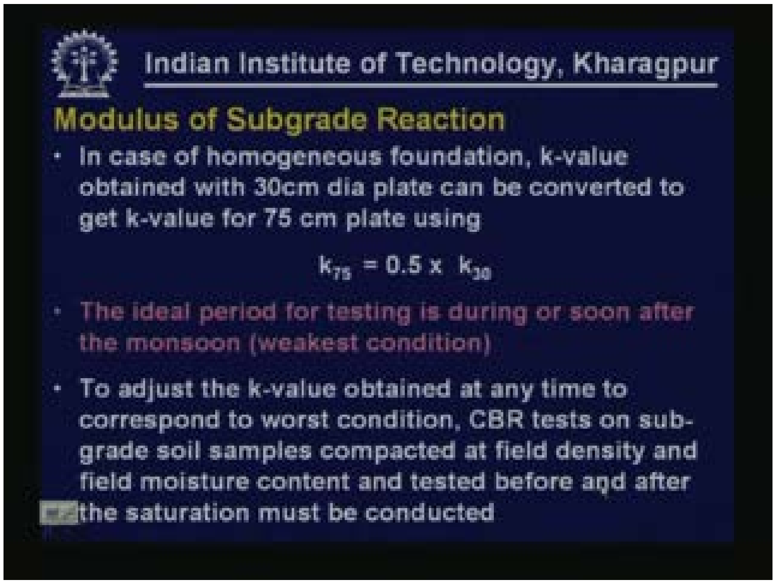

In case we are not able to conduct the test using a 750 mm dia plate the other plate normally that we use is a smaller size plate because with 750 mm dia we have to apply large magnitudes of loads which may not be possible in all cases so we can go for a smaller plate 300 mm dia plate if the subgrade or foundation is of homogenous nature then approximately k value corresponding to 75cm or 750 mm dia plate can be obtained using this correlation. The k 75 is half the value that we obtained using a 30cm dia plate.

As an adjustment the ideal period for the testing conducting this test is during or soon after the monsoon where we expect the foundation to be in its weakest condition. to adjust the k value obtained at any other time which is not its weakest condition to correspond to its worst condition so from the k value that is obtained at any other time to obtain the k value that could have been obtained in its worst condition we can make some adjustments to the value that is obtained in a given season by conducting CBR test on subgrade soil samples compacted at field density and field moisture content and tested before and after the saturation.

So we have to find out saturated or soak CBR value, we also have to find out the CBR value on the specimen which has been prepared corresponding to the field density rather the moisture content which corresponds to the period in which we have conducted the plate load test. Therefore similar moisture will have to be used in preparing the specimen, the CBR value has to be determined. Similarly this specimen will have to be subjected to soaking for four days and that value has to be determined. So the comparison of these two CBR values will give us an idea as to how much adjustment has to be made to the k value that has been obtained in a given season for particular moisture content.

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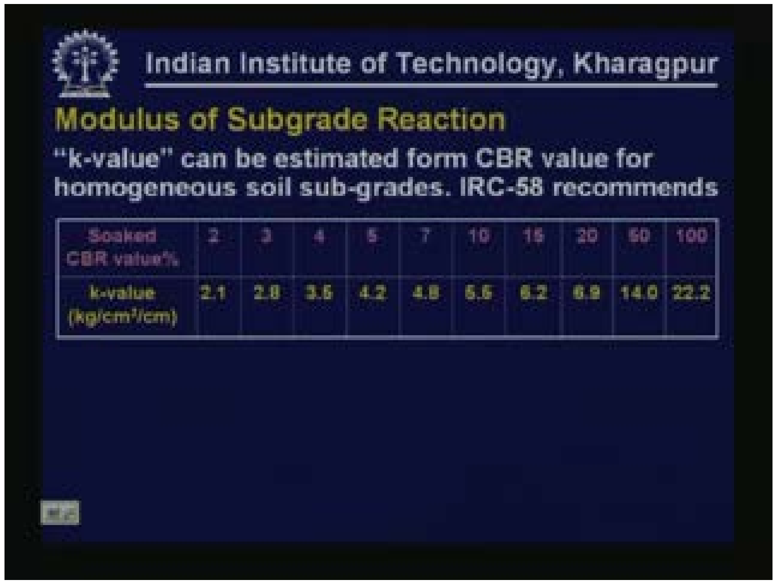

But obtaining k value by conducting plate load test is not always feasible may not be always required. So many a times the k value is estimated from CBR value. This can be done using the table that is recommended by IRC: 58.

For example, for homogenous soil sub grades k value can be estimated using CBR value. This is not a linear relationship so k value is expressed in terms of kg per centimeter square per centimeter because this is pressure per deflection. If the soak CBR value is 4% the corresponding k value can be obtained as 3.5, if the soak CBR value is about 20 the corresponding k value is about 6.9. Of course this is an approximate estimation in case we are not able to conduct the plate load test and obtain the k value.

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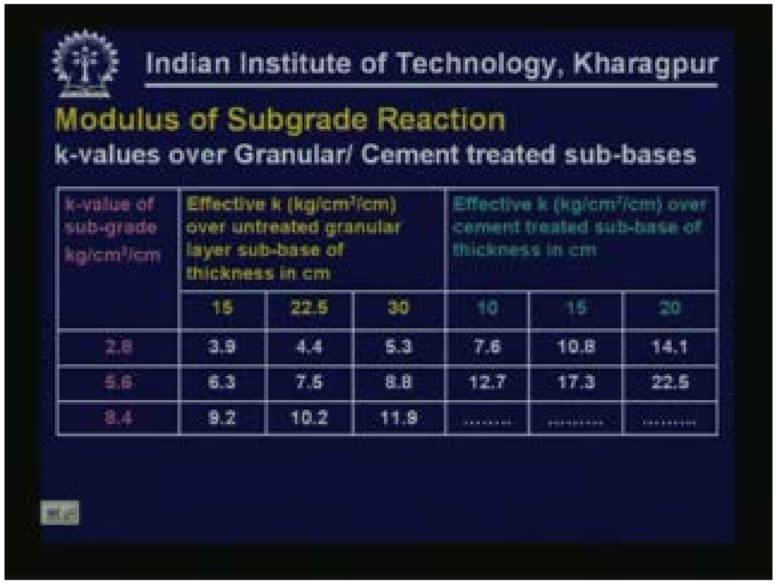

k-value of sub-grade kg/cm²/cm	Effective k (kg/cm²/cm) over untreated granular layer sub-base of thickness in cm			Effective k (kg/cm²/cm) over cement treated sub-base of thickness in cm		
	15	22.5	30	10	15	20
2.8	3.9	4.4	5.3	7.6	10.8	14.1
5.6	6.3	7.5	8.8	12.7	17.3	22.5
8.4	9.2	10.2	11.9	………	………	………

But most of the times especially for highways we do not normally place the slab directly on subgrade so we either have a granular surface or granular base or a cement treated base so the cement treated base plus the subgrade forms the foundation. There is slab below that you may have one layer, two layers or three layers and all these layers that are there below the slab they form the foundation. So we have to have one equivalent parameter that is k value representing the strength of all three or four layers that we have below the slab.

For example, if there is granular or cement treated subbase over subgrade the effective k value can be obtained if you know the k value of the subgrade. That is if you know the CBR value of the subgrade then we can estimate the k value of the subgrade and the effective k value over untreated granular layer of subbase with different thicknesses. That means over the subgrade if you place granular subbase of different thicknesses say 15cm so if a 15cm thick untreated granular layer of subbase is placed over a subgrade having 5.6 kg per centimeter square per centimeter k value then the combined k value of both these layers subgrade of 5.6 and 15cm granular subbase will be 6.3. Similarly, if a 15cm thick cement treated subbase is used on this same type of subgrade then the combined k value will be 17.3. So this is the value we are going to use in the analysis.

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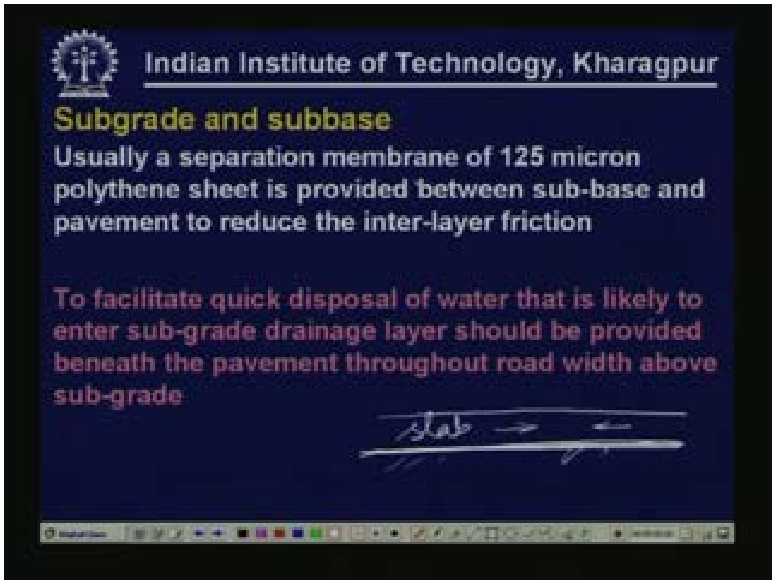

Usually a separation membrane of about 125 micron polythene sheet is provided between subbase and pavement. This is the condition that is recommended by Indian Roads Congress. Some agencies do not recommend this. The implication of this says if this is the slab and below this you have the foundation so we are placing a polythene sheet between this making this ideally a smooth interface.

The advantage of this is when the slab tries to contract especially we are concerned about contraction of the slab because that is going to induce tensile stresses on the slab so when it tries to contract the restraint offered by the foundation will be reduced because of the smooth interface. Thereby the transverse cracking that comes because of contraction or shrinkage of the concrete will be reduced significantly. If one is very much concerned about this type of failure this would be good idea to provide a smooth interface between slab and the subbase. This smooth interface can be provided by a membrane of 125 mm micron thick plastic sheet.

But by doing this if there is a Dry link concrete base, nowadays a Dry link concrete base is recommended to be placed over subgrade and over the Dry link concrete base a concrete slab is placed. So, Dry link concrete base or subbase also has significant strength. When the concrete slab is roughly bonded with Dry link concrete base it can mobilize more strength out of the DLC and that can reduce the overall wheel load stresses. It depends upon which stresses we are considering to be more critical. If we are trying to reduce wheel load stresses. It may be a good idea to make the interface to be a rough one by not providing this plastic sheet. But if you are concerned about shrinkage stresses, contraction stresses then the plastic sheet may be a better idea.

Also, to facilitate quick disposal of water that is likely to enter the subgrade drainage layer should be provided beneath pavement throughout the road width above subgrade. If there is a significant requirement of drainage a drainage layer over subgrade can be provided.

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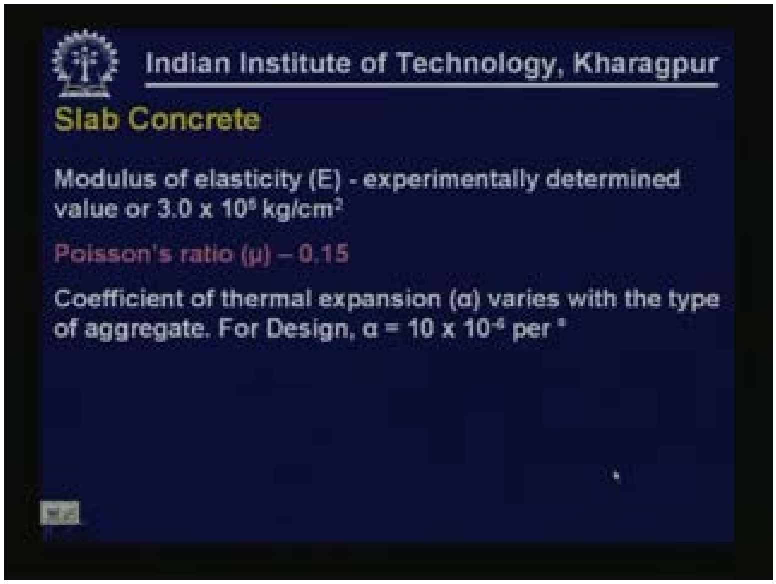

The slab concrete is typically represented in terms of its elastic modulus value, Poisson ratio value and coefficient of thermal expansion. So these values are to be determined experimentally. For a given grade of concrete that is going to be used the value of E value of mu and also the value of alpha are to be determined experimentally. But we can take the values recommended by IRC. These are the typical values only as modulus value to be 3 into 10 to the power of 5 kg per centimeter square, Poisson ratio value as 0.15, coefficient of thermal expansion which of course varies with the type of aggregates used but a typical value can be 10 into 10 to the power of – 6 per degree.

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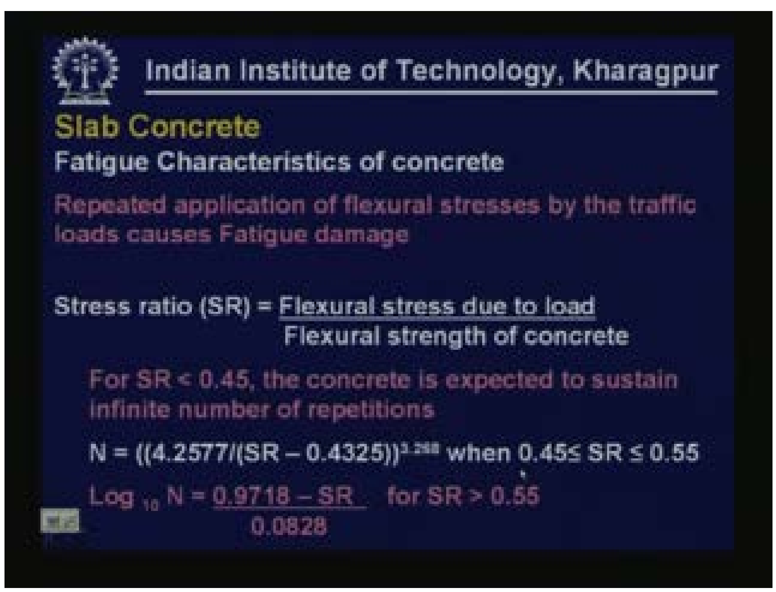

Another characteristic of concrete that has to be considered and a very important one is the fatigue behavior. As we understand, when concrete whether the beam or slab or any other structural membrane when it is subjected to repeated application repeated flexure then the accumulated damage that is going to be caused by these individual wheel loads or individual load repetitions will subsequently ultimately lead to fracture or failure of the member. This is what is known as fatigue. Repeated application of flexural stresses by the traffic load causes fatigue damage.

We use the parameter known as stress ratio to identify the magnitude of individual load that is applied with reference to the failure load. Stress ratio is defined as flexural stress due to a given load. Whether it is a beam or slab when a given load is applied we can calculate the tensile stress using a certain theory so it is that stress that is divided by the flexural strength of the concrete.

Again on the same member if you keep on applying incremental load it will fail at some point of time so using that load if you calculate the tensile stress then that is the flexural strength of the concrete. Therefore the applied stress divided by flexural strength is known as stress ratio. Thus for a stress ratio of 0.45 that means the applied load is of such magnitude that the stress ratio would be less than 0.45 then it is expected that the concrete will be able to sustain infinite number of repetitions of that particular magnitude of load.

So, if the same load arrival lesser loads are applied repeatedly any number of times it is believed that the member will not fail in fatigue mode. But if the stress ratio is more that means a load applied is more than the magnitude that is sufficient to cause a stress ratio of 0.45 then there is going to be damage that is going to be accumulating so the number of repetitions the concrete can sustain is given as a function of stress ratio. For stress ratio between 0.45 and 0.55 N number of load repetitions to failure is given as a function of stress ratio with this expression.

If this stress ration value is greater than 0.55 for heavier loads it is given by a logarithmic relationship log N = 0.9718 – SR by 0.0828. So this is a two segmental relationship. For different ranges of stress ratio, there are different relationships that is to be used, to define the number of repetitions of failure for a given stress ratio.

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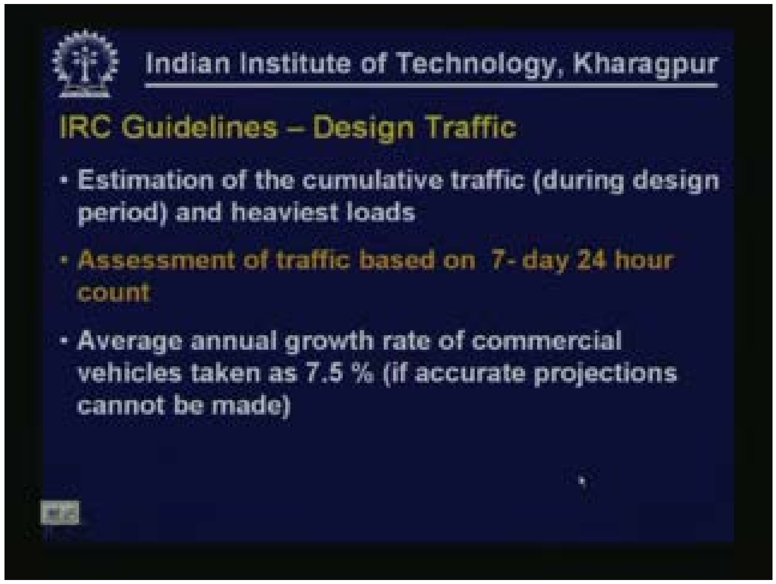

That means if you know how many number of repetitions are going to be applied on the pavement during its service life period, whether it is 10 years or 15 years or 20 years it could be 50 million to 100 millions. If you know what would be the order of magnitude of loads of each one of those loads then we can apply that load on the pavement and calculate the tensile stress, calculate the stress ratio. Using this stress ratio if you know 5 to 6 tons loads about 10000 loads are going to be applied so what is the total damage caused by all these 10000 loads of this magnitude can be computed using this expression.

The estimation of cumulative traffic during design period and heaviest load has to be made. This is how we consider the design traffic. We are interested in what is the total number of repetitions of commercial vehicles and what are the loads that are going to be carried by these loads and what will be the heaviest loads that are going to be applied so we have to have an assessment of the total traffic volume and also the heaviest loads. Assessment of traffic usually has to be based on a 7 day 24 hr count.

Obviously we have to make traffic projections for the future that is for the next 25 years or 30 years of design period. But this has to be based on the traffic counts that we make in the present situation for a short time period so this has to be done for a 7 day continuous 24 hr period.

For making projections, an average annual growth rate of commercial vehicles we are only interested in commercial vehicles because these are the vehicles that carry more load heavy loads and then these are the vehicles that are going to be causing damage to the pavement so we are interested in only commercial vehicles. So the average rate of growth of commercial vehicles typically can be taken as 7.5% but this has to be actually worked out on the basis of various exercises. But if it is not available IRC recommends you can take a value of report 7.5%.

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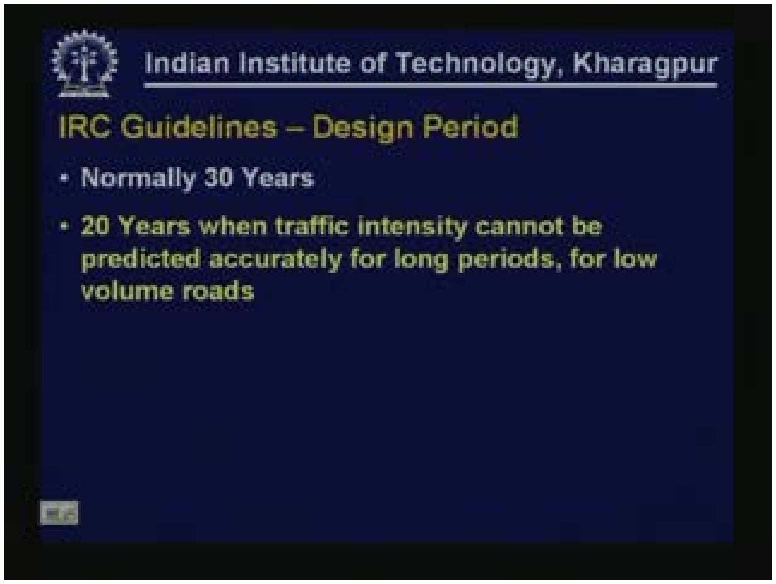

The design period is normally considered as 30 years, it can be taken as 20 years when traffic intensity cannot be predicted accurately because building concrete pavements is a very costly exercise with very high initial cost. As 30 years is the design period recommended by IRC: 58 for concrete pavements so if you are not very sure about the total volume of traffic that is going to be utilizing the facility over the next 20 years or 25 years or 30 years then we can design the pavement for shorter duration that is 20 years. Also, for low volume loads we design it for 20 years.

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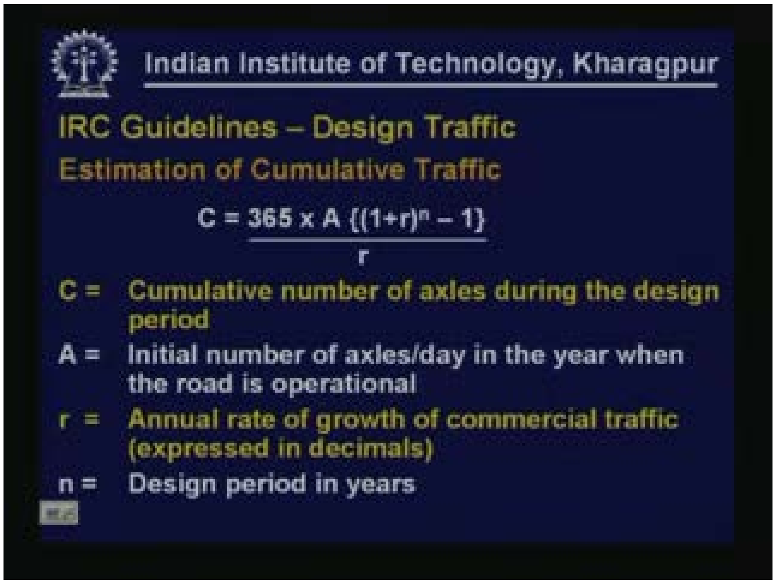

The estimation of cumulative traffic can be made on the basis of initial traffic counts that we make given as; C is cumulative number of axles during the design period, we are not dealing in terms of individual vehicles we are in fact dealing in terms of individual axles. So C is the cumulative number of axles during the design period, it is given in terms of A initial number of axles per day in the year when the road is operational, it is not the number that we obtained when we actually conduct the traffic survey, that has to be converted or again projected to the year when the pavement is actually completed and when it is ready for operation. ‘r’ is the annual rate of growth of commercial traffic expressed in decimals, ‘n’ is the design period in years.

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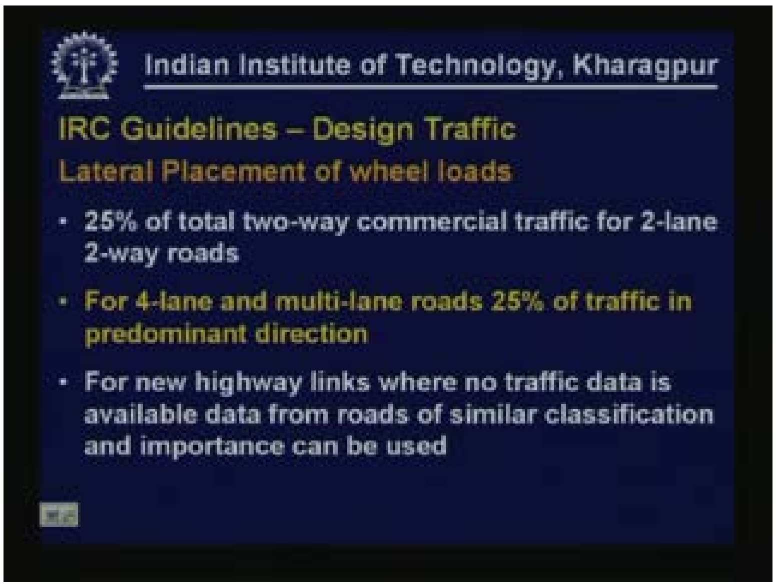

Another important characteristic of traffic loading that has to be considered is the lateral placement of wheel loads on the slab.

The IRC: 58 recommendations are to consider 25% of total 2-way commercial traffic for 2-lane 2-way roads. If you have 2-lane road and there is going to be 2-way operational on that then 25% of the total 2-way traffic has to be considered for design not the 100% total 2-way volume, we will discuss why this has to be so.

Similarly for 4-lane and multi-lane roads it is 25% of traffic in the predominant direction. If you have multi-lane roads in terms of either 4-lanes, 6-lanes or 8-lanes so there is going to be one predominant direction either in terms of the load that it carries or in terms of number of vehicles that travel in that particular direction. So once we identify the predominant direction we have to take 25% of the traffic traveling in the predominant direction.

For new highway links where no traffic data is available data from roads of similar classification and importance can be used. Obviously when there is no road available there is no current traffic so we cannot conduct any traffic survey on any existing road so we have to take data from similar roads having similar importance and similar classification.

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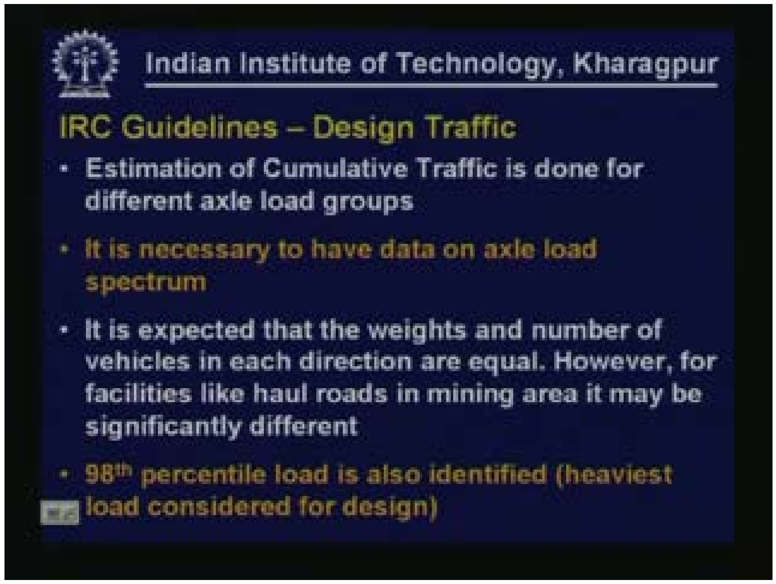

The estimation of cumulative traffic is done for different axle load groups. We have to classify all the axle loads and find out in each axle load what is going to be the percentage of traffic or how many repetitions of traffic axles are going to be there during the design life period, so this number is required. It is necessary to have data on axle load spectrum. We have to have some idea, we should be able to project what is going to be the axle load spectrum that is going to be utilized in the facility like 0 to 2 tons how many axles, 2 to 4 tons how many axles, what are the load classification that we make and for different axle load classifications axle load groups we should be able to project the corresponding frequency.

It is expected that the weights and the number of vehicles in each direction are equal. Typically this is how we assume but we know that in many situations traffic in one direction carries heavier loads compared to the traffic coming from the other direction. If that be so we can also take that into account in the design. We also need to have information on the heaviest loads because we are also concerned about the damage caused by very heavy loads.

We are of course concerned about the fatigue damage caused by repeat application of number of loads but we are also concerned about the failure caused by one single application of very heavy load. So, a very heavy load is concerned to be the 98 percentile load. That means out of all the loads that we have observed or all the loads or the facility that we have projected to be using in the future only 2% of the loads will be heavier than the 98 percentile load. So we will never have any idea about the 100 percentile load but we consider the 98th percentile load which may be exceeded about 2% of the time. So this is the load for which we are going to check whether the pavement is going to be safe or not.

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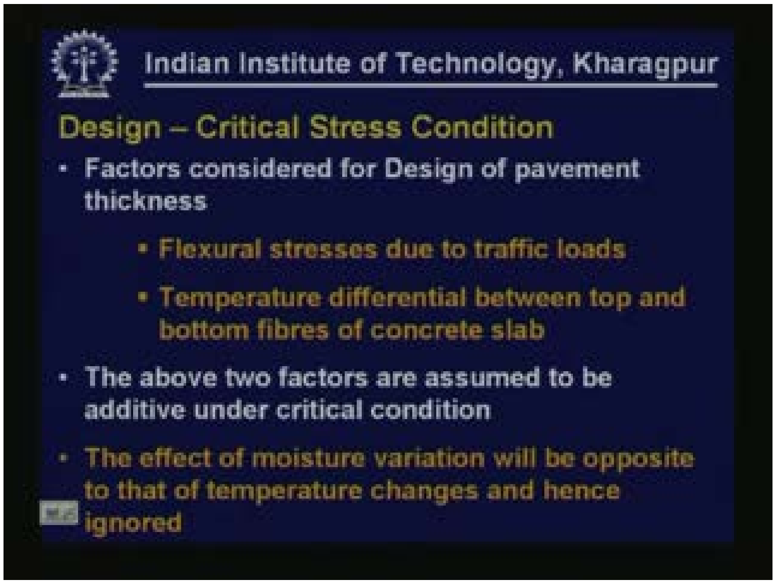

The critical stress condition that is considered in IRC: 58 - 2002 takes into account the factors considered for design of pavement thickness such as; flexural stresses due to traffic loads, temperature differential between top and bottom fibers, result in curling and result in temperature stresses so these are the two stresses that are considered as we discussed earlier. These two factors are assumed to be additive under critical conditions. Critical conditions should be during noon time when both the curling stresses and wheel load stresses will be additive. The effect of moisture; if there is variation moisture from top to bottom that also can produce moisture gradient and then result in some stresses but usually this is neglected because this will usually act opposite to that of the temperature changes and hence it is ignored.

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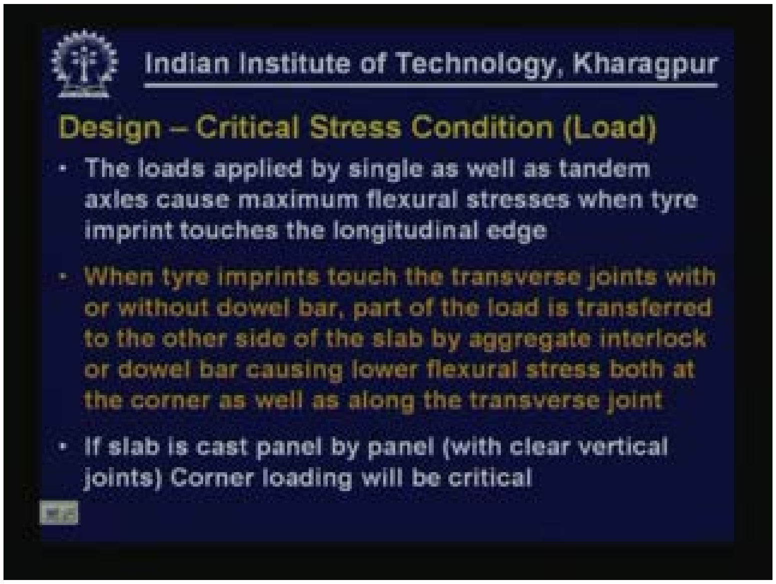

The loads applied by a single as well as tandem axles cause maximum flexural stresses when tire imprint touches the longitudinal edge, this is a critical position. So, when tire imprint touch the longitudinal edge that is considered to be the critical position of the wheel loads.

When tire imprints touch the transverse joints with or without dowel bar part of the load is transferred to the other side of the slab by either aggregate interlock or by the dowel bar system that is in place so this causes lower flexural stresses both at the corner as well as along the transverse joints. We are trying to identify which is the critical region in the slab as far as the load placement is concerned.

As you see here if the loads are placed with tire imprints tangential to the longitudinal edge that is considered to be critical, if you consider them tangential to the transverse edge then because of the continuity that we have across the other slab in terms of granular interlocking or in terms of dowel bar system then there is some amount of load that is transferred on to the next slab so the flexural stresses will be significantly be reduced because the next slab is also participating in sharing this load. Whereas the along the longitudinal edge this side of this you do not have any continuity so when the load is placed here there is going to be heavier stresses compared to the situation where the load is placed across the transverse joint.

However, if the slab is cast panel by panel with clear vertical joints there is discontinuity along both the directions in the corner region. So obviously that is the critical region. So when you place a load there corner flexural stresses will be the maximum. Especially when there is no continuity where there is no load transfer mechanism between these two slabs then the corner is going to be the critical region.

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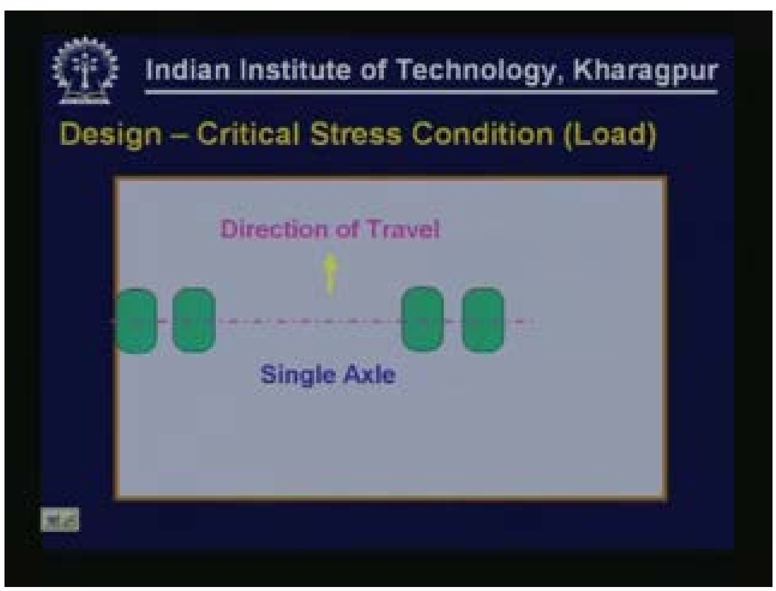

What we just stated is reflected here. So this is the case where the tire imprints are placed tangential to the longitudinal edge. This is the longitudinal edge (Refer Slide Time: 34:20) this is the direction of travel so the tire imprints are placed close to the tangential edge and this is the critical position.

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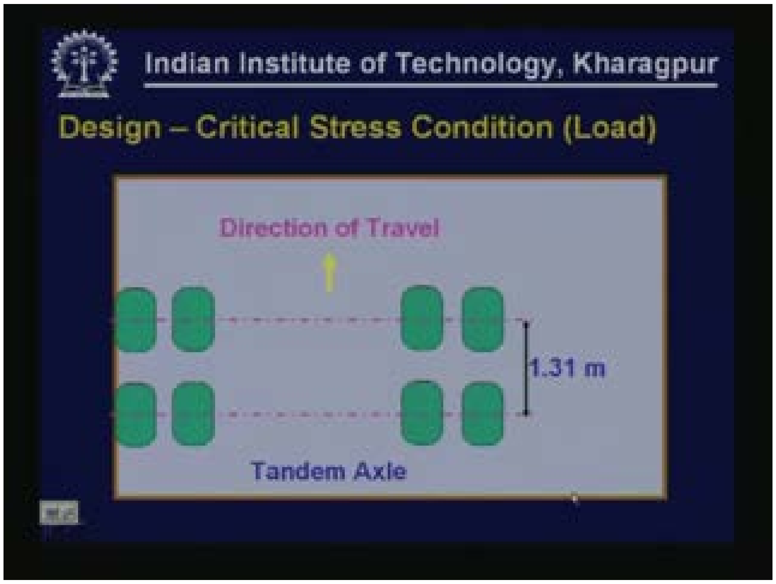

Similarly, this is the tandem axle with tire imprints placed tangential to the longitudinal pavement edge.

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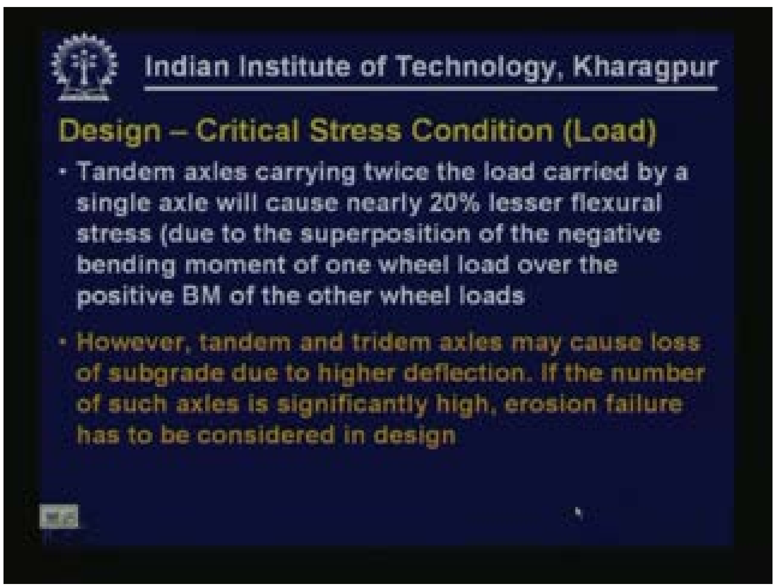

Tandem axles carrying twice the load are carried by a single load. For example, if we consider single load carrying 10 tons and if you also consider tandem axle carrying 20 tons which is double the load carried by 10 ton load, tandem axles will carry nearly 20% lesser flexural stress due to the superposition of the negative bending movement of one wheel load over the positive bending movement of the other wheel loads. So tandem axles can carry twice the magnitude of loads that is caused by a single wheel load but the resulting stresses that we produced by tandem axle loads will be about 20% lesser than that produced by single axle load.

But however tandem and tridem axles these are multiple axle loads may cause loss of subgrade due to higher deflection. These produce higher deflection although the flexural stresses are much less than those produced by single axle load they produce higher deflection. If the number of such axles is significantly high erosion failure has to be considered because the slab is going to deflect significantly along the joints and near corners so this would lead to loss of subgrade support because of pumping. So when you have large percentage of these multi axle vehicles then we have to be concerned about erosion failure. In India still we do not have very significant percentage of multi axle vehicles that's the reason why IRC: 58 have not taken into account the erosion failure in its design considerations.

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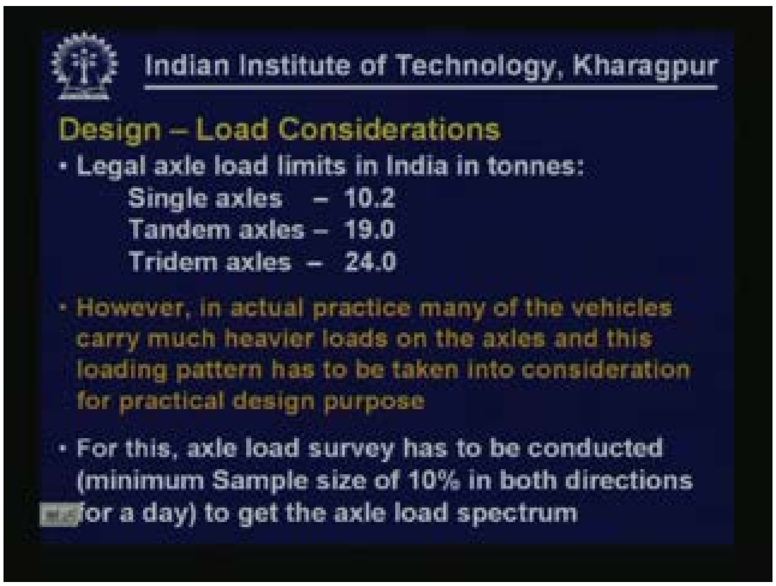

We know that the legal axle load limits in India for single axle load is 10.2 tons; tandem axle is nineteen tons, tridem axle is 24 tons. However, in actual practice many of the vehicles carry much heavier loads on the axles and this loading pattern has to be taken into account. We cannot believe that these are the legal axles' limits so we are going to design for these as heavy loads only. Because we know that there is going to be much heavier loads that are going to be applied we have to actually take that actual practical loading pattern into consideration and design accordingly. Obviously for this we have to conduct an axle load survey. Minimum sample size of ten percent of the total vehicles in both the directions will have to be sampled to get a proper axle load spectrum.

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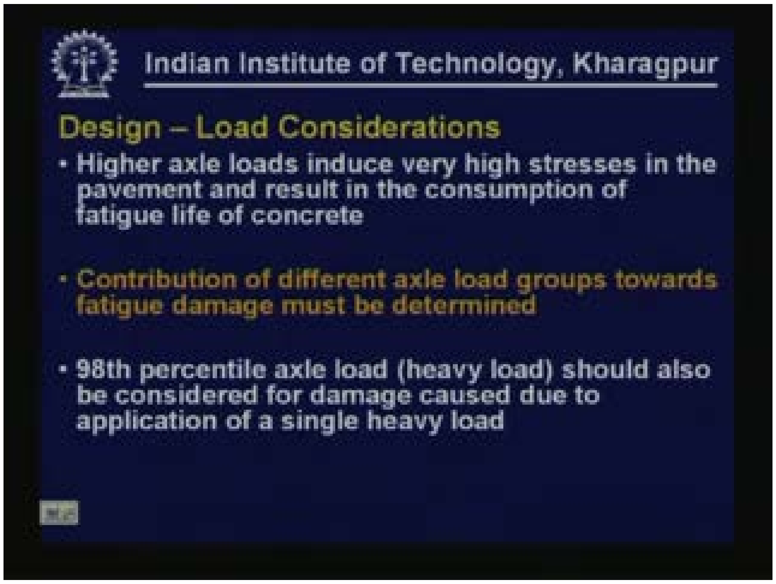

Higher axle loads induce very high stresses in the pavement and result in consumption of fatigue life of concrete.

Contribution of different axle load groups towards fatigue damage must be determined.

98th percentile axle load which is considered to be heavy load should also be considered for damage caused due to application of single heavy load.

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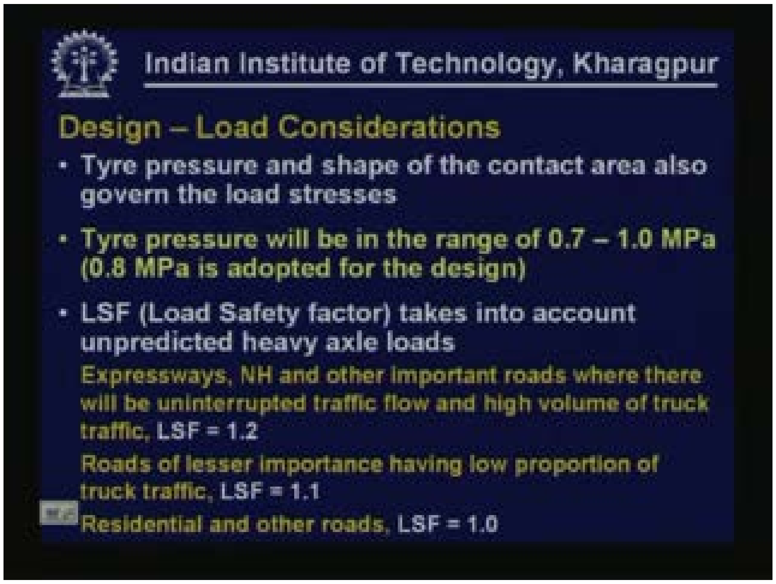

Other traffic related or road related considerations are; tire pressure and shape of the contact area also govern the load stresses. Tire pressure will be in the range of about 0.7 to 1 MPa so 0.8 MPa is recommended for consideration the design.

Load safety factor is also used which takes into account the unpredicted heavy axle loads. For express ways this brings an additional safety factor into the design.

For express ways National Highways and other important roads where there will be uninterrupted traffic flow and high volume of truck traffic we are going to use slightly higher safety factor LSF of 1.2.

Roads of lesser importance having low proportion of truck traffic LSF of 1.1 will be used. For residential and other roads of no additional safety LSF of 1.0 is used.

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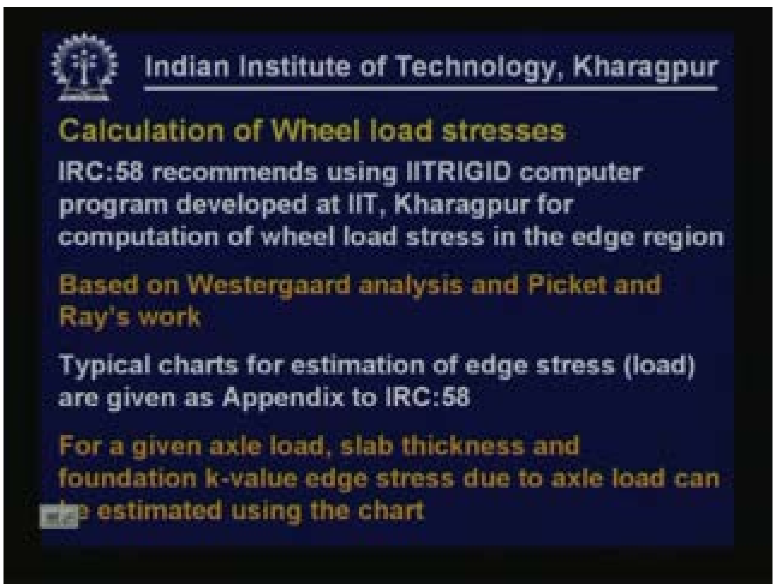

For calculation of wheel load stresses Indian Road Congress: 58 - 2002 guidelines recommend use of IITRIGID computer program developed at IIT Kharagpur for computation of wheel load stresses in the edge region.

As identified already edge region is considered to be the critical region as far as wheel loads are concerned. So this computer program gives wheel loads stresses in the edge region because of the application of single load, tandem loads, single axle and tandem axle. This computer program is based on Westergaard's analysis and Picket and Ray's analysis. For those who do not use this program, typical charts for estimating edge stress due to wheel loads is also given as appendix in IRC: 58.

For a given axle load, for a given slab thickness and for a given foundation k value edge test due to axle load can be estimated using the chart.

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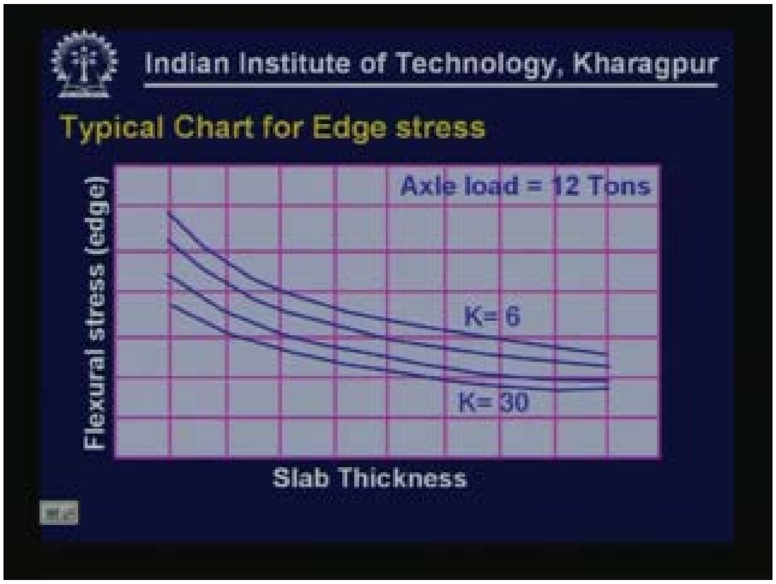

A typical chart looks like this: for a selected slab thickness and for a selected k value, it can even be a combined k value, so for a given axle load the flexural stress due to this load in the edge region can be obtained directly from the charts. One can of course use the computer program, and for any intermediate load or for any intermediate k value and for any slab thickness the flexural test can be computed.

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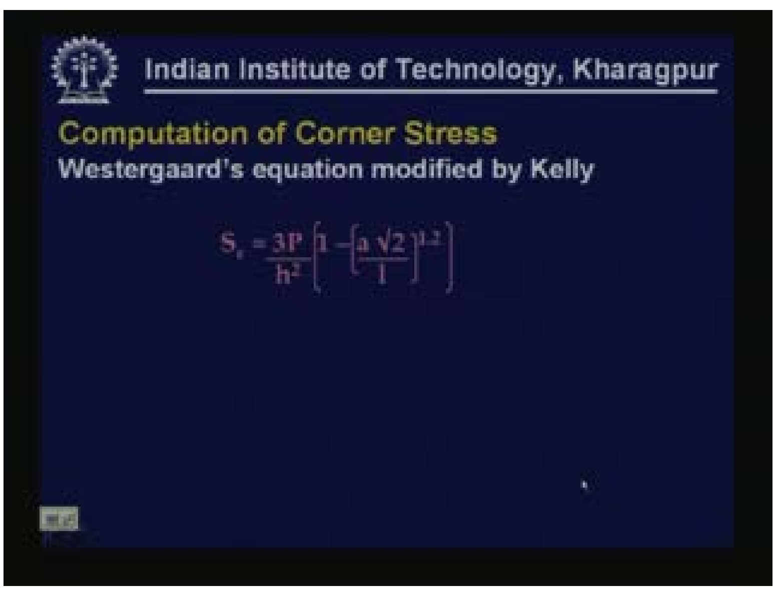

This is the expression adopted in IRC: 58 for computation of corner stress. This is the Westergaard's equation modified by Kelly. In this it is given as 3P by h square where P is the wheel load, 'h' is the thickness of the slab into 1 – a under root 2 by l, this is 'l' where 'a' is the radius of load contact area, ‘l’ is the radius of relative stiffness, this is the parameter that we have discussed in the earlier lessons.

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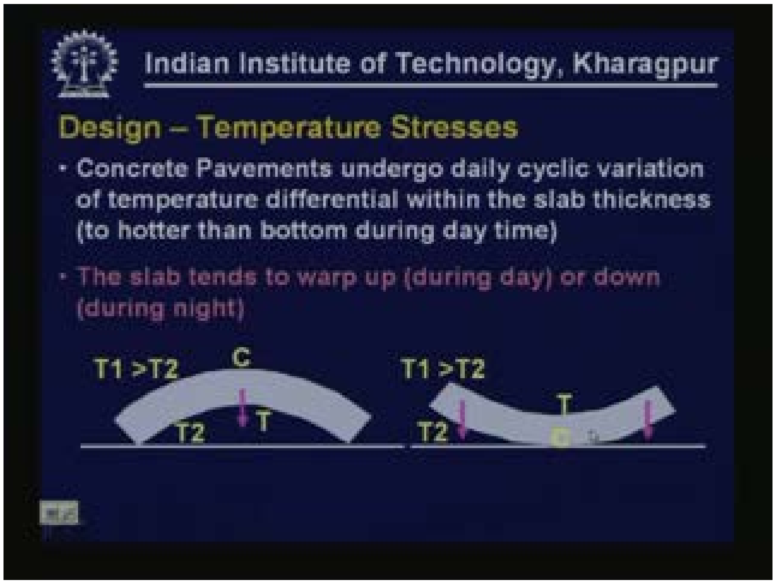

IRC: 58 also considers temperature stresses because of variation in temperature within the slab thickness the concrete pavements undergo daily cyclic variation of temperature differential within the slab. Top is usually hotter compared to bottom during the day time so the slab tends to warp up during day or warp down during night time. These two situations are depicted here. If the top temperature is more than the bottom temperature it is going to be taking this shape (Refer Slide Time: 41:44). If self weight or any other restraint that is available from the foundation then it is going to pull this down resulting in tensile stress at the bottom and compressive stress at the top. On the other hand if the top temperature is less than the bottom temperature this is how it is going to take shape and the self weight of the slab is going to pull this down resulting in tension at top and compression at the bottom.

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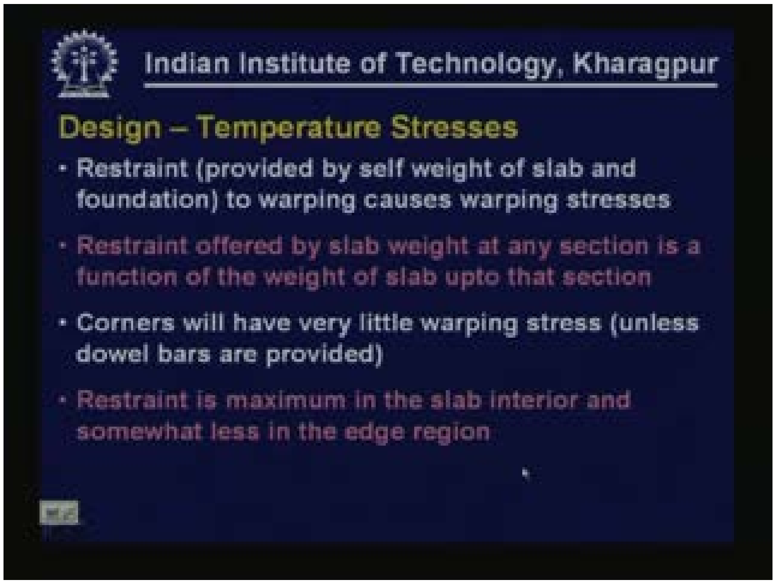

The restraint provided by self weight of the slab and foundation to warping causes warping stresses. Restraint offered by slab weight at any section is a function of the weight of slab up to that section so corners will have very little warping stress unless dowel bars are provided.

Restraint is at its maximum in the slab interior and somewhat less in the edge region. So the restraint or curling stresses are going to be maximum in the interior, next it will be slightly lower in the edge region and they will be almost negligible in the corner region.

Typical temperature differentials are recommended by IRC: 58. Because for a given region we have to assume some maximum temperature differential from top to bottom so these are recommended by IRC: 58 these values can be seen from the guidelines.

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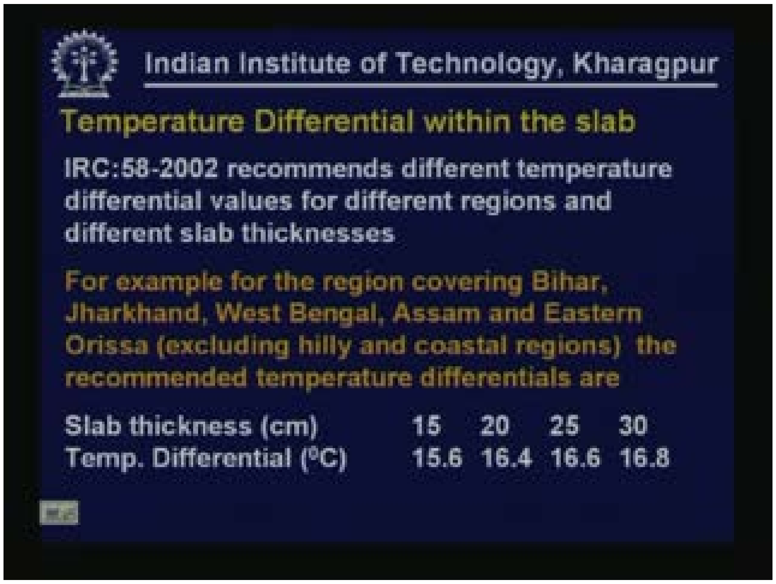

For example, for the region covering Bihar, Jharkhand, West Bengal, Assam and Eastern Orissa excluding hilly and coastal regions the recommended temperature differentials are; for different thickness of slab different temperature differentials are recommended. For example, for 20 cm thick slab in this region the temperature differential to be assumed is 16.4 degree centigrade.

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For computation of warping stresses especially in the edge region although we know that for the interior region the warping stress is going to be more but since we are combining both the wheel load stresses and the warping stresses and considering this combination to be critical so we are considering this combination to be critical in the edge region. That’s why we are calculating wheel load stresses in the edge region and also the curling stresses or warping stresses in the edge region. So the expression for computing warping stress in the edge region is given using Bradbury's coefficients as a function of modulus value of concrete, coefficient of thermal expansion of concrete 't' is the temperature differential from top to bottom within the slab and 'c' is the Bradbury's coefficient.

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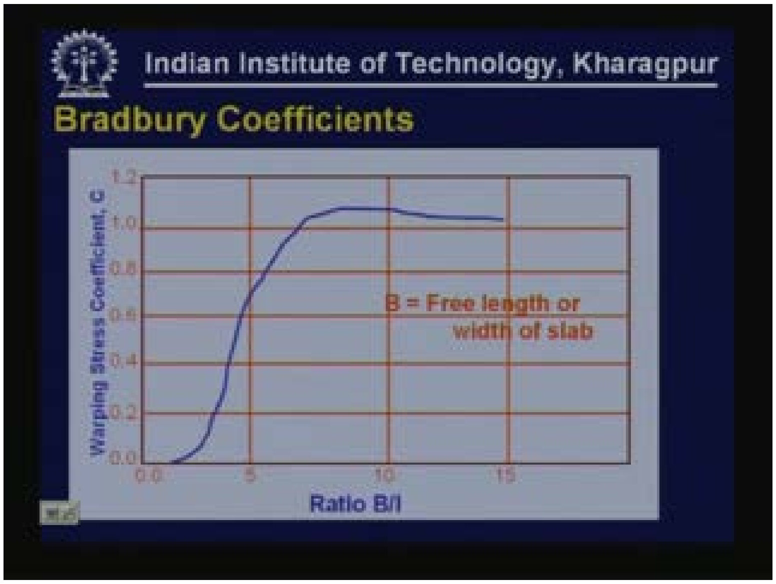

Bradbury coefficient as we have seen in the lesson on analysis of concrete pavements can be obtained from the dimension of the slab and from the parameter radius of relative stiffness where B is the free length or width of the slab. Since we are considering the edge region we will be considering the length of the slab in the longitudinal direction. So, from the dimension of the slab we can obtain the coefficient to be considered and this can be substituted in the expression that we have seen in the previous slide and we can compute the edge stress.

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So the critical combination of stresses for wheel load corner stress will be more because of discontinuity in two directions, it will be more than edge stress while edge stress is going to be more than the interior stress. Whereas in warping stress the interior will be more than edge and the edge will be more than corner. During day time interior and edge is the critical combination, load and warping produce tensile stress at the bottom, night time load and warping stresses produce tensile stresses at top. The combination of stresses in the edge region is generally considered to be critical. So it is necessary to also check for corner loads. Although we are concerned about the edge region IRC recommends that we should also check for the corner load stresses.

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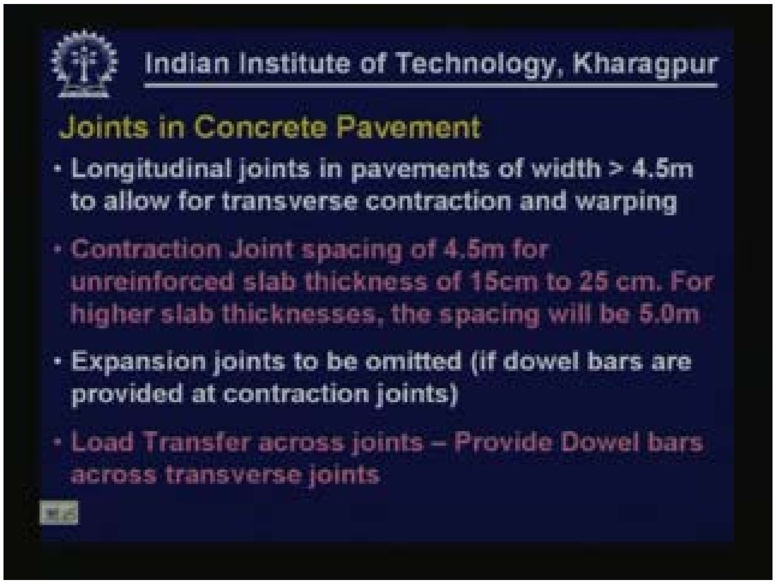

There will be different types of joints in the concrete pavement. Longitudinal joints on the pavements of width, is more than 4.5 m to allow for transverse contraction and warping. Contraction joint spacing of about 4.5 m for unreinforced slab thickness of 15 cm to 25 cm, for higher slab thicknesses this spacing will be about 5 m. Expansion joints are normally to be omitted if dowel bars are provided across contraction joints. The load transfer across joints is to be provided by dowel bar system across transverse joints.

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In the design approach the main inputs will be axle load spectrum. We have to have information on the axle load spectrum, the temperature differential, grade of concrete we are going to use, foundation strength and the dimensions of the slab which can be obtained after fixing the joint spacing. So the slab is to be designed to sustain fatigue damage and also flexural damage due to the application of heavy loads. The erosion failure though is considered to be important if we have multi axle vehicles which produce higher deflections. But it is not very common that we see many multi axle vehicles at the present situation. IRC does not recommend any analysis for erosion. But however it recommends provision of paved shoulder up to 1.5 m beyond the pavement to reduce erosion and pumping.

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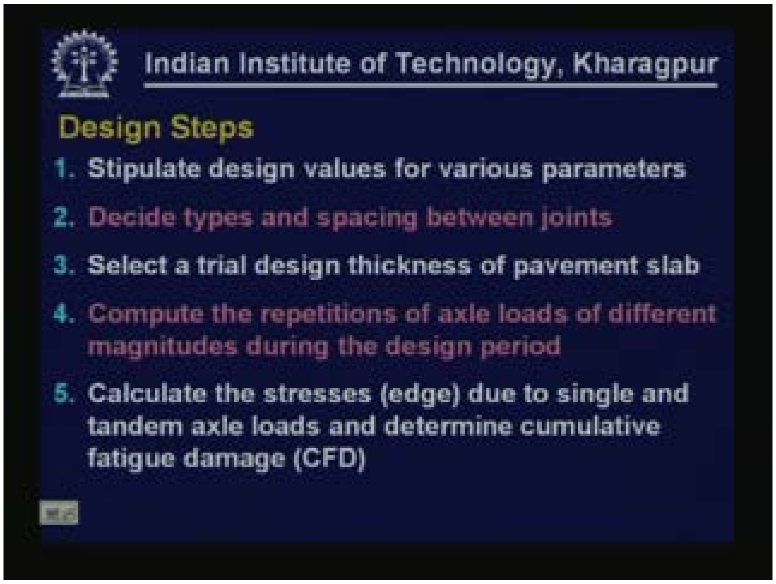

The design steps are; we have to stipulate the design values for various parameters, decide the type and spacing of joint, we have to select a trial design thickness and then compute the repetitions of axle loads of different magnitudes during the design period, calculate the stresses in the edge region due to single and tandem axle loads and determine the cumulative fatigue damage.

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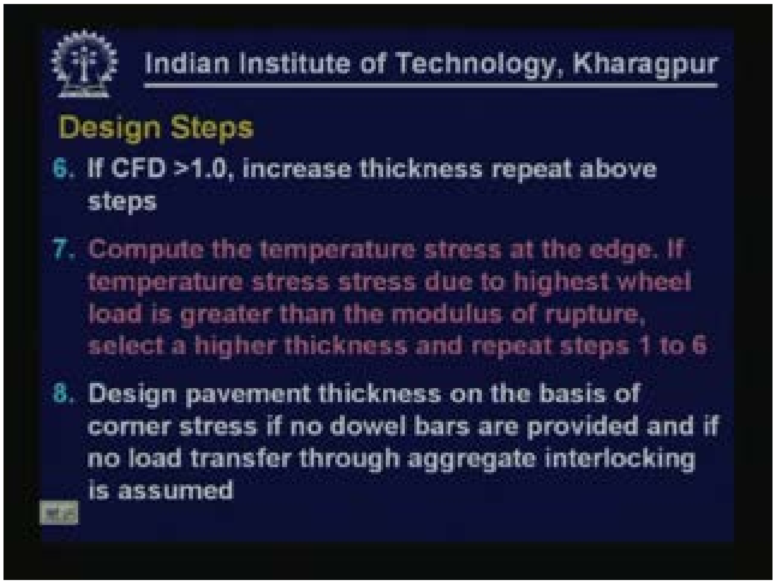

If the cumulative fatigue damage CFD is more than 1 increase the thickness and repeat the above steps till we are satisfied that the cumulative fatigue damage is going to be less than 1 we have to go on increasing the thickness of the slab. Then compute the temperature stress at the edge region. If the temperature stress due to the highest wheel load is greater than the modulus of rupture select higher thickness and repeat steps 1 to 6.

Design pavement thickness on the basis of corner stress if no dowel bars are provided and if no load transfer through aggregate interlocking is assumed.

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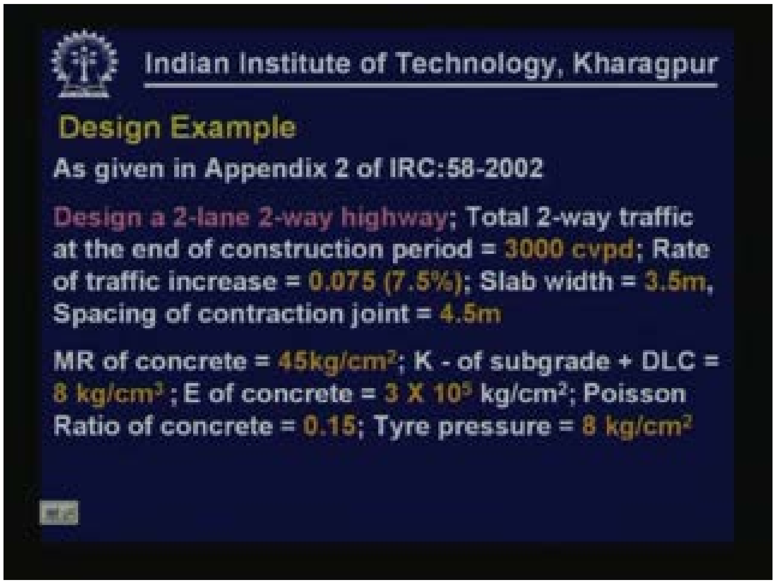

Let us take up a design example. This is an example given in the appendix two of IRC: 58 – 2002 and the same is produced here. We are trying to design a 2-lane 2-way highway. The total 2-way traffic at the end of the construction period is expected to be 3000 commercial vehicles per day. The rate of traffic increase is expected to be 0.075 that is 7.5%, the slab width, this is being a 2-lane 2-way highway so for each lane there is a longitudinal joint in the middle so width is 3.5 so this is how it is constructed.

There is a longitudinal joint here and the transverse joints are placed at 4.5, total width is 7 m so this is 3.5 so the dimension of the slab is 3.5 by 4.5. So spacing of contraction joint is 4.5, modulus of rupture of concrete that is the tensile strength of concrete is 45 kg per centimeter square these are all inputs that we need to design, K of subgrade plus DLC is a combination, the combined value is taken as 8 kg per centimeter cube, modulus value of concrete is 3 into 10 to the power of 5 kg per centimeter square, Poisson ratio of concrete is 0.15, and tire pressure is taken as 8 kg per centimeter square.

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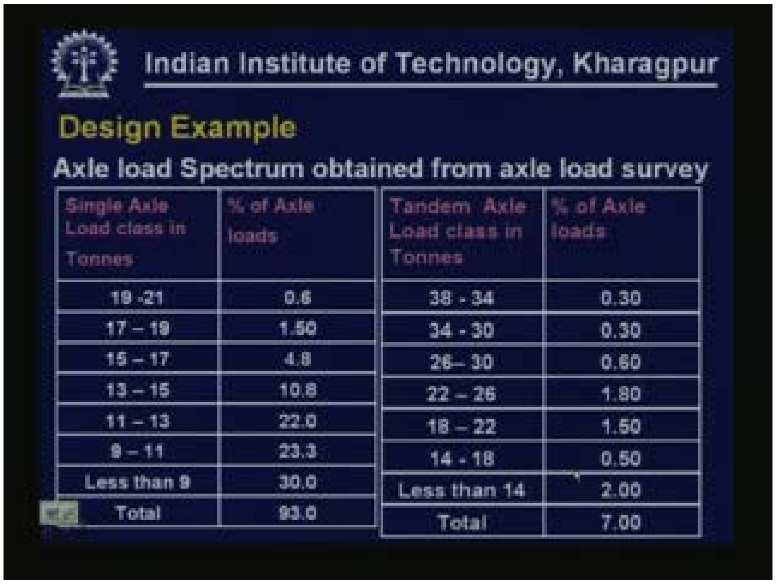

This is the axle load spectrum obtained from an axle load survey. For single axle loads the load groups are 19 – 21, 17 - 19 and so on, 9 – 11 and less than 9. So, for different axle load groups the corresponding percentage of axle loads are given. Out of the 100% axles 93% are single axles and remaining 7% are multi axles basically tandem axle loads. So the distribution of tandem axle loads is also given here.

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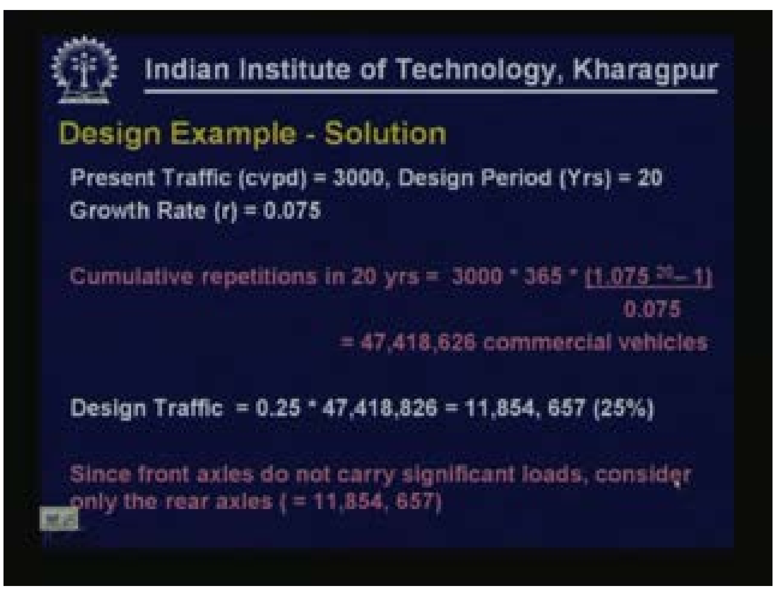

The present traffic in terms of commercial vehicle per day is three thousand commercial vehicles. A design period of 20 years has been taken, growth rate is 0.075. Thus, using this cumulative repetitions that are going to be there during 20 years is computed as 3000 into 365 into 1.075 that is 1 + r to the power x that is 20 – 1 divided by r that is 0.075. The total number of commercial vehicles that are projected to the using this facility in 20 years is 47 million commercial vehicles. Considering 25% of this for design 0.25 into this value is 11.854 millions. Since the front axles do not carry significant loads we are only considering the rear axles so we are going to have rear axles to be considered in the design which are about 11.854657.

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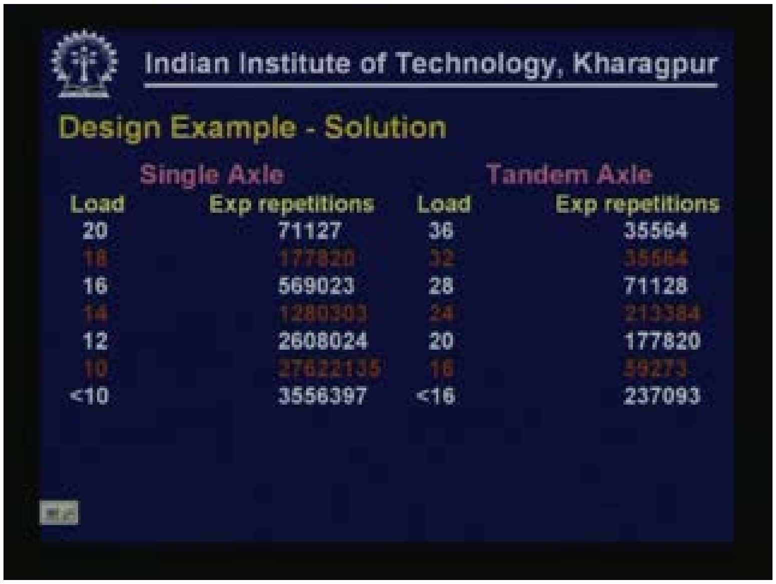

To solve this we are considering the midpoint for each load group such as for single axle 20 18 16 14 12 10 and so on. We have worked out the expected repetitions in terms of the percentage. Similarly for tandem axle also for different load groups the expected number of repetitions is also indicated here.

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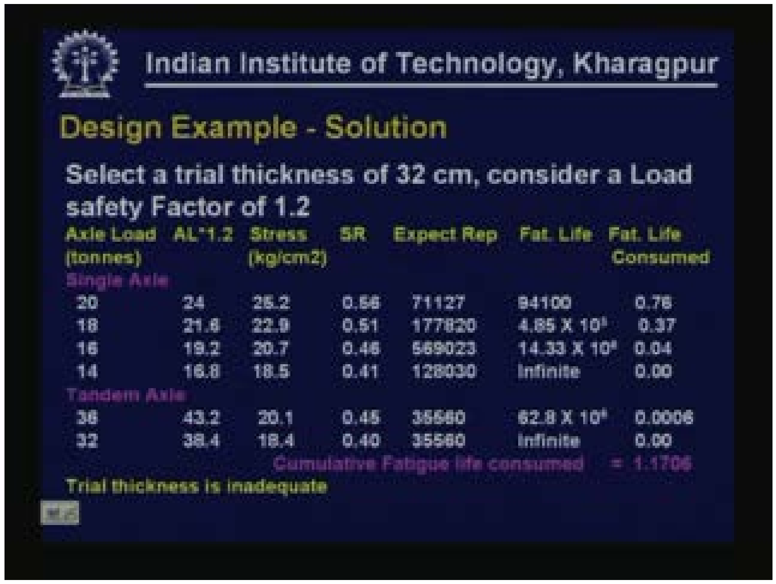

We have selected a trial thickness of thirty-two centimeters and we have considered loads safety factor 1.2. so the axle load is given here axle load multiplied by load safety factor 1.2 is also given, the corresponding stress as read from the chart is given, the corresponding stress ratio stress divided by modulus of rupture is given so for this the expected repetitions as shown in the previous slide is given, the fatigue life is obtained using this stress ratio, as we have discussed earlier by substituting this in the fatigue equation, this is the total fatigue life that is consumed (Refer Slide Time: 52:56), and these are the expected repetitions. So directly this ratio (Refer Slide Time: 53:17) gives you the fatigue life that is consumed. Similarly the fatigue life consumed is worked out for all the other load groups. The fatigue life consumed is also worked out for tandem axle load groups.

For loads less than 32 tandem axle loads it is not worked out because in 32 itself the fatigue life is coming out to be infinite, the cumulative fatigue life consumed is about 1.1706 so obviously the thickness is inadequate.

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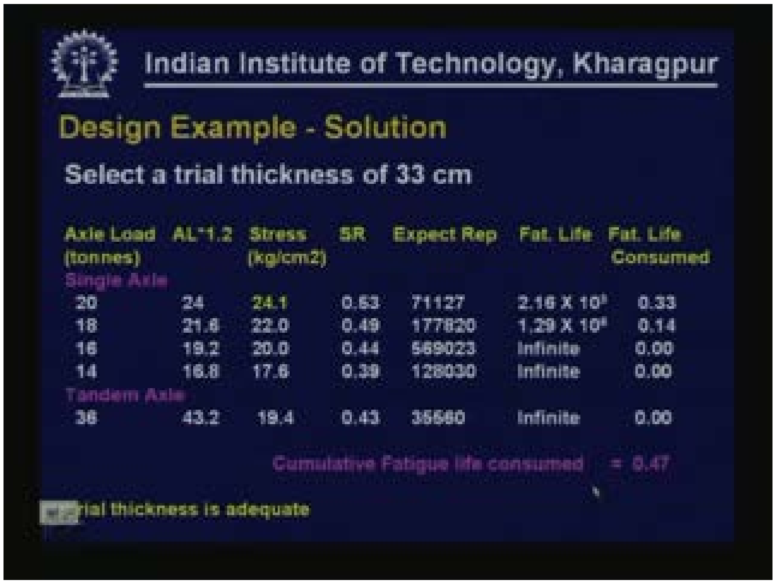

So the exercise is repeated with another trial thickness of 33. We can see that the cumulative fatigue life consumed here is 0.47 which is acceptable. Therefore this slab is now safe from fatigue considerations.

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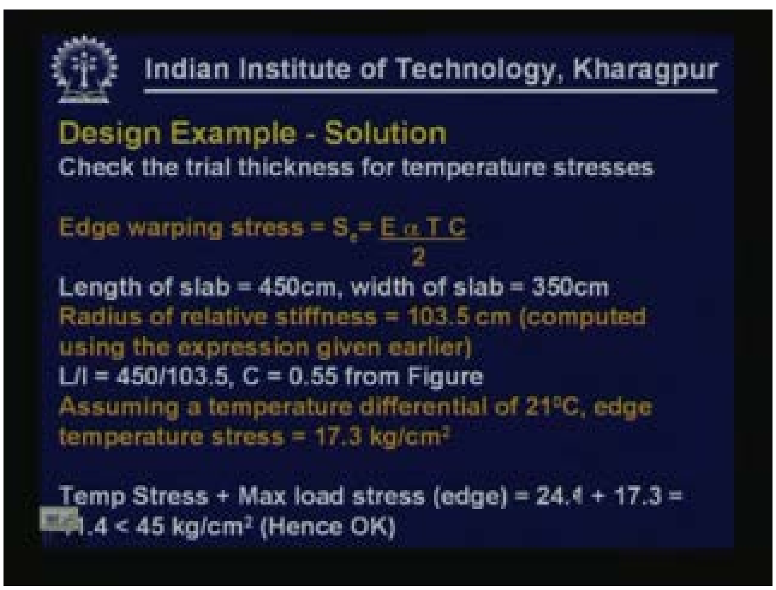

The slab is now checked for warping stresses also, calculated using this stress. For a length of 450 cm and width of 350 cm the Bradbury coefficient from the figure is 0.55 and the corresponding temperature stress is 17.3 for a temperature differential of 21. Hence the temperature stress plus maximum load stress 24.1 + 17.3 works out to be 41.4 which is less than 45 kg per centimeter square hence this thickness is okay from this consideration also.

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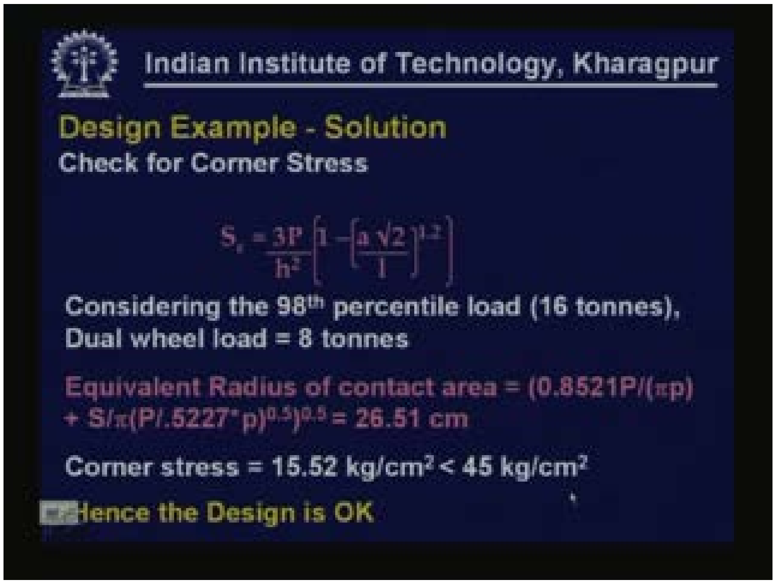

This slab is again checked for corner stress considering the heaviest load that is a 98th percentile load which is considered to be 16 tons, dual wheel load is 8 tons so the corresponding corner stress works out to be 15.52 which again is much less than 45.

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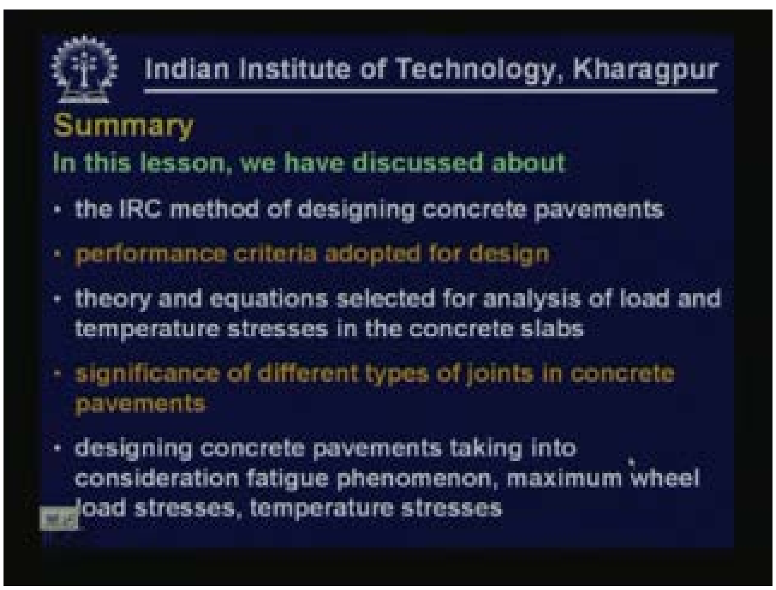

To summarize: in this lesson we have discussed about the IRC method of designing concrete pavements. We also discussed about the performance criteria adopted for design in these guidelines. We also talked about the theory used to model concrete pavements and the equations or the models used for analyzing the load and temperature stresses in concrete slabs as per IRC: 58 – 2002. We also discussed about the significance of different types of joints in concrete pavements, we have done this very briefly. We also discussed as to how to design concrete pavements taking into consideration fatigue phenomena, maximum wheel load stresses and temperature stresses.

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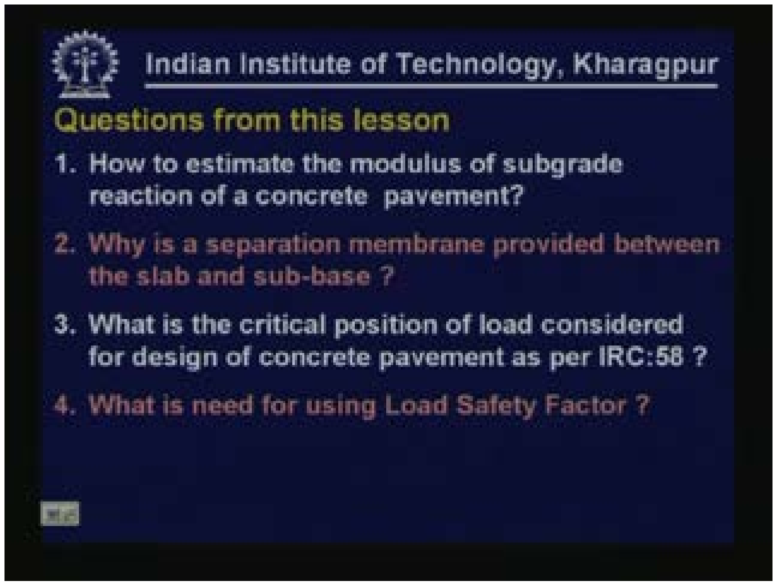

These are some questions from this lesson, answers to this will be provided in the next lesson.

1) How to estimate the modulus of subgrade reaction of a concrete pavement?
2) Why is a separation membrane provided between the slab and subbase
3) What is the critical position of load considered for design of concrete pavement as per IRC: 58
4) What is the need for using load safety factor in the design of concrete pavements as per IRC: 58 – 2002?

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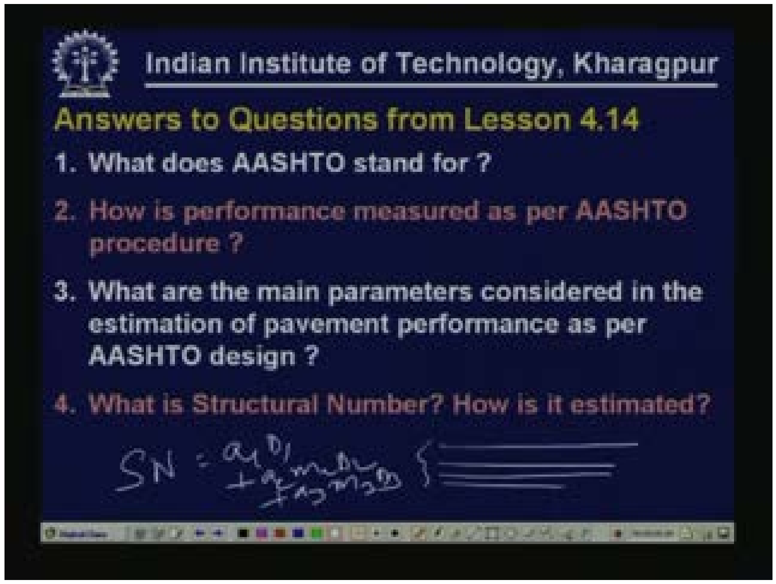

Now let us discuss the answers for the question that we asked in lesson 4.14 which was on design of flexible pavements as per as AASHTO designed guidelines.

What does AASHTO stand for?
AASHTO stands for American Association of State Highway and Transport Officials.

How is performance measured as per AASHTO procedure?
As per the AASHTO guidelines performance is measured or represented in terms of present serviceability index. In fact the performance is to be represented in terms of the parameter known as present serviceability rating which is to be given by a panel of experts. This rating has to reflect the comfort that is pursued by the road users while traveling on a particular road. By correlating the physical features of the pavement to the present serviceability rating given by the panelists an index termed as present serviceability index has been developed. This can be estimated as a function of various physical features of the road such as slope variants which indicates the longitudinal variation in the profile and roughness especially for flexible pavements, slope variants, cracking, patching and rut depth.

What are the main parameters considered in the estimation of pavement performance as per AASHTO Design?
This is the question which refers to the AASHTO performance equation which correlates the number of repetitions of standard axles that is W_{18} that the pavement can solve satisfactorily. So the parameters that are considered significantly are; residual modulus value of the subgrade, loss and serviceability delta PSI, reliability factors and terminal serviceability index these are the important parameters that are selected.

What is structural number how is it estimated?
Structural number is an index that gives the combined strength of the pavement. If you have four layers so SN is given as a1 D2 + a2 m2 D2 + a3 m3 D3 where D1, D2, D3 are the thickness of

the top three layers and a1 a2 a3 are the layer coefficients and m2 m3 are the drainage coefficients so the structural number gives us an indication the strength of the pavement. Thank you.