Analysis and Design of Bituminous Pavements

Prof. J. Murali Krishnan

Department of Civil Engineering

Indian Institute of Technology Madras

Lecture - 02

Pavement Design Factors - I

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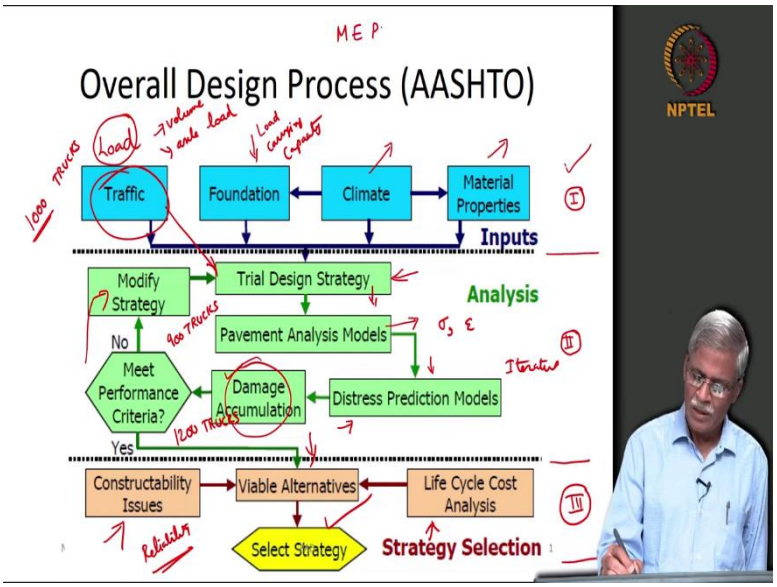

So, let us continue our discussion on what we talked about the Design Process related to Bituminous Pavement. So, let me reiterate. We will be talking this as a bituminous pavement engineering design process. So, there are three steps as we discussed yesterday. The first step is the inputs that you provide; the second step is the analysis that you will be carrying out to compute what is really mentioned here as damage and the third step is very important, but slightly outside the typical scope of what you really call as the design.

For instance, it goes into the purview of reliability, it goes into the purview of life cycle cost analysis, it goes into the purview of constructability you know more about pavement construction pavement management and the associated reliability, but the actual design is completed in the first two steps.

Now, see in a sense the pavement engineering that you actually see here is always referred to as MEPD. So, there is a mechanistic part, there is an empirical part. Now, what exactly

is the empirical part that as we go along we will be discussing it, but to just to give you a brief outline about what I think as.

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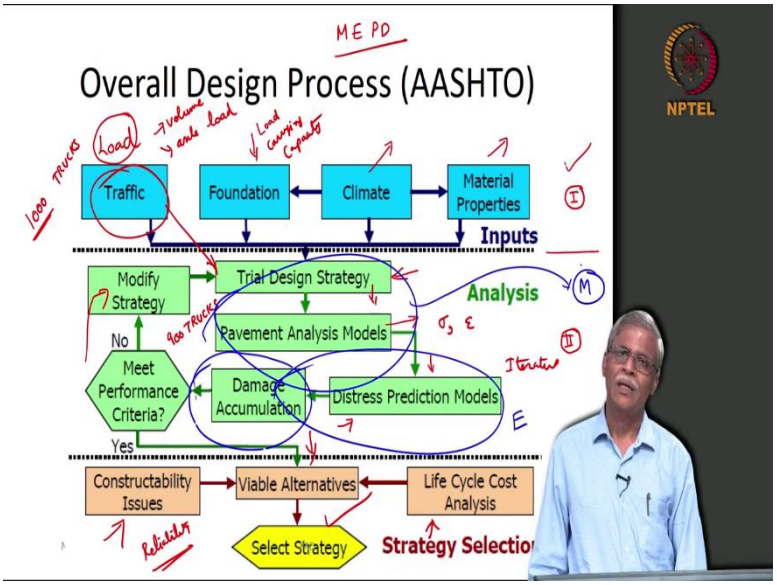

So, this comes under the empirical part this comes under the mechanistic part. So, now, what is the origin of this empirical part and for that what we need to do? We need to go back in history.

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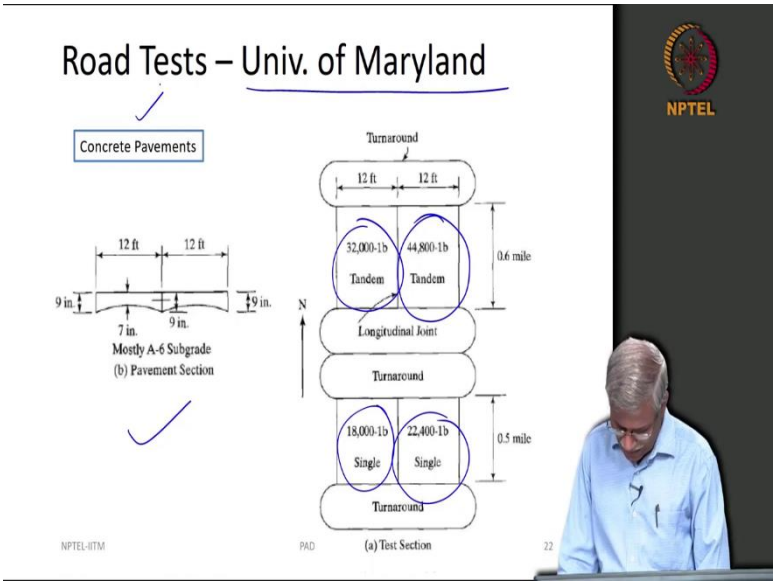

And, talk little bit about the road tests that were carried out in United States. These things happened immediately after the Second World War. So, there was an increased emphasis

on road construction in United States, and in fact, most of the road engineering that you see throughout the world has some kind of a genesis related to what happened in United States during the 1950s and 60s. So, first and foremost thing the University of Maryland constructed its first road test and in fact, you can actually see the cross-section that was used. And, the typically the road test track that was used here different types of axles with different weights were used here. So, this was mainly constructed to have some understanding of the concrete pavement.

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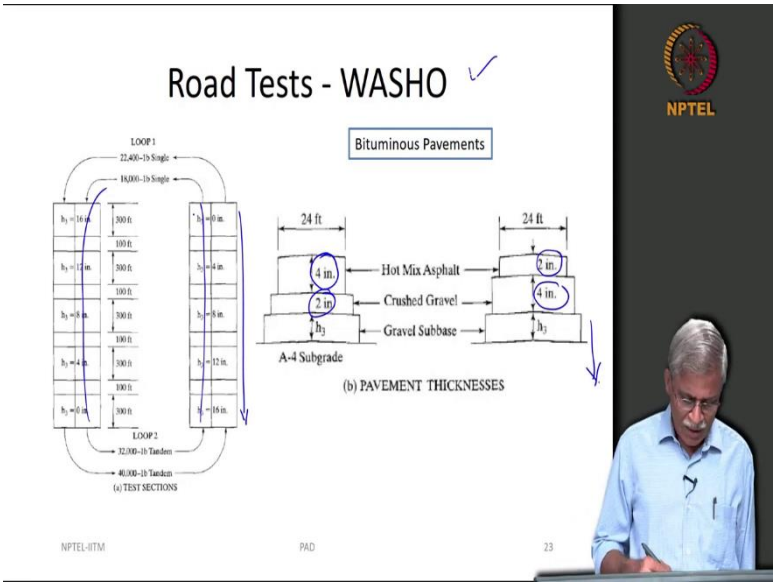

The next and the most important road test was constructed by the Washington State Highway Officials what is really called as the WASHO road test. So, what they did was they basically were looking at in the influence of you can see layer thickness. So, 4 inches, 2 inches and this is something that is variable hot mix asphalt and crushed.

And, there were many stretches that were constructed here and in fact, we can see different layer thicknesses of the third layer that is provided here and so, you can say different types of axles just going around it and they had some kind of LVDTS that were capturing the deformation.

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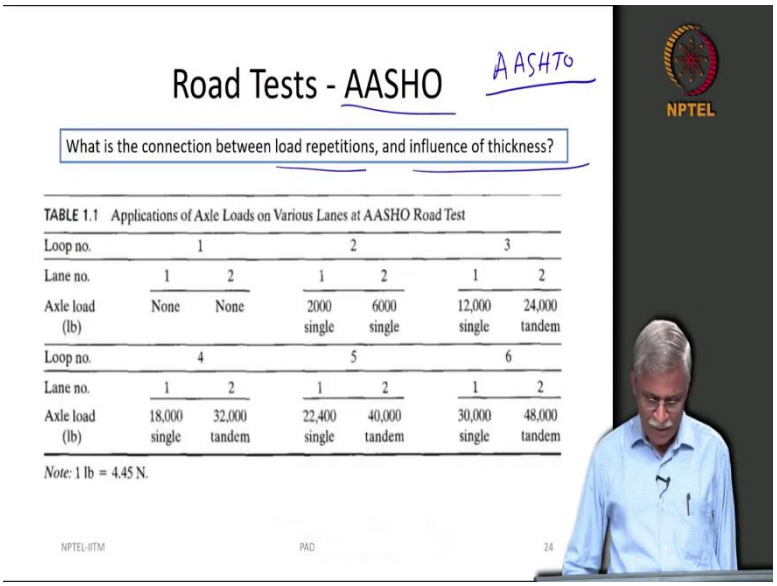

So, now let us come to the most important one with which right now is called as AASHTO, but in those days it was called as AASHO. So, American Association of State Highway Officials the transport was added later. So, it is now American Association of State Highway and Transport Officials AASHO. The main emphasis was what is the connection between load repetition and the influence of thickness?

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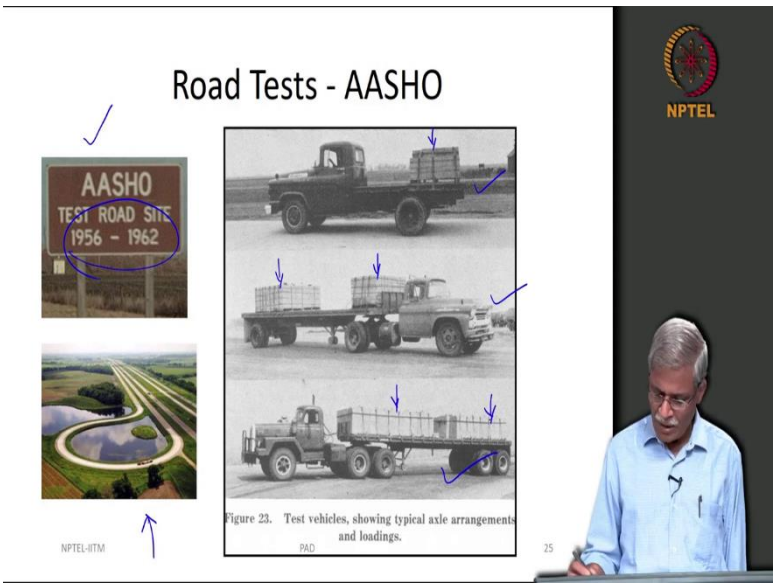

So, different loops were constructed. So, this is the AASHO road test. So, this was carried out for something like 1956 to 1962 and you can see this is the test track a picture of the

test track. So, typical arrangements were carried out here you can actually see vehicle type 1, vehicle type 2 and vehicle type 3 and they loaded it in this way you can see that exactly on top of the axles these things were loaded. And, so, different types of axle loads were applied and data was collected.

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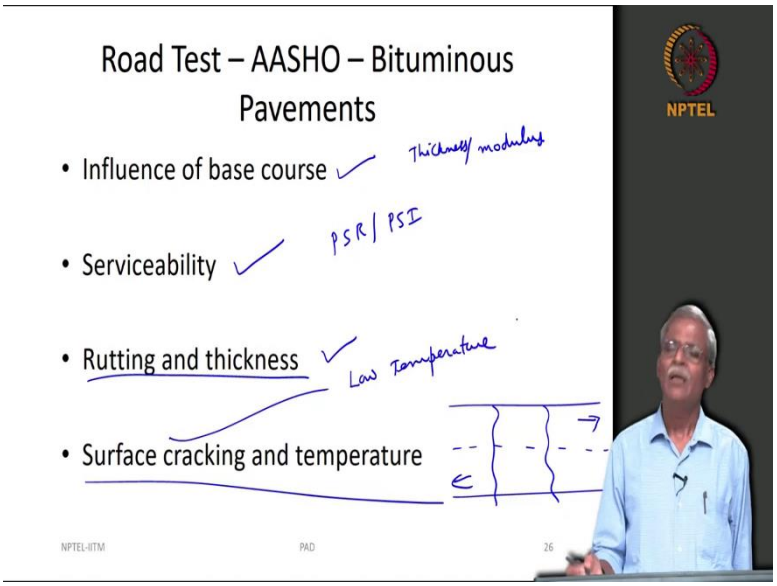

Now, what these things basically resulted in? What exactly is the influence of base course so, in terms of thickness in terms of modulus? Then the next and the most important concept was something to do with the serviceability in terms of the rideability, ride comfort and this resulted later in what are called pavement serviceability index, pavement serviceability rating and all those things. The third important thing that they were looking at is, what is the relation between rutting the longitudinal depression in the wheel path that you see and the associated pavement layer thickness. And, then they were also looking at whether the surface cracking that you see and when I am talking about surface cracking. So, let us say this is your plan view of your highway. So, they were looking at cracks that were emanating perpendicular to the direction of traffic. So, what is the influence of temperature? So, in a sense we can say so, they were looking at low temperature cracking and also fatigue damage all these things were really looked into it.

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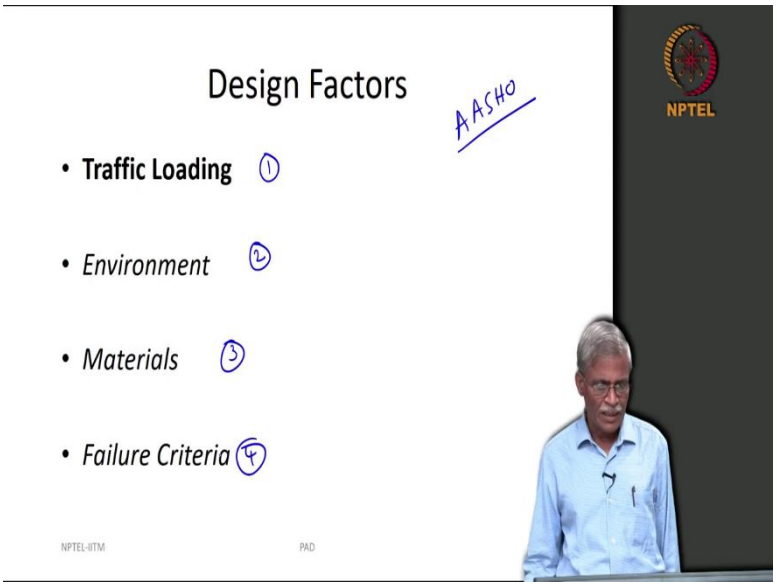

So, this results these test results AASHO test, WASHO test, University of Maryland test basically compilation of all these things resulted in the first ever design code which was released by AASHO. And, later it went into several revisions before what we see here as me MEPDG 2008, 2004 it was supposed to have been released, but they finally, released it in 2008.

Many of the design standards throughout the world have been significantly influenced by the findings from the AASHO road test including IRC 37 that you see. In fact, if you take a look at IRC 37 2018 you can actually look at the skeleton and see clearly what are all the important guidelines, frameworks that have been originally adopted by MEPDG how it has resulted in the design code that we have. So, when you work out problems you will be able to understand and appreciate it.

Then before we get into the stress analysis there are few important things about design factors that I need to talk about. So, the first and foremost thing is traffic loading, second is environmental condition, third is material and fourth is what is really called as the failure criteria.

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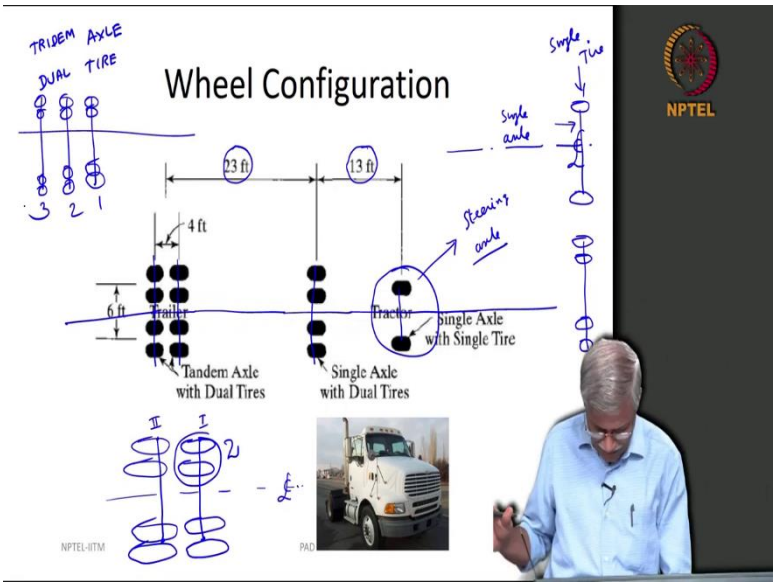

So, let us talk about the traffic loading. So, now, you need to understand few things very important here. So, this is the terminology that we are going to use throughout this course and you should know it very clearly. Now, you can convert all these things into appropriate units that you are comfortable with.

So, a single axle with the single tire is given like this. So, this is the one. So, you have a single axle and there is a single tire on either side. So, when we are talking about truck, you are really talking about the center line. So, you have one tire here, you have one tire here. So, this is what we call as single axle and single tire.

Now, the next configuration that you are looking at, so, let me draw the portion through it, is single axle with dual tire. So, there is one single axle. So, there are two tires on either side. So, this is called as single axle with dual tires. Now, you also need to take a note of this. So, this is the tractor. So, what you can say is to make life easier for you, we will talk about what is called as the steering axle the front most axle typically that is single axle with a single tire, right. Then you can have single axle with dual tires here.

So, this configuration can be built. So, you can actually add many such configurations here to do it and the next and the most important thing that we are going to talk about is called as tandem axle with dual tire. So, what do I mean by tandem axle? There are two axles. So, that is why the word tandem and each axle has two tires on either side. So, this is your center line.

So, tandem axle, axle 1, axle 2 and each axle has two tires. So, this is the configuration that you can you are going to see. You can also have what is called as tridem axle dual tire. So, that means, it is very straightforward. So, you are going to have three axles and you are going to have two tires on either side 1, 2, 3. So, like this you can have many combinations. So, a typical truck and its trucks chassis is basically built with these kind of axle configuration.

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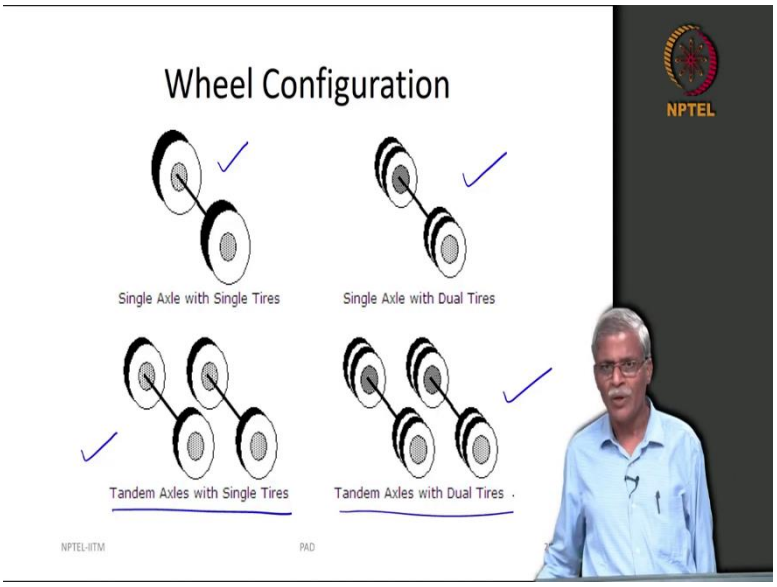

So, to just give you a brief perspective about this thing is single axle with single tire, single axle with dual tire, tandem axle with single tire, tandem axle with dual tire. Of course, you can also have tandem axle with single tire and in fact, next time after you listen to this video and when you just go watch in the road and focus your attention on the axle configuration, you will see that there are some Indian trucks that will also have a tandem axle with a single tire.

And, in fact, many times the truck drivers will raise it only they will lower it to touch the road surface only when they are carrying the load when they are not carrying the load they will just raise it. So, these are what are called tandem axle with dual single tire and then you will you are going to have tandem axle with dual tire.

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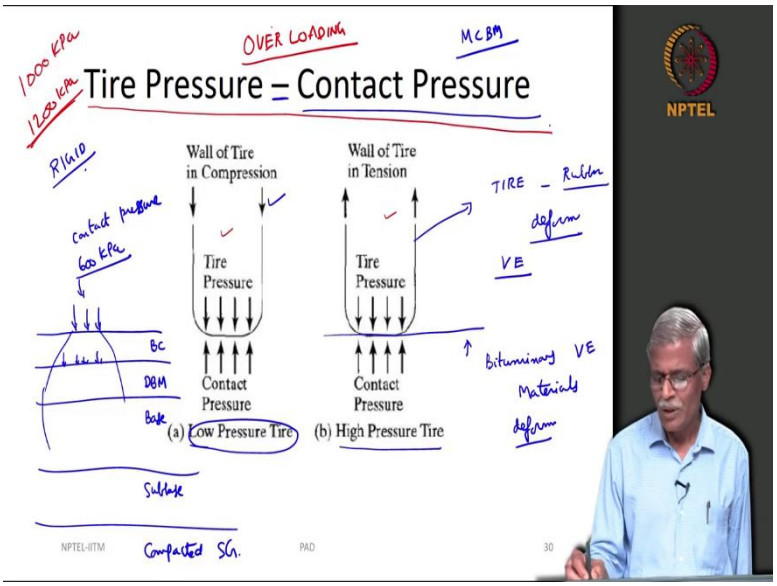

Now, comes the most important concept and the most important assumption that we are going to make as far as pavement engineering is concerned bituminous pavement engineering is concerned. Now, we you all know what exactly the tire is made of. The tire is typically made of rubber.

Now, this rubber can deform. Definitely it will deform and what about this pavement? So, this is made of bituminous material. Obviously, this also will deform. In fact, this is the most important reason why you are taking this course how to limit the deformation, how to limit that your pavement road surface will give you the adequate serviceability with the required reliability within the design period. These are all the important words that you keep in your mind.

Now, rubber will deform bituminous material also will deform and I am just going to add little more complexity. Here the rubber is a viscoelastic material. Bituminous material is also a viscoelastic material. Now, if you are not really sure of what exactly is viscoelasticity, I advise you to go and watch our course on mechanical characterization of bituminous material that we ran successfully for 3 times in NPTEL. I think these videos must be available in YouTube. I have given some lectures. Professor Padmarekha also has given some lectures in small amplitude oscillatory shear in frequency domain testing. So, you can watch it now what exactly this means is when you are having a truck with the

rubber tire, the rubber tire deformation will be time dependent, the bituminous material deformation also will be time dependent. So, just keep that in mind.

Now, come to the main important criteria here now what I really want to ask you is. So, it will be a nice if you are sitting in front of me because I could ask you lot of questions and get an answer from you and understand whether you are following in the same track. But, since that is not going to happen here. So, let me ask you this. So, we are interested in designing the pavement. So, if you are designing the pavement what is the most important thing that you want to know – what is the load that is applied from the tire to the pavement or how much load is transferred from the tire to the pavement?

Now, if I say, it is actually very simple, whatever is the tire pressure you know you go to the petrol bunk you fill up petrol and once in a while also you kind of try to put check your air and then fill it up 32 psi or 30 psi or 40 psi or 50 psi depending on the vehicle that you drive. So, if I tell you that the load that is transferred or the load per unit area that is transferred is let us say 600 kPa you do the conversion 30 psi to kPa how much it comes you can find it out.

Then you are going to say no that is not really true tire pressure the air in the tire inside the tire that is the pressure that you are talking about, but what is the important assumption that you have made here; the important assumption that you have made here is the tire walls are rigid. So, since the tire walls are rigid the load that is transferred, the load per unit area that is transferred from the tire to the pavement is nothing but the tire pressure.

Now, relate this with whatever I mentioned about rubber tire and bituminous material they have a time dependent deformation, again just keep that in the back of your mind. So, when the tire walls are rigid whatever is the load that is transferred from the tire to the pavement is nothing but the tire pressure. So, the tire pressure and what we are interested is to find out see because we are not really going to talk like this anymore.

We are only going to say so; this is my bituminous layer. So, let us say this is bituminous concrete and this is dense bituminous macadam, this is base course and this is going to be subbase and this is going to be compacted sub grade. So, you are only going to be interested in how much is the load that is transferred because you want to really use this and do your calculation. So, how much is the stresses and strains that are transferred at a different location.

And, if I say that you do not need to really worry about it whatever is the pressure in the tire is the contact pressure. So, when I make such a statement, the assumption that I have made here is the tire pressure is equal to contact pressure, but in real life what will happen? If you have a low pressure tire, then what can really happen is, if you assume that the tire pressure is equal to contact pressure the walls of the tire basically are going to be in compression.

And, if you are having a tire pressure a high pressure tire the walls of the tire are going to be in tension. So, I will explain this little more and for this I just need to give some little bit of a side story here. You must have heard from many people highway agencies newspaper reports and all those things that the roads are failing frequently. They are not even able to withstand 2 years or 3 years of traffic and all those things. One reason important reason – overloading. So, we will not get into the what you can say the legal aspects related to overloading that is not really the purpose of this course. As a road engineer you should be able to design whether your roads are overloaded or under loaded or laden, completely as per the legal axle limit. So, you need to understand what exactly is this overloading.

Most of the time many of the transport agencies commercial truck operators will slightly try to load more than what is the legal axle load limit. Now, you can actually ask so, what about the tire pressure there. So, they are basically going to say that you know let us say it is 1000 kPa then you will be asking actually so, you are saying he is overloading it and he is having a tire pressure of 1000 kPa. So, how does this translate into in terms of my contact pressure? So, when you overload and if your tire pressure is let us say that you have kept is 1000 kPa what will happen? The tire walls will deform under the load pair contact area will actually increase, so that 1000 kPa times the area of contact will actually more or less equate for the additional load that has come in. But, then immediately you will ask, but this is not really making sense to me because if these people overload it and if their tire contact area is now more there is going to be more wear and tear and what is the profit that these people are making out of it. Then since we know people are very smart.

So, what normally they will do, they will also slightly increase the tire pressure. So, when they increase the tire pressure and if instead of 1000 kPa if it becomes 1200 kPa, you are going to see that the contact area is less. So, the load per unit area is more the contact area is less and so, what will really happen to your pavement in the summer?

The short small area of contact subjected to extremely high intensity of loading is going to result let us say in the month of June let us say you live in Rajasthan and let us say the air temperature is 45 to 46 ^{o}C and the pavement temperature is 65 ^{o}C, this is literally like knife cutting through the butter that is what will really happen and that is what really happens also.

So, now come back to this you are going to see that if you are going to have a high pressure tire the walls of the tire are going to be in tension, and if you are going to have a low pressure tire the walls of the tire are going to be in compression resulting in a contact area which is more. So, the contact area here is going to be more and the contact area here that you see is going to be less. So, this is something that you should keep in your mind. So, this is a very important concept that what we are doing is we are assuming that the tire pressure is equal to contact pressure, right.

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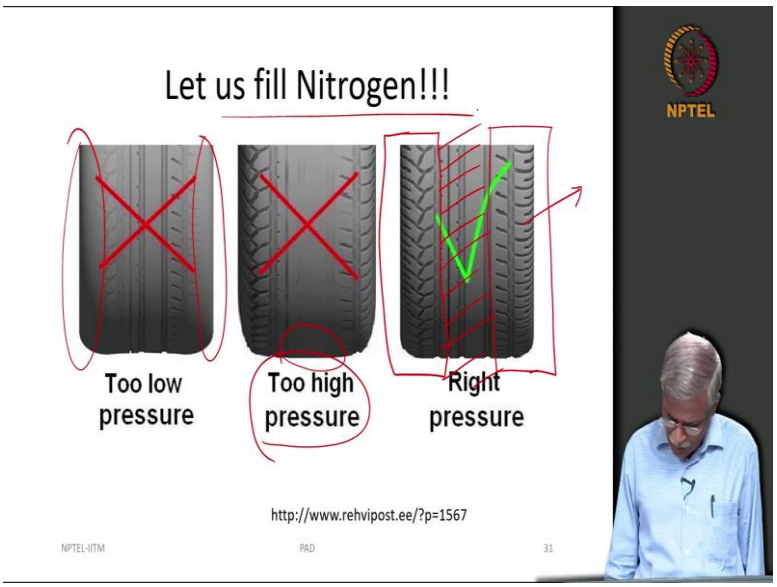

So, if you actually look at little more closely about what really happens, you will see something very interesting here. So, if you see that these are the tire walls and this central portion is what a tire manufacturer would call as tire carcass or something like that. So, these are your tire walls. The tire mechanics technology has advanced substantially in terms of material science design and all those things. So, we you will not get into those details, and that is not our intent also, but what really will happen is when you are and the tire walls, the stiffness variation across this tire walls also can be considerably different.

So, which means the tire walls could be very rigid and the central portion could be may not be necessarily that rigid.

So, what can really happen if you are going to have too high a tire pressure you are going to have wear and tear mostly here as can be seen here if you are going to have too low tire pressure you are going to see a wear and tear in this particular area, but if you fill it up with correct amount of tire pressure you are going to see an excellent service life of the tire. So, in fact, I just titled this as let us fill it with nitrogen, so, you can find out what exactly filling nitrogen will do to a tire here.

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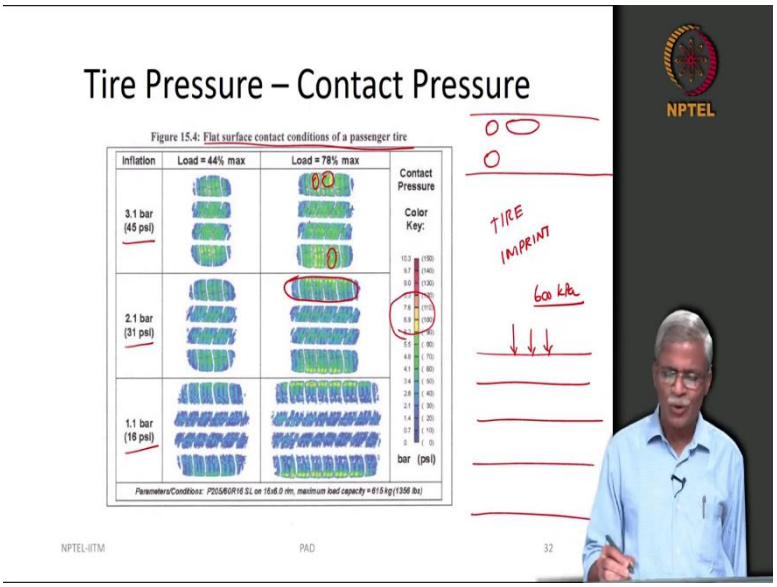

And, the tire pressure contact pressure needs to be understood little more carefully here because you can actually see these are the flat surface contact conditions of a passenger tire you can actually see how you know when you are going to have 16 psi, 31 psi, 45 psi and how the contact area here that you see keeps varying. And, if you also look at the color key here you are going to see that this portion ok where you can actually see these streaks here they are going to be different. But, what is very important for you to understand is that this contact area seem to be slightly elliptical. So, this is going to be very important for it.

So, the flat surface contact conditions of a passenger tire in fact, there are people research groups in South Africa who have done extensive work on trying to find out what is really called as the tire imprint to clearly find out the tire contact area. Now, if I go back to my

previous discussion that I had let us say these are your pavement cross sections and I mentioned something about 600 kPa. Immediately you are going to ask me, but what is the shape of the tire contact area because you only do something like this. So, we need to solve this problem in real life. So, let us if you look at it from the plan view so, you want to ask this question whether the contact area will be assumed as a circle or whether it is going to be actually something like this because the shape also matters. If you are really going to do the stress analysis the actual shape of the tire, contact area becomes very critical.

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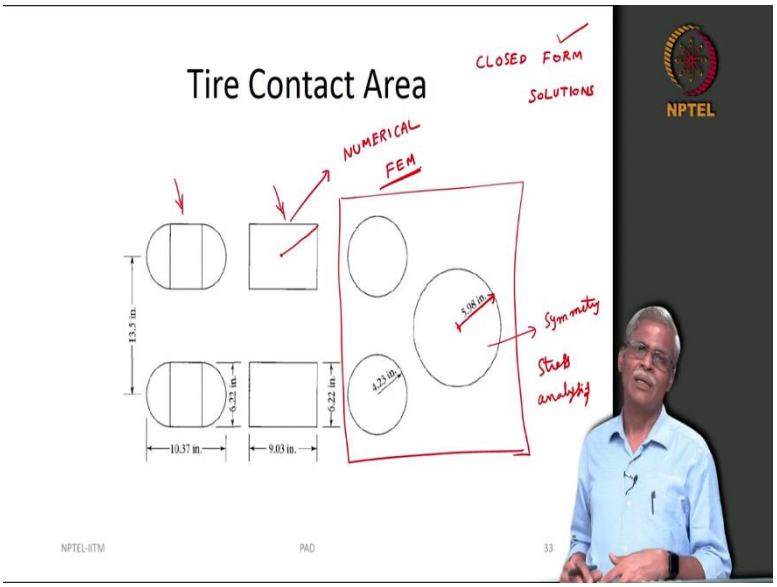

Now, we can have different types of tire contact area. The correct way of doing it will be this you could also do it this way, but what we are going to do is in this way. Why? Because there is a symmetry here our life becomes very easy when we are going to do the stress analysis part because, since there is a symmetry here all I really need to do is to compute the stresses and strain across one radial direction and this whole thing can be computed.

If I am going to use let us say something like this rectangle since there is no symmetry here I need to compute the stresses and strains in a lot more complicated way. So, here I need to make a note of what are really called as closed form solutions. So, if I have a symmetric load contact area, I could straight away give you a formula that you could use to compute the stresses and strain.

But, when this is there I need to go and solve the problem only using numerical methods. For instance, some FEM analysis have to be done using Abacus, COMSOL, ANSYS whatever you want. So, that is the critical area, but now immediately you will say no, but for a road engineer it is necessary that we give him a design chart or a table or some expressions in which this can be done. There are many arguments for or against. None of the road contact area that you see is actually circular in shape. The tire walls deform; the bituminous layers also deform. So, that means, the load contact area over a period of time let us say the vehicle is stationary can keep changing.

So, you can make it very complex on one side or we can make it very simple on the other side and that is the strategy that we are going to adopt. Hopefully, in future when we give a course on advanced pavement analysis and design some of these issues can be actually tackled, but for that you need to have some good background on numerical analysis.

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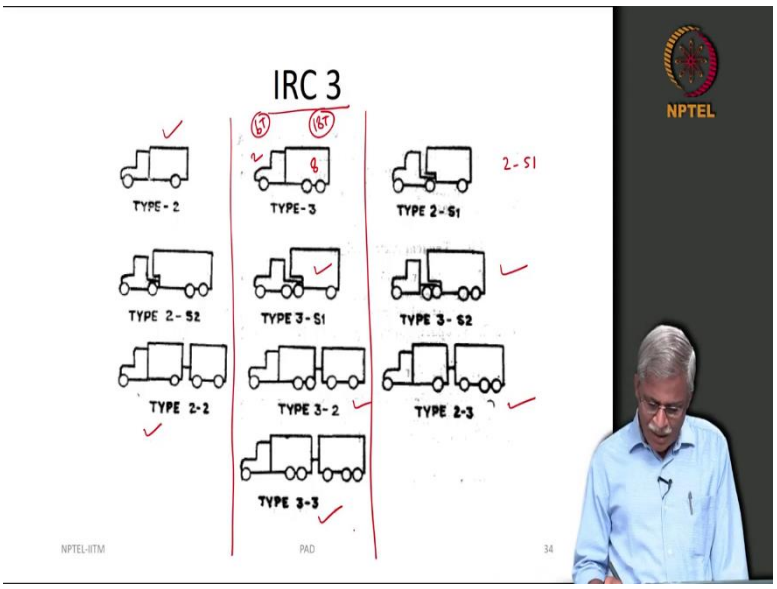

So, now in India we have the IRC 3. So, this is Indian roads congress document that gives you details about what are the standard dimensions axle weights of many of these things. So, there are you can say different types that are given here there is a type 2 that you will see here there is a type 3 that you will see here, and here in type 2 also you will be able to see S1 2-S1, 3-S1, 3-S2, then 2-2, 3-2, then 2-3, 3-3. So, various combinations are actually given here.

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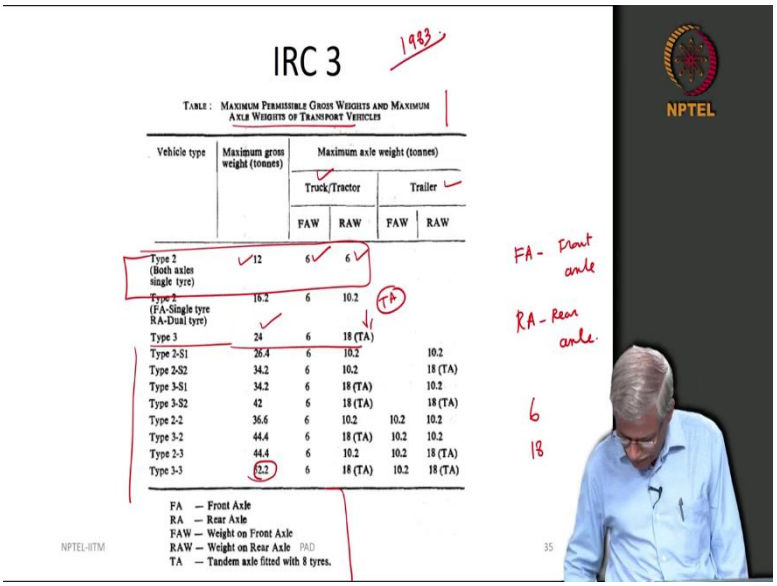

And, in fact, you can actually see the maximum permissible gross weights and maximum axle weights of transport vehicle. So, these are government regulations that are promulgated. So, some of these terminologies I need to explain. So, FA is your front axle it is written here in the footnote, but I just want to emphasize it here RA is your rear axle.

So, let us take the case of the type 2. So, the total weight is 12 and FA is the weight on front axle and RAW is the weight on rear axle. So, this is the truck or the tractor trailer combination. So, when it is a truck it is single unit; when you are going to have a tractor, trailer combination it is going to be dual unit. And, in fact, you can actually see here type 3 here. So, there is 6 and 18 and this comes under what is really called as the tandem axle.

So, let us go to type 3 here and you can actually see here. So, there are going to be tandem axle. So, now, recollect tandem axle means 2 axles dual tire. So, each axle has 4 tires. So, there are going to be 8 tires here, there are going to be 2 here and what IRC says here? This can be 6 tonnes, this can be 18 tonnes. So, the total weight can actually go up to 24.

So, similarly many combinations are given here and you will see that there are type 3 that you see here which has a tractor, trailer combination in which you can actually go up to 52.2 tonnes. So, these are the standard thing that were given and this was originally released in 1983.

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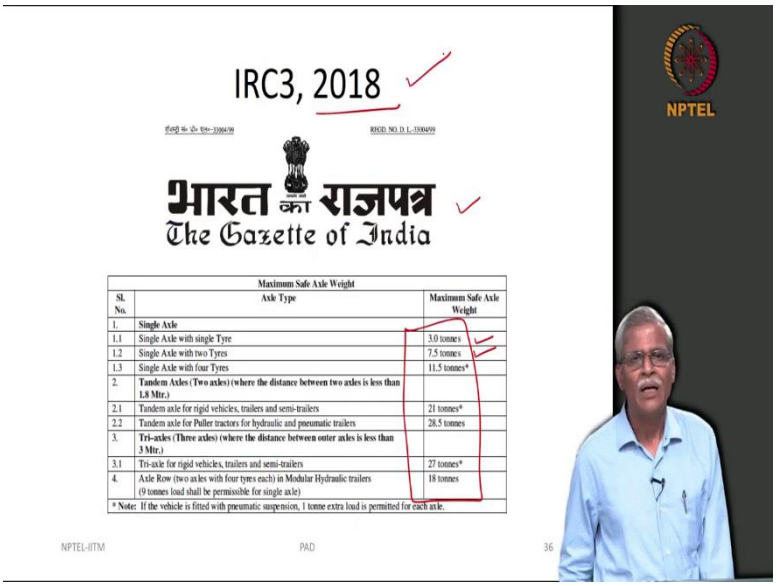

And, the government of India through a gazette notification basically changed some of the values. So, this is this was the gazette notification that was released in 2018. So, you just need to be watchful of some of the changes that are happening here. So, you can actually see the single axle with the single tire and single axle with the two tire. You can you should be able to relate this. I would not be telling you may want to go back to the previous slide and see what happens.

And, in fact, as if you relate this whatever has shown in the previous table you will be able to answer few simple questions here. So, tandem axle and tandem axle for rigid vehicles, tandem axel for puller tracks so, all these values were slightly modified and released in 2018.

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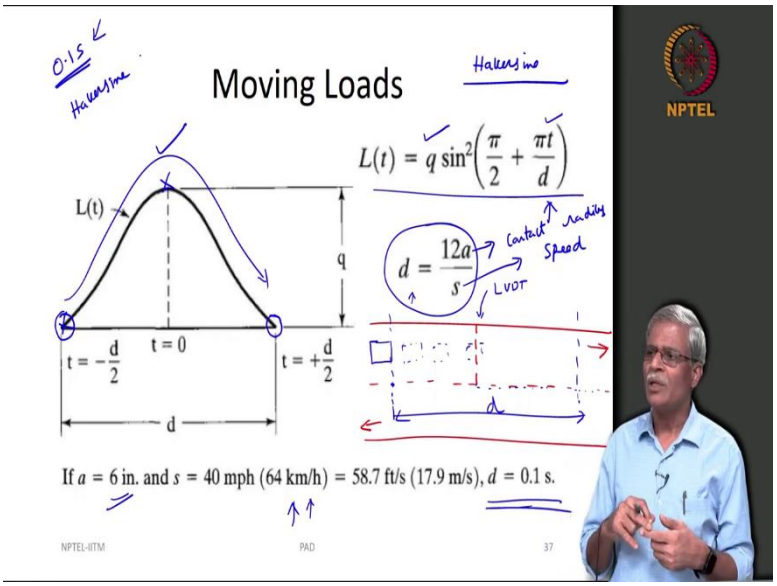

Then there are few other things that I need to say before we conclude our today's talk one is about what is the moving load. So, how do we really do that? See, because why is this moving load becomes important. So, let us say this is your lane. So, you have traffic moving in this direction, you have traffic moving in the opposite direction.

So, let us say we place some LVDT is here. So, means deformation measurement devices and you have a let us mark some boundary here boundary here and so, you are going to see that when the vehicle enters here the reading that you are going to see here is going to be 0 and as the vehicle moves fast, moves fast, moves fast and it when it comes here the defamation is going to be maximum here and as it moves fast crosses this thing again it is going to be 0.

So, if you collect the deformation that is being recorded as part of this LVDT and plot it what you are going to see is a graph something like this. So, this is the graph. So, now, what we really want to do is, we want to find out what exactly is the how exactly is the load is moving and what is the time period associated with that and the distance because that is very important for us.

So, normally we can associate this variation with what is really called as a haversine formula.

$$L(t) = qsin^2\left(\frac{\pi}{2} + \frac{\pi t}{d}\right)$$

So, you see that q is the maximum value given here and t is the time duration that you see here and d is the total width. Now, this d is assumed to be of the following form. So, what is the following form? So, this is the speed, this is basically the contact radius of your tire.

So, you can actually see that this particular distance that you see here is 12 times your contact radius of your tire. So, that is the simple approximation that we make here. So, the total distance that you want to really find out where the load is varying like this could be approximated based on 12 times the radius that you see here and you need to understand in pavement engineering a is normally used for the contact radius.

So, if let us say you are driving at 64 kmph and in fact, these are interesting problems that you can actually work out and if the contact radius is let us say 6 inches roughly around 15 cm, the time duration of loading is going to be 0.1 second. So, that means, if I am driving at let us say 64 kmph, and if I am going to focus my attention on this particular distance, which is given here as d, I will cross this spot in 0.1 second loading. Now, why I emphasize on this 0.1 second loading because most of the pavement engineers when they want to compute the modulus value, they will always give a load pulse of duration 0.1 second and the shape will be haversine. Because you when you want to design your payment you need some kind of a modulus, and that modulus should be determined based on the realistic load that is being applied on top of the pavement and that realistic load has to be something like a moving load. So, that means, at any given point the load has to increase and then decrease. So, the most important thing is q is anyway your tire pressure, no problem; the most important thing is what is your time duration of loading and what is the waveform.

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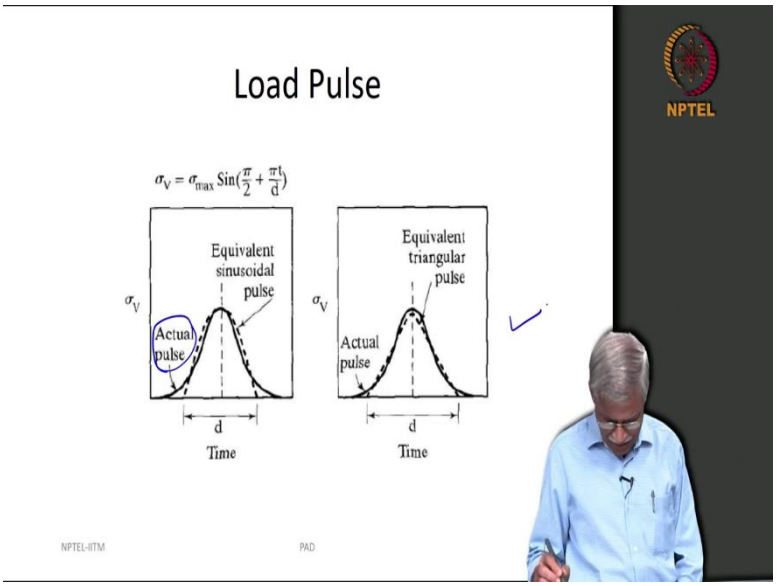

So, this is what is the waveform here. And, in fact, the actual pulse is going to be something like this. You could write it in terms of equivalent sinusoidal pulse or equivalent triangular pulse.

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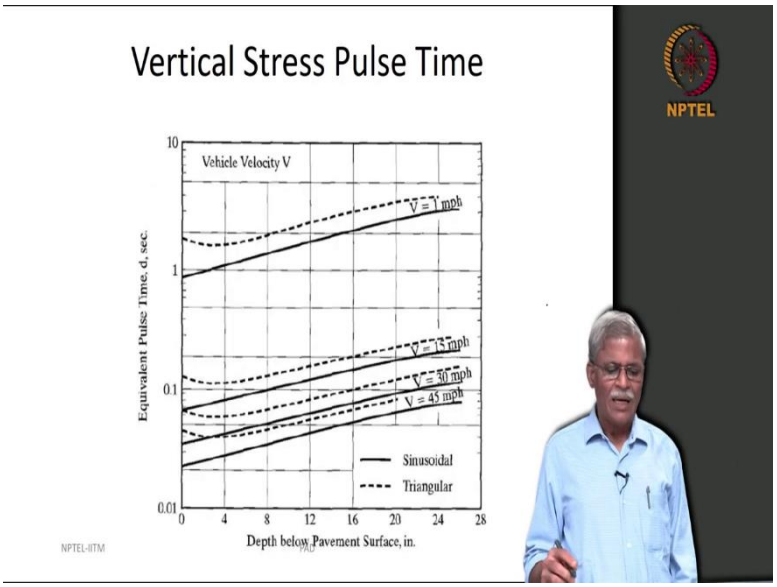

And, interestingly as you go down in the depth at various layers below the surface of the pavement, you are going to see the time duration that you see here is going to be increased. Because as you go down the pavement the load contact area you can see the pressure bulb

that we normally see which we will be discussing as we go along, it will keep reducing here.

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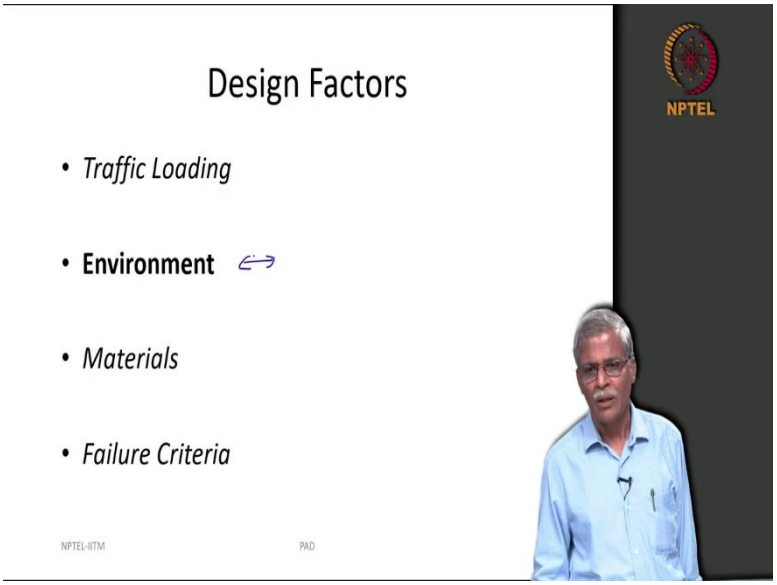

So, let me stop here. We will continue our discussion related to the Environmental Conditions in the next class.

Thank you.