Analysis and Design of Bituminous Pavements

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Lecture - 50

Overview of Mechanistic-Empirical Pavement Design Methods - Australia - Part I

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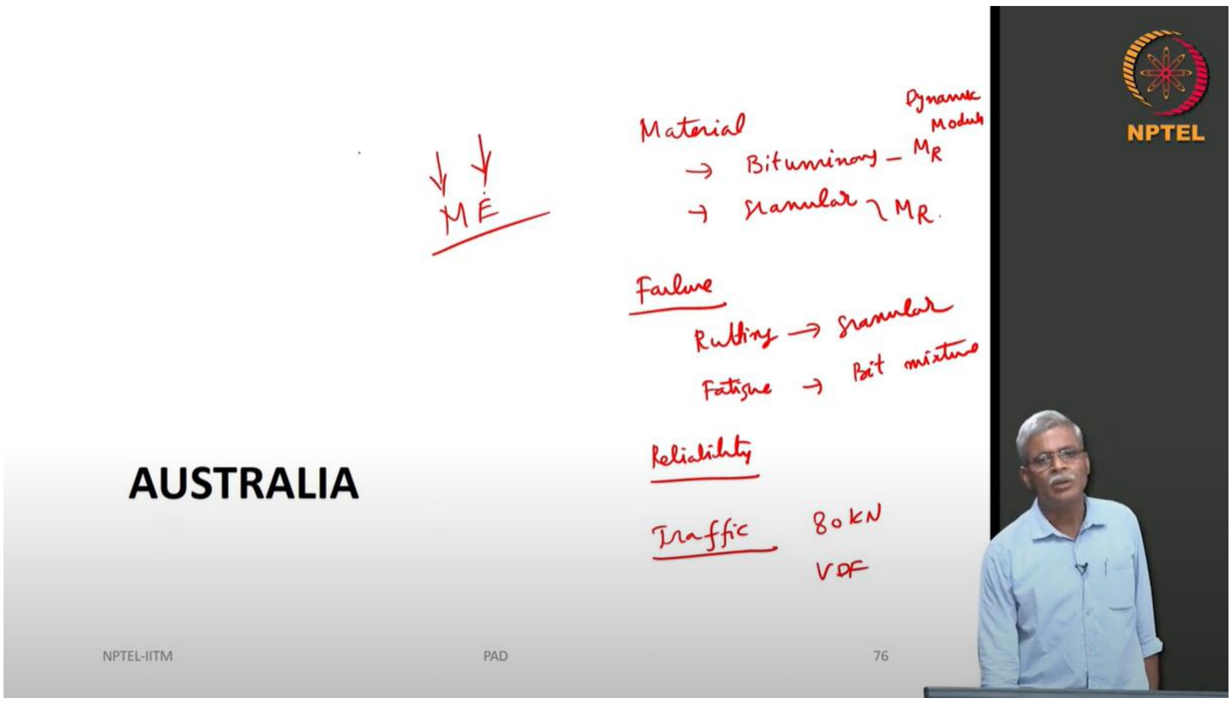

So, let us continue our discussion about the various pavement design methods that we are really looking at. Again to emphasize, almost all of them will follow more or less the same thing. How do you characterize the material? The material characterization will be different for bituminous mixtures, it will be different for granular material wherein you will be talking in terms of some modulus. It could be resilient modulus, dynamic modulus, etc.

Then what are the failure criteria? You can say very generally, rutting of the full pavement system, fatigue of the full pavement system or you can talk in terms of rutting of the granular layer alone or fatigue of the bituminous mixture alone. When it comes to reliability, now you can talk in terms of specifics for reliability, reliability for each layer, and reliability for the whole pavement system. It all depends on how much data that we have processed in writing this pavement design code.

Then comes the traffic. You can take straight away everything in terms of 80 kN standard axle load. Then you can use the vehicle damage factor approach that we follow in IRC or you can talk in terms of truck factors with different growth factors and different axle load distributions. There are enough variations that you can look into. So, the South African method will score in terms of having a detailed procedure for each and every one of these steps.

Australia will be different in it and my idea especially for the students here is to make you understand how the same pavement cross section is designed by different countries in a completely different method. But all of them will say that they are mechanistic empirical and we know what is the mechanistic part, we also know what is the empirical part. Now, let us talk about the Australian pavement design code.

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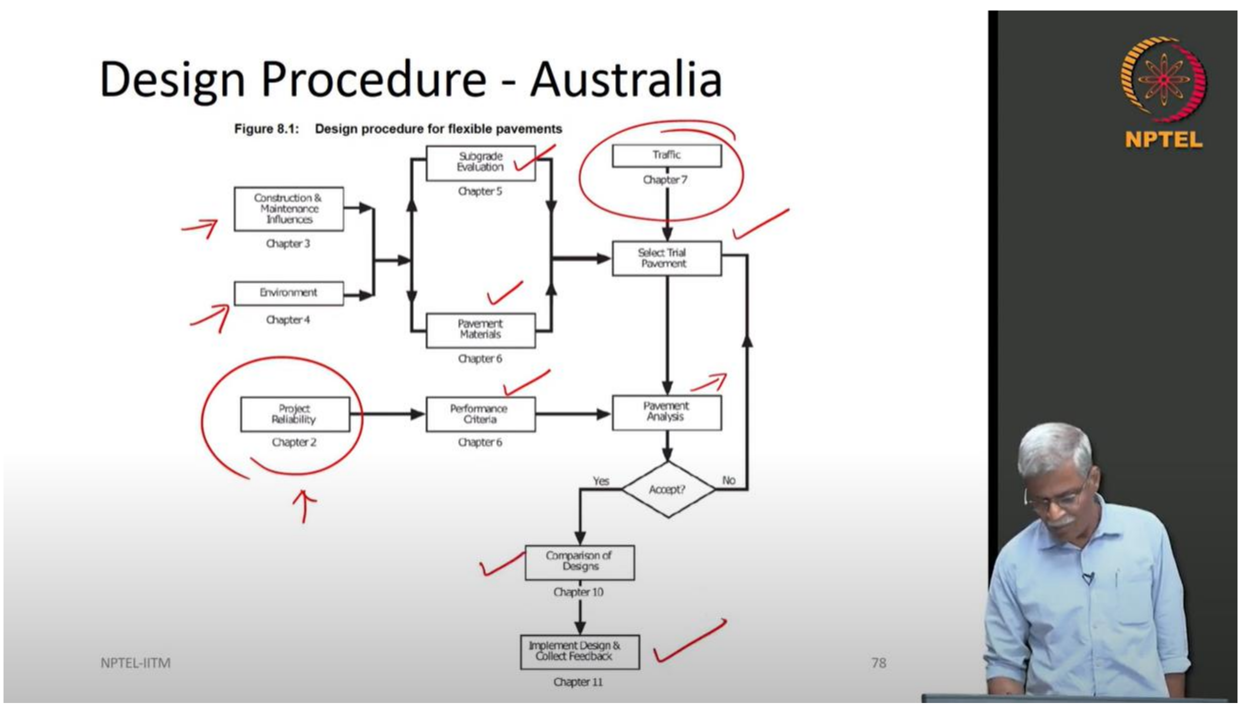

Now, Austroads has a lot of very useful wealth of information and all you really need to do is to just go create a username and password. Most of the manuals 90% of the pavement related manuals can be downloaded for free.

In fact, what you see here is the guide to pavement technology, an excellent manual for you to read and understand how pavement should be designed. You just need a username and password created, download it, and you will be able to read it. What I am going to do is, I am going to take this particular approach and show you a brief outline. And in fact, you can actually teach around 8 to 10 hours only specifically using the Austroads but I am not going to do that. The idea is to just give you a brief overview. Now, this is the design procedure for the flexible pavement that they have given here. So, each chapter number is also mentioned here.

Now, this is very interesting if you go through chapter 3, they talk about construction and maintenance influences. So, the starting point is not stress analysis. The starting point is not material characterization. The starting point is from the construction and maintenance influences. And next comes the environment. Reliability is something that comes in chapter 2 and this is where you basically start talking about what is the expected reliability for any pavement construction. Now, if you go back and look at IRC 37 or in the Huang textbook that we more or less followed, reliability comes a lot later. It first starts with the stress analysis. The different countries have different approaches. Here, it also includes the construction and maintenance influences, environment, subgrade evaluation and pavement materials.

Then comes a very important chapter which is what I am going to cover in today's lecture which is on traffic. With the input, which is the subgrade and the material that you are going to use, you will take a trial pavement cross-section and perform the analysis. The pavement analysis is the mechanistic part. Compute the stresses and strains and use the performance criteria and compare the designs and implement the design. So, this is the overall design procedure that is followed in Australia.

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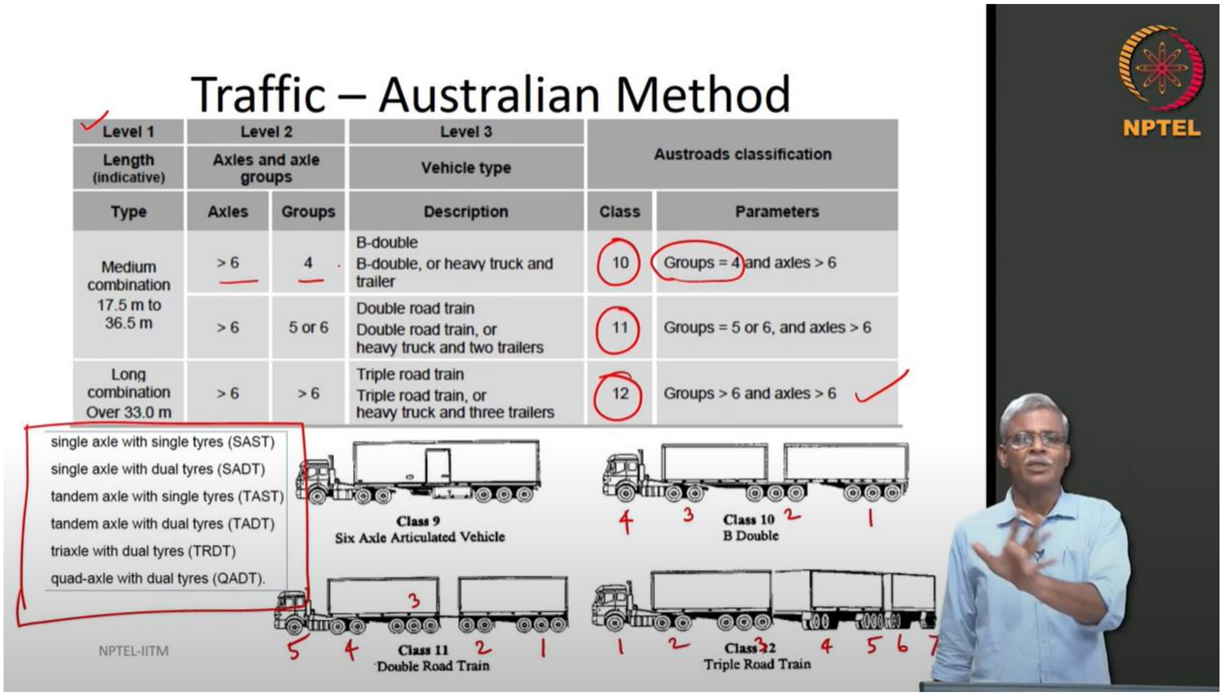

So, what we are going to do now is to talk about the traffic. And similar to what I have mentioned earlier, the pavement design guidelines should always integrate the actual traffic for which it is being designed. What we have in India is IRC 3, which is standing outside of IRC 37. It should be an integrated part of it. So to just give you an idea I have shown you the traffic and how it is handled in the Australian method.

Now focus your attention on this portion first. These are the various types of axles that are being considered namely, single axle with a single tire, single axle with a dual tire, tandem axle with a single tire, tandem axle with a dual tire, tridem axle with a dual tire, quad axle with a dual tire. And in fact, they have a class starting from 1 and all the way going up to 12. But what I did is to just pick class 10, class 11 and class 12.

Now if you just take a look at the groups and these groups are going to be very important to you as we go along. So how many groups of axles are there? 1, 2, 3, 4. So this is class 10. This could be a tridem, 2 tridems, 1 tandem and 1 single. Similarly, if you look at class 11, it could be either 5 or 6.

So this is 1, 2, 3, 4, 5, it could also be 6. But look at 12 which is what is really called the triple road train. So this is 1, 2, 3, 4, 5, it can have 6 and then 7. So these many groups could be there and the number of axles are going to be appropriately the same as the groups that you are looking at. Now depending on the type of design that you are really looking at, you can actually talk in terms of combinations or you can talk in terms of the axles and the groups here.

So this is the length, this is the axle and group and this is the vehicle type. These are the three levels under which the traffic is classified. So please keep this in mind. This is the kind of detail that we really need.

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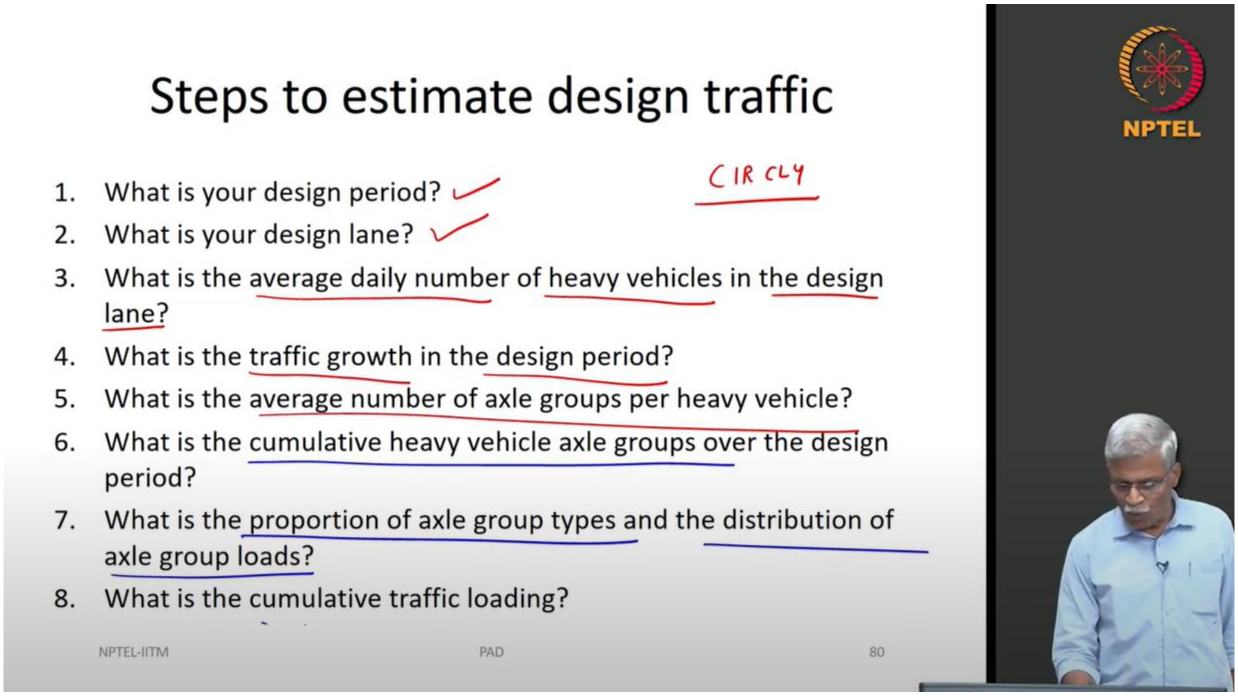

Now these are the steps I have summarized after having read through it many times and after having taught from it. And in fact, they have a wonderful software called Circly. There is a student version that is available. You can use it for a trial period of one month or something. Try to download it and start using it. The first thing is what is your design period? Do we ask this question in IRC 37? Yes.

What is the average daily number of heavy vehicles in the design length? Slowly we start deviating and the details that are required as part of the Australian design method become a lot more comprehensive as you go along. So what is the average daily number of heavy vehicles in the design length? Then what is the traffic growth in the design period? Now, this is tricky and they actually account for it if you have the traffic growth more than what you expected after you have constructed if it happens within the first 3 years or 5 years. So different traffic growths are also accounted for.

What is the average number of axle groups per heavy vehicle? Now what are these axle groups that you are really looking at? What is the cumulative heavy vehicle axle group over the design period?

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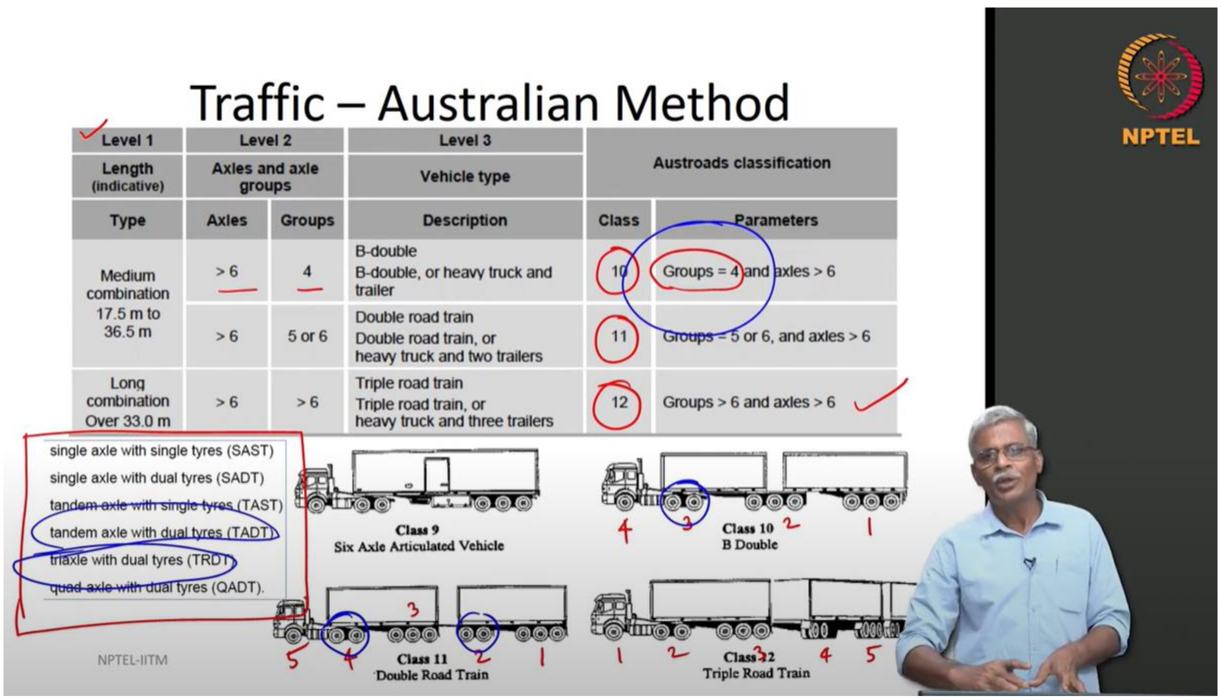

So now let us go back and look at it again. So if this is one axle group, let us say tri-axle or let us say tandem with dual tires. So there is a tandem with a dual tire here. There is also a tandem with a dual tire, tandem with a dual tire. So let us say you have some 100 vehicles of class 10 and another 100 vehicles of class 11 and if you take all these axles separately and their load distributions and adjust them, this is what you are going to get. So what you really need to do is what is the cumulative heavy vehicle groups, axle groups over the design period and what is the proportion of the axle group types, and the distribution of the axle group loads. When you collect your axle load data, what is the actual proportion? In the total axle groups, what is the proportion of single axle, tandem axle and dual axle? And what is the cumulative traffic loading? So we will try to address each of these as we go along.

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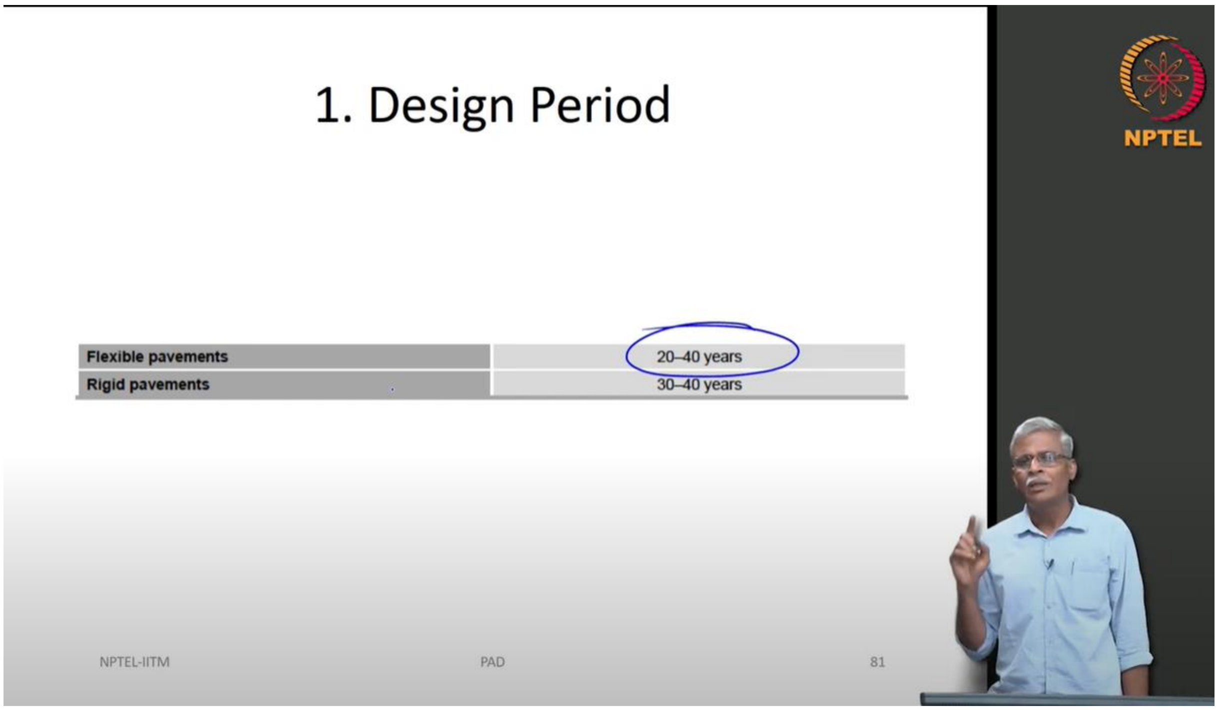

Now what I did is I have also given some information related to the various sections from which you can find this information that we are discussing, so that it will become easy for you to use these slides, listen to this lecture and also take a look at the manual that is available to you.

The design period, first question is 20 to 40 years. Now understand the difference between design period, analysis period and performance period.

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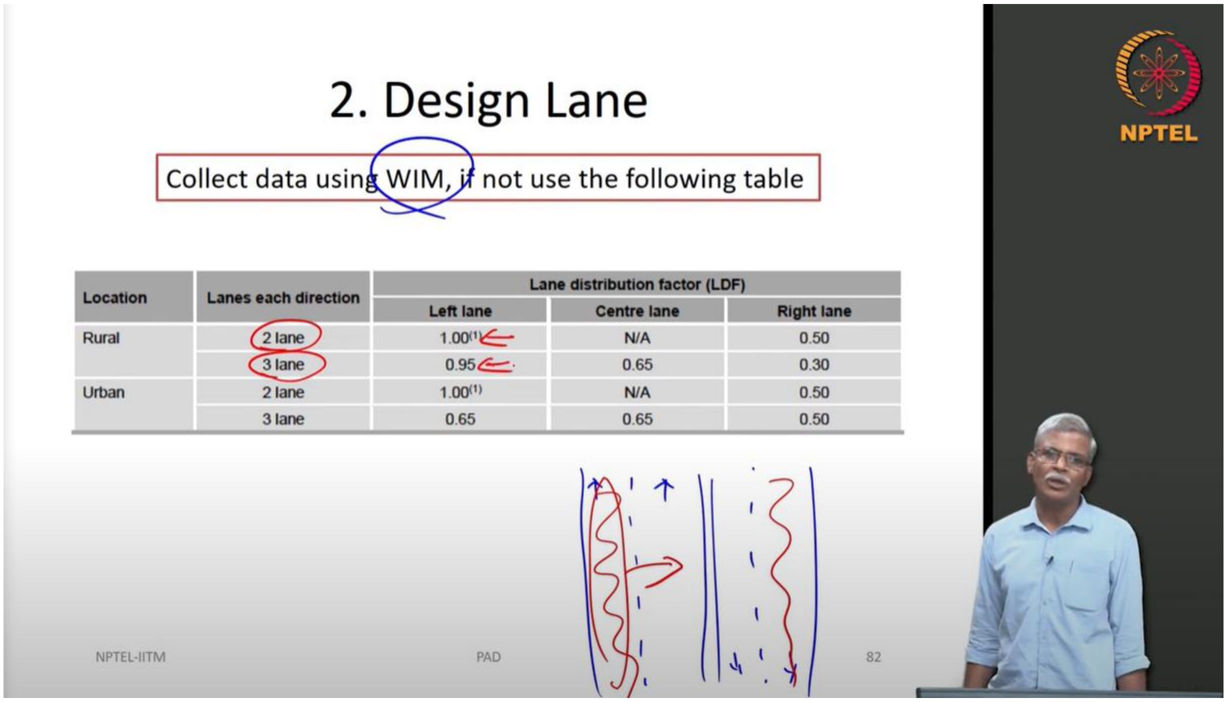

What is the design lane, in fact, there is an extensive day-to-day data collection i.e. 24 by 7 data collection that is carried out by Australia using what is called weigh-in-motion sensors. And you are expected to collect the data using the weigh-in-motion sensor only. So based on the data that you collect from the weigh-in-motion sensor, you will find out what is the design lane.

Now a question that I would like to ask the students here is what do you think is the design lane in National Highway in India as per the current practice and what is practically happening? What exactly is the design lane? Let us say, I have this National Highway with two lanes. This is the northbound direction, this is the southbound direction. So you expect a design lane to carry the maximum heavy axle group loading. So you will basically say that, I really think outer lane should be the one. But what really will happen if you drive along the highway is, see most of your trucks will not be driving on the outer lane rather they will be driving on the inner lane.

So this is what you can say is not desirable driving practice. So that means as the country is growing, as we are constructing more and more roads there is also some amount of driver education that is needed on how to drive on a rural road, National Highway, or expressway. The slow-moving vehicles always move to the outer lane and then they keep driving at a constant speed. So that is the typical practice that you will see in most of the countries.

This is our lane distribution factor that you are really looking at. If you are talking in terms of a two-lane, you can actually see that the left lane is taken as the design lane and if you are talking about a three-lane, this is what you are really looking at. Now immediately you will realize what are the numbers ideally we are looking at.

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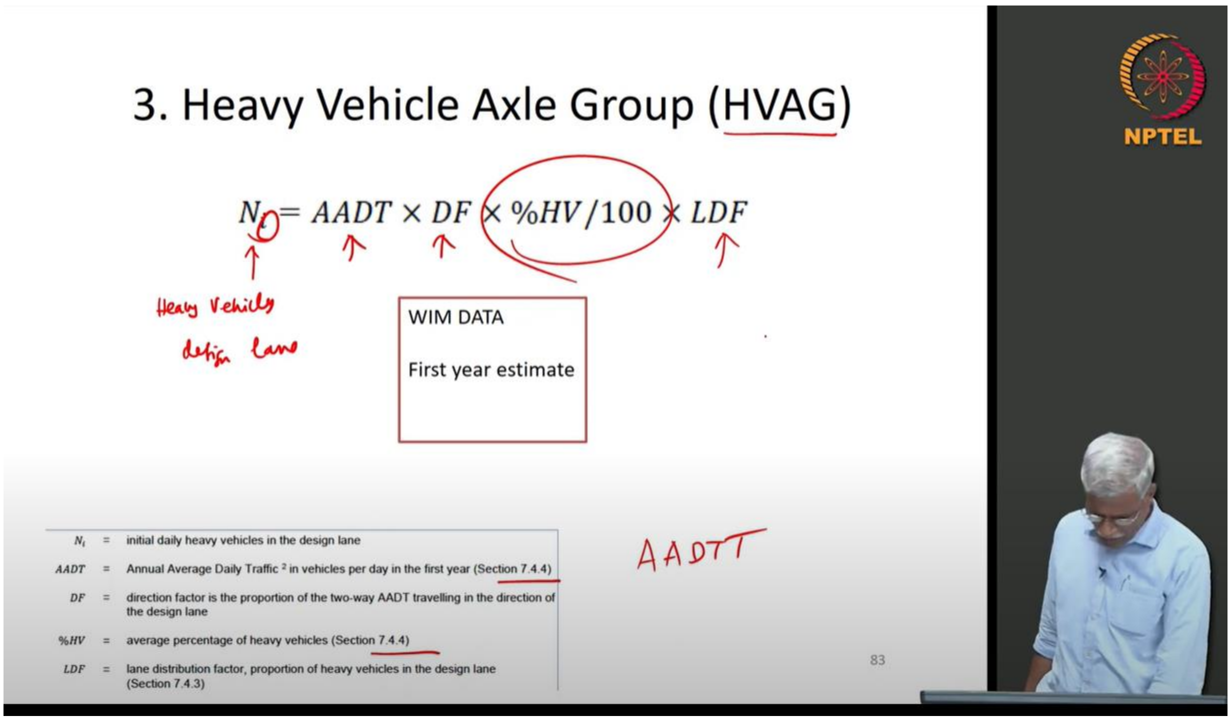

Now what is the next thing that we need to do? What is the heavy vehicle axle group?

$$N_i = AADT \times DF \times \frac{\%HV}{100} \times LDF$$

That is what we really need to understand. Now this is something that we need to do for the first year estimate that is what we need to do we need to use the WIM data.

AADT is annual average daily truck. In fact, if you are using the AASHTO, you will be talking in terms of annual average daily truck traffic and not the daily traffic, since we are using the percentage of heavy vehicles (%HV). I have given appropriate section numbers here so that you can actually go and read it. This is the initial daily heavy vehicles in the design lane.

DF is the direction factor you know because ideally, you will be collecting this full data. So you will be trying to find out how much is the proportion in the northbound direction, southbound direction, eastbound, or westbound. And similarly, this is your lane distribution factor and LDF is the percentage of the heavy vehicle in the design lane.

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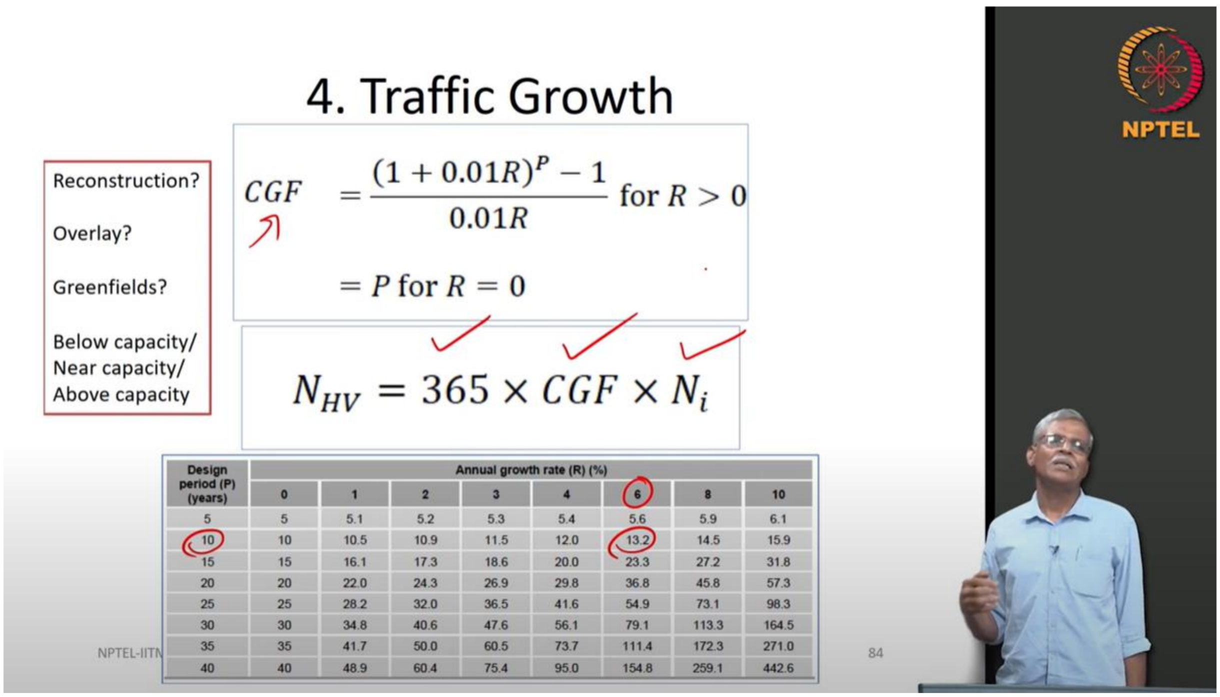

The formula for computation of cumulative growth factor (CGF) is given below.

$$\mathrm{CGF} = \frac{(1+0.01\mathrm{R})^{\mathrm{P}}-1}{0.01\mathrm{R}} \text{ for } \mathrm{R} > 0$$

$$= \mathrm{P} \ \text{ for } \mathrm{R} = 0$$

$$\mathrm{N_{HV}} = 365 \times \mathrm{CGF} \ \times \mathrm{N_i}$$

Let us say if you are looking at a design period (P) of 10 years, and if R is 6%, design heavy vehicle ($\mathrm{N_{HV}}$) is computed using the above equation. Things are going to be different for reconstruction, overlay and green field project. And this is where Australian traffic analysis starts taking a deviation similar to what we have seen in IRC. Now they start looking at below capacity, near capacity, and above capacity.

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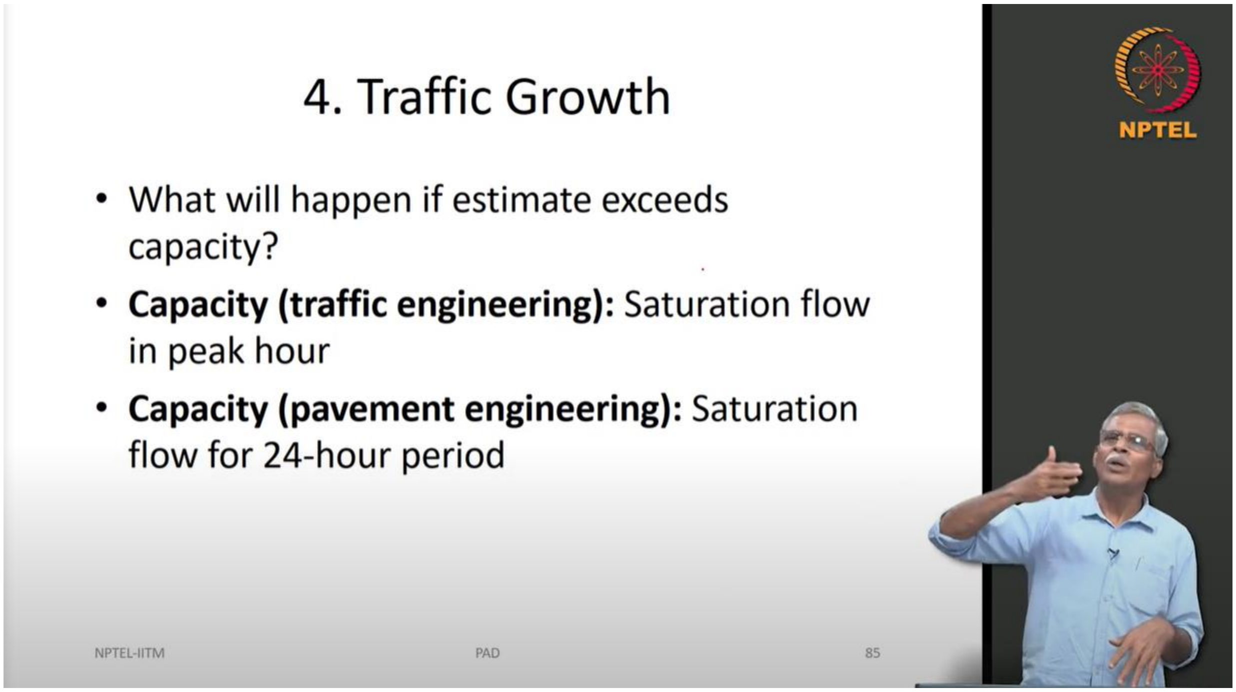

Now the question that you want to really ask is, what will happen if the estimate exceeds the capacity that can happen? Now we need to understand how capacity is defined in traffic engineering. Capacity is defined in traffic engineering as saturation flow in peak hour because you are basically looking only in terms of how this facility that you have constructed is able to service the traffic that is going on it with the least congestion and least delay. That is the whole idea as far as traffic engineering is concerned. But when you are talking about pavement engineering, we are talking in terms of the saturation flow for the full 24 hour period. So that means you want the truck to be moving one after the other in the 24 hour period.

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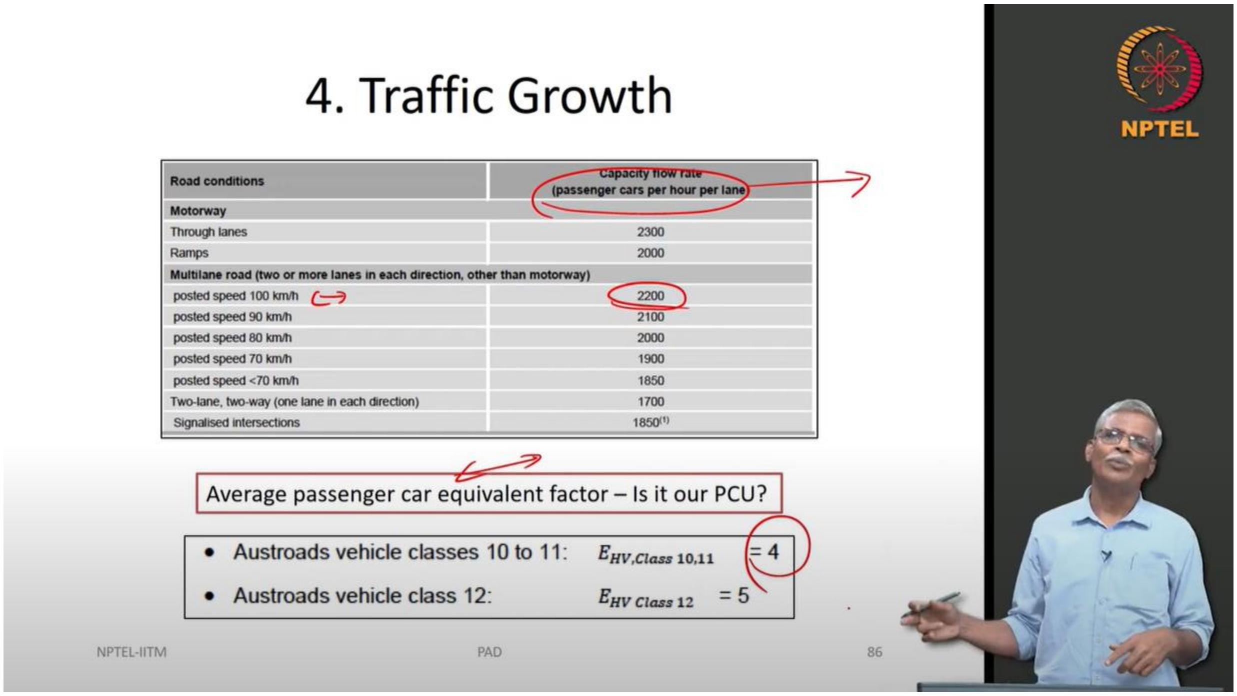

Now if you are looking at the traffic growth pattern, there is a passenger car per hour per lane. These are all the capacity flow rates that are given here. If you are talking in terms of through lanes, they are talking in terms of 2,300 cars per hour per lane.

Of course, this is passenger car and if it is a multi-lane road and if the posted speed is let us say 100 kilometers per hour, one is looking at 2,200 passenger cars per hour per lane. Now, the interesting thing that you are going to use is the average passenger car equivalent what is given here is something similar to our passenger car unit that we are familiar with. Now as far as the Austroads vehicle classes 10 or 11 is concerned, this passenger car equivalent factor for the heavy vehicle is of the order of 4. So now you need to understand really how we are linking the saturation flow capacity with our traffic growth pattern that we are really looking at. So it is going to be something like 4 or 5.

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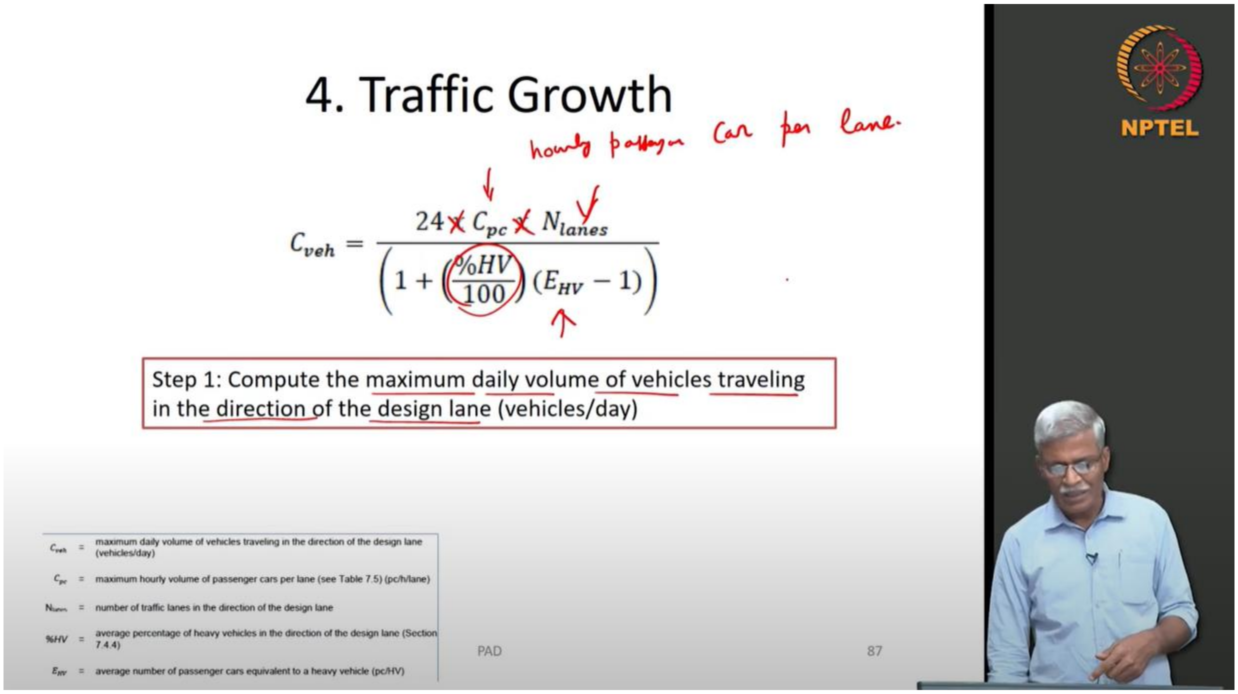

How do we use this information? The following formula tells you how to compute the maximum daily volume of vehicles traveling in the direction of the design lane (C_{veh}).

$$C_{veh} = \frac{24 \times C_{pc} \times N_{lanes}}{\left(1 + \frac{\%HV}{100}\right)(E_{HV} - 1)}$$

C_{pc} is your maximum hourly passenger car per lane and N_{lanes} is the total number of lane. So E_{HV} is the passenger car unit kind of a factor and %HV is the percentage of the heavy vehicle.

You are basically trying to compute the maximum daily volume of the vehicles that are traveling in the direction of the design lane.

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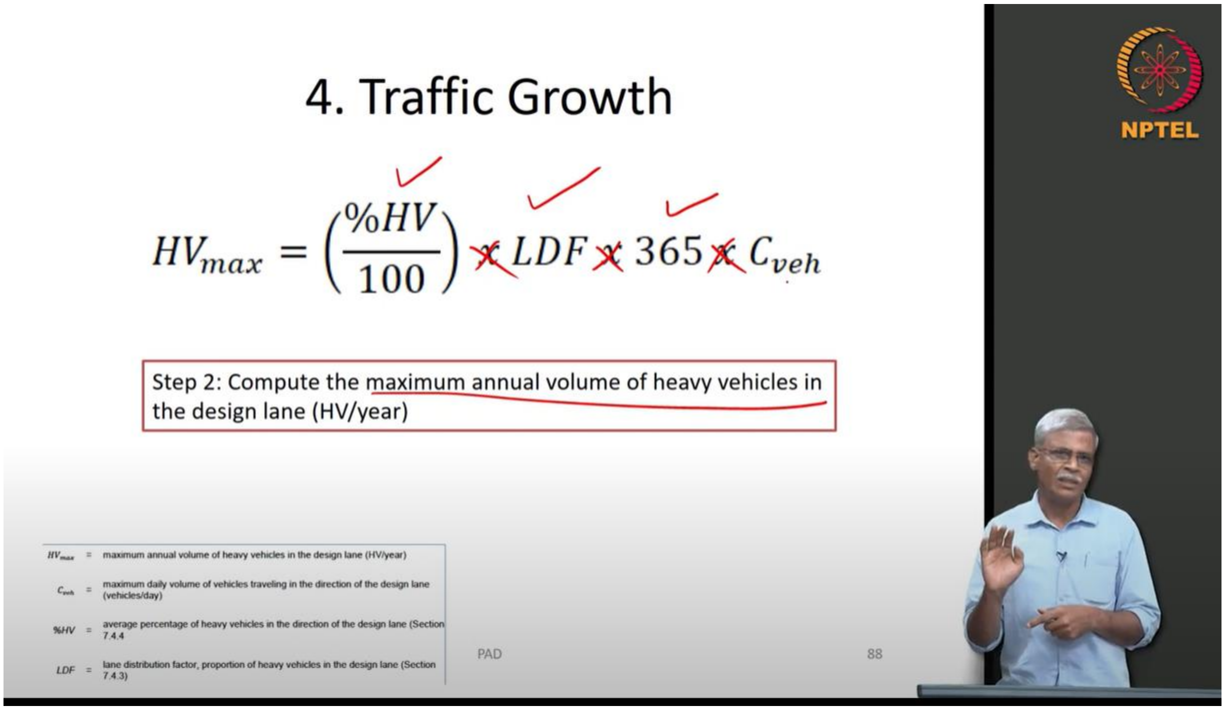

The next step that we are going to do is to compute maximum annual volume of heavy vehicles in the design lane (HV_{max}).

$$HV_{max} = \left(\frac{\%HV}{100}\right) \times LDF \times 365 \times C_{veh}$$

%HV is the average percentage of the heavy vehicle in the direction of the design lane, LDF is lane distribution factor and C_{veh} is maximum daily volume of vehicle traveling in the direction of the design lane.

This gives you the maximum annual volume of heavy vehicle in the design lane. Many a time you sit down and do the axle load computations and most of the time this axle load computations that you do are based on the axle load. But where are these axles coming from? These axles are coming from the volume count that you basically do. Now what is the connection between the actual load carrying capacity or the geometric capacity of the road and the computations that you are really doing? So these two things have to be related.

So how do we relate this? So let us now go back in this step. So what is that you really want? You really want the maximum annual volume of heavy vehicle in the design lane. So that means it is the percentage of the heavy vehicles that you are going to see in the design lane and then you are going to multiply it with the maximum daily volume of the vehicles that are traveling in the direction of the design lane. Now how do we compute this C_{veh}? C_{veh} is based on the maximum hourly volume of the passenger cars per lane. So you know that you know this is the typical data that is given here.

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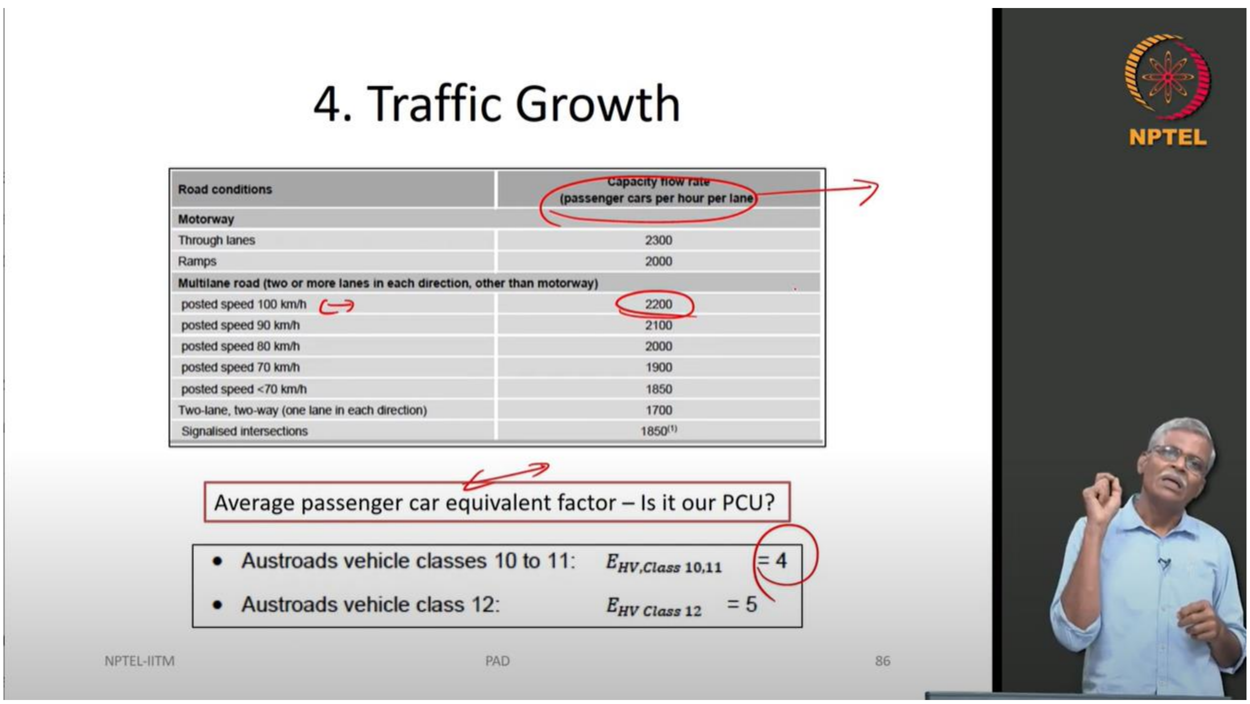

2300 is what you can do here. Now if you take this 2300 and then use your heavy vehicle factor, you might come back and say, you know what, this axle load computation that I have made based on some growth factor that I have assumed might result in a flow condition which will be more than the capacity of what the road can take. So when we do our axle load a computation, this particular aspect is not emphasized and, this is where we are emphasizing it here as far as the Austroad is concerned.

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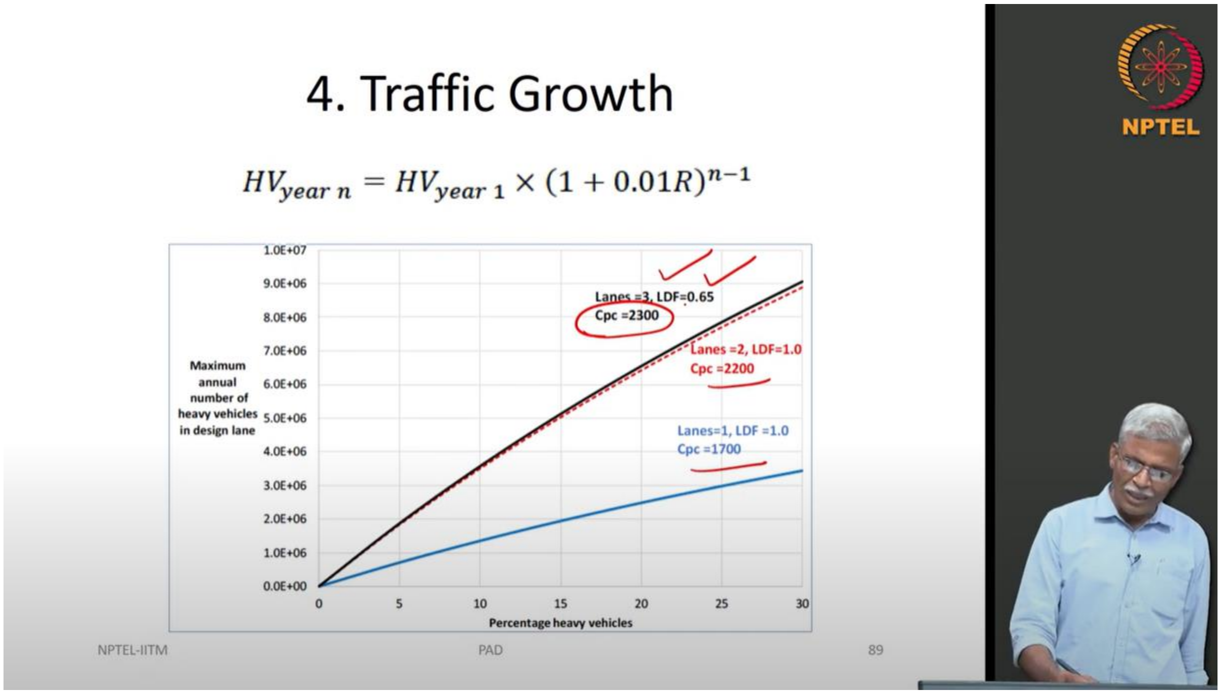

So some graphs are given here. What you see is maximum annual number of heavy vehicles in the design lane versus percentage of the heavy vehicles. So you can see lane 3 and the corresponding lane distribution factor.

So this is your cumulative percentage of the vehicles that you are getting. So C_{pc} corresponds to a value of 2300. So it could be 2200, 1700, 2300. Using this, you can actually compute what is the heavy vehicle in the design lane for the corresponding year.

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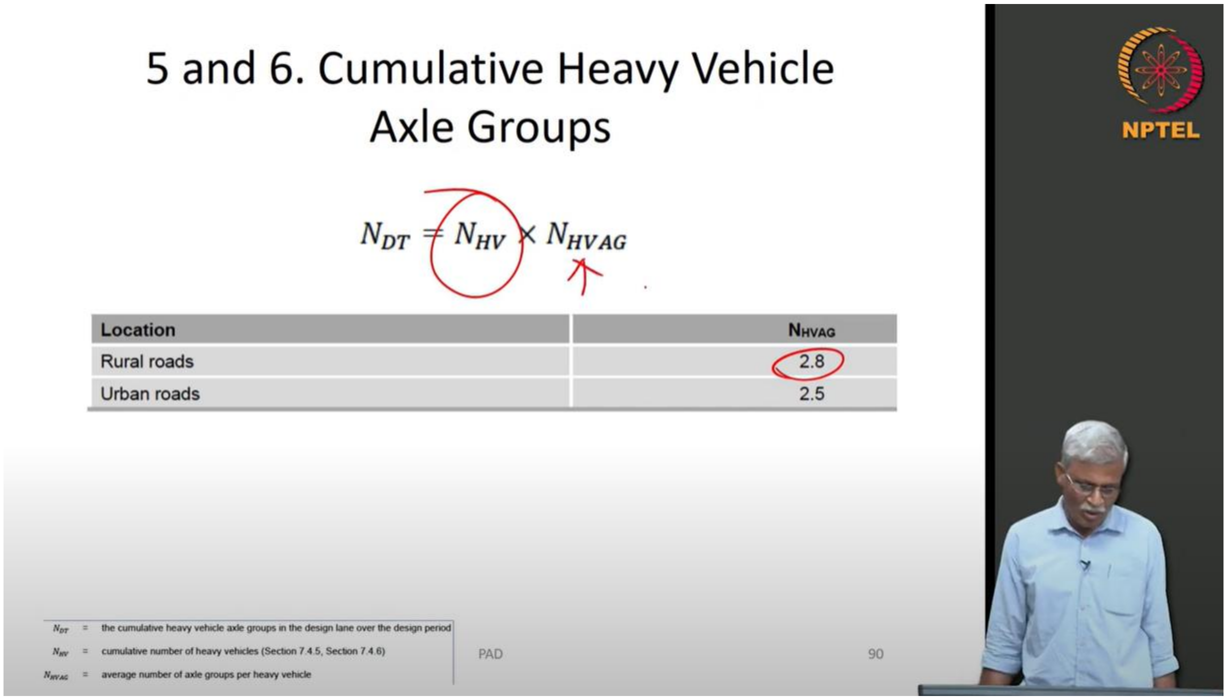

The cumulative heavy vehicle axle group in the design lane over the design period (N_{DT}) is computed using the following formula.

$$N_{DT} = N_{HV} \times N_{HVAG}$$

N_{HV} is cumulative number of heavy vehicles and N_{HVAG} is the average number of the axle groups per vehicle. You should always collect the data. If you do not have the data, you could use something like 2.8 or 2.5, which they are basically talking about. So these are the average axle groups that we are looking at it. This is the average number of axle groups per heavy vehicle.

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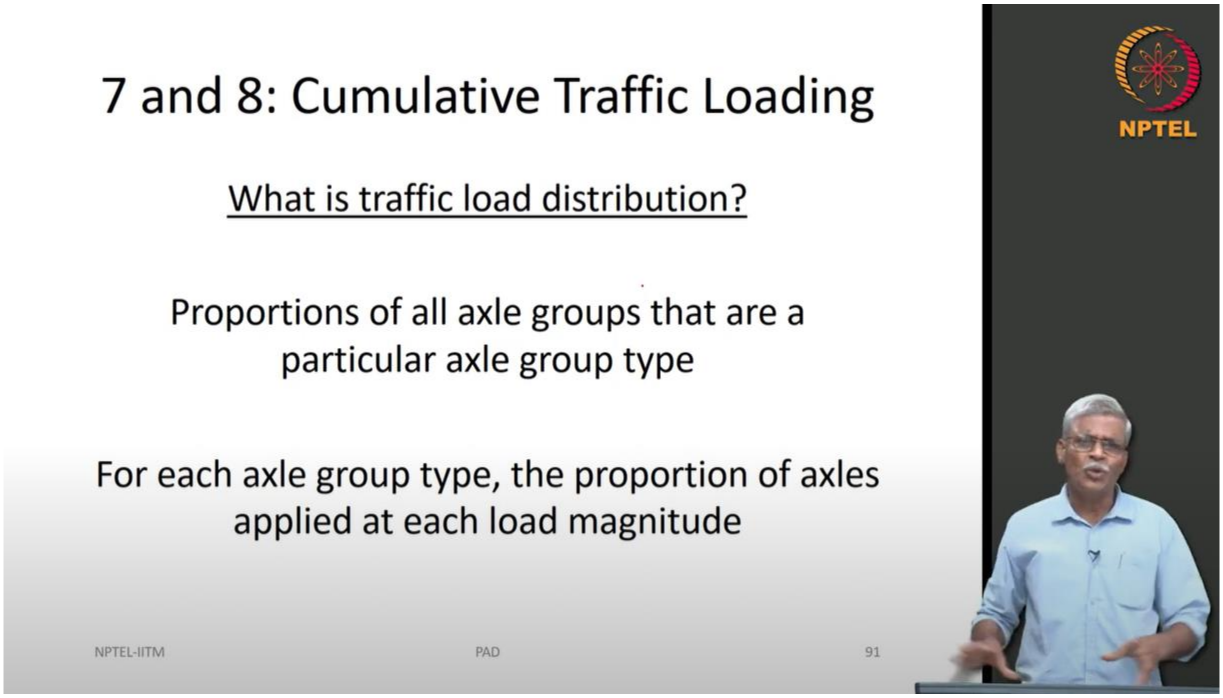

Now comes the next part. What is the traffic load distribution? So what you are going to do is you take the proportion of all axle groups that are a particular axle group type. So let us say you have tridem separately, tandem separately, a single axle single tire or single axle dual tire. These are all the proportions for each of these. And for each axle group, you need to construct your statistical distribution. So the proportion of the axle that are applied at each load magnitude. So I will show you one sample data and then it will become very clear to you now.

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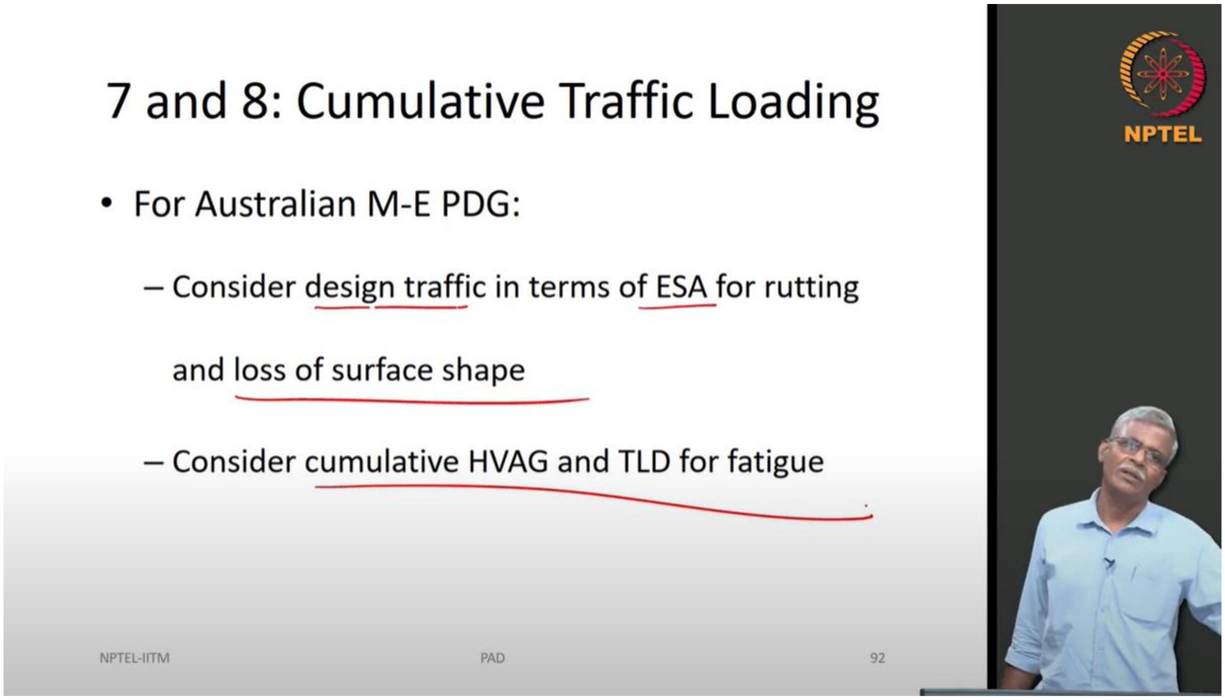

So for Australian MEPDG, you will consider the design traffic in terms of equivalent standard axle load for rutting and loss of surface shape. This is only done for the rutting. The heavy vehicles and their associated repetitions i.e., the traffic load distributions are considered for fatigue. But for computing the rutting related thing, you use the load equivalency factor.

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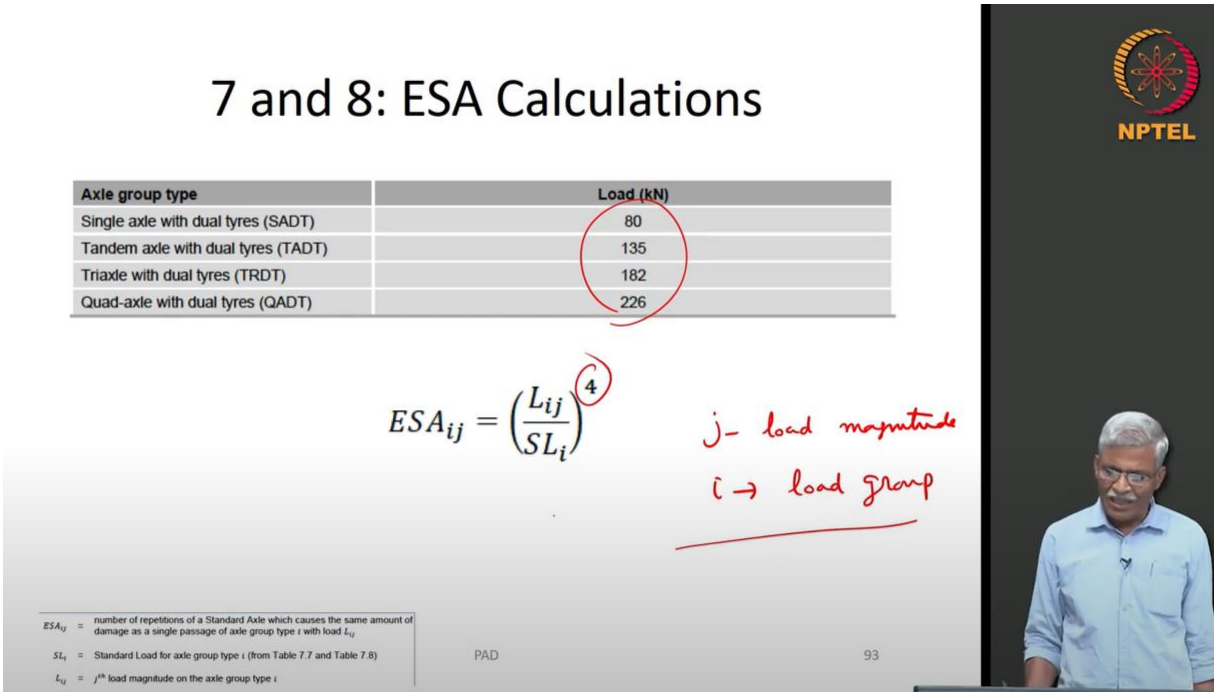

Now I think it should be very clear how we are deviating. So how do you do the ESA calculation? It is the same thing. So what is this ESA?

$$ESA_{ij} = \left(\frac{L_{ij}}{SL_i}\right)^4$$

ESA_{ij} is number of repetitions of a standard axle which will cause the same amount of damage of a single passage group of type i. So it could be a single axle with a dual tire, tandem axle with a dual tire, etc., with the load L_{ij}. So what is this j? j is the load magnitude and i is your load group. So what is that you are using? You are using fourth power and this is the value that you are going to use here. So whether it is going to be 80, 135, 182 and 226? Can you go back to IRC 37 and compare the values that are shown there with the values that are seen here?

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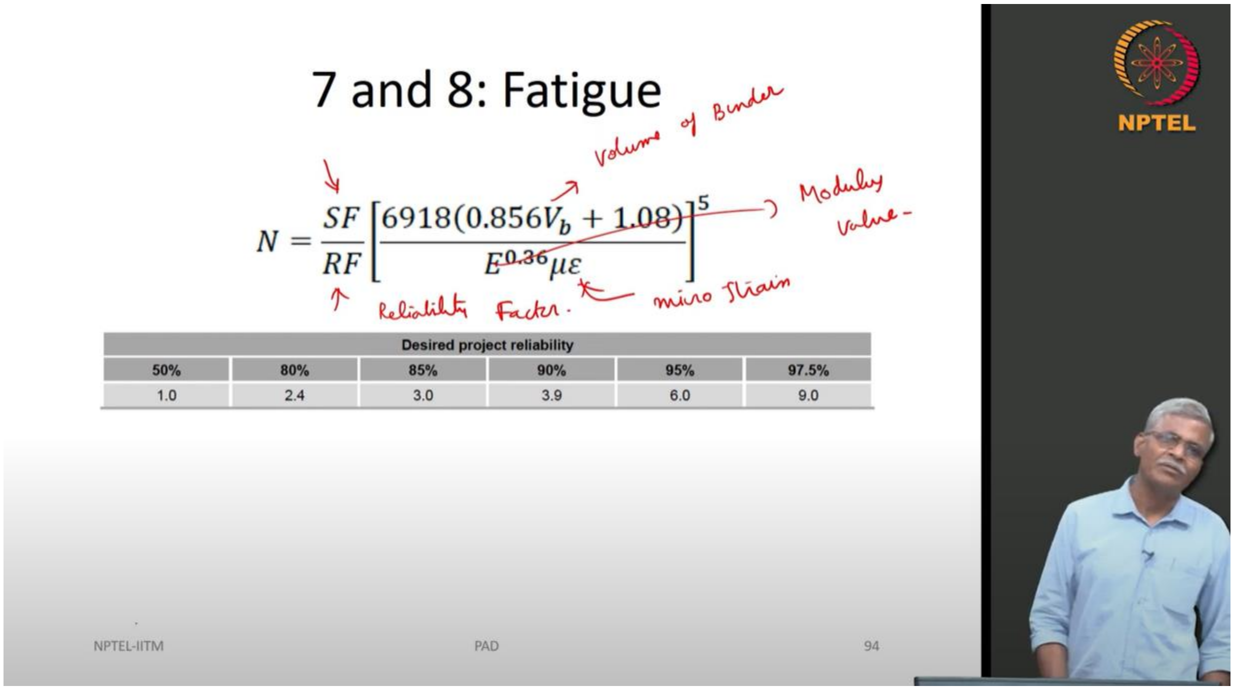

So what do we now do for the fatigue? There is an interesting distress equation that is given here for the fatigue calculation.

$$N = \frac{SF}{RF}\left[\frac{6918\ (0.85V_b + 1.08}{E^{0.36}\mu\varepsilon}\right]^5$$

RF is reliability factor, V_b is volume of binder, ε is the micro strain and E is modulus value and these are your calibration factors.

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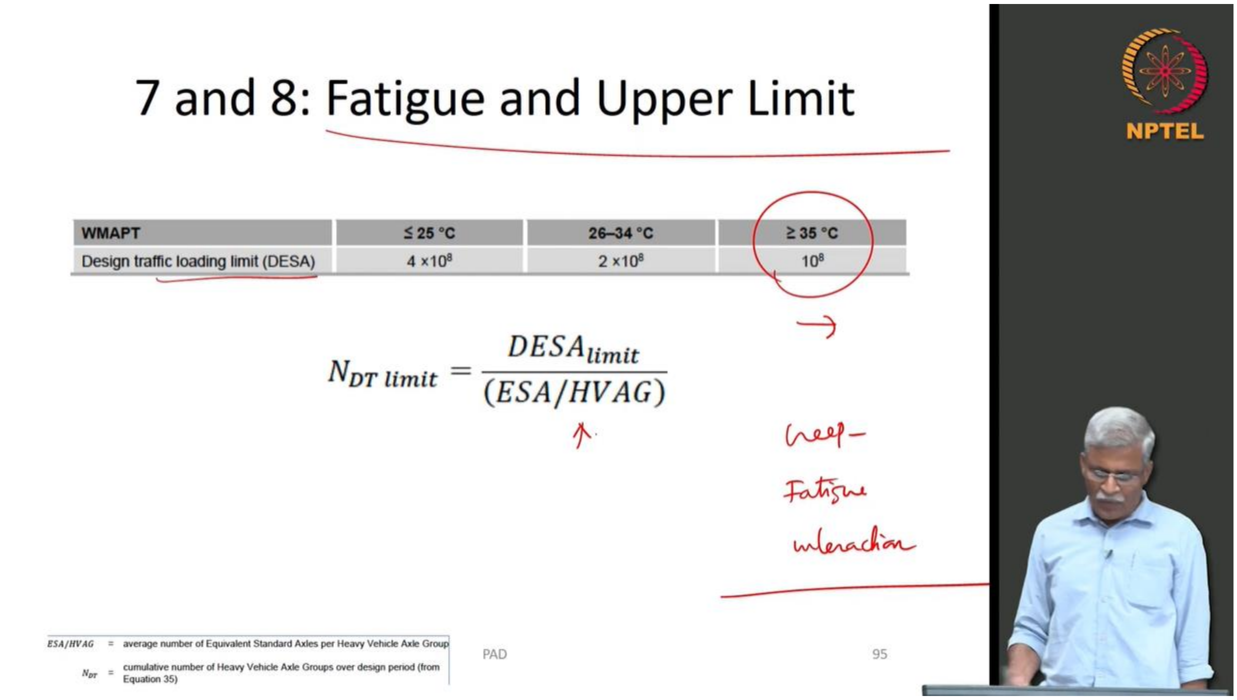

They also give you some kind of an upper limit for fatigue.

$$N_{DT\ limit} = \frac{DESA_{limit}}{(\frac{ESA}{HVAG})}$$

Now, why as the temperature increases the fatigue design traffic loading limit which is called the DESA is reduced is something that we can discuss only in an advanced course. There is something to do with stress relaxation, healing and all those things that can happen and some of them happen at different temperatures. At high temperatures, what can happen is, there could be accumulated permanent deformation. And there are also a lot of interesting issues related to creep and fatigue interaction. We would not get into all those details because immediately you should be thinking, why is this temperature greater than 35°C and why is this teacher talking about traffic loading limit at 35°C and above? Will we really have fatigue? Yes, you will have fatigue. $N_{DT\ limit}$ is the cumulative number of heavy axle groups over the design period? ESA/HVAG is the average number of equivalent axles per heavy axle group.

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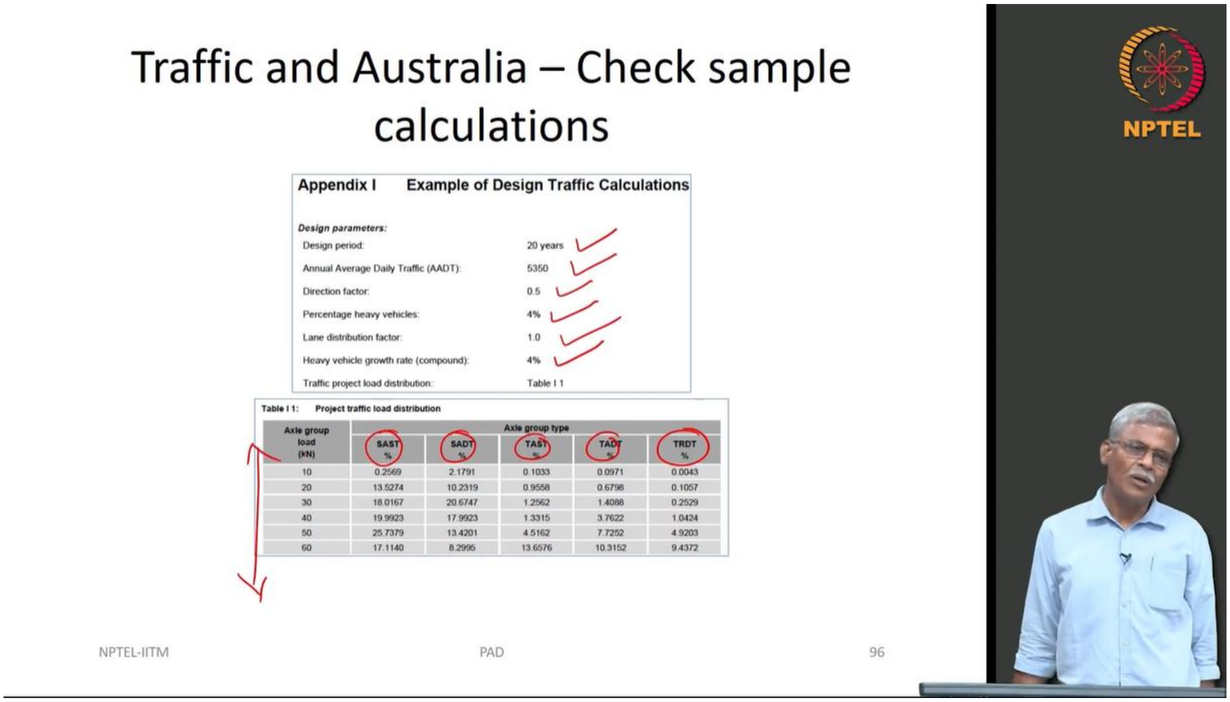

Now there are some sample calculations that are shown here. You can actually see 20 years is the design period, AADT is 5350, direction factor is given, percentage of heavy vehicle is given, lane distribution factor is given, 4% is the growth rate factor and this is the traffic load distribution. In fact, this is what you are really talking about SA DT, TAS, TTA, DT, TRDT and the axle load group is given here. So what I would request all of you is to go to this particular appendix, try and see whether you can do the calculations. So in the next lecture what we will do is to talk about materials. Thank you.