Analysis and Design of Bituminous Pavements

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Lecture - 32
Reliability in Pavement Design - Part 02

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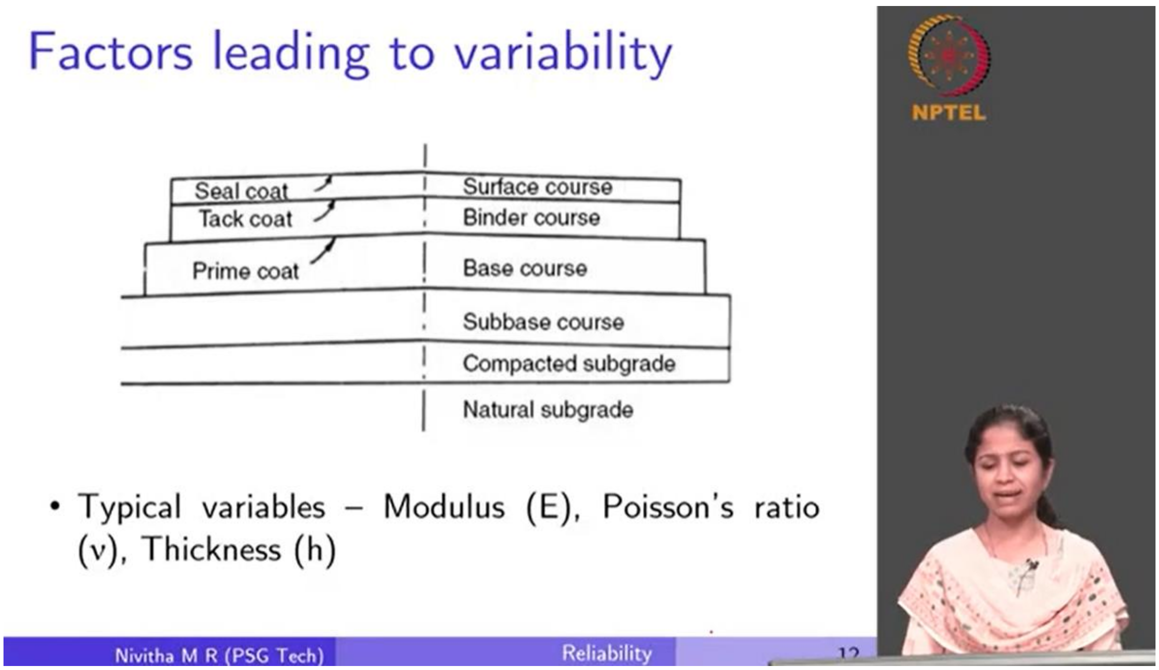

Now, let us take a specific example from IRC 37. We have all these layers in our pavement. We have a modulus value, we have a Poisson's ratio and we have thickness parameters that we usually use for design. So, what is the variability associated with each of these parameters?

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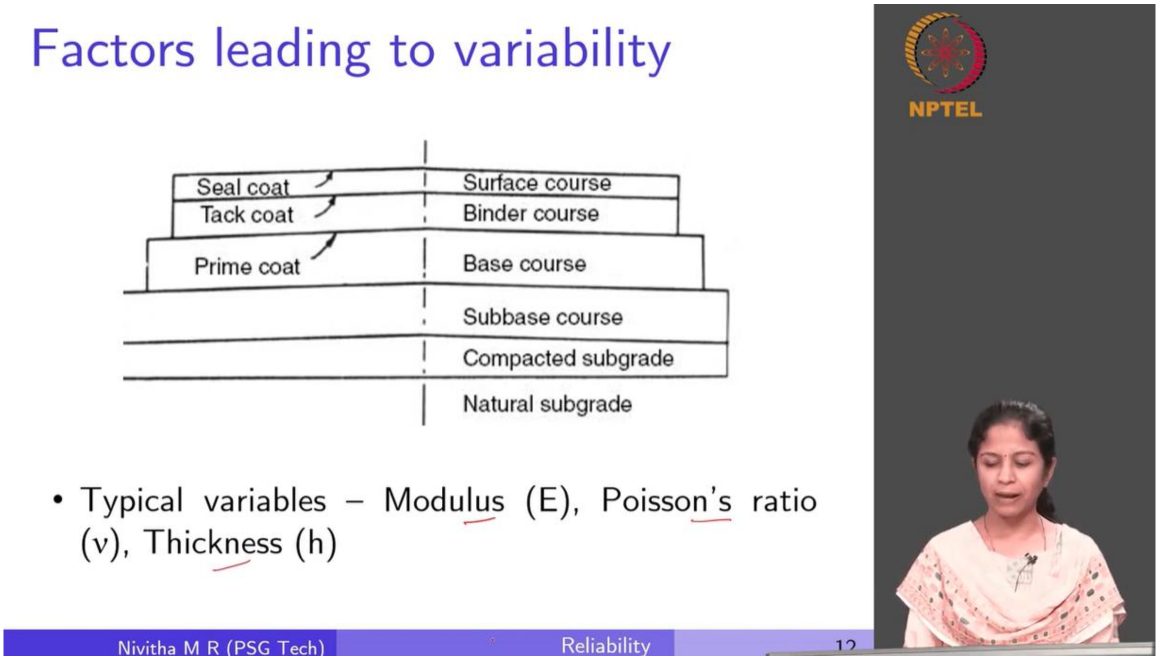

So, there is some literature that has measured all these things on a given pavement system and they have quantified how much will be the variability for each of these 3 parameters that we usually use for design. With Poisson's ratio, we will not be able to observe modulus and thickness yes.

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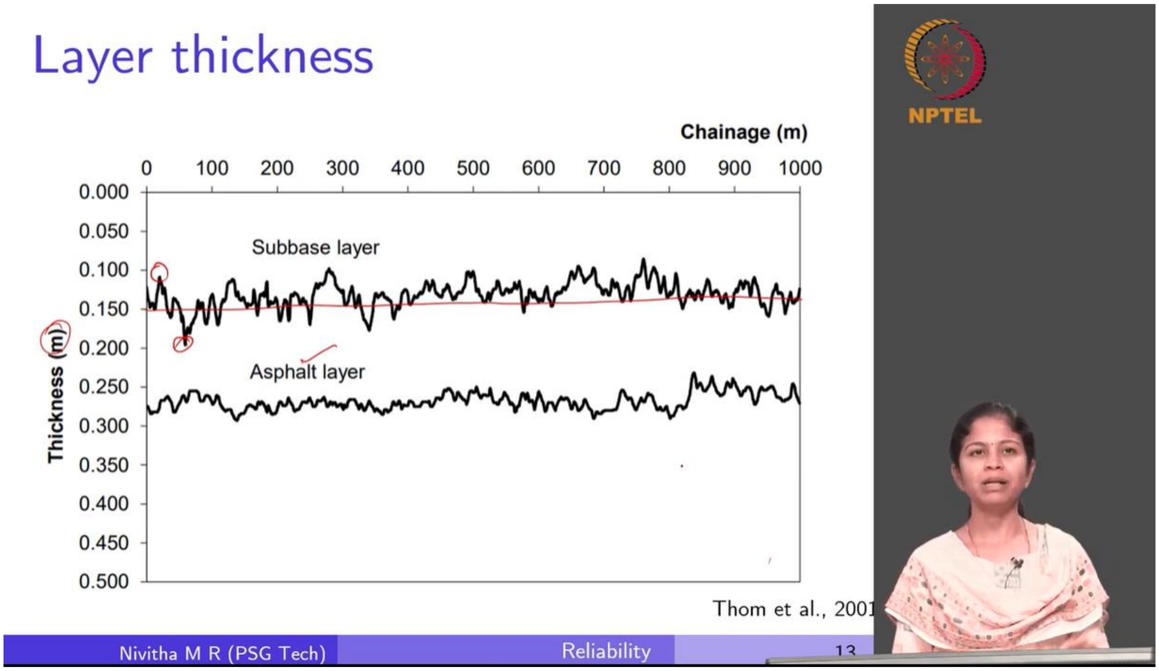

If I take a particular layer, this is a sub-base layer; you can see here that this is the thickness in meters so it is 150 mm. You can see how much the variability is, so this is 150 mm. If I am trying to draw a line at 150 mm, you can see that it has varied around it. In some cases, it has gone even closer to 100 mm and in some cases, it has gone closer to 200 mm. This is like once in a while but in most cases it is around 150 mm. Similarly, if you see it for the asphalt layer, you can see that it is again varying over a range. So, this is the amount of variability that we can observe in layer thickness if we go measure it for a pavement because it is practically impossible to construct a pavement for exactly the design thickness. The best we can do is to minimize the variability but we cannot avoid this variability.

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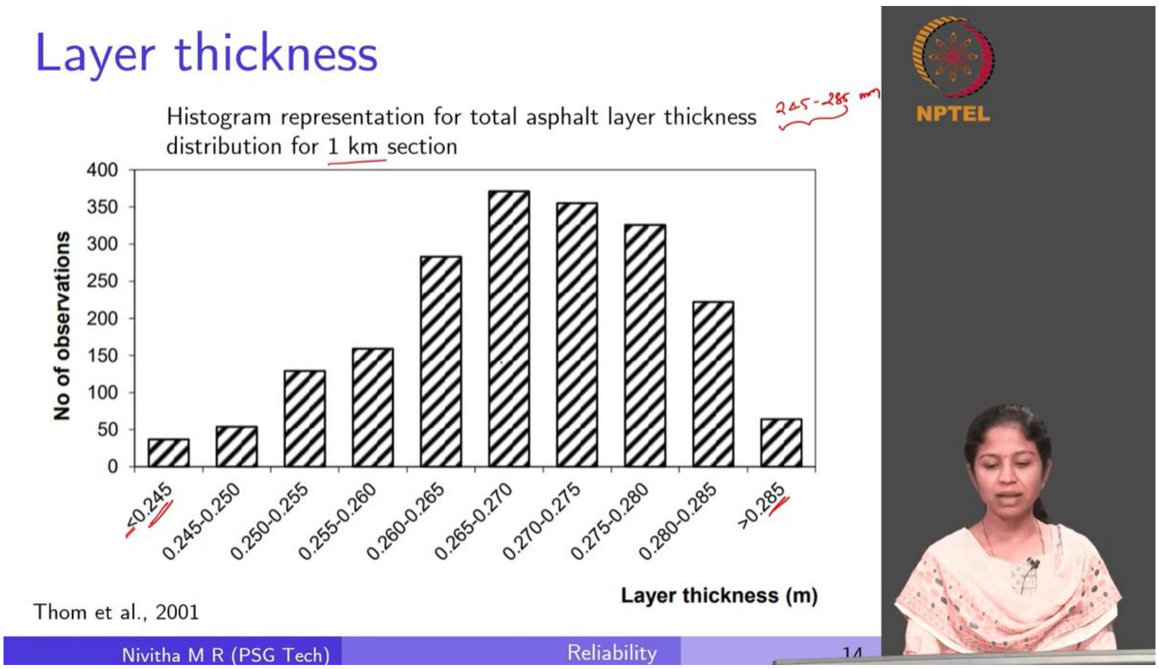

So, this is for the layer thickness, again if I am representing that in the form of histogram for the total asphalt layer for 1 km section. If I am taking measurements at 1 km section and drawing a frequency distribution you can see, there are a few sections which have values as less as 245 mm some greater than 285. So, the range is somewhere between 245 to 285 mm. Again we are not sure whether this is the exact range because it is less than 245 but let me just assume that it is going to vary at this range. So, this is the amount of variability that we are seeing for the layer thickness for the bituminous layer.

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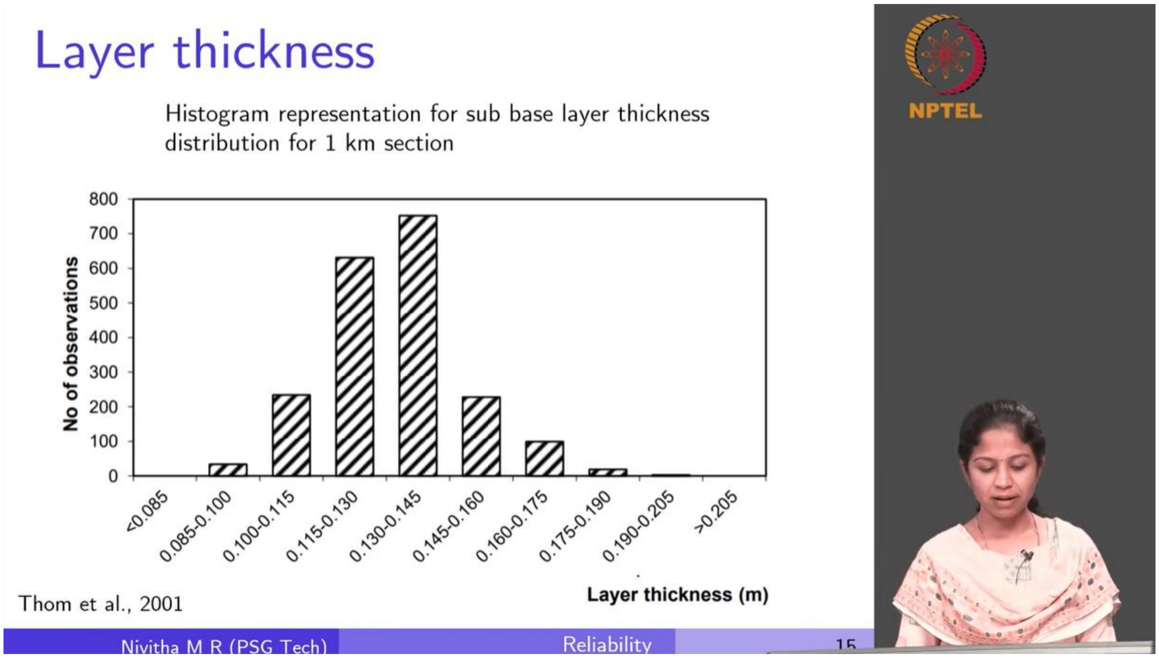

Similarly, we can also see the variability for subbase layer. Again you can see it varies from 85 mm to 200 mm. So, this is the amount of variability that we see. Again for each layer when we measure, we will be able to observe the degree of variability.

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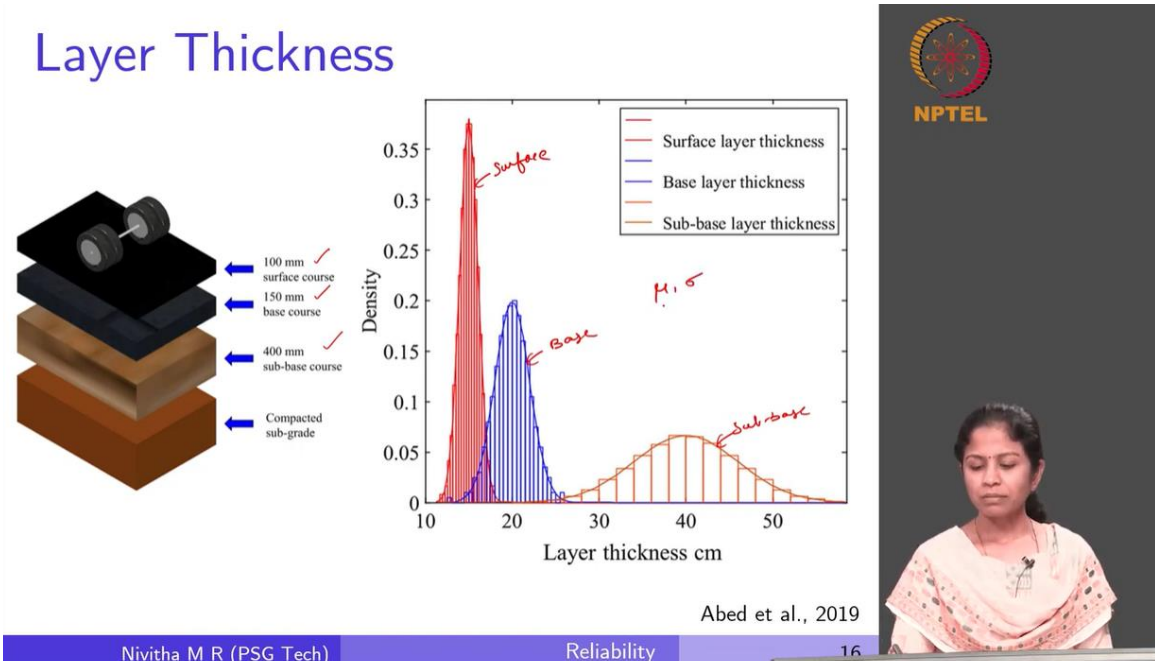

So, now if we take a system let us say it has 4 layers again one is your subgrade. If a system like this is taken which has a 100 mm surface course, 150 mm base course, and 400 mm subbase course, and if I am able to measure the thickness this could probably be the variation in thickness that we can observe for each of these layers. If I am plotting a histogram of this variability, let us say if I am plotting a histogram most of the cases, we might be able to approximate it with the normal distributions. In some cases, we will also observe different other kinds of distributions like log-normal or beta distribution or extreme value distribution.

So, different kinds of distributions may be observed but many times we will be able to approximate it with a normal distribution. So, if I am assuming a normal distribution for this case, this is the amount of variability that you can see for each layer. So, this is the surface layer, this is the base layer and this is the subbase layer. As we go to the surface course, we are able to minimize the variability but in a base layer, the variability is large. So, this variation that we observe in the field we can plot it and we can approximate it with any appropriate distribution. We know that a normal distribution is usually characterized by two parameters, one is the mean value and the other is the standard deviation. Using these two parameters, we will be able to describe the variability for any parameter.

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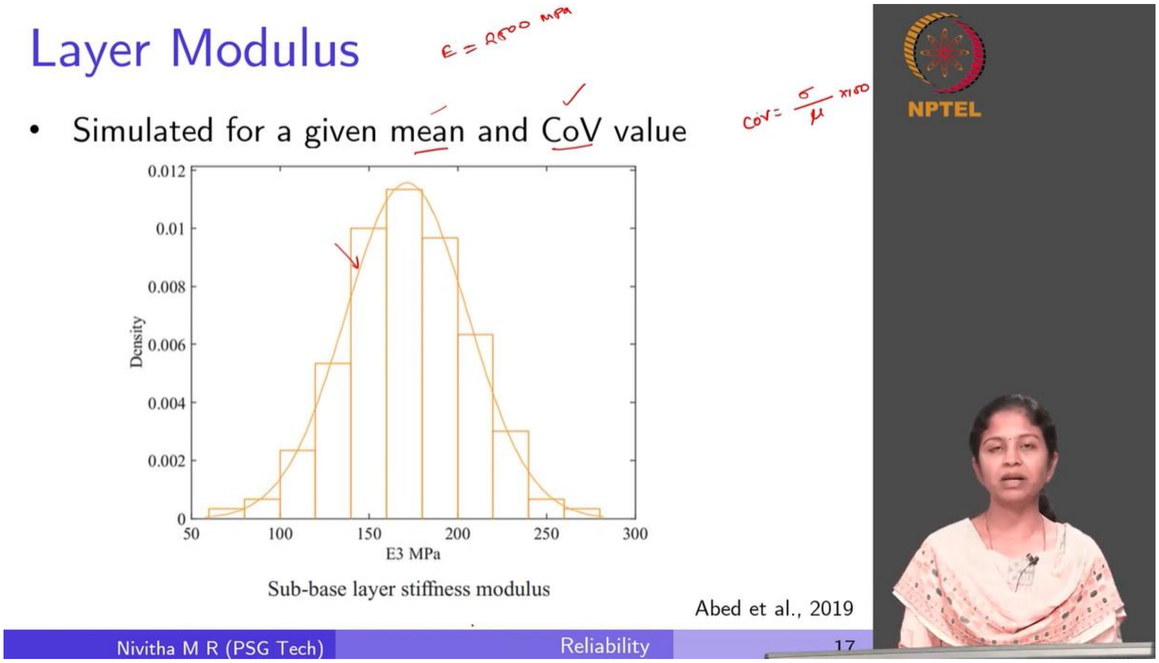

This is the modulus for a given mean and coefficient of variation. So, using the mean and standard deviation, we compute the coefficient of variation just to have an idea of how much is the variability of a given parameter with respect to its mean. The coefficient of variation is usually defined as the standard deviation divided by the mean into 100. So, the amount of variability that we see in a pavement system is quantified in terms of this coefficient of variation and it is always associated with the mean value. If I know a mean value let us say my target is 2500 MPa for a given layer, if my E value is 2500 MPa I can use it as my mean value. And depending upon what is the expected variability for this particular layer I will be able to generate this kind of distribution for any given input parameter. So, only if we are able to identify a distribution, then it becomes simple to incorporate this into the design process.

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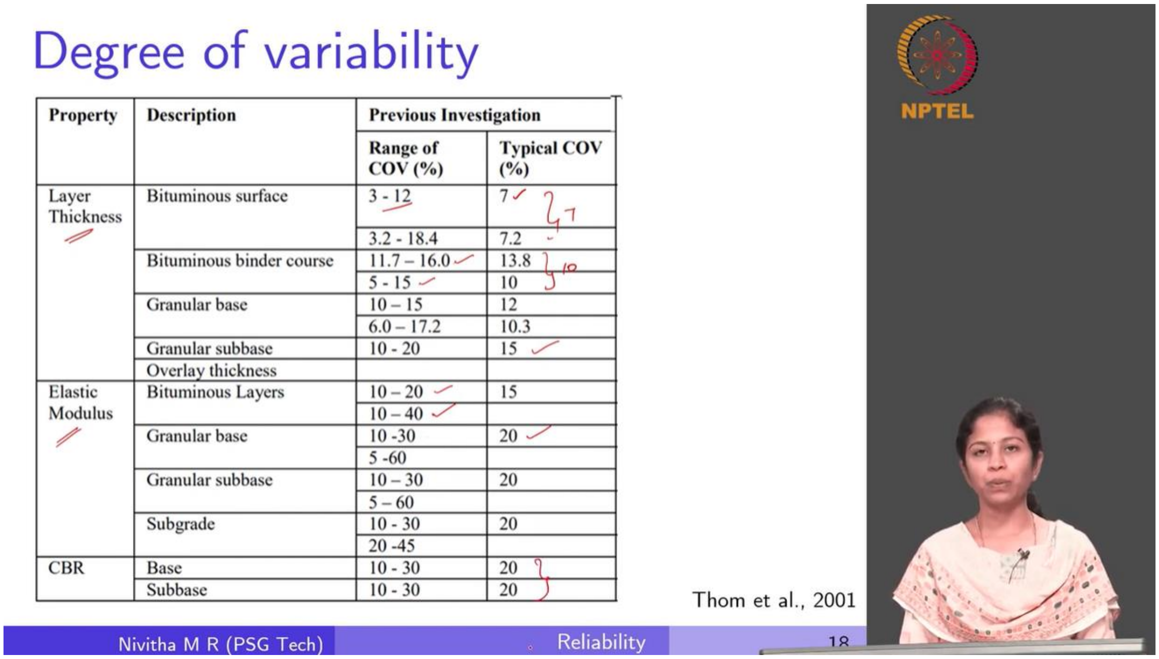

Property	Description	Previous Investigation	
		Range of COV (%)	Typical COV (%)
Layer Thickness	Bituminous surface	3 - 12	7
		3.2 - 18.4	7.2
	Bituminous binder course	11.7 – 16.0	13.8
		5 - 15	10
	Granular base	10 – 15	12
		6.0 – 17.2	10.3
	Granular subbase	10 - 20	15
	Overlay thickness		
Elastic Modulus	Bituminous Layers	10 – 20	15
		10 – 40	
	Granular base	10 -30	20
		5 -60	
	Granular subbase	10 – 30	20
		5 – 60	
	Subgrade	10 - 30	20
		20 -45	
CBR	Base	10 - 30	20
	Subbase	10 - 30	20

Now let us see what are the coefficient of variation and mean values for different layer thicknesses and modulus values for different layers. If I take the layer thickness of the bituminous surface, this is the range for the coefficient of variation. So, the typical value which is used is around 7 percent. So, there are some other studies as well that report the CoV to vary between 3 to 18 percent. And for a bituminous binder course which is kind of like your DBM, the coefficient of variation varies from 11 to 16 in one case and 5 to 15 in another case. So, we assume somewhere around 10 for this layer we assume 7 for this layer, and if it is a granular base course it is 10 to 15 or 6 to 17.

It is around 10 to 12 for a granular sub-base of 10 to 20. We use a higher value, as we move to the bottom layers the variability becomes higher. So, we use a higher coefficient of variation for the low-lying layers. So, this is the range of coefficient of variation, and the mean could be any target mean value that we desire. Then if you look at the elastic modulus for bituminous layers, it is between 10 to 20 percent. This value is nothing but the coefficient of variation which is the standard deviation divided by the corresponding mean value. Again from another study, 10 to 40 percent for granular base 10 to 30 or 5 to 60. So, it is usually 20 percent you can see. Thickness is better approximated we have less coefficient of variation values for the layer thickness. But when it comes to modulus it is usually around 20 percent even for your base and sub-base layers when we measure CBR we use a coefficient of variation of 20. So, this is the typical degree of variability that we observe for most of these layers and these are all values reported from different studies.

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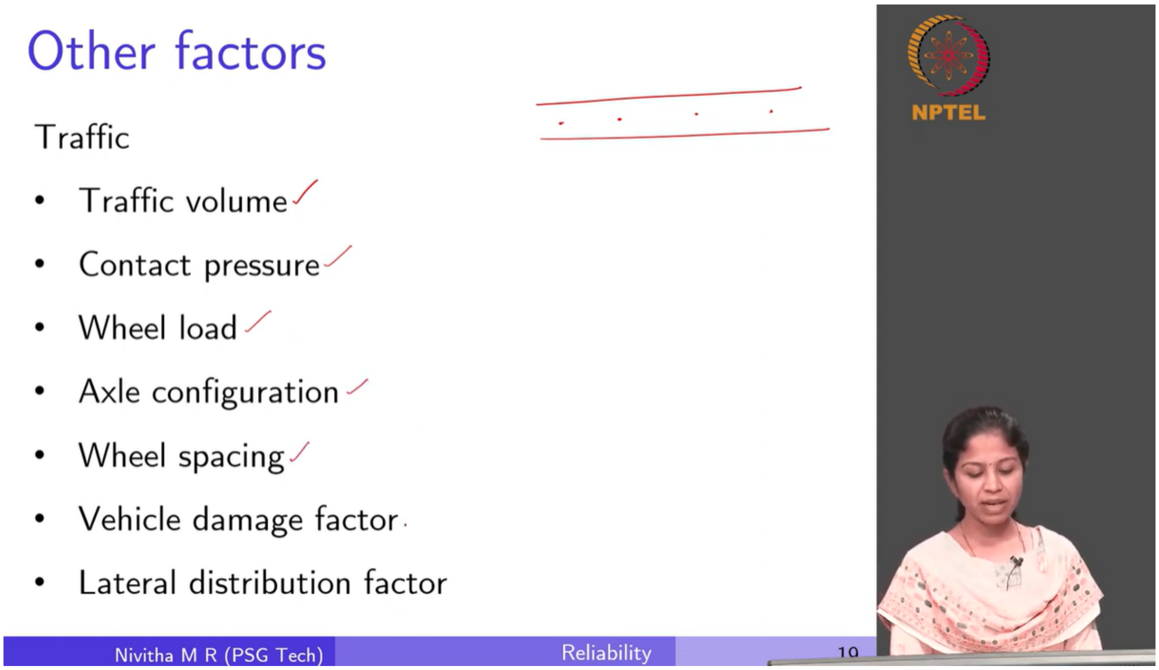

Now if we look at other traffic parameters as we discussed earlier, we have traffic volume. So, again if I do a spot speed study at different locations, we might have variability, especially if you use a sampling methodology rather than surveying the entire population. Similarly contact pressure, wheel load, axle configuration, the spacing between the wheel, vehicle damage factor, the lateral distribution factor. So, like that there are many parameters with respect to traffic also. Subsequently, we will see two or three parameters.

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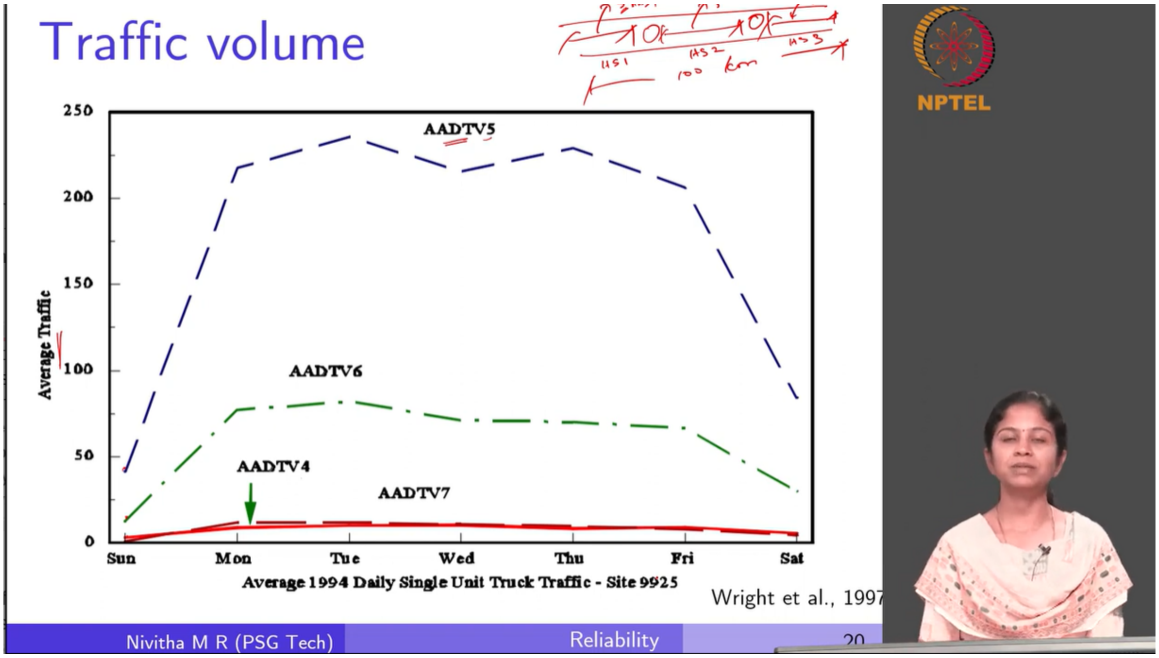

This is a traffic volume, it is the average traffic given in terms of AADT. So, this is measured at different locations. So, location V5, V6, V4, and V7 and it is done for different days in a week. So, for a given day you can see how it varies from different locations. Why does this become important? If I have a 100 km stretch of the road let us say I have two intersections here, we probably assume this to be one homogeneous section, we assume this to be another homogeneous section, we assume this to be another homogeneous section. Let us say I am considering 5 traffic surveys here, 5 traffic surveys here, and 5 traffic surveys here, and we do different design procedures for this homogeneous section 1, this section 2, and this homogeneous section 3. Now if I get 5 values here and let us say there is some degree of variability in all these 5 AADT values. So, let me call these 5 AADT values, which AADT among these 5 values will I use for design? Will I use an average value or will I take the maximum value or minimum value? So, that is where this concern comes in. So, if I measure at different locations like this and if each of them is going to show me this much amount of variability which parameter will I use for design, or how to consider all this variability in my design process and use one or a few representative values that becomes the major challenge here.

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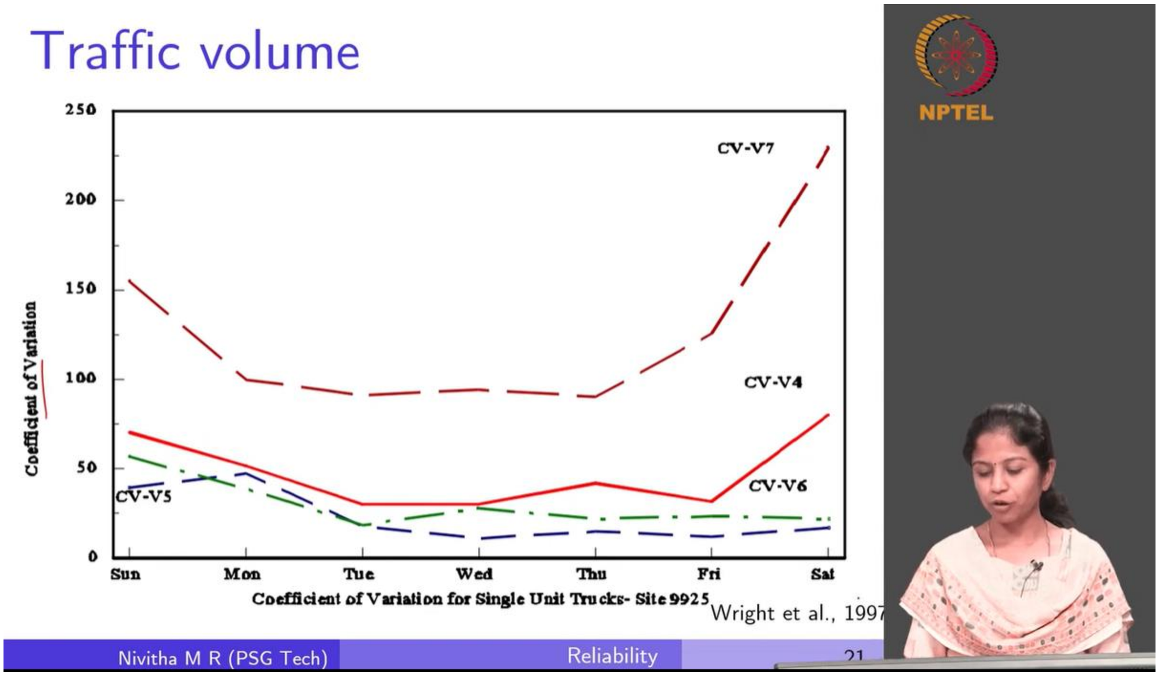

Now this is the AADT variation at different locations for a given week and if we are computing the coefficient of variation, this is the coefficient of variation for these different locations. So, the variability is large for some locations and less for some cases. So, like we quantified the coefficient of variation for material parameters, we will be able to do the same thing for traffic-related parameters also.

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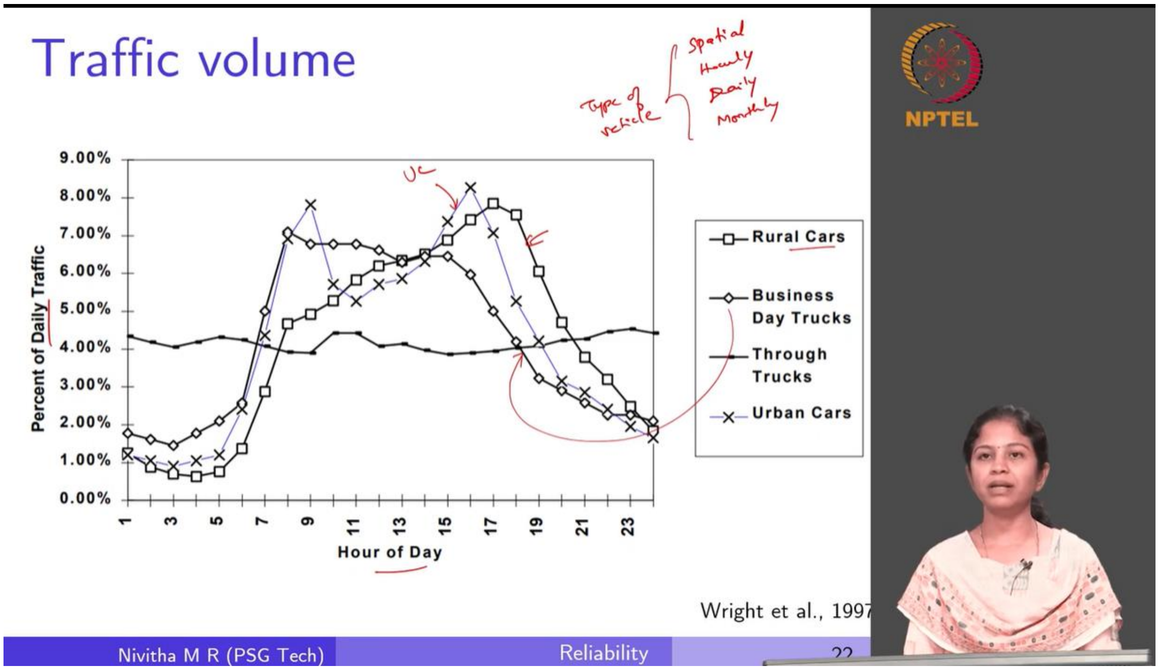

And this is the percent of daily traffic for different hours of the day. When I am doing a traffic survey, we have spatial variation, we have hourly variation, we have daily variation and again all monthly, yearly all those things will come in. All these things will come in. Again all these things are going to depend upon the type of vehicle. If I am going to measure the percentage of daily traffic, it is going to vary in different manners. If I take rural cars, this is rural cars. If I am going to measure it for business day trucks, it is this symbol here. So, if I use it for urban cars, this is the urban cars. So, each of them has a different pattern. Again, how am I going to take all of this into my design? Am I going to approximate or design each of them separately considering their variability? How is it going to be taken into account in the design process? So, this is another set of variations that we are seeing here with respect to day.

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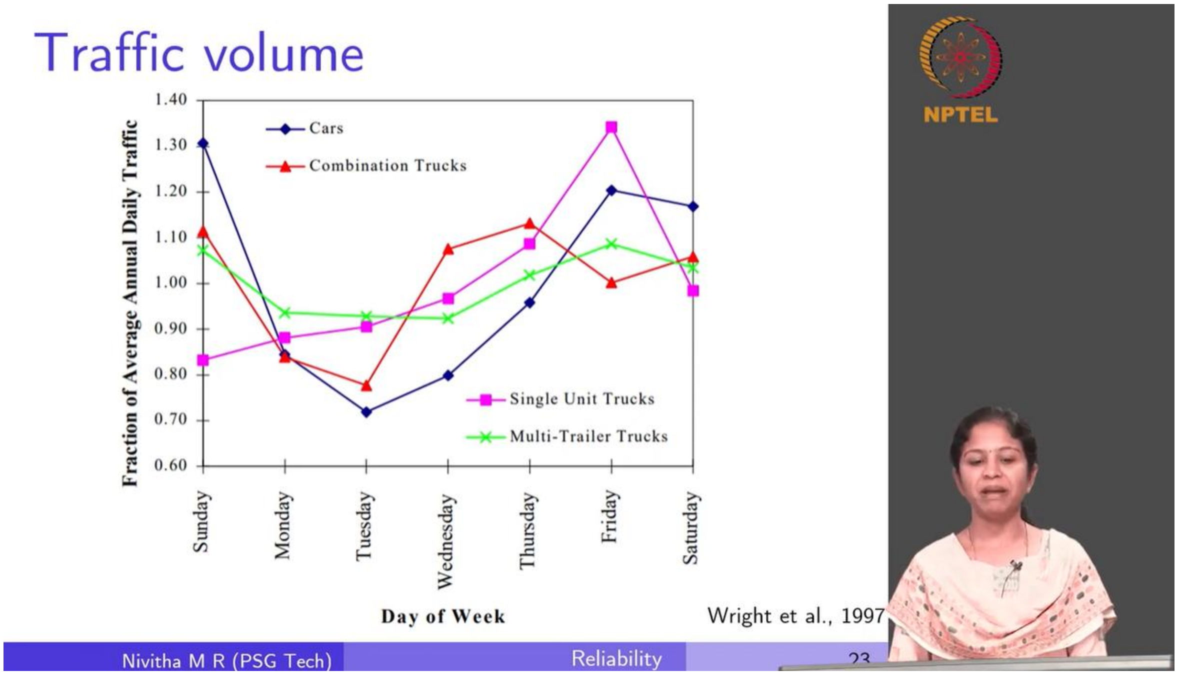

And this is again the weekly variation with respect to the vehicle type. We are all aware of this, the different factors which contribute to variability in traffic volume. How do we consider all these things? How do we combine all this variability and use a representative value which will more closely represent the damage that is experienced by the pavement? So, that is the major challenge in the design process.

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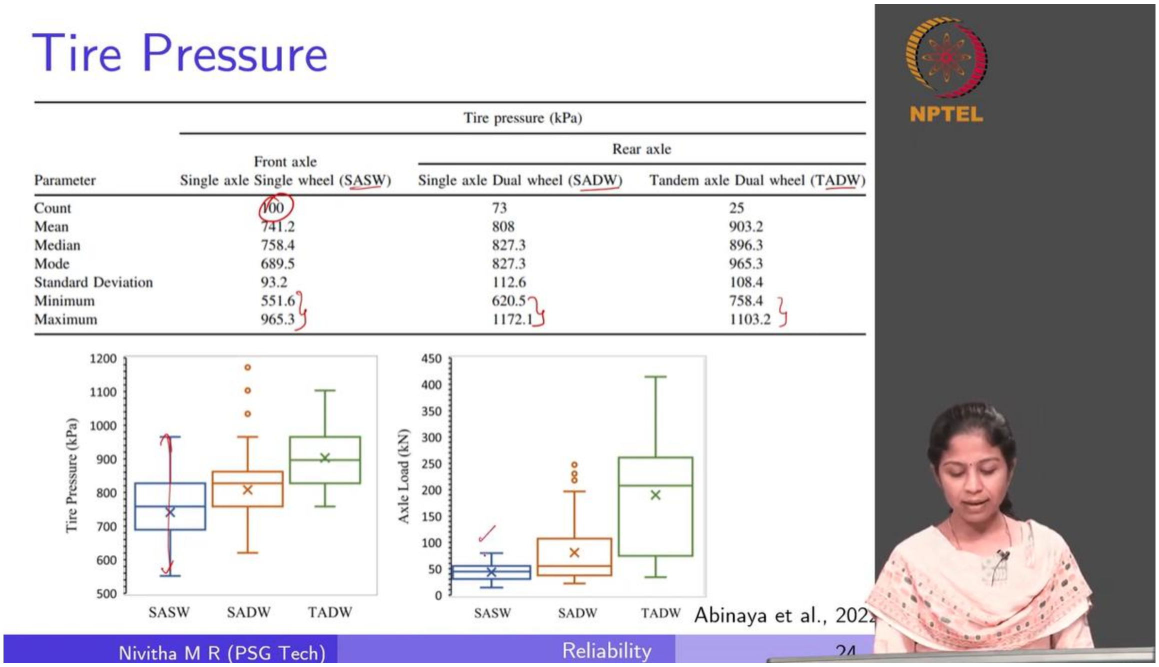

Again, we have tire pressure. This is from one of our studies which we have conducted at a few specific locations in Chennai. So, the tire pressure data was collected for 100 vehicles. You can see here this is for the front axle which is a single axle single wheel. This is single axle dual wheel, tandem axle dual wheel. You can see the minimum and maximum. So, the minimum is as low as 551 and the maximum goes up to 965 kPa. Similarly, for single axle dual wheel and tandem axle. So, if I am plotting the tire pressure value for the single axle, I am getting a range of values. So, this is the degree of variability associated with this particular parameter. Similarly, single axle dual wheel and tandem axle. Similarly, if I am plotting the axle load for these vehicle categories, the range of variability is given here for single axle single wheel, single axle dual wheel, and tandem axle dual wheel. So, this is another parameter from the traffic perspective.

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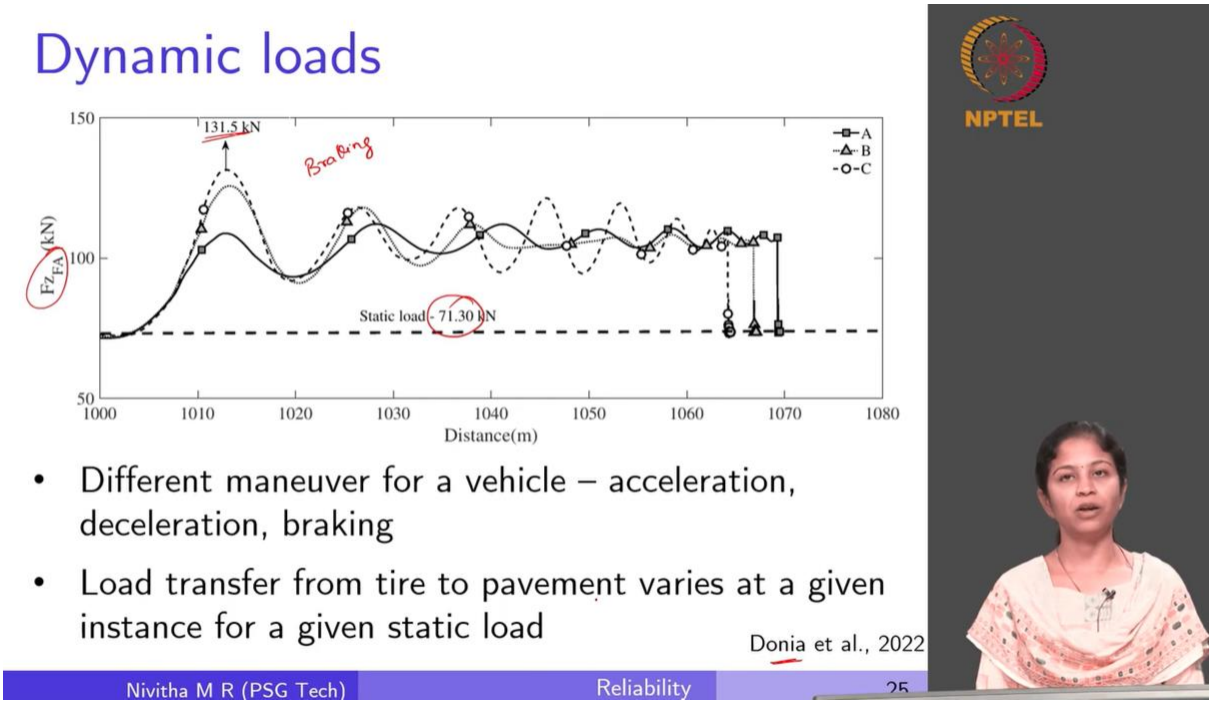

The next is the dynamic load. So, what is dynamic load? For pavement design, we usually use a static axle load. The static axle load is nothing but the load transfer from the vehicle to the pavement when the vehicle is in a standstill condition. So, we use a weigh pad or we even get the data from the weighbridge where the vehicle is standing and the load transfer is measured. So, the vehicle is there in a standstill condition. But in a real scenario when the vehicle is traveling on the pavement, it is not in a standstill condition.

The vehicle is in motion. So, depending upon the different actions that we perform on the vehicle, the load transfer is going to vary. The different maneuvers that we observe for a vehicle are acceleration, deceleration, and braking. So, what is this acceleration? Let us say we are moving at a constant speed and suddenly we want to increase the speed. So, when we step onto the accelerator and when the speed is increased, we are suddenly pushed back. When you are traveling in a car and when you suddenly accelerate, you should have observed this.

Similarly, when we are traveling at a constant speed and when the brake is applied suddenly, you should have observed that we tend to move forward. This is a braking phenomenon that we observe. So, during each of these, similarly, you can say deceleration when you are trying to slow down. During each of these phenomena, Donia has done a lot of studies on different types of vehicles and she has simulated the load transfer that is observed from each of these phenomena for a given static load.

So, she has assumed a static load of 71.3 kN. So, when this load is applied, this Fz_{FA} is the force in the z direction which is nothing but the vertical direction for the front axle. So, when a static load of 71.3 kN is applied to a given vehicle and the different maneuvers are simulated, this is for braking phenomena. She has seen that the wheel loads will go up to 131.5 kN. So, at a moment when this braking phenomenon happens, the load is as high as 131.5 kN. So, even the axle load which we assume to be a constant for a given vehicle is not a constant, but it varies depending upon this kind of maneuver. So, this is one kind of variability.

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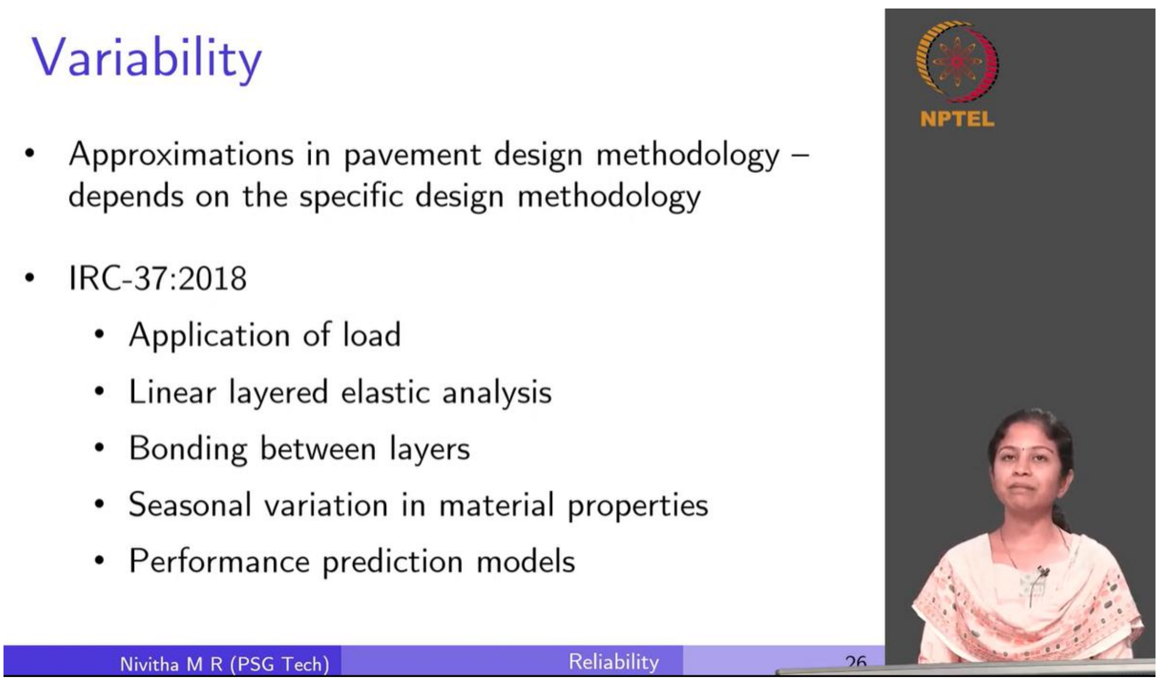

Now, there are other variabilities associated with the design methodology as well. Now, let us take IRC 37 design procedure and let us see how reliability is addressed in this particular design procedure.

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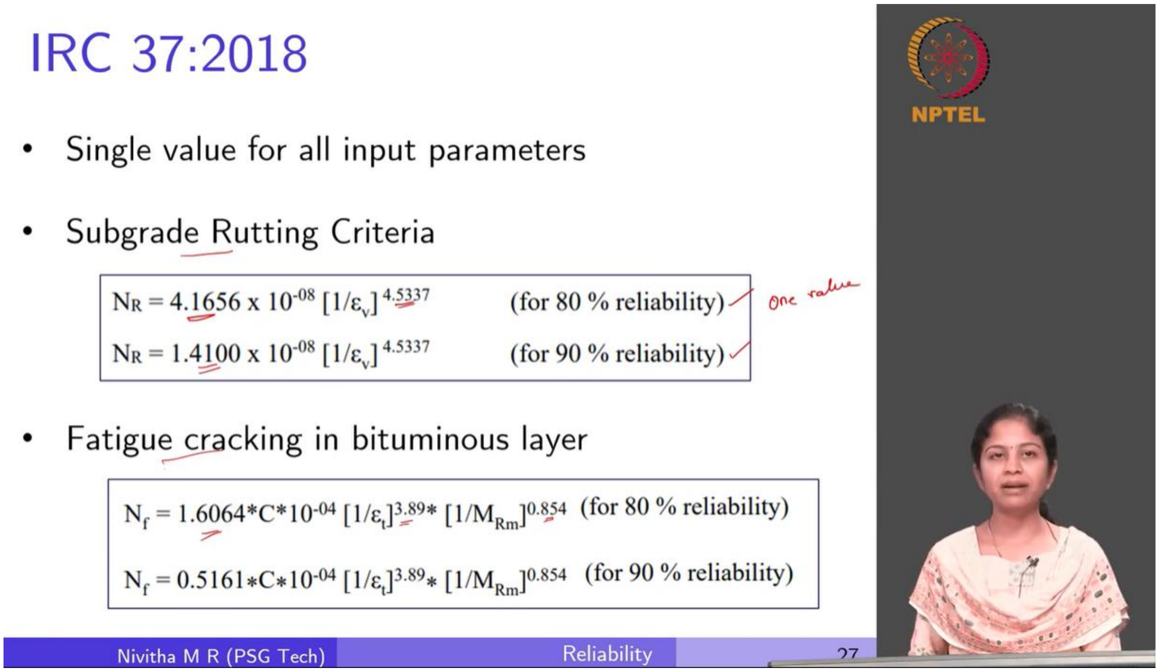

If you look at the IRC 37 procedure, you should have seen that we use a single value for all input parameters. So, we have thickness, modulus, Poisson's ratio, axle load, and tire pressure. For all these parameters, we use one value and typically we tend to resort to using a mean value. It is one single value for all input parameters and even the design procedure is deterministic, we give all the input parameters, and we get critical strains corresponding to this combination and that is used in the distress transfer function.

So, in the transfer function, you can see that it is specified for two different reliability levels. We have one equation for 80% reliability and another equation for 90% reliability for both subgrade rutting and fatigue cracking in the bituminous layer. This is the only aspect through which reliability is incorporated into the design procedure. Now, if you look at these N_f and N_r values, we are going to get one value, one single point value based on this design procedure. But we have seen that there is variability with respect to all the input parameters, even the constants that you use here. These constants are calibrated from a specific set of studies at a specific location or at a few locations. There is going to be variability associated with each of these input parameters as well.

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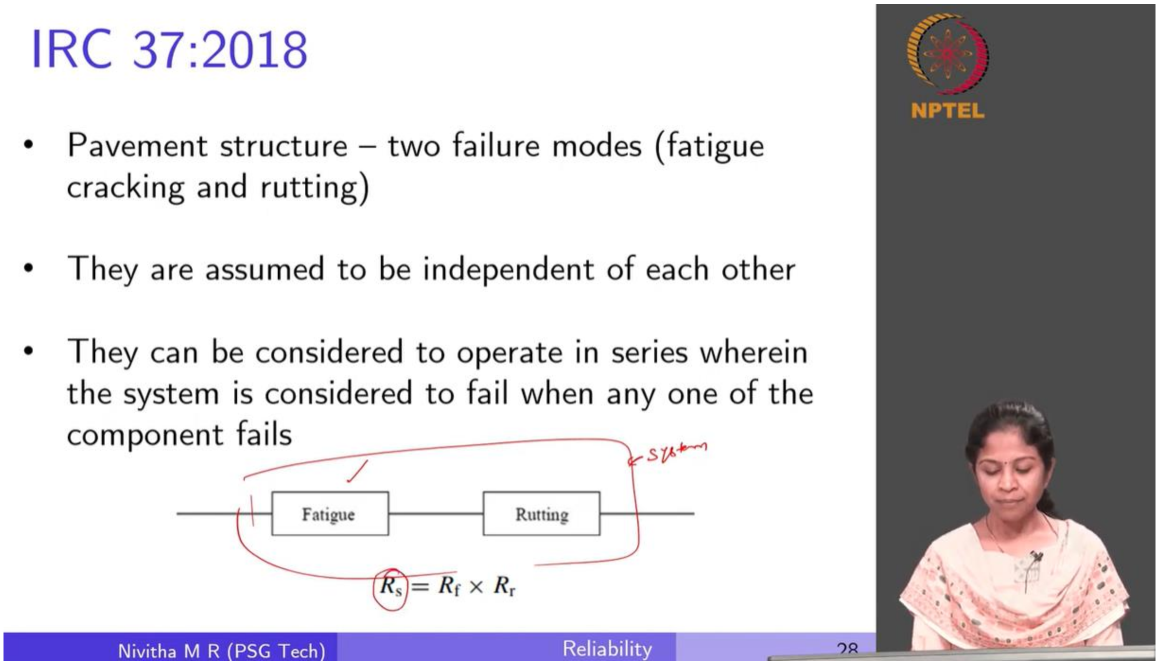

Considering all that if all of them are incorporated, what will be the degree of variability in my output? For a pavement structure, there are two failure modes that are considered as we have defined earlier, one is fatigue cracking and the other one is rutting. Typically the assumption is that they are independent of each other. If a pavement fails by rutting, not necessarily that it is going to fail by fatigue cracking. Though there are a lot of studies that talk about this creep-fatigue interaction and all those things, for the moment let us say that they are independent of each other. Then they can be considered to operate in series, wherein this whole system let us say this is my whole pavement system. This system is considered to fail only when any one of the components fails. So, either it can fail by rutting or it can fail by fatigue cracking. When one of these distresses happens, then it is said that the pavement has failed. So, the total reliability of the system is given as the reliability of fatigue cracking times the reliability of rutting so that if 1 becomes 0, then the reliability of the system will become 0. This is one assumption based on which the reliability of the IRC 37 design procedure can be specified.

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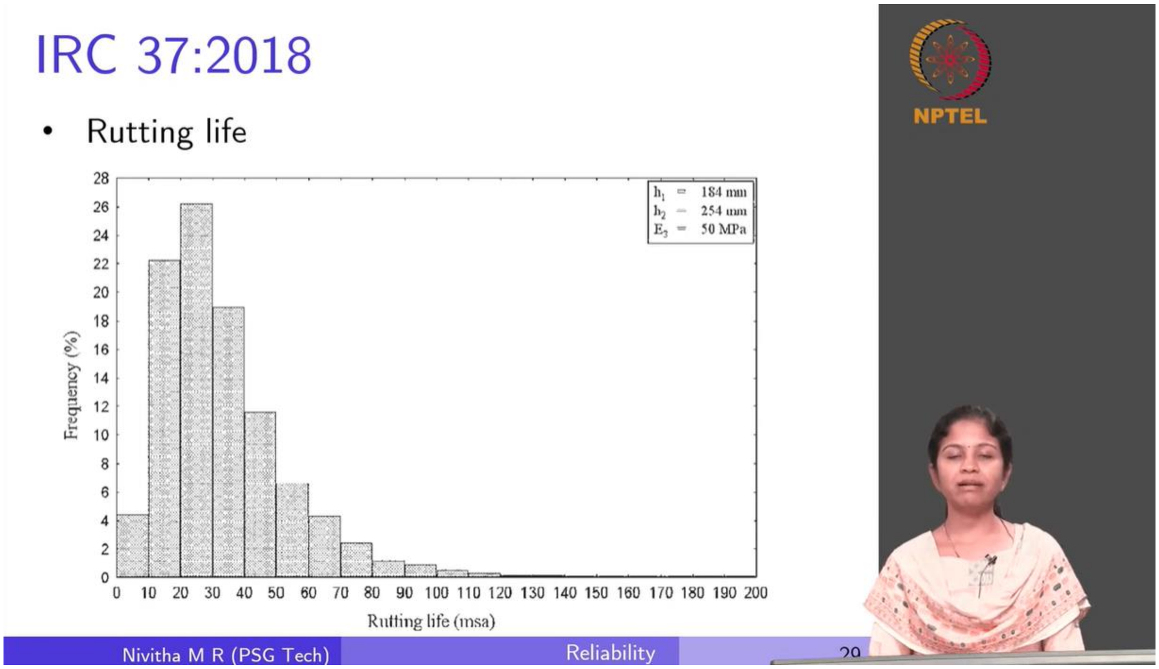

Now considering the variability of all these input parameters, if I consider the rutting and fatigue life in the pavement, you can see this is how it varies. It is not a given value. We will not get one N_f and one N_r value, but this N_f and N_r value are going to be a distribution rather than a single point measurement and this considers the variability of all these input parameters. Later, as I said two, or three lectures down, we will go through a procedure wherein we will be able to arrive at this kind of distribution for the rutting and fatigue life for the pavement.

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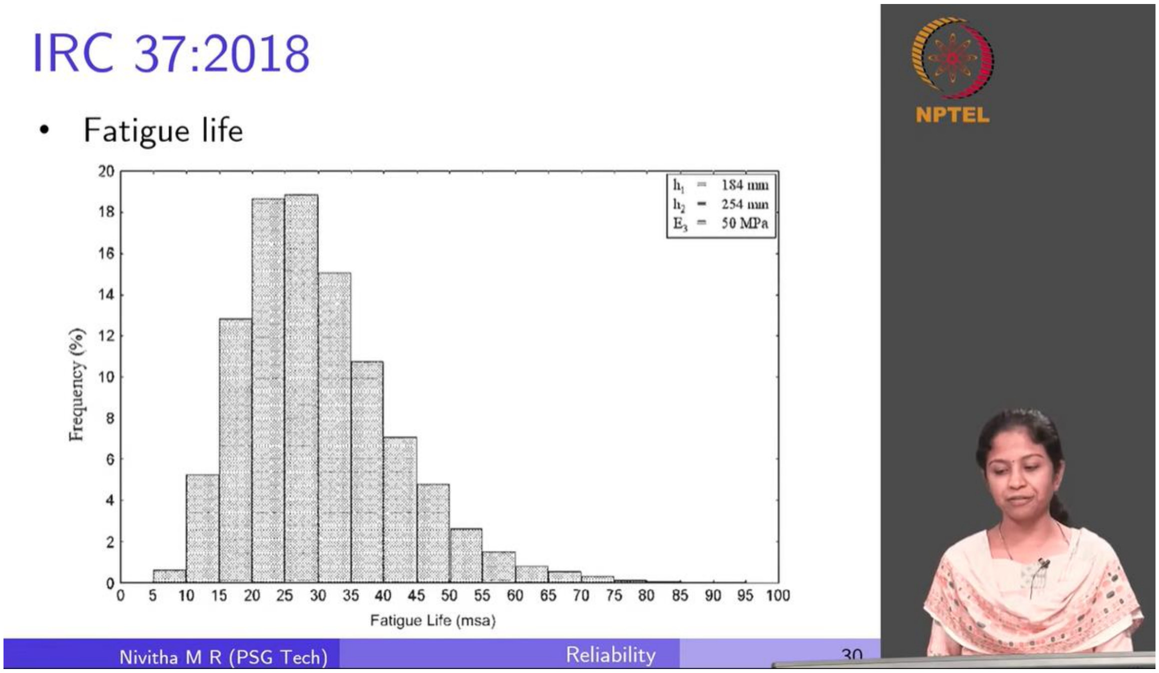

This is for fatigue life. So, ideally, we should be getting this, but what we get in IRC 37 is one deterministic value.

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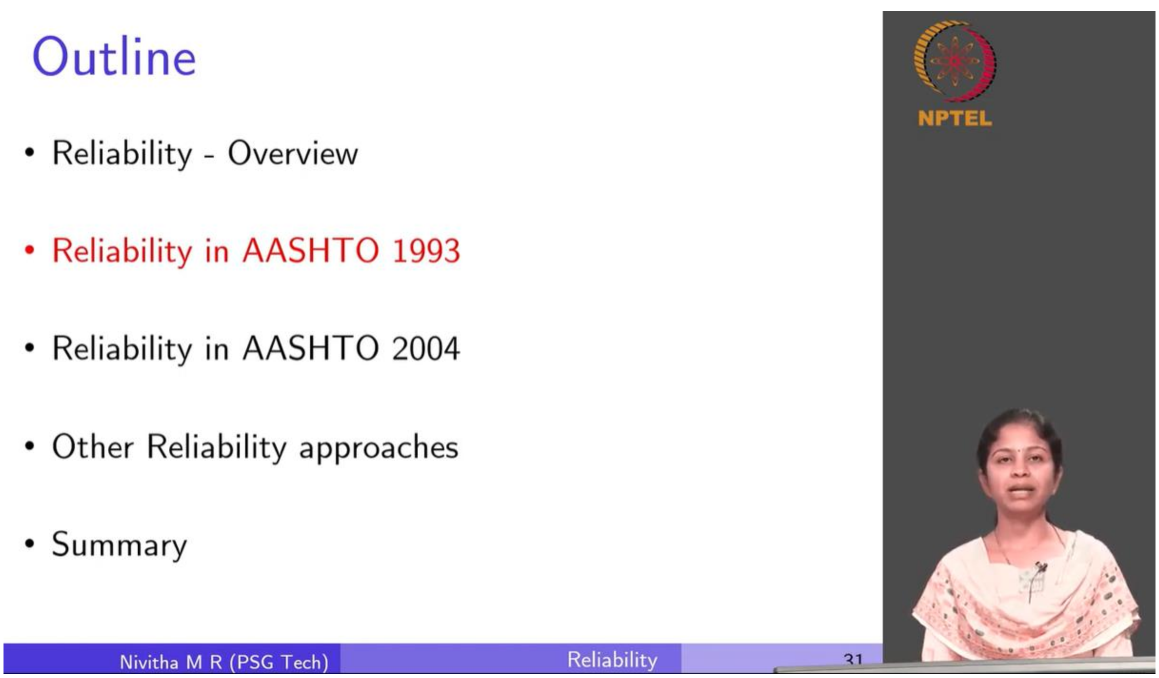

So, this is an overview of reliability, its consideration, the factors contributing to reliability in pavement design, and their considerations in IRC 37.

I will stop this lecture here. In the next lecture, we will talk about reliability in the AASHTO 1993 design procedure in specific. Thank you for your time.