Analysis and Design of Bituminous Pavements

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Lecture -19

Traffic Analysis - Load Spectra Factor

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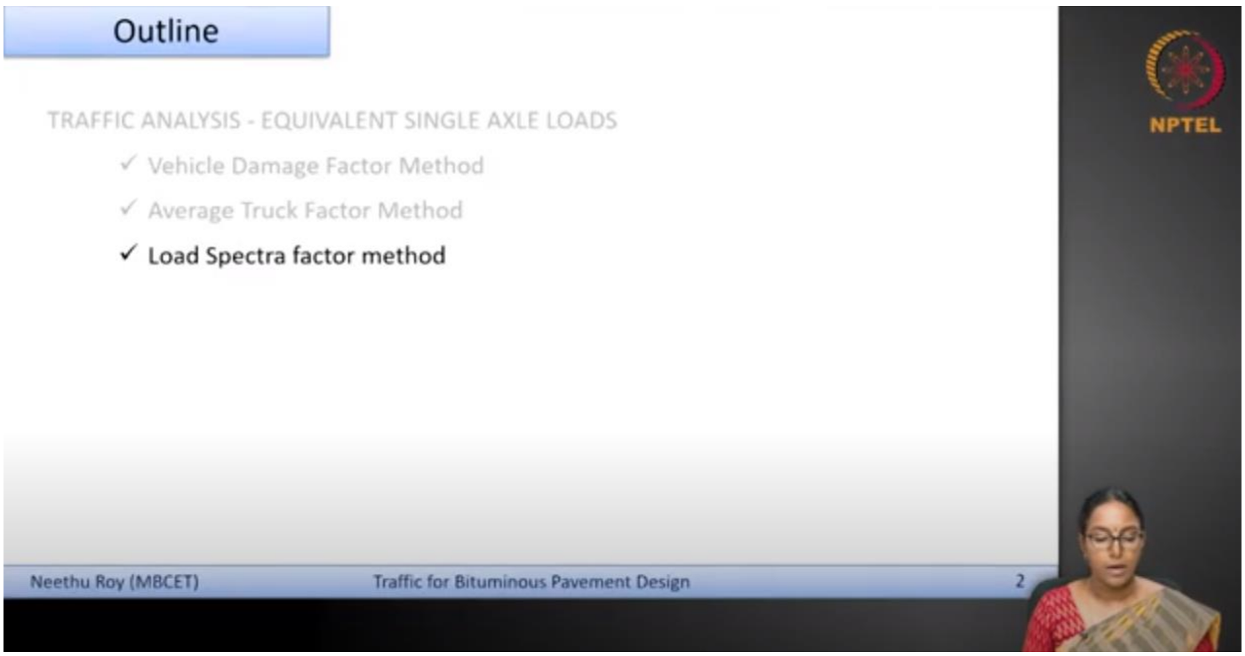

In this lecture, we will see how a load spectra factor method can be used to estimate the equivalent single axle loads. In the previous lectures, we have seen how a vehicle damage factor is computed and or truck factor is computed to estimate the equivalent single axle loads or the design traffic. So, in this lecture, we are going to discuss about this load spectra factor method.

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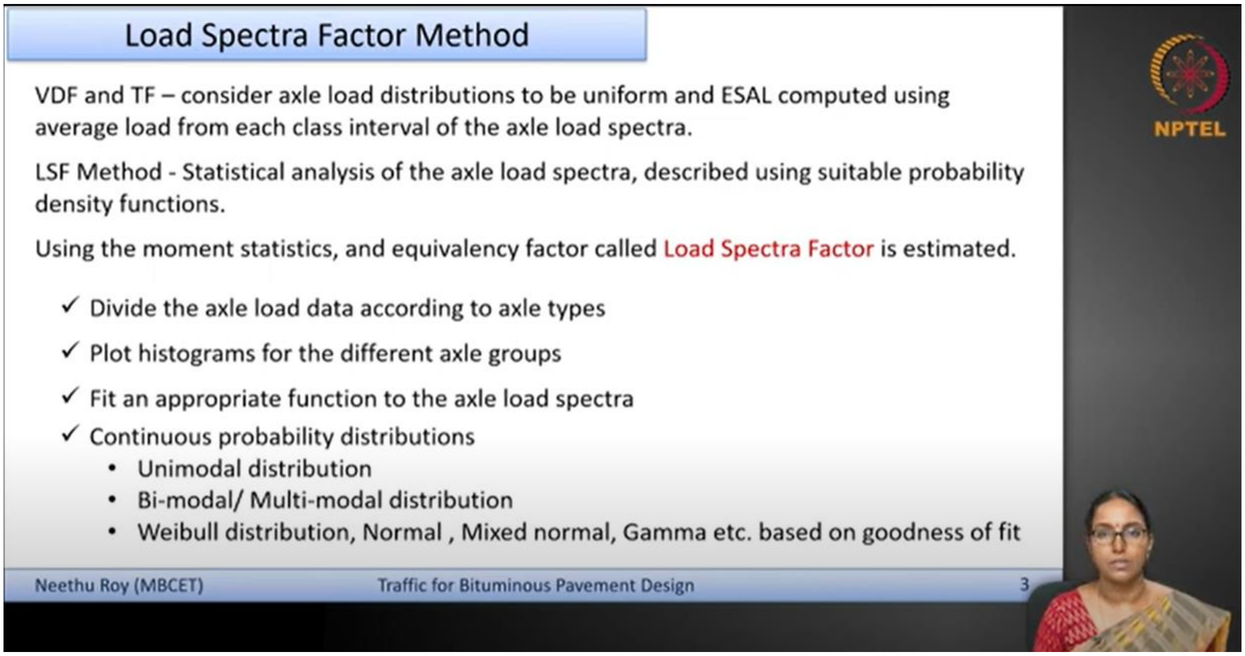

See in the VDF or TF, that is a vehicle damage factor or the truck factor, what we have done is that we have considered the axle load distribution to be uniform in a vehicle class interval. And the equivalent single axle loads were computed using the average load from each class interval of that load spectra. Whereas in this case of this load spectra factor method, you are not going to take an average value from a load bin or a load group and then find the ESAL. Rather than doing that, a statistical analysis of the axle load histogram or the axle load spectra will be done using a suitable probability density function. In the previous lectures, we have seen how a vehicle damage factor or an average truck factor is determined for the axle load data to convert the given axle load spectrum into equivalent number of standard axles for the design of a pavement structure.

Now, in this lecture, we will discuss a new concept which is called the load spectra factor method. So, in the VDF or the truck factor method, we actually consider the axle load distributions to be uniform within a certain range. And the ESAL will be computed using the average load from each class interval of that particular load spectrum. So, your distribution is essentially considered to be uniform within that load group. Whereas in this load spectra factor method, we will use the axle load histogram and do some statistical analyses to that axle load spectra as such and it is explained in terms of some probability density functions.

And using the moment statistics or taking the multiple moments of that probability density functions, you can develop an equivalency factor which is called a load spectra factor can be estimated. Now, this load spectrum can be a factor that can be used like a vehicle damage factor to compute the design traffic. So, here what you do is that the axle load data will be divided into according to its axle load types like for example, you can divide it into single axle single wheel, single axle dual wheels, tandem axle, tridem axles etc. And then you can plot the histograms in of the different axle load groups. Now, for the axle this histogram you try to fit appropriate load spectra.

Now, since these are positive values, you can choose any continuous probability density distributions that best fit this data. Essentially, sometimes, you know models like unimodal distributions may work and sometimes that you may go for bimodal or multimodal distributions as well. So, weibull distribution, normal distribution, mixed normal distribution, gamma distribution etc. Some of the distributions which are now commonly used to fit this axle load histogram.

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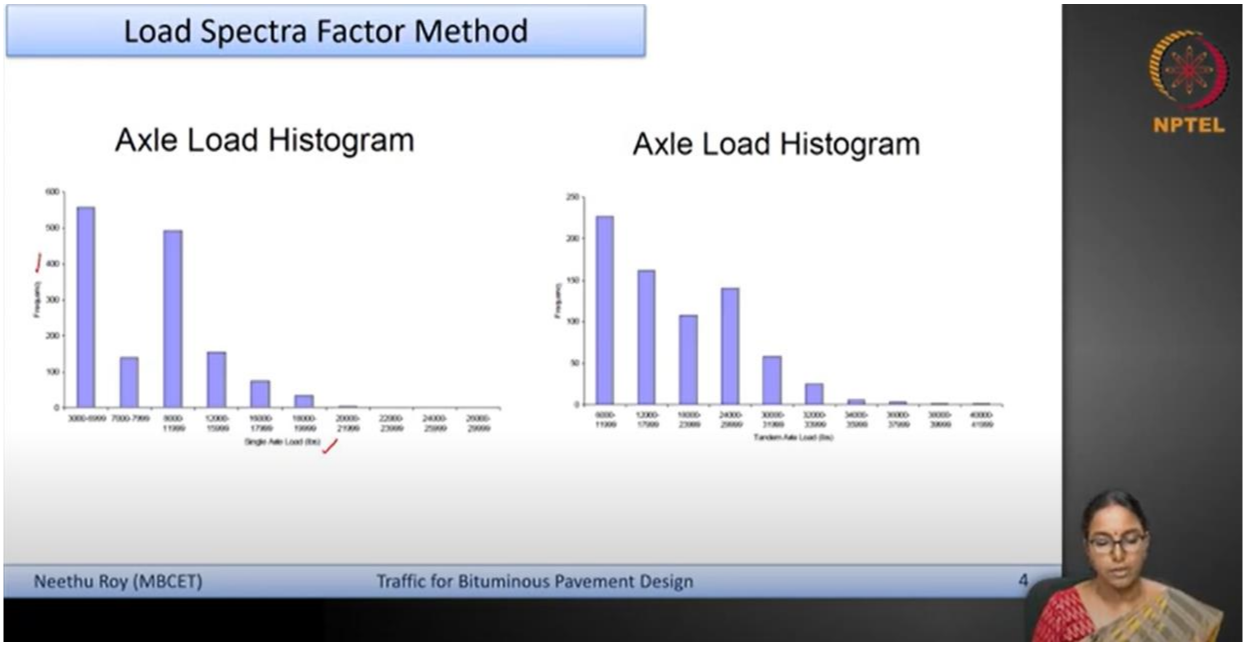

So, here you can see, so here you see the axle load histograms which are plotted for a single axle load and a tandem axle load and for this data, you can fit appropriate distribution functions.

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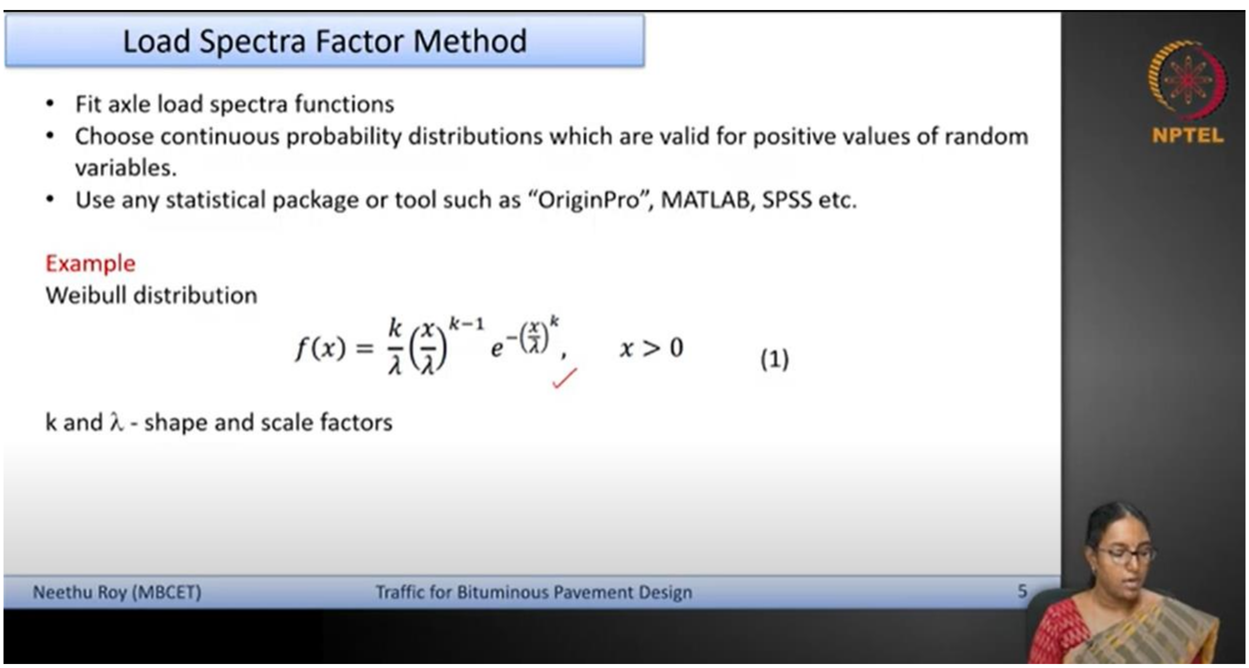

So, you have to choose continuous probability distributions which are valid for positive values of random variables. And in order to fit this, you can use some statistical packages like SPSS or you can use OriginPro or MATLAB or R programming can be used to fit this functions. See, as you can see, there is an example of a Weibull distribution given by this distribution function, which is used to fit certain data.

$$f(x) = \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^{k}}, \quad x > 0$$

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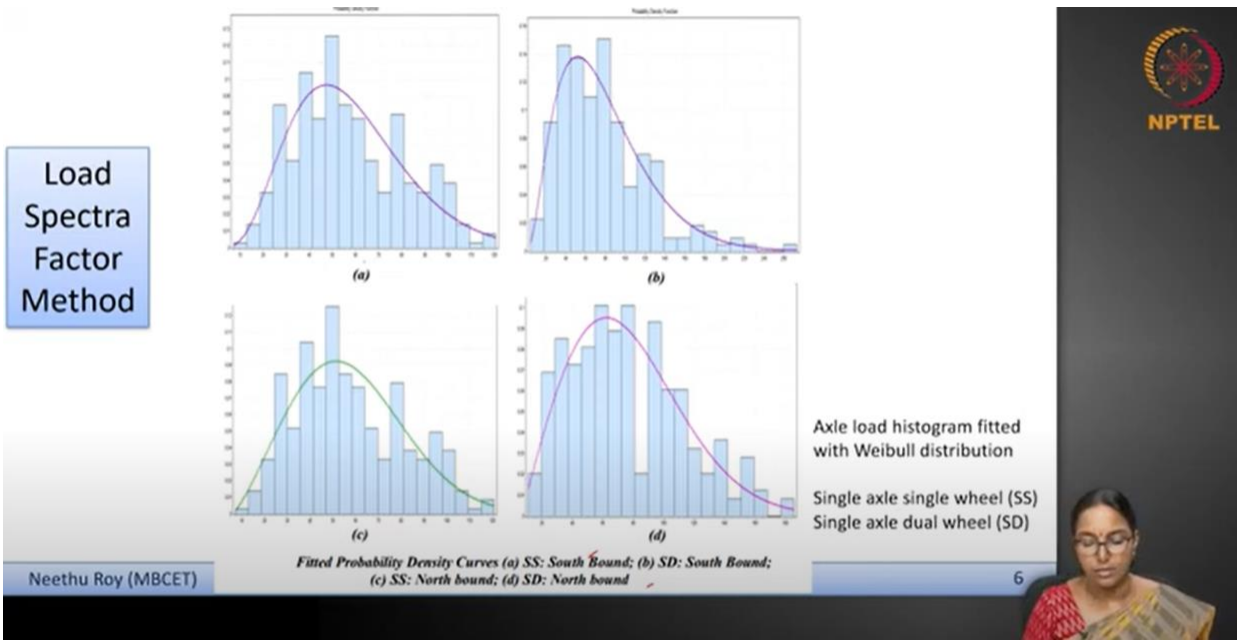

So, you see here this is a density curves that are fitted using Weibull distribution for a single axle single wheel and a single axle dual wheel in two directions of traffic. So, just noted here as south bound and north bound and so on. So, you can see here that the axle load distribution does not follow all the axle load distributions even in the same road in the north and south bound directions, you see that the distributions are not matching. So, they can have different distributions. Here, the one weibull distribution is fitted for all. It need not be the case always, you may have to go for different distributions for each of these load spectra.

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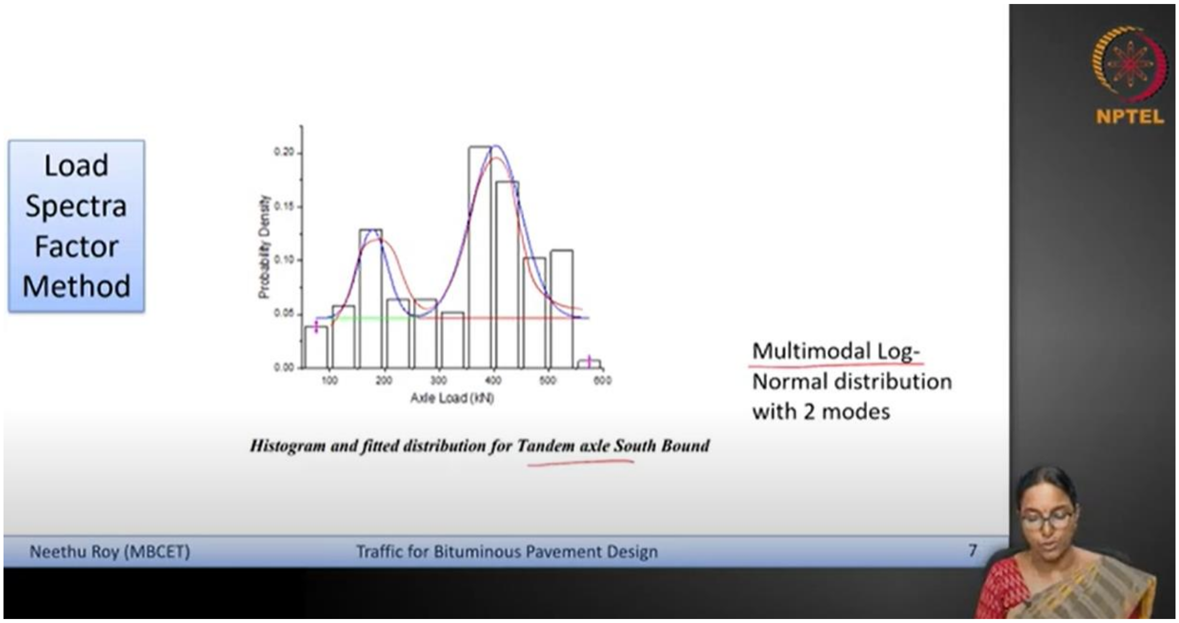

And here you see that so, this is for a tandem axle in one direction, the histogram is plotted and you see that it is necessary to go for a multi modal log normal distribution as shown in this figure. So, likewise, you can use some statistical parameters like chi squared test or something to see what the best fit distribution is and fit the data with this distribution.

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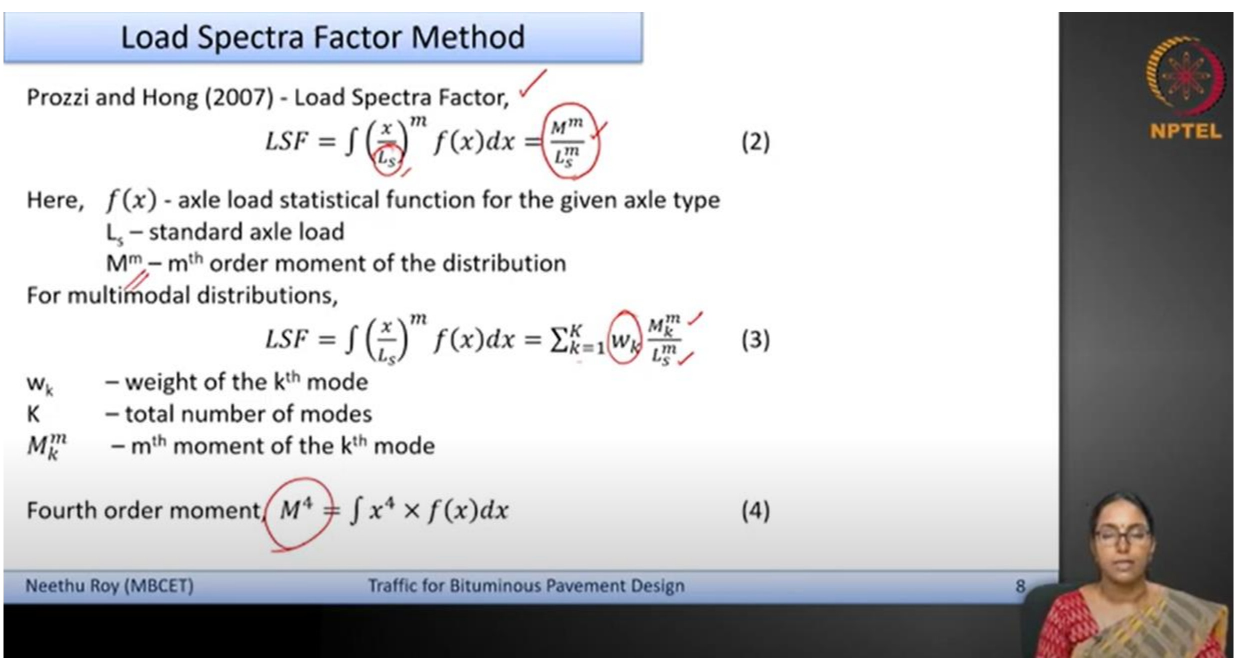

Now, Prozzi and Hong has defined a load spectra factor given as follows.

$$\mathrm{LSF} = \int \left(\frac{x}{L_s}\right)^m f(x)dx = \frac{M^m}{L_s^m}$$

What this load spectra factor is that from this distribution data, you are actually now converting it into a factor which can convert this data to a standard axle load wherein the L_s represents the standard axle load and M^m represents m^{th} order moment of the distribution. So, what you are trying to do is that use this m^{th} order moment of that distribution function and know the standard axle.

So, use this conversion factor to find what is the effect of the given axle load spectrum as compared to the standard axle load. So, this is for a single load distribution. For multimodal distributions, the load spectra can be defined as,

$$\mathrm{LSF} = \int \left(\frac{x}{L_s}\right)^m f(x)dx = \sum_{K=1}^{K} w_k \frac{M_k^m}{L_s^m}$$

Here, K represents the number of modes and w_k represents the weightage that is given for each modes of the multimodal distribution and M_k^m represents the small m^{th} moment of the k^{th} mode of the distribution and L_s represents the standard axle load. Now the standard axle load can be chosen as per the design strategy that you use like for example, if you are choosing IRC 37 approach, then L_s will take the value of 65 if it is a single axle single wheel. It will take a value of 80 kN if it is a single axle dual wheel. 148 kN if it is a tandem axle load and 224 kilo Newton if it is a tridem axle load and so on. So, the same approach can be used here, but the only difference is that you are not dividing your data into different bins and take the mid value of that for finding the equivalency factors. Rather, you are fitting it with a distribution and use the moment factors of those or the m^{th} moment of that distribution to estimate the load spectra factor. So, it is normally you know it is convenient to choose or it is you can use any moment but any order of the moment but normally you use the fourth order moment.

$$M^4 = \int x^4 \times f(x)dx$$

According to the distribution that you have chosen, you can use the same statistical packages to get this fourth order moment as well.

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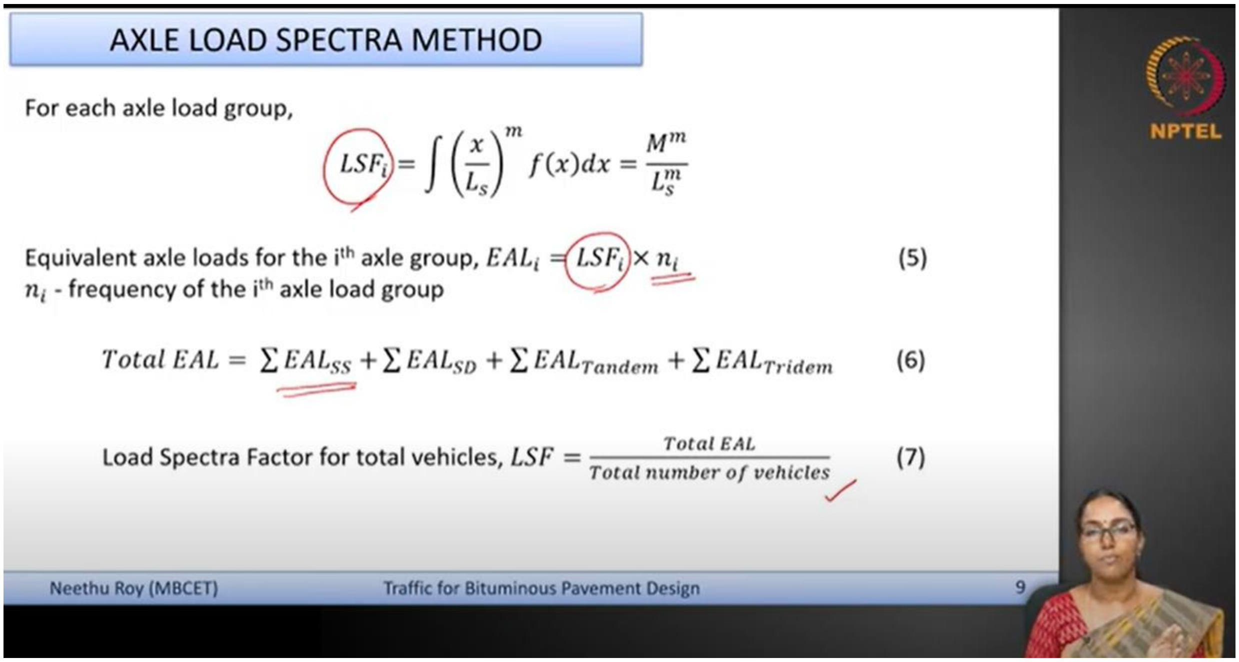

So, for each axle load group as I said you can divide it into axle load groups as single axle single wheel, tandem axle, tridem axle etc. For each axle load group you can determine what the load spectra factor is. Now, the equivalent axle loads correspond to that load group can be the load spectra factor multiplied by the frequency that is a number of axle loads in that group.

$$\mathrm{EAL_i} = \mathrm{LSF_i} \times \mathrm{n_i}$$

And then the total equivalent standard axle loads can be computed as summation of the equivalent axle loads computed for the each category of axle load group like the single axle single axle dual wheel, tandem tridem and so on.

$$\text{Total EAL} = \sum \mathrm{EAL_{SS}} + \sum \mathrm{EAL_{SD}} + \sum \mathrm{EAL_{Tandem}} + \sum \mathrm{EAL_{Tridem}}$$

$$\mathrm{LSF} = \frac{\text{Total EAL}}{\text{Total number of vehicles}}$$

So, that you will get the total ESALs equivalent axle loads and then divide it with the total number of vehicles which will give you the load spectra factor. So, this you can say that it is identical to the vehicle damage factor wherein for the entire vehicle class you have determined one factor which is called the load spectra factor but the advantage of this method is that you are not categorizing into different load groups and it is the representation of the spectra or the variation of the spectra over different load ranges is taken as such.

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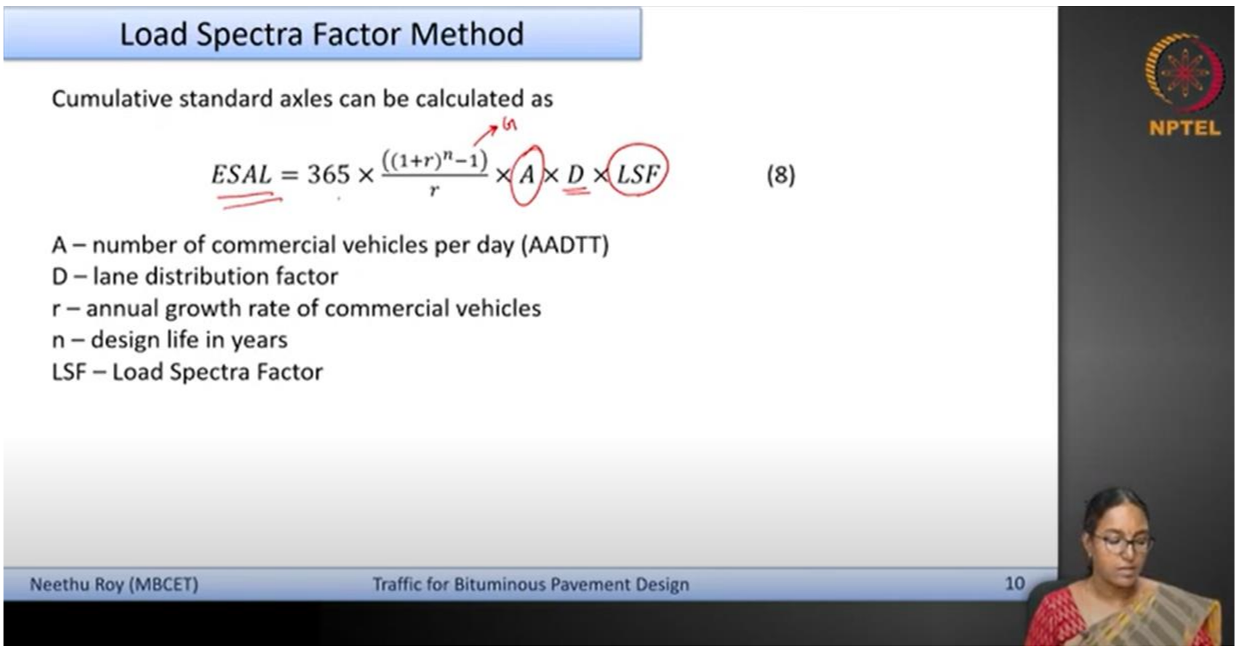

Now, how do we get the cumulative standard axles?

$$\mathrm{ESAL} = 365 \times \frac{((1+\mathrm{r})^{\mathrm{n}} - 1)}{\mathrm{r}} \times \mathrm{A} \times \mathrm{D} \times \mathrm{LSF}$$

A is the initial traffic, r is the growth factor, D is lane distribution factor. So, you multiply it with the load spectra factor you can get the design traffic or the equivalent standard axle load factors. So, this is how a load spectra factor method is used in comparison with a vehicle damage factor or a truck factor method.