Analysis and Design of Bituminous Pavements

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Lecture -18

Traffic Analysis - Examples

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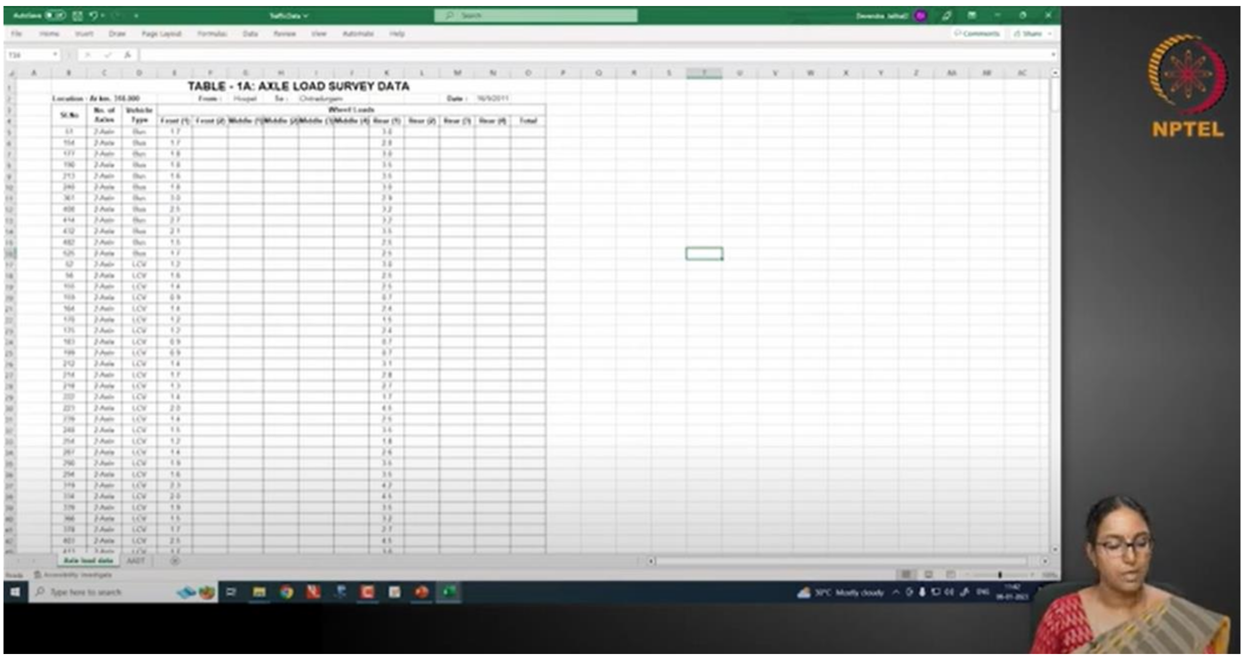

Hello everyone. Using a template, I will show you how this truck factor method and the vehicle damage factor method is used to determine the equivalent standard axle loads. So, what you see here is the template in which you actually mark the axle load data that is being collected. You can see here, there is the serial number and the number of axle. You can read the serial number part. This is a traffic which comprises of 2 axle truck, 3 axle, 4 axle and 5 axle. We will see what the different classes are. For the different classes or the vehicle types, you measure the wheel loads. Here, a portable small weigh pad was used wherein you will note the wheel loads essentially and not the axle load as such. So, you can see here that the wheel load is noted here as 1.7 and for the rear wheel it is noted as 3. Likewise, you have commercial vehicles, bus, etc.

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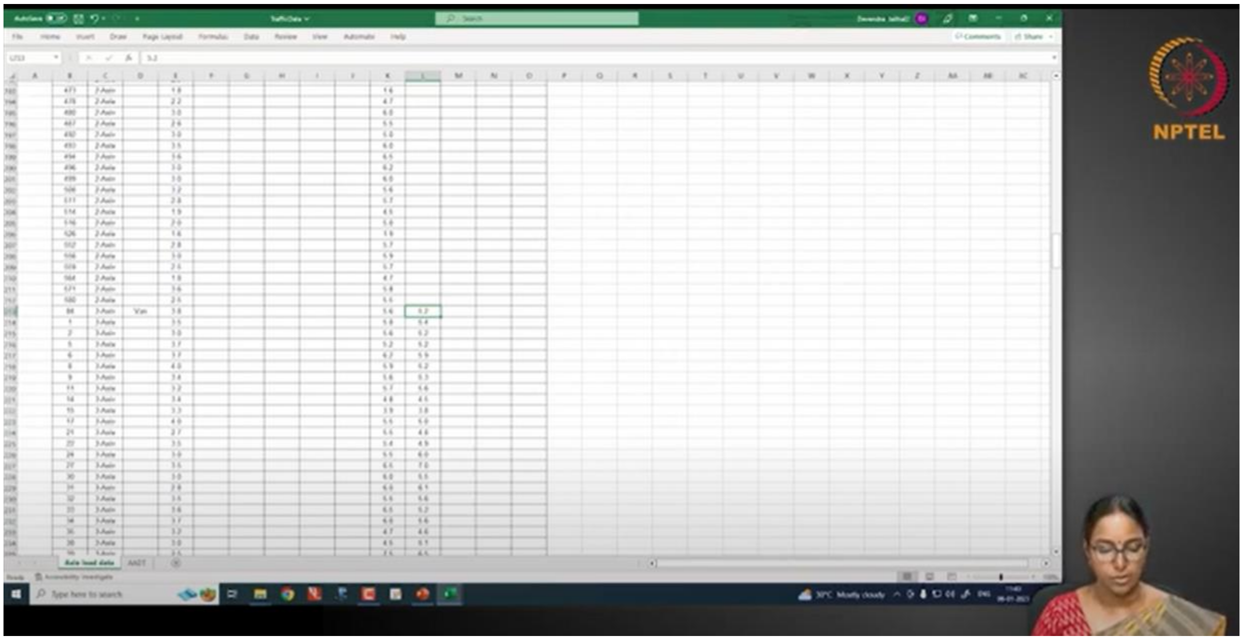

And when you go to three axles, there is a front axle and in the rear, you have a tandem axle. In the tandem axle, you note the load on the first wheel of the front axle and the second wheel of the front axle and so on. The data is collected like this.

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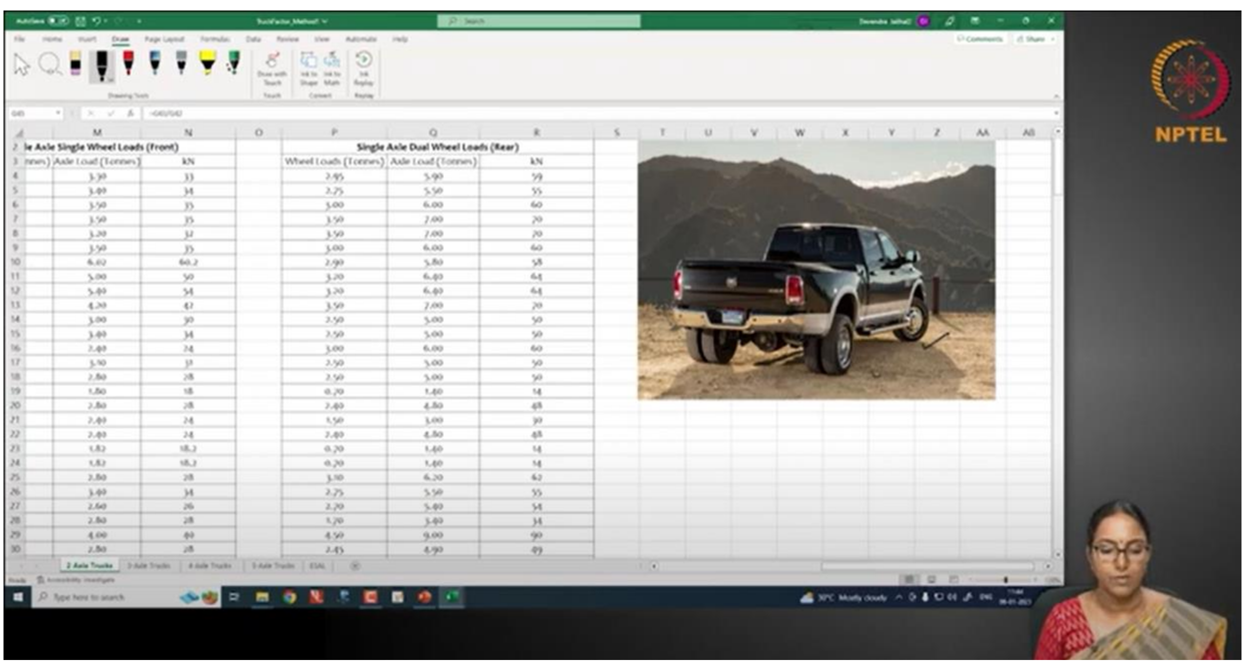

Once the data is collected, you can see that in this excel sheet I have marked it as different pages. One is the 2 axle truck, the other is named as 3 axle truck, 4 axle truck, then 5 axle truck and so on. So, if you see there is a 2 axle truck, this is an example of the 2 axle truck that you are considering. There is a front axle with a single axle single wheel and a rear axle with a single axle dual wheel. This class is categorized as a 2 axle truck in the study.

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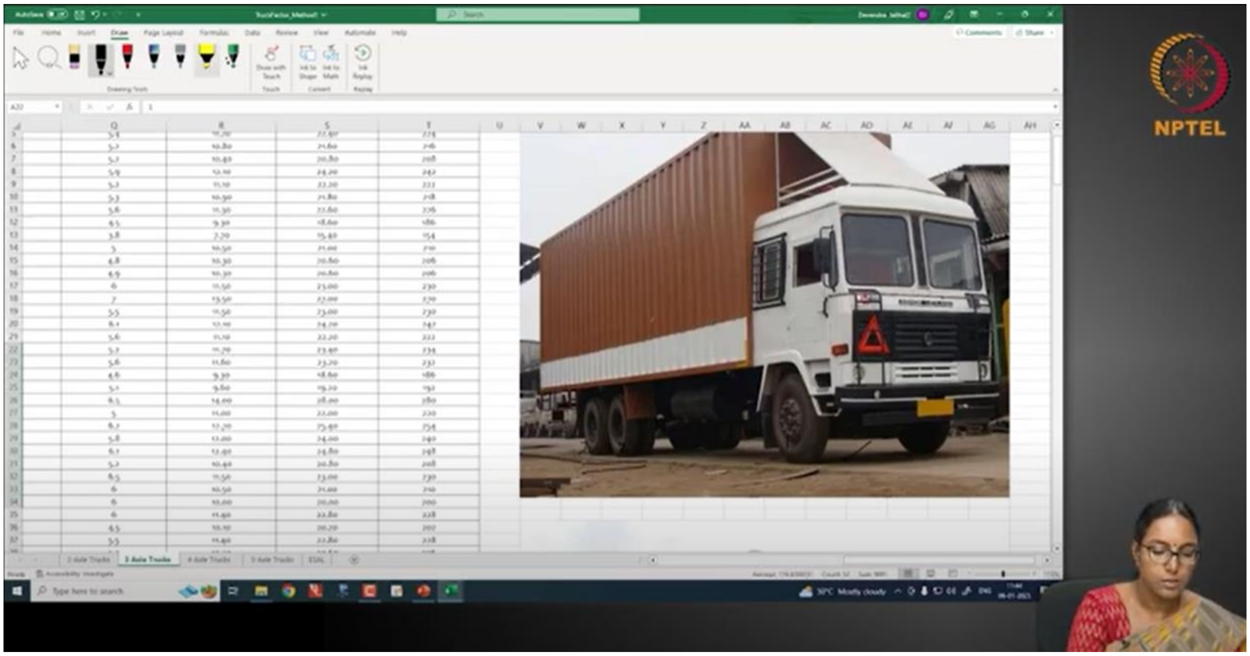

We will move on to the next one which is a 3 axle truck. As you see here in this picture, there is a front axle with single axle single wheel and at the rear there is a tandem axle. But for convenience it is written as 2 axles. Altogether, there are 3 axles. This is why this class is named as 3 axle truck.

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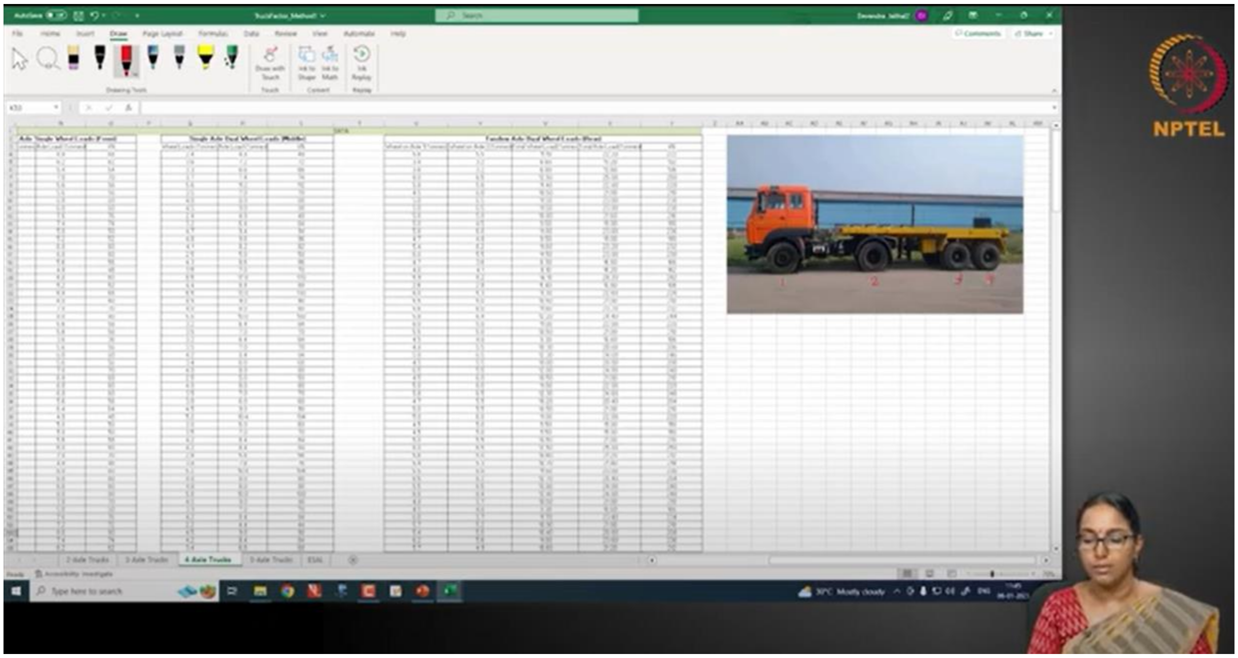

And then you have a 4 axle truck here, you see that at the front there is a single axle single wheel assembly and then you have a single axle dual wheel assembly and then there is a tandem axle which is counted as 3 and 4. So, there are 2 axles. Altogether there are 4 axles. So, this class of vehicle is classified as a 4 axle truck.

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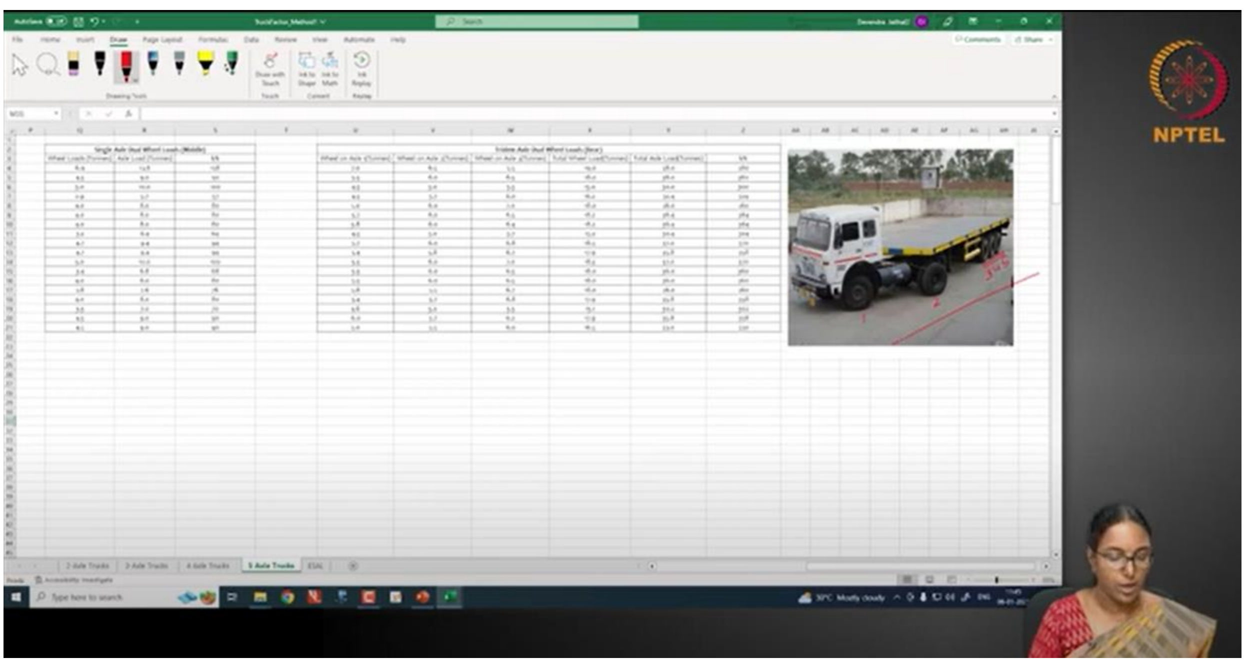

And then comes the 5 axle truck. You see here that there is a front axle which is single axle single wheel and there is a single axle dual wheel which is your axle number 2 and there is a tridem axle with dual wheels. So, altogether there are 5 axles. This class of truck is named as 5 axle for convenience. So accordingly, I have all these axle sheets here.

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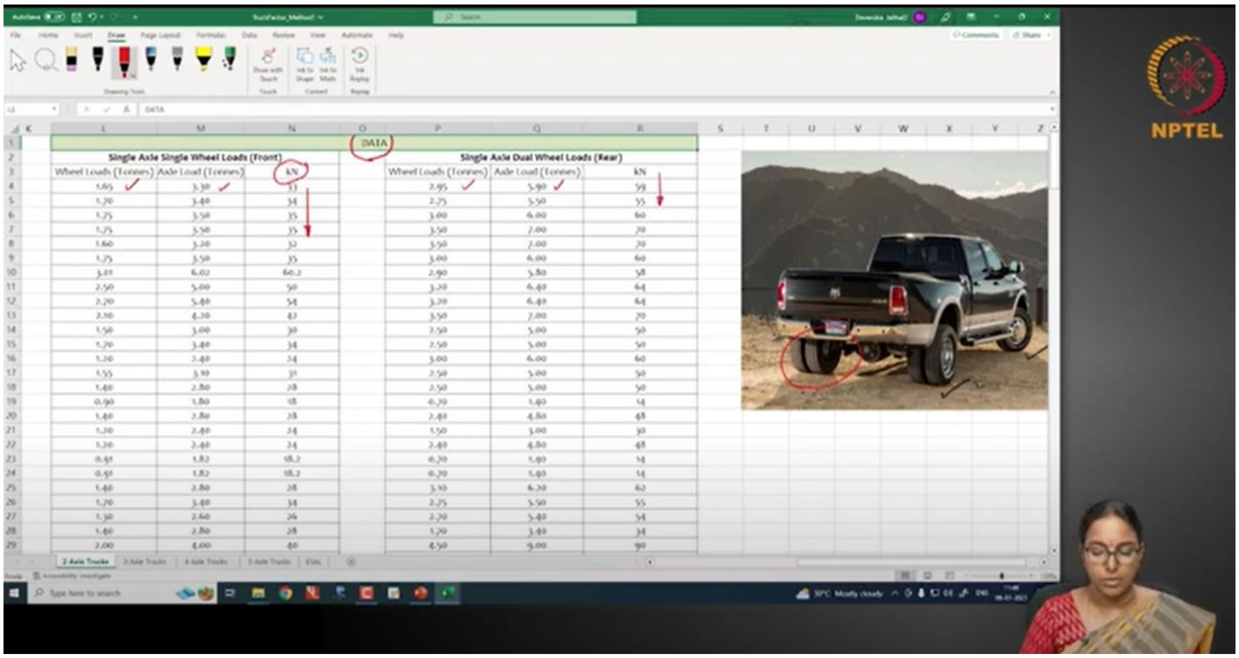

Let us see how the data is tabulated in this table. This is the original data as you see here. So, this is the data in which the single axle single wheels of all those loads are presented. So, this is a wheel load in tons as 1.65, 1.7 and so on for each of the vehicle and it is multiplied by 2 to get the axle load. So, in the single axle single loads, you have the load in tons, it is then converted into kN. This is the axle load data that you have collected for the front axle of this 2 axle truck. And similarly, on the rear axle, you have a single axle dual wheel. For all the trucks that you have surveyed, you see that the wheel has the wheel loads are 2.95, 2.75 and so on, which is multiplied by 2 to get the axle load, which is then converted to kN. So, you get the axle loads on the rear.

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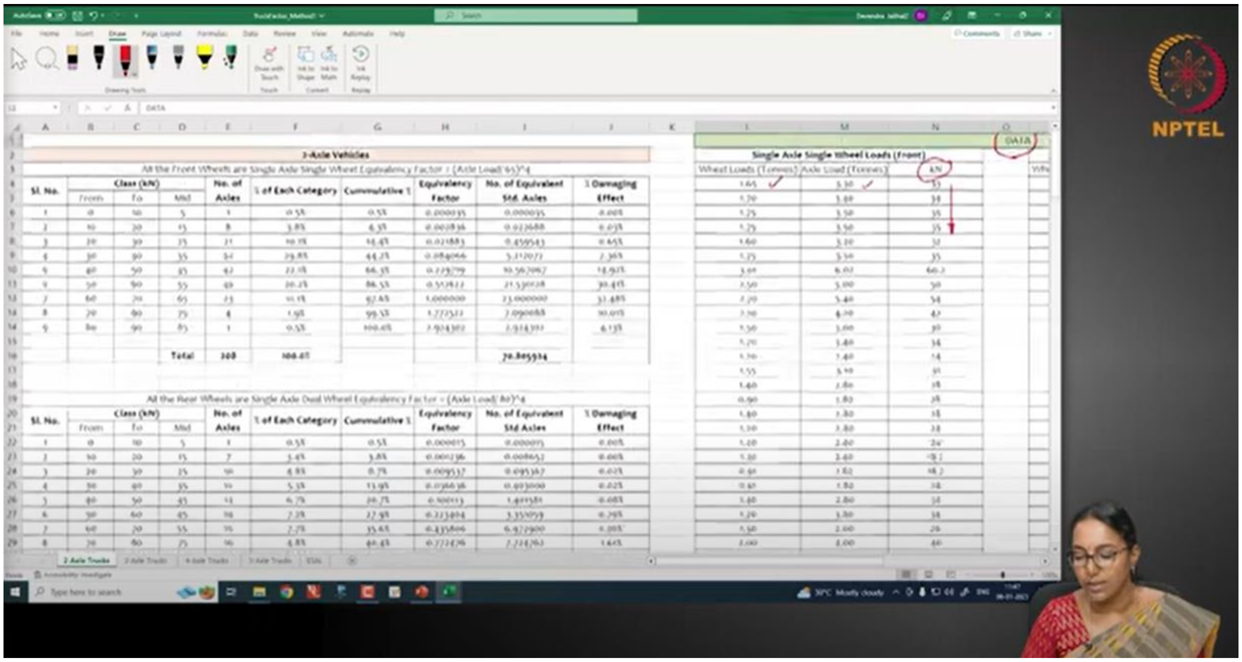

A total of 208 vehicles were surveyed and you have measured the front axle load and the rear axle load for all vehicles. Now, let us see how the equivalent standard axle loads are calculated. This is a 2 axle vehicle as you see here. Now, the front axle as I said is a single axle with single wheel on either side. The standard axle load is taken as 65 kN for single axle single wheel and the equivalency factor can be computed.

$$\text{Equivalency factor } = \left(\frac{\text{Axle load}}{65}\right)^4$$

This data has to be grouped into different axle groups. IRC suggests that for single axle dual wheels, you can have a bin size of 10 kN. As the single axle single wheel load is not mentioned in the code, we have taken a bin size of 10 kN. This is a class interval. From 0 to 90, you have divided into 9 class intervals based on what is the minimum and the maximum values that comes in this data. Now, this gives you the mid value of each bin. For 0 to 10, the mid value is 5 and for 10 to 20, the mid value is 15 kN and so on. Now, you find what the frequency of each one of these load groups is. From this data, you have counted how many fall in the 0 to 10 category, how many axle loads are in the 10 to 20 kN category and so on. This is the frequency table. This gives you the frequency distribution of the load.

You can say what is the percentage of each one of these loads in this category. You see that 29.8% of the load comes in the 30 to 40 kN category in this group. And also a cumulative percentage is calculated so that you can just see whether all the vehicles are included in the analysis. Just for the sake of convenience, we find the cumulative percentage or if you want to draw a cumulative frequency chart, you can use this information.

Next you have to get the equivalency factor by considering the mid value of each load group. So, for the first class from 0 to 10, 5 is the mid load group.

$$\text{Equivalency factor} = \left(\frac{\text{Mid load value}}{\text{Standard axle load}}\right)^4$$

$$\text{Equivalency factor for single axle single wheel} = \left(\frac{\text{Mid load value}}{65}\right)^4$$

For the next class 15 is the mid value. So, 15 divided by 65 raised to 4 will give you the equivalency factor. Likewise, for each load group you have determined the equivalency factors. Now you have to convert the number of axles in each of these groups to the equivalent standard axle by multiplying the number of axles in that group with the equivalency factor. So, as you see here in the first category 0 to 10 kN, you had only one axle. So, that one axle multiplied by 0.000035 was the equivalency factor, you got the total number of equivalent standard axles. Likewise, for each load group you have the equivalency factors and multiply with the frequency in that load group or the number of axles in that load group to get the equivalent standard axles. You add all of them together to get the equivalent standard axles that is formed from all the front axles of this 208 vehicles that you have surveyed. And the purpose of this is that the equivalent standard axle essentially tells you how damaging this axle was. So, it contributes to around 70.85 of which you can see that, 32% is due to the vehicles which come with a load range of 60 to 70 kN. You have found out the equivalent standard axles due to the front axle for all the vehicles.

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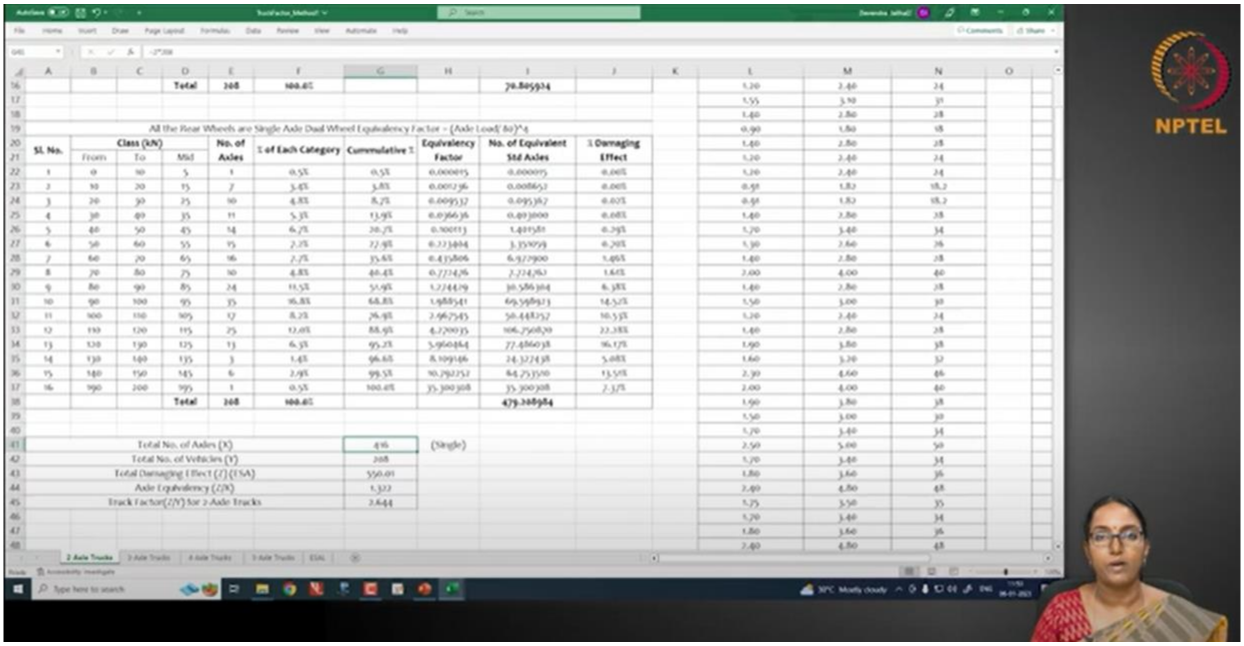

Now, moving on to the rear axle which is a single axle dual wheel for which the standard axle load is 80 kN. You can see that the load is grouped into 10 kN groups. You can see that the ranges are 0 to 10, 10 to 20, 20 to 30 and so on. It is divided into class groups and the mid value is taken as the load for that particular class group. The number of axles or the frequency is estimated from the data as I have already shown here. Then you see the percentage of each category and its cumulative percentage of all also is marked here.

Let us consider the 50 to 60 load range for which 55 is the mid value. The equivalency factor will be 55 by 80 raise to 4. The equivalency factor multiplied with the number of axles in that group which is 15 will give you the total equivalent standard axles of that load group. Likewise, you find out the equivalent standard axles of all the rear axle of all the 208 vehicles that you have surveyed. You get a sum which is 479. So, the damaging effect that is caused by the rear axles is 479. Now, you have counted 416 axles because there were 208 front axles and 208 rear axles or the total number of vehicles is 208. The total damaging effect is due to the front axle plus that due to the rear axle, which comes to around 550. Now, you can find the truck factor for this two axle truck is given by the total damaging effect.

$$\text{Truck factor} = \frac{\text{Total damaging effect}}{\text{Total number of vehicles}}$$

$$\text{Axle equivalencey factor} = \frac{\text{Total damaging effect}}{\text{Total number of axles}}$$

Truck factor is 550 divided by the number of trucks that you have considered (208). Suppose, you want to find the axle equivalency factor, you can divide this total damaging effect divided by the number of axles. So, this 1.322 is essentially like of an axle equivalency factor. But what you need is a truck factor, which is the total equivalent single axle loads from the front and the rear put together and divided by the number of vehicles that are counted. The truck factor is 2.644 for two axle trucks.

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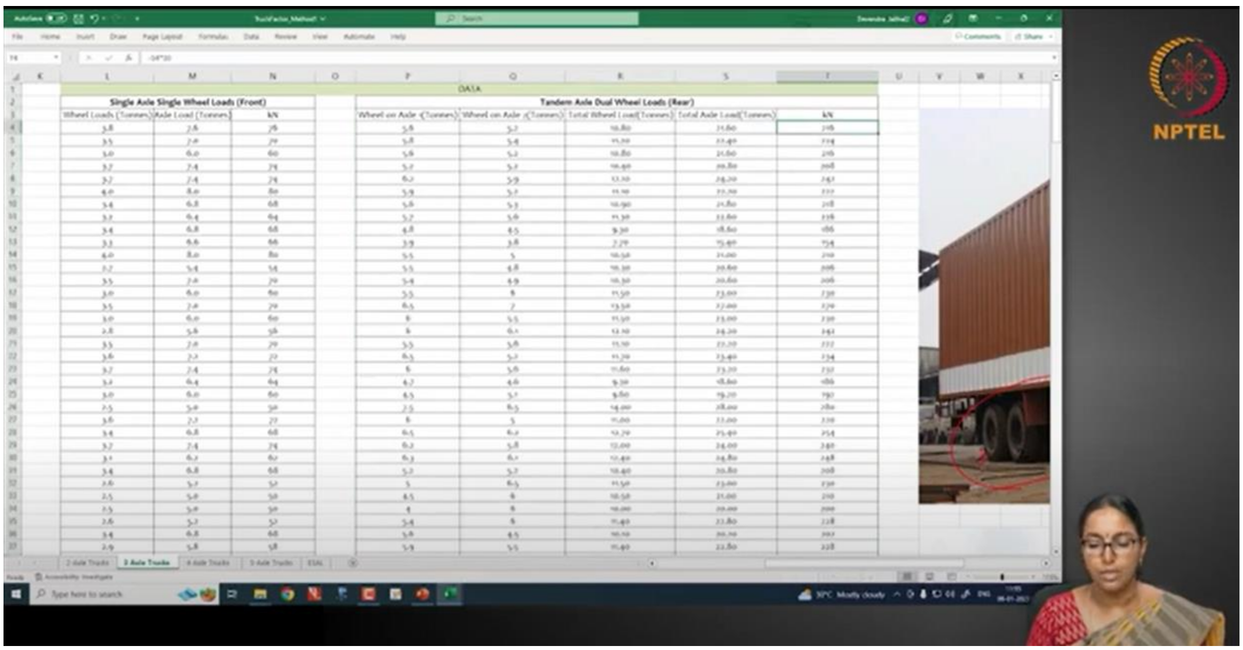

Now, let us move on to the three axle truck. As you see here in the three axle truck, there is a front single axle single wheel and the rear which is a tandem axle. In the case of the tandem axle, the weight on the first axle, the one wheel of the first axle and the weight on one wheel on the second axle is noted. The weight on one wheel multiplied with two will give you the weight on that particular axle. So, you got the axle load on one axle of the tandem wheel and the other axle of the tandem wheel and it is summed together to get the total tandem axle load. So, this is how you collect the data from the field and you sum it up together to get the axle load. So, you can see that 216 kN is the axle load of the first vehicle, 224 is the tandem axle load of the second vehicle and so on.

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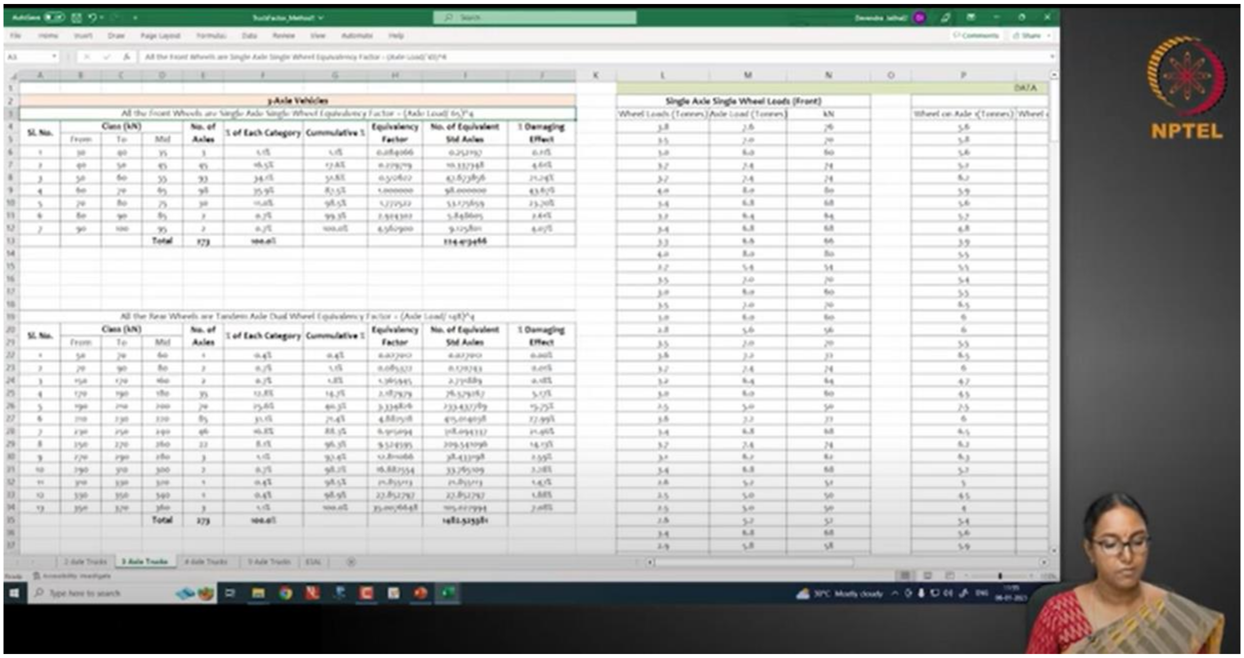

So, again, the truck has two classes of axles. The first is the front axle which is a single axle single wheel with the standard load of 65 kN so that the equivalency factor can be calculated. In the rear you have the tandem axle where the standard load is 148. As per IRC, for the tandem axle, you can get the equivalency factor as axle load divided by 148 raise to 4. The frequency is put into the load groups. We have started from 30 to 100 kN and in between there could be some load ranges where there are no vehicles, so which is omitted from this table. The mid values are written here and then the number of axles or the frequency is noted. Equivalency factor for each of those mid values of load is noted and then multiplied with the frequency will give you the total number of standard axles. So, the front axles will give you a total damaging effect of 224.

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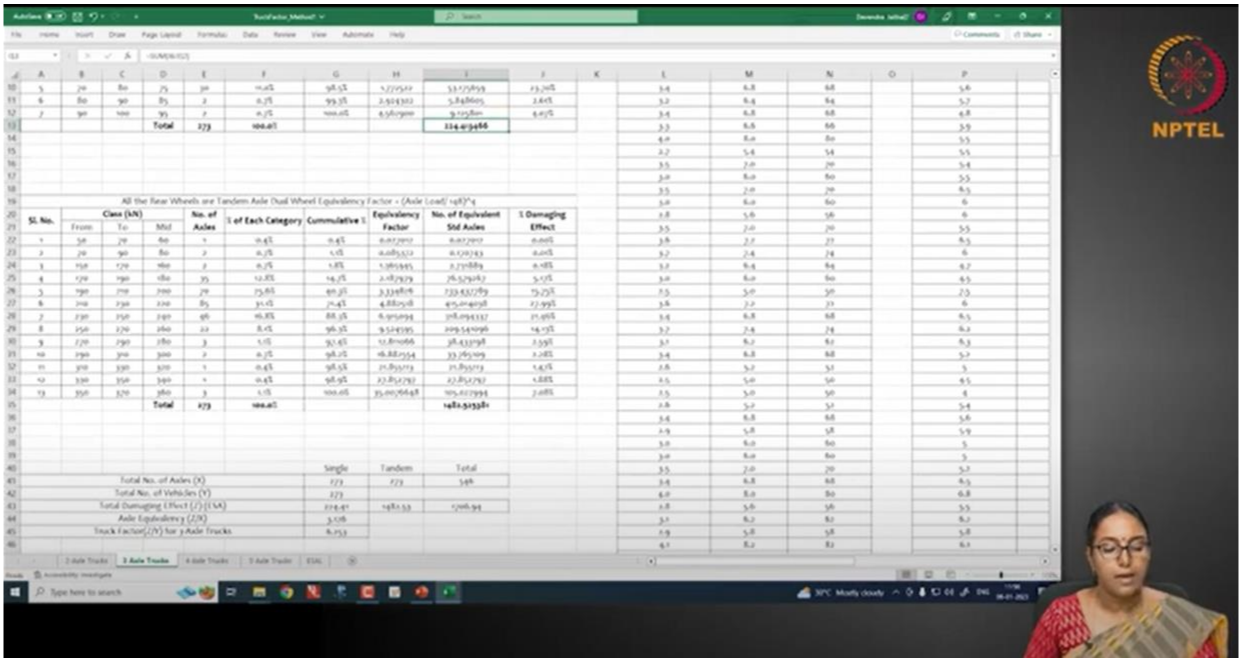

Likewise for the tandem axle, you see that the load range is taken in the range of 20 kN since it is a tandem axle you can take a larger range. And then the mid value, the frequency, the percentage of frequency in each category and the cumulative frequency is also noted here. Then the equivalency factors are computed using the equation and each equivalency factor multiplied with the corresponding frequency will give you the total equivalent standard axles which is summed together which comes out to 1482. You get the vehicle damage factor for this category by summing up the damaging effect due to the front single axle and the tandem axle. You get the truck factor by dividing the total damaging effect (1482+224) divided by the number of vehicles surveyed (273), which is 6.25.

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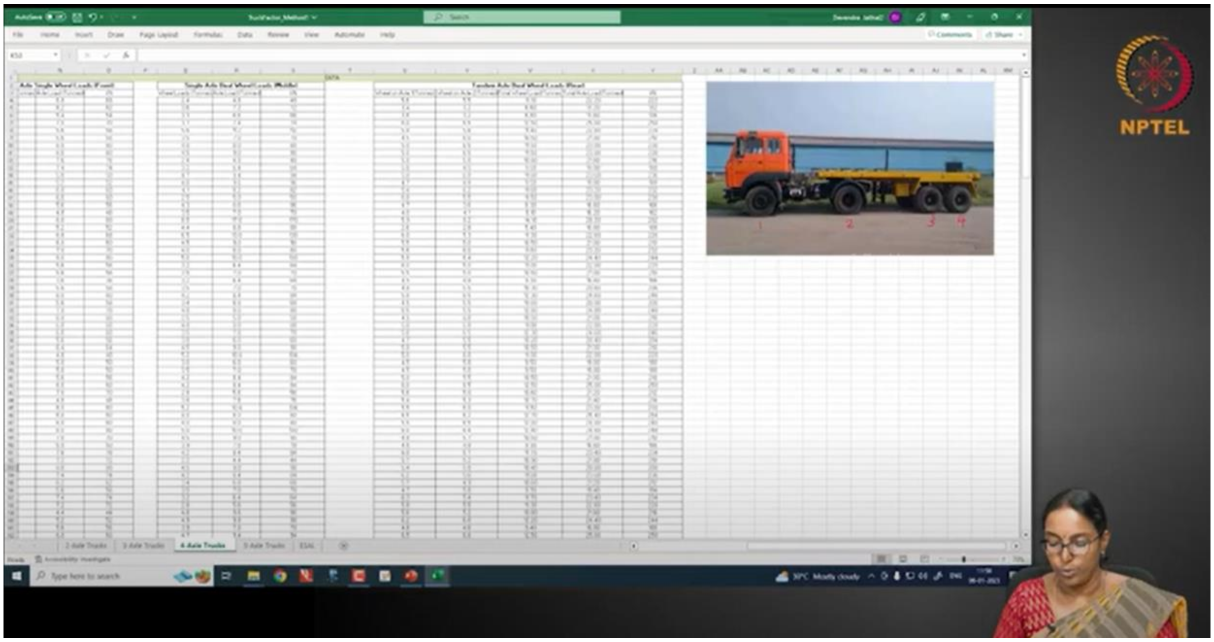

The next truck category is a 4 axle truck. First of all you have data for the single axle single wheel, and then you have data for the single axle dual wheel, then tandem axle. So, equivalency factor can be obtained for the first one using a standard axle load of 65 kN, the second one with a standard axle load of 80 kN and the third which is a tandem axle, with a standard load of 148 kN.

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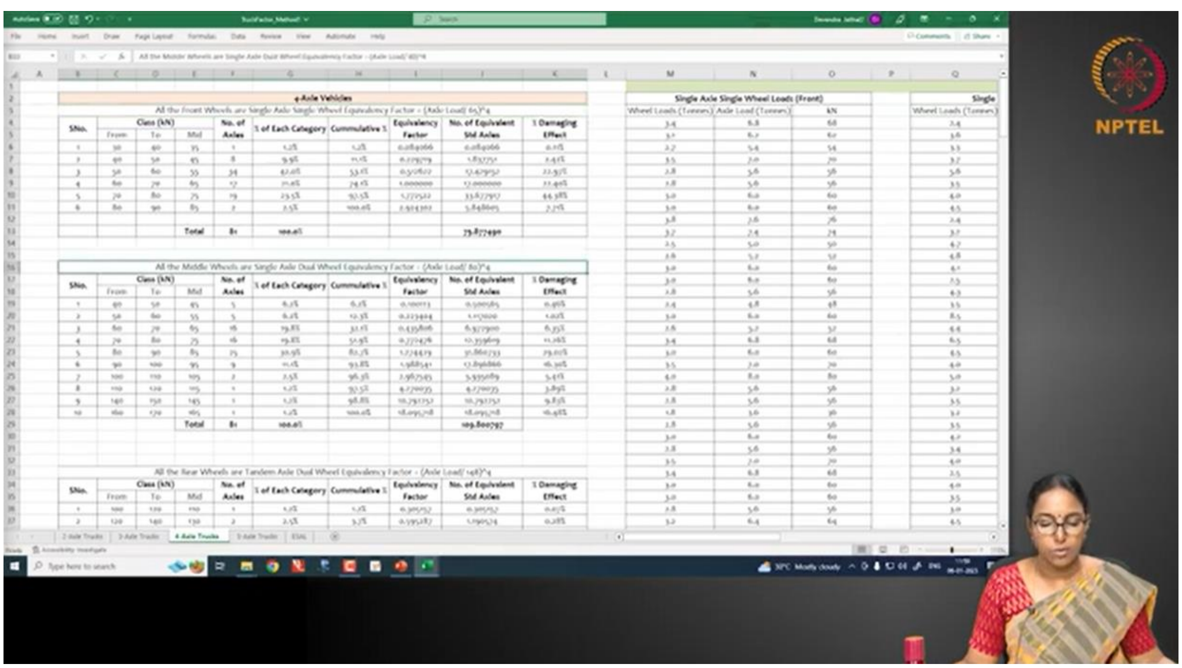

The data is divided into different axles, and then the damaging effects for each one of them are calculated as before.

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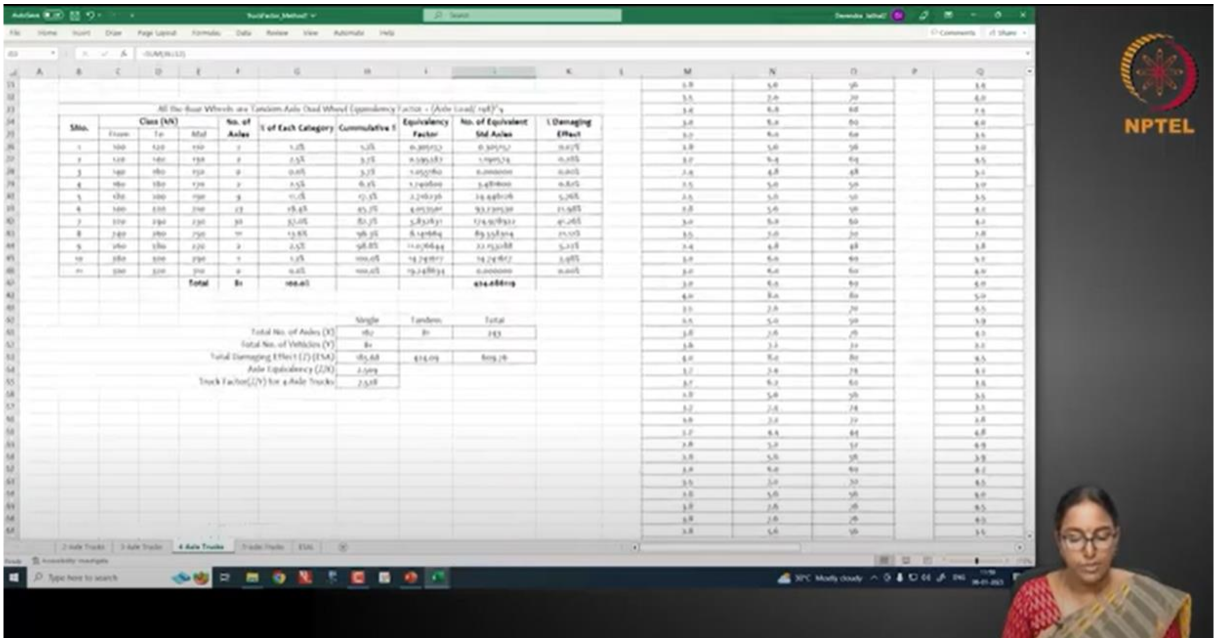

The total damaging effect is computed which comes to 609 and 81 vehicles were there in this category. So, 609 divided by 81 will give you the vehicle damage factor for this category as 7.5.

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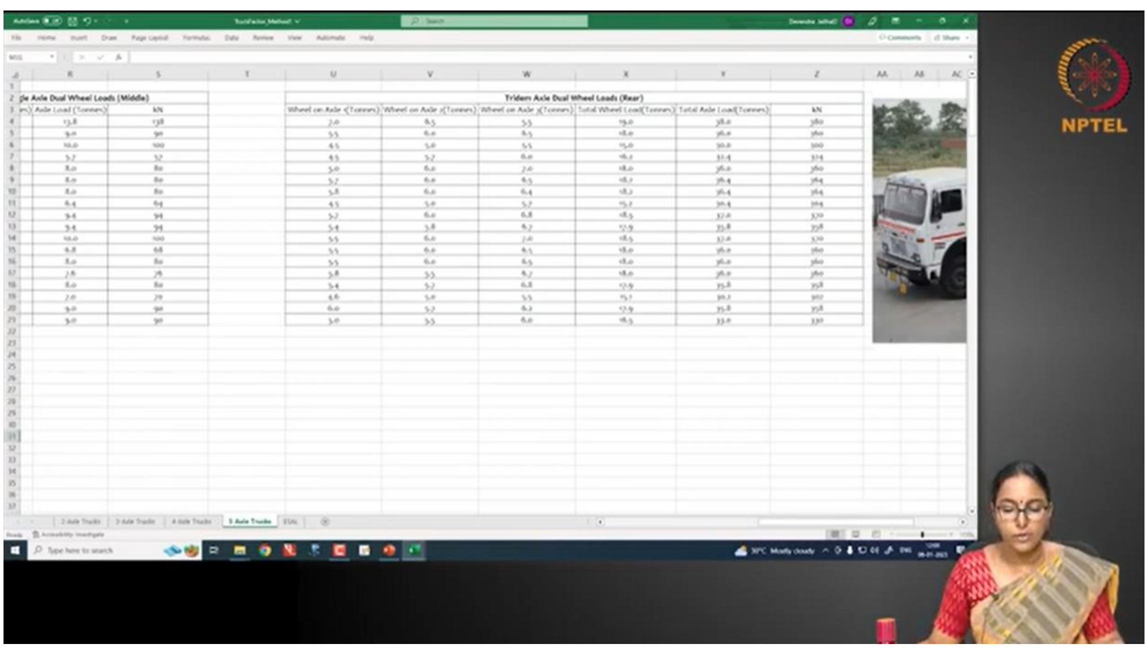

The next category is the 5 axle truck. 18 five axle trucks were there in this group. Let us see how the data was collected for the tridem axles. In the tridem axle you have 3 axles. The weight of one wheel is measured for each axle. So, this is wheel number 1, wheel number 2 on the second axle and wheel number 3 on the third axle. Now, each one of them will be multiplied with 2 to get the axle load on the first, second and third axle. Add them together to get the total tridem axle load which is 380 kN for the first vehicle and likewise for all the 18 axles.

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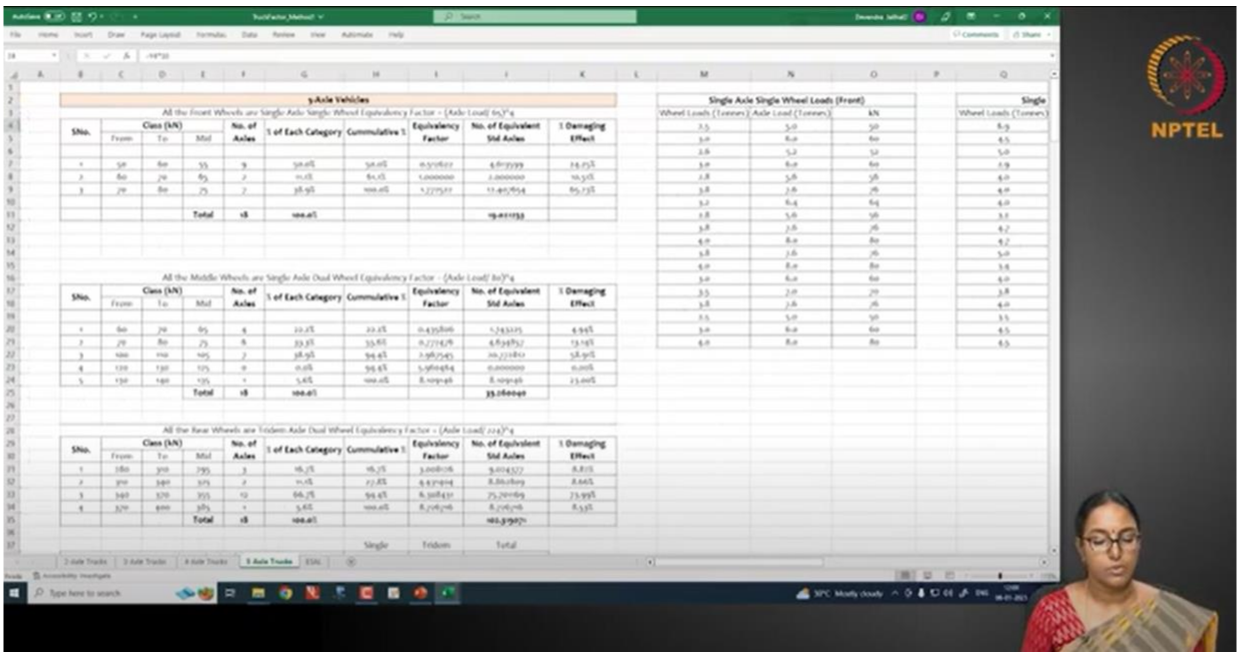

These five axles are divided into 3 axle groups. There are 18 front axle, which is single axle single wheel, then middle axles which are single axle dual wheel and that the last one which is a tridem axle, wherein the equivalency factor is computed as axle load divided by 224 raise to 4 because for tridem axle the standard load is taken as 224.

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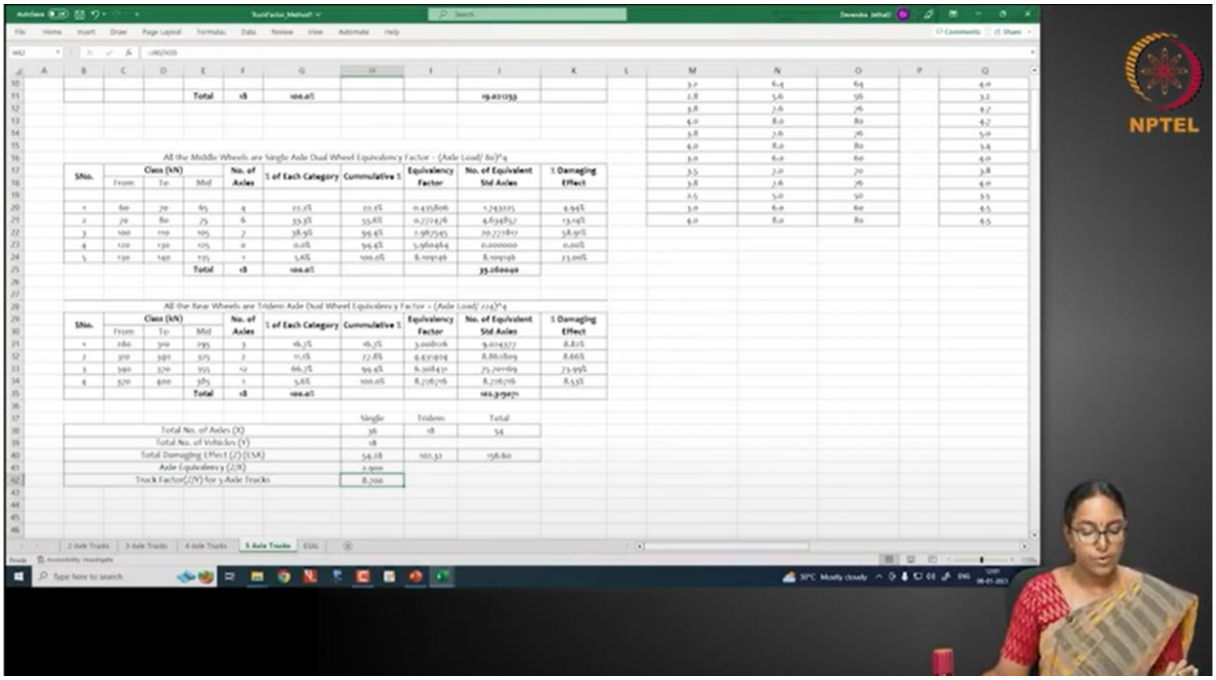

Likewise, all the damaging effects are summed together and divided by the number of vehicles to get a truck factor of 8.70. So, for all the 4 truck categories we have determined the truck factor separately.

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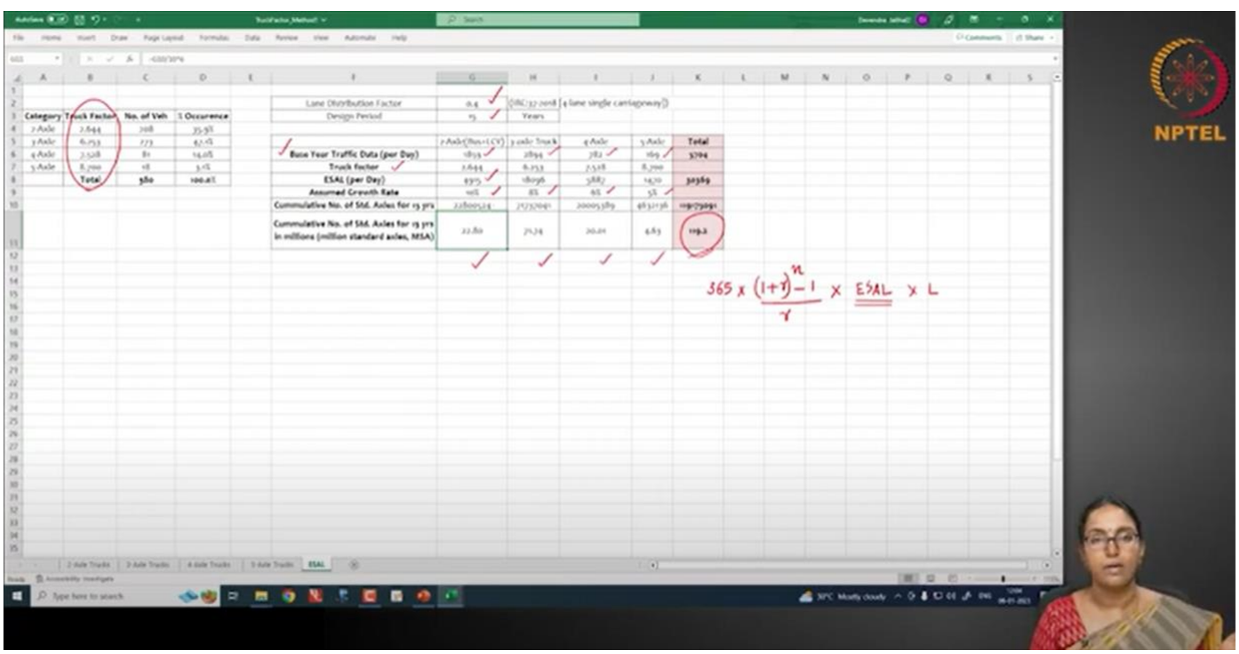

Now, let us see how the equivalent standard axle load is computed. Let us assume that you know this is a 4 lane single carriageway, for which you can take a lane distribution factor of 0.4. Let us say you have assumed a design period of 15 years. Now, the base year traffic data, the annual average daily traffic is computed for all the 4 classes of vehicles. Let us say, the base year traffic for the 2 axle vehicle is 1859 per day and the 3 axle trucks are 2894, the 4 axle vehicles are 782 and 169 is the base year traffic data of the last category of vehicles. Now, the truck factors that you have measured for all the 4 categories are here which is 2.6, 6.2, 7.5 and 8.7 respectively. By multiplying the base year traffic with the corresponding truck factor, you can find the equivalent standard axle for each of these categories per day. We can convert this per day traffic to ESAL by assuming a growth factor separately for different vehicles. Different growth rates are assumed here, say, first type of vehicle has a growth rate of 10%, the next has 8%, the next has 6% and last one has 5% growth factor. You can use the equation to compute the ESAL for a design period of 15 years.

$$\text{ESAL or } N_{des} = 365 \times \left[\frac{(1+r)^n - 1}{r}\right] \times A \times D \times L \times VDF$$

Now, divide it with 10^6, you can express it in terms of million standard axles. The result is 22.8 million standard axles of first category, 71 from the second category, 20 from the third and 4 from the fourth category of trucks. So, the total equivalent standard axle loads or the design traffic as you say is 190 ESALs. This is how we can use this template to input the data and calculate the truck factors for each of these categories and the advantage is that you can consider different growth rate for each of the categories and then the total ESALs for the design can be calculated.

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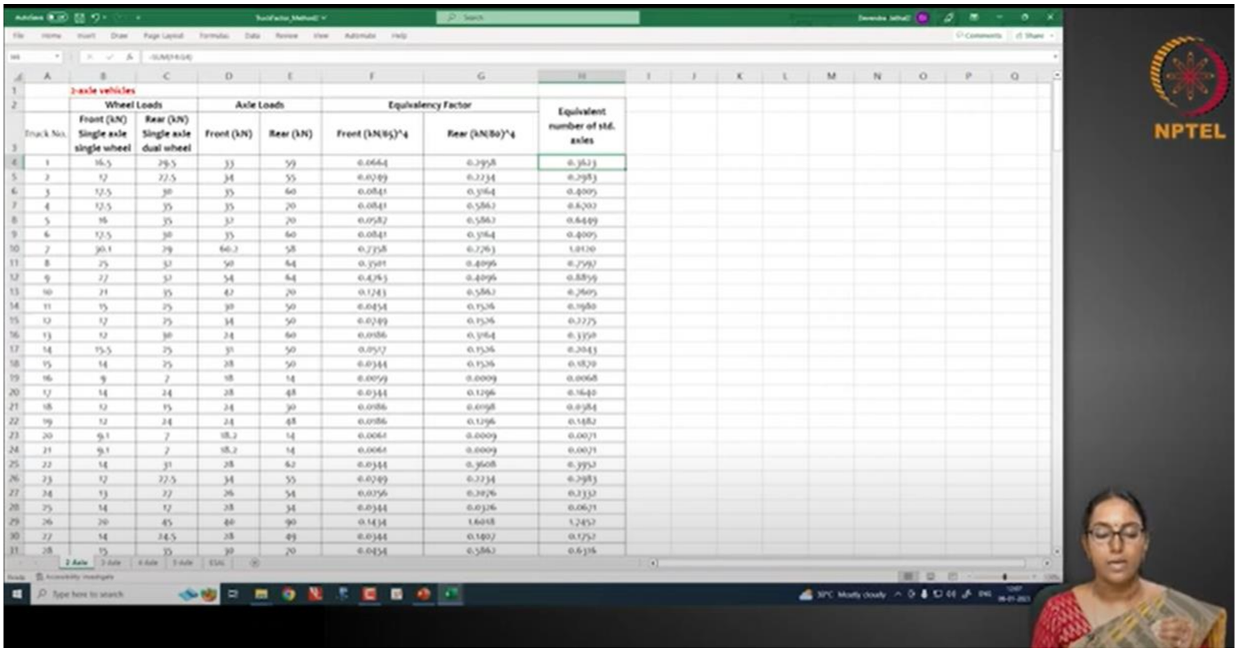

Now, let us see a slightly simplified or different approach wherein you can get this by truck factor method. What we have seen is that from the axle load data, you have grouped these axle loads into different load groups or different bins of 10 kN or 20 kN groups and the mid value of that is taken as the average load value for that particular group. Now this could be erroneous if the axle load data is not uniformly distributed in that bin or if it is skewed in one direction. What could be done is that, rather than dividing it into different axle, putting in different bins, you can just compute the equivalent standard axles for all the axles directly by taking the equivalency factor for each one of them.

Let us see how that is computed. We see here that you have the two axle vehicles. In the two axle vehicles, you have the front axle load as well as the rear axle load. So, I mean the first two columns or the second and third column here gives the wheel load. The wheel load multiplied with 2 will give you the axle load. Here, column D gives you the front axle load and column E here gives the rear axle load of that two axle truck that we have discussed. For the front axle which is a single axle single wheel load, its standard axle load is 65 kN and the equivalency factor is the load divided by 65 raise to 4. So, for each one of these trucks, the equivalency factor for the front axle as well as the equivalency factor for the rear axle is computed.

For the rear axle here, it is a single axle dual wheel. So, the equivalency factor is load divided by 80 raise to 4. There is no mid value that is considered, you are straight away taking the load of that axle and then finding its equivalency factor, then multiply the front axle with its equivalency factor and add it to the rear axle and its equivalency factor. This will give you the total equivalent number of standard axles of the truck number 1. Likewise, you can calculate for all the 218 trucks. So, in this method, you have calculated the equivalent single axle loads rather than grouping them into any bins.

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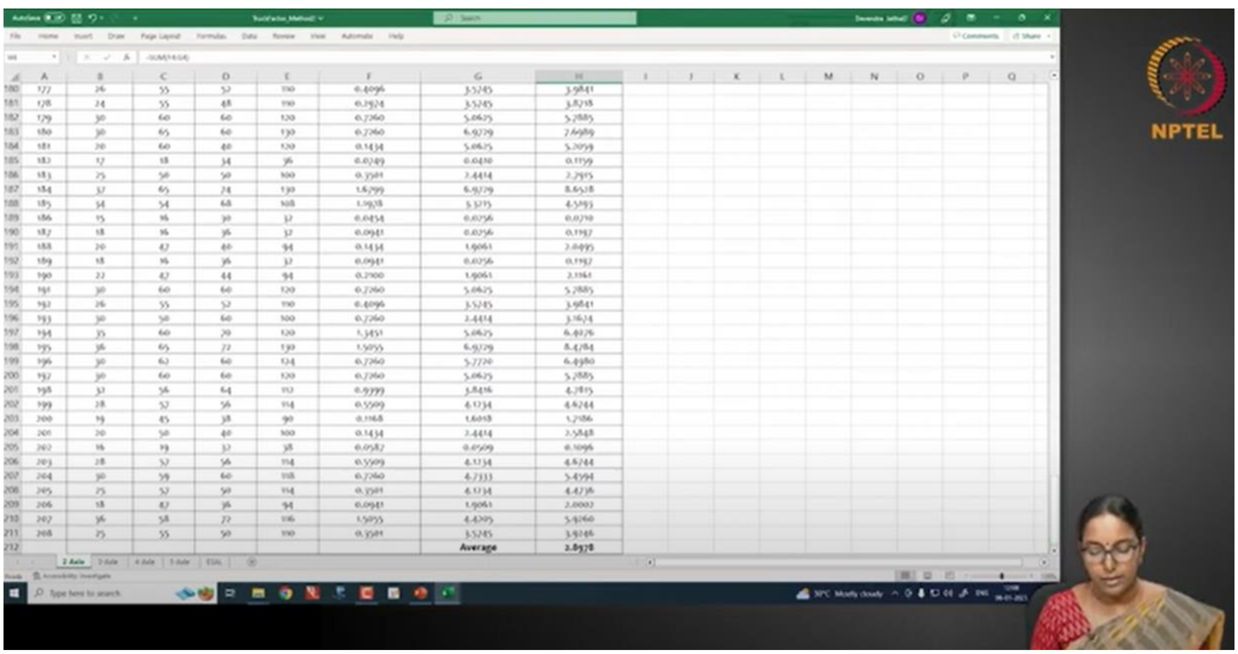

Then take the average of all this total number of equivalent standard axle loads to get the truck factor for that category. This has come out as 2.8978. So, this is for the first category of vehicle.

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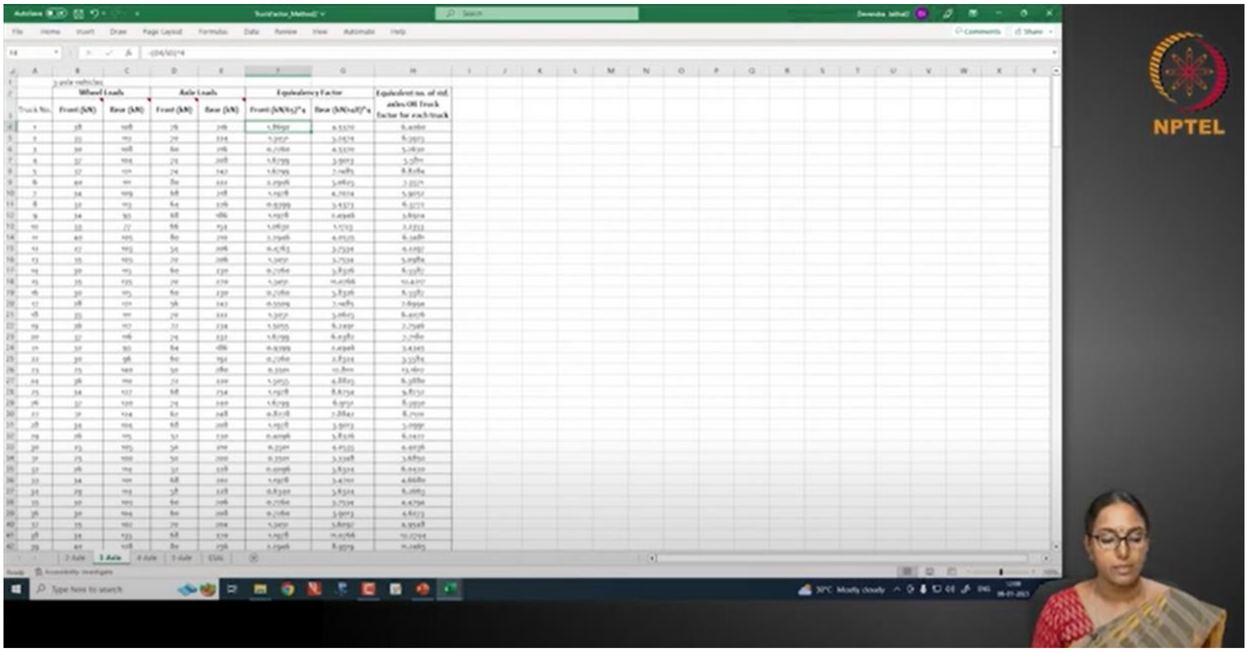

Now similarly for the second category of vehicles, you see that this is 3 axle truck. So, equivalency factor for the front axle and the rear axle (tandem axle) is calculated. The total equivalent standard axles or truck factor for each one of the trucks is calculated.

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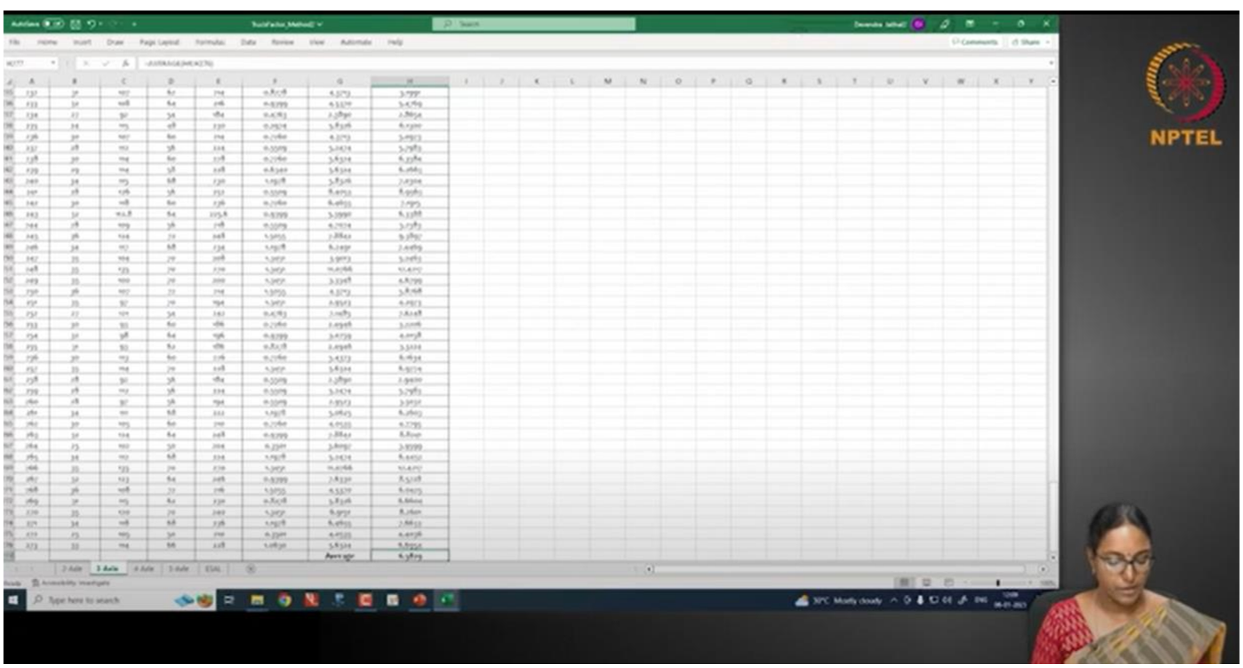

The average truck factor for this category is 6.58.

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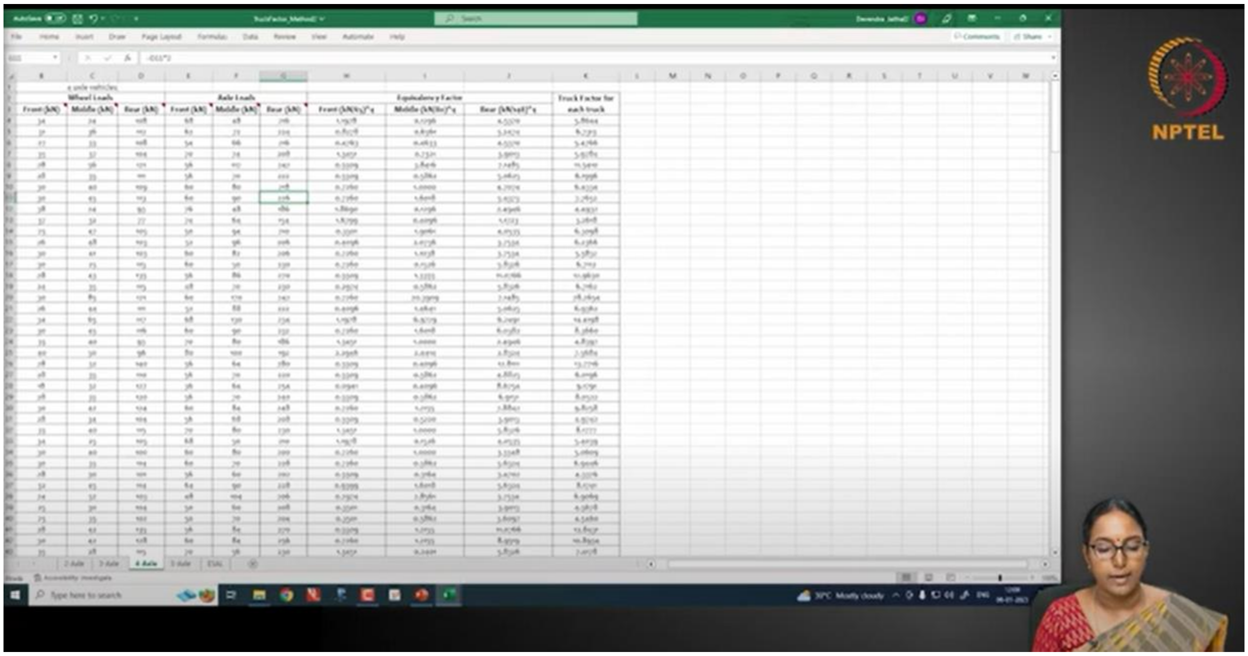

Now similarly for the 4 axle truck, the average truck factor comes out to be 8.31

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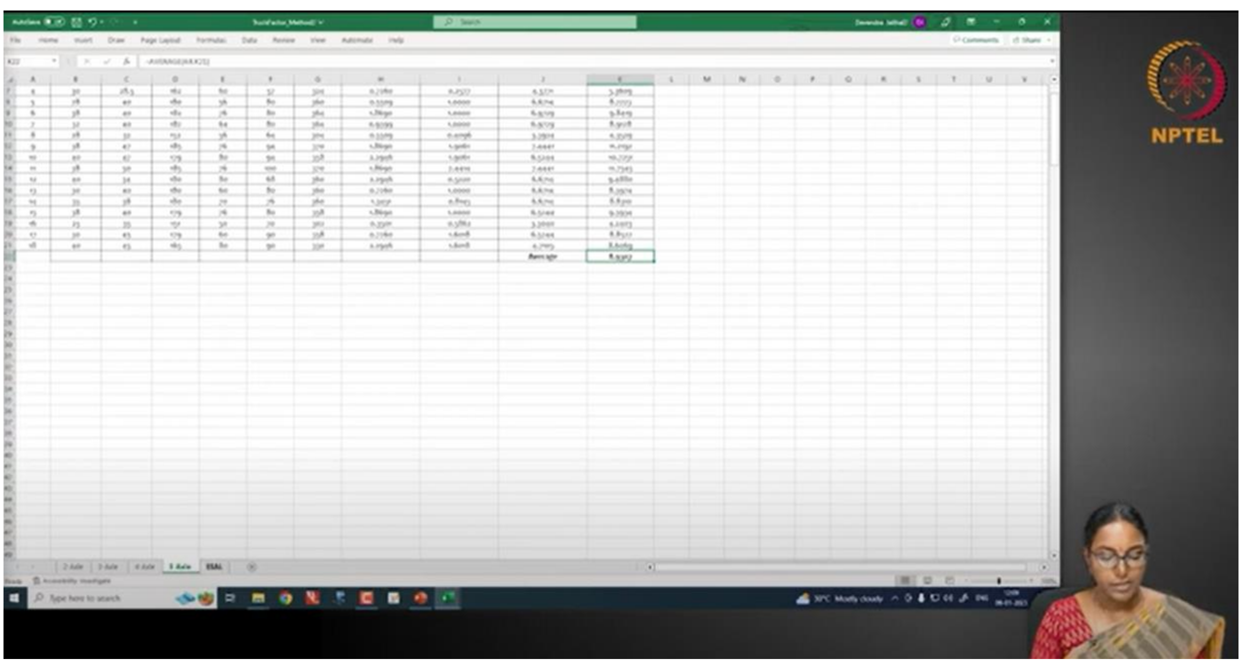

For the 5 axle it came out as 8.93.

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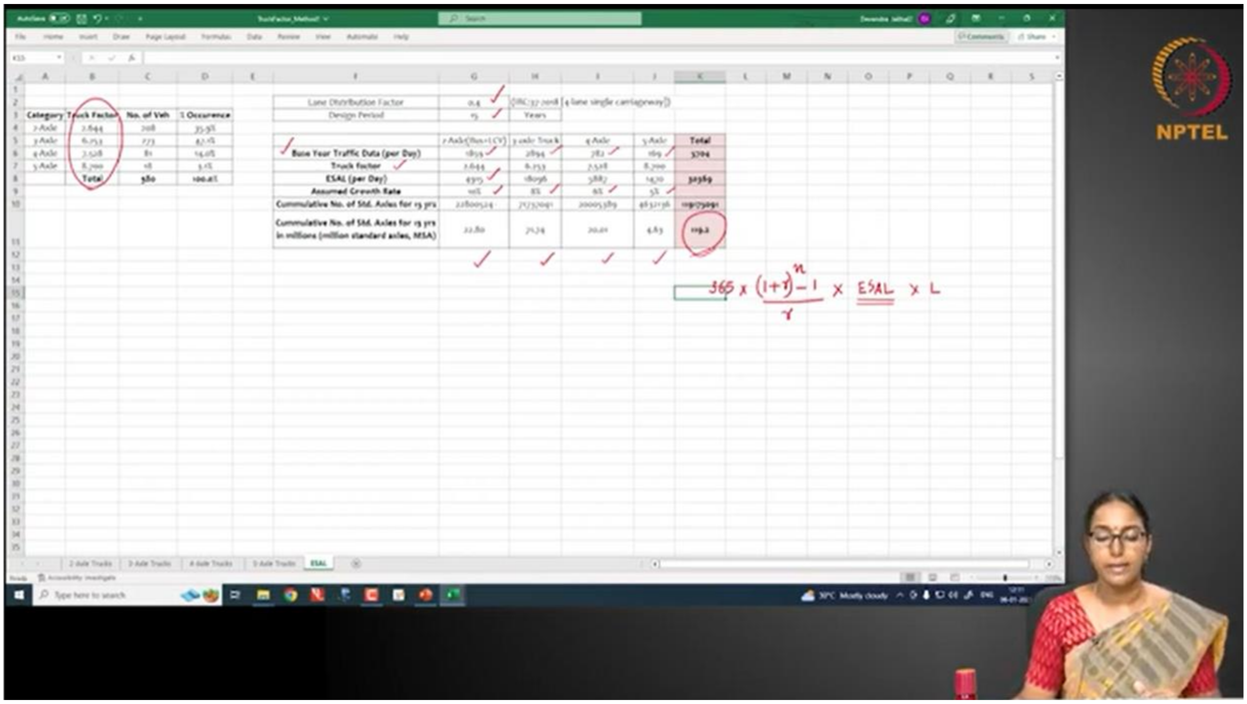

Then the rest of the computations are similar. You see that the base traffic data is given. You get the ESALs by multiplying the truck factor by the base traffic. Then by applying the growth rate and the direct lane distribution factors and growth factor for 15 years, you get the total equivalent standard axles, which are 127. What we have observed is that, if you apply the truck factor, you have got the design traffic as 127 million standard axles, but what we have observed from the method 1 wherein it is divided into different load groups is that the design traffic is 119 MSA only. There could be slight difference.

The problem associated with that is, if you put it in different bin groups, some of the traffic may get overestimated or some traffic may get underestimated. These are the two approaches by which you can calculate the truck factor for each truck category and arrive at the cumulative number of standard axles for the design. We will see how the vehicle damage factor is calculated from the axle load data and how the equivalent single axle loads or the design traffic is estimated.

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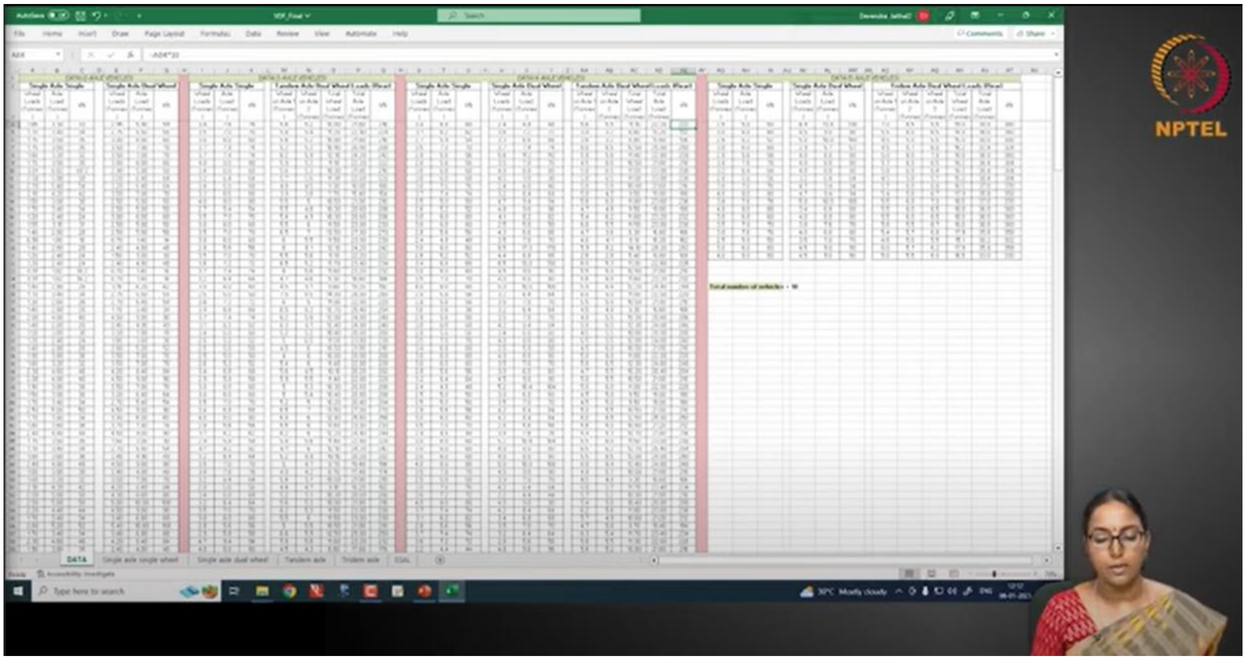

So, this is the same data that we have used for computing the truck factor and the ESALs based on the truck factor method.

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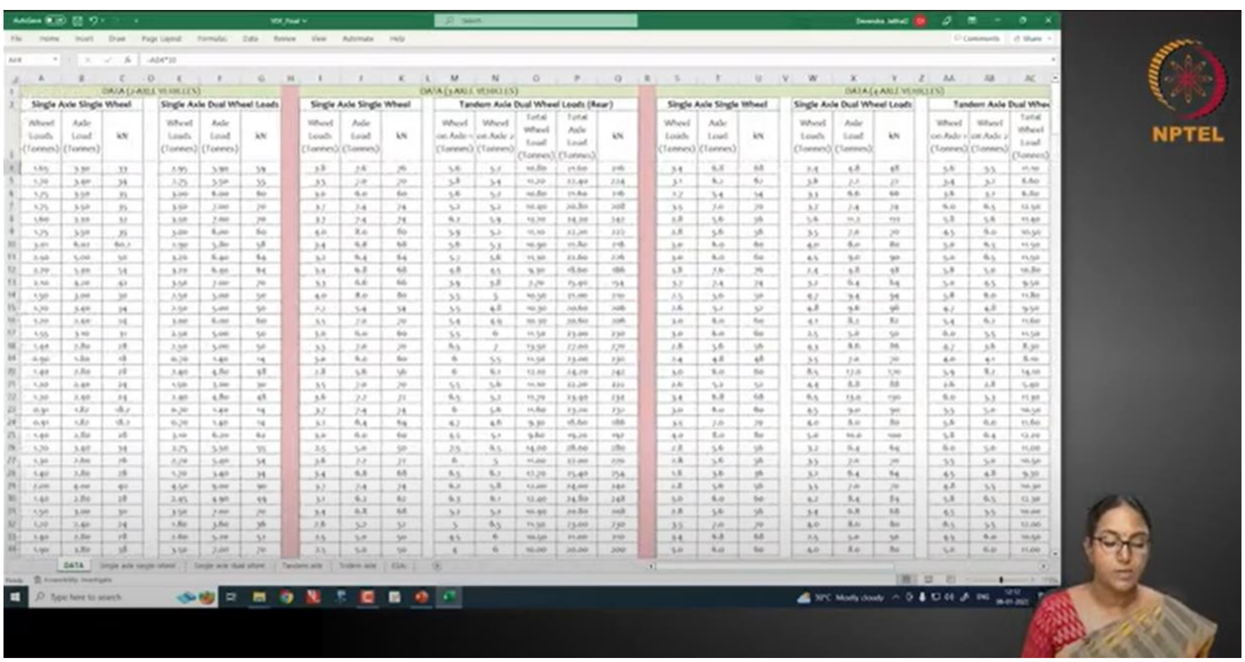

As we have already seen, there were like 4 classes of vehicles which were named as 2 axle vehicle, 3 axle vehicle, 4 axle vehicle and 5 axle vehicle for convenience. So, this is the data for 4 classes of vehicles. Compile all the single axle single wheel loads together. From all the 4 categories, single axle single wheel will be put together and you determine the equivalent standard axle loads from that category of axle.

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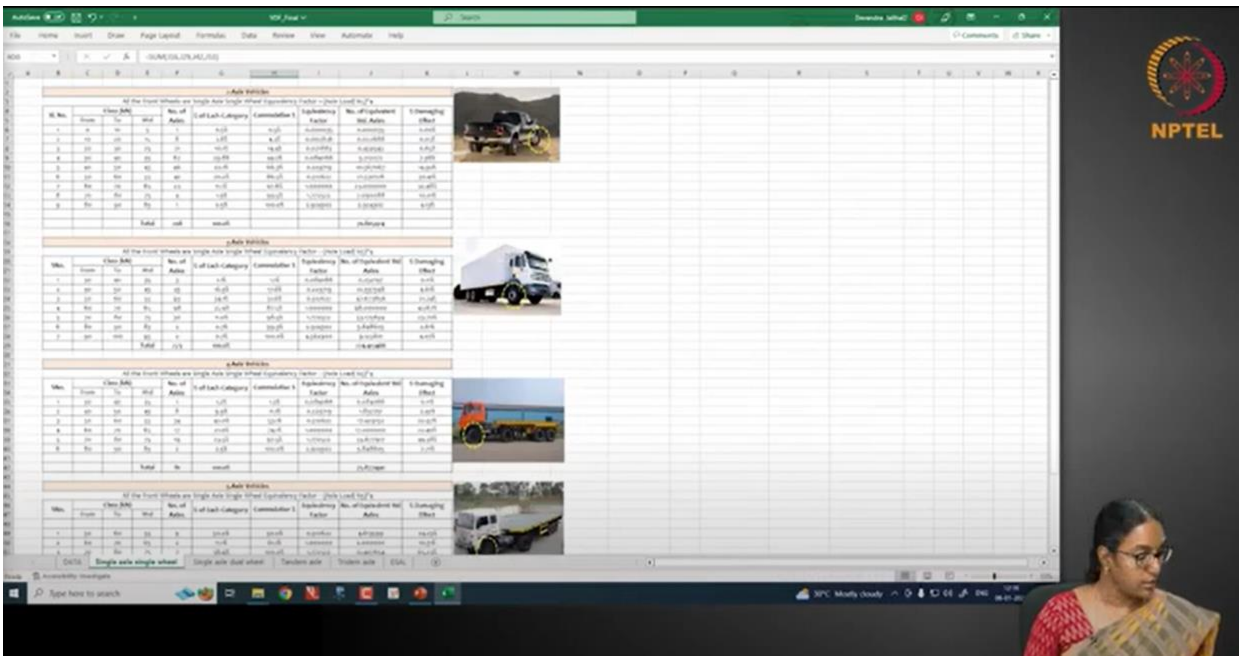

The second sheet here is for the single axle single wheel. For each category of trucks, the front axle data is given here. So, from all the 4 trucks, the identical axle categories are put together in 4 tables.

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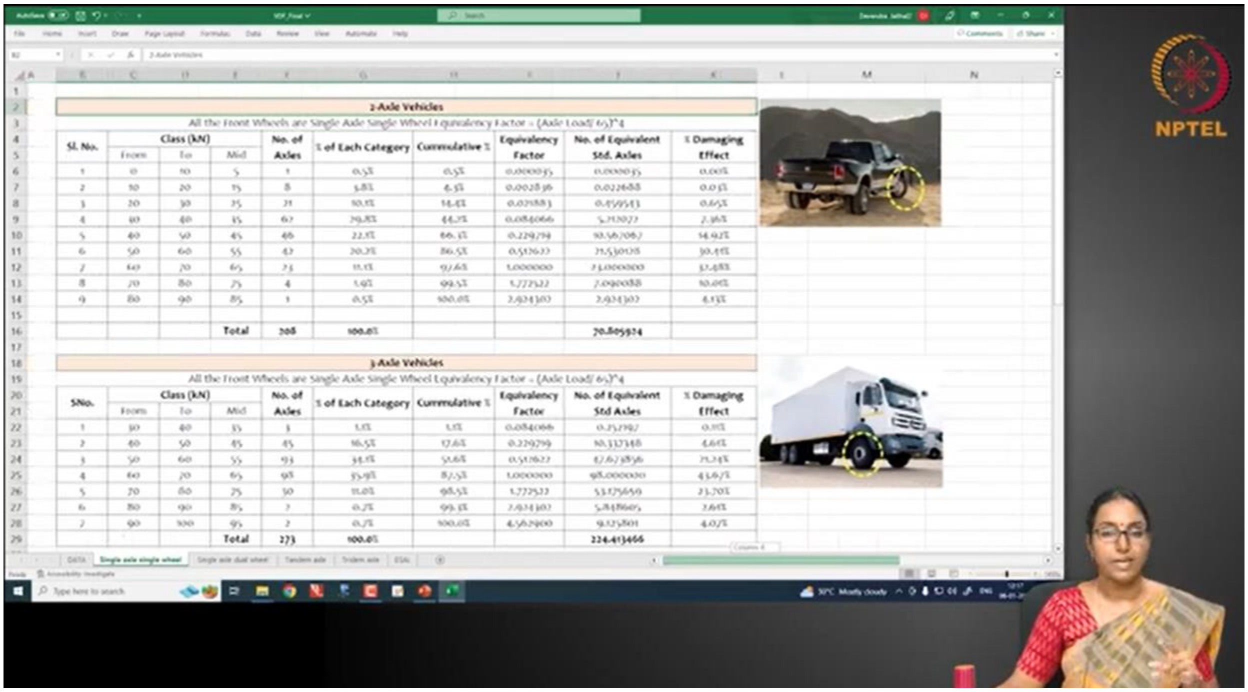

You can put the axles in different class categories, the frequency can be measured. And then we can calculate the equivalency factor for this particular class of truck using the standard load. So, multiply the number of axles with the equivalency factor to get the total equivalent standard axles. So, from the first class of vehicle, you got 70, the second class of vehicles is 224, third class of vehicles is 75 and the fourth class of vehicles it is 19.

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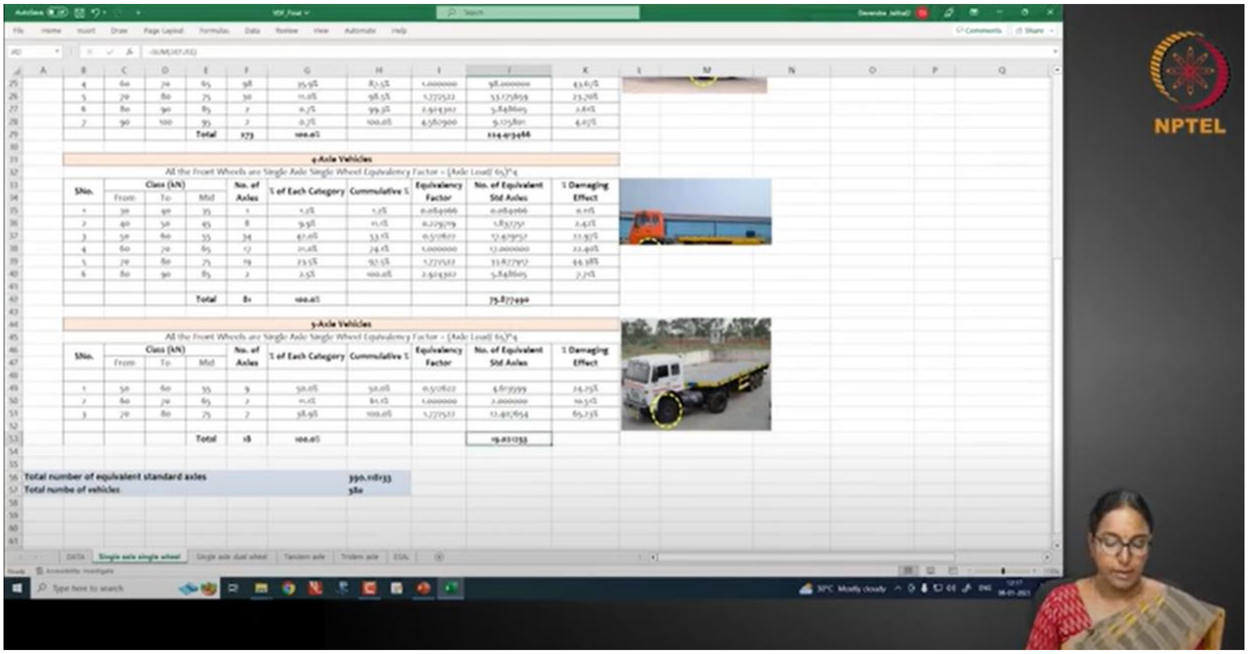

If you sum it up together, you will get the total number of equivalent standard axles from these front axles alone and the total number of vehicles that you have counted is 550 altogether.

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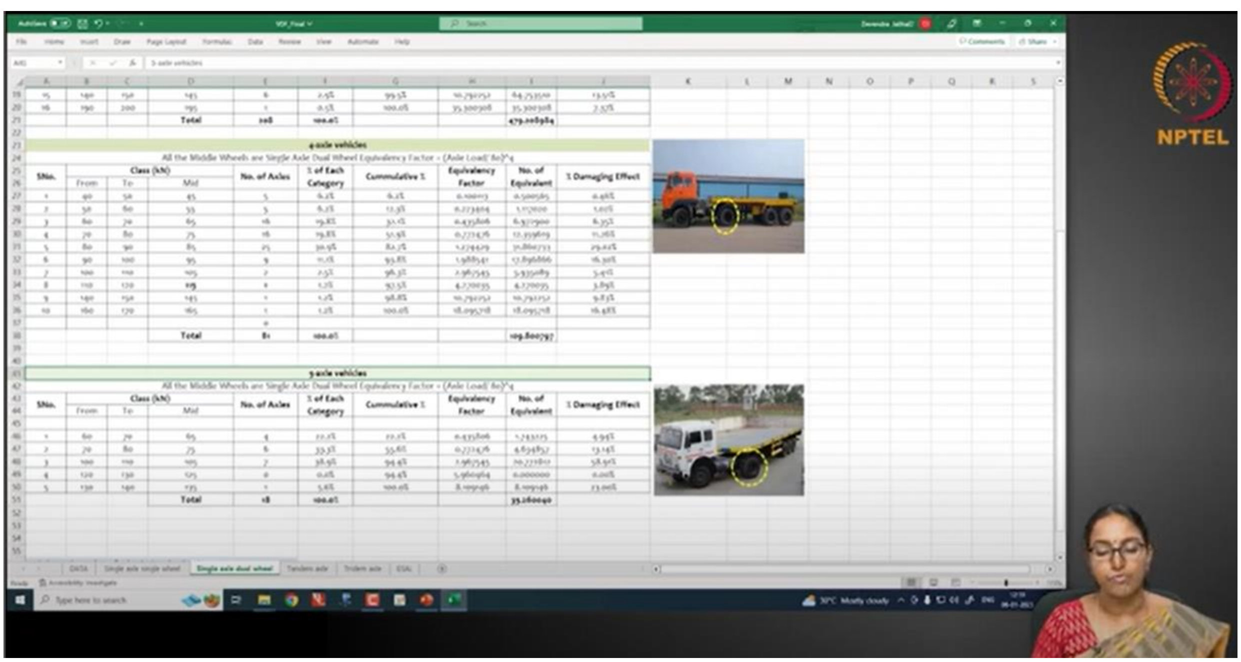

Now, moving on to the second data computation, the next category of axle is your single axle dual wheels. In the 3 axle vehicle, there are no single axle dual wheels. Now, coming to the 4 axle vehicles, there was a single axle dual wheel and on the 5 axle vehicle also there was a single axle dual wheel. So, all this single axle dual wheel data are clubbed together.

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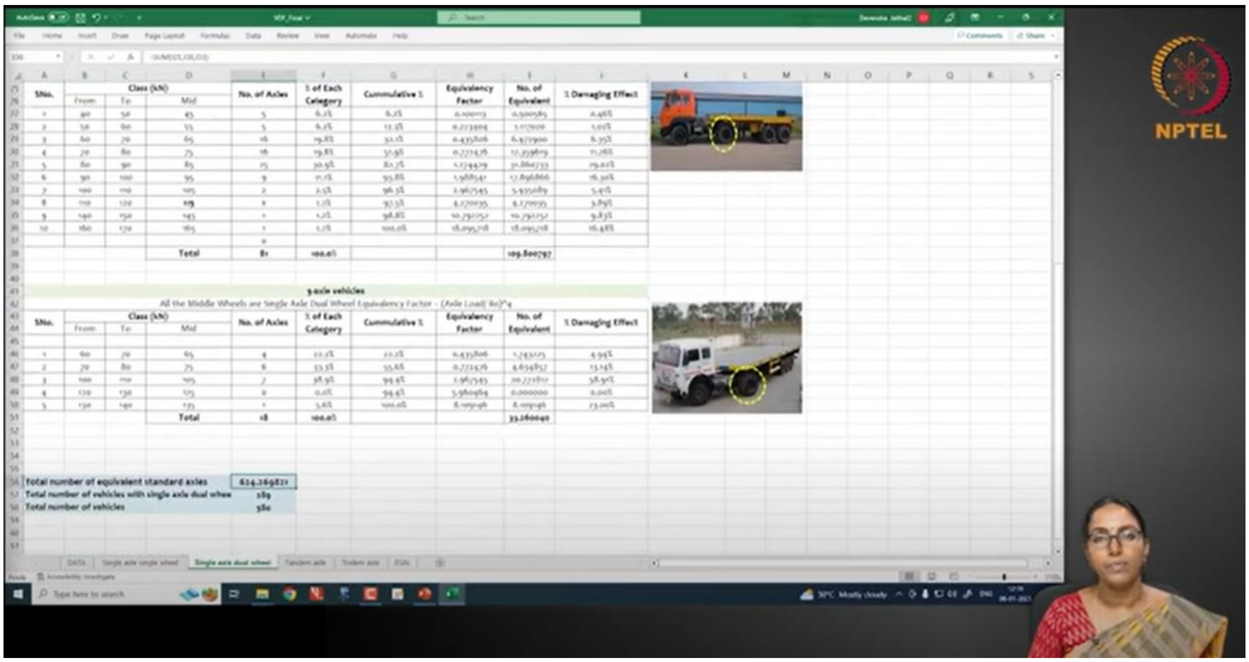

You see that this is from the first type of vehicle, this is from the second type of vehicle and this is from the third type of vehicle, all common type of axles with a standard axle load of 80 kN. Now, using the same approach, you find the equivalent axle loads, you sum up together. So you get the total equivalent single axle loads due to this axle type.

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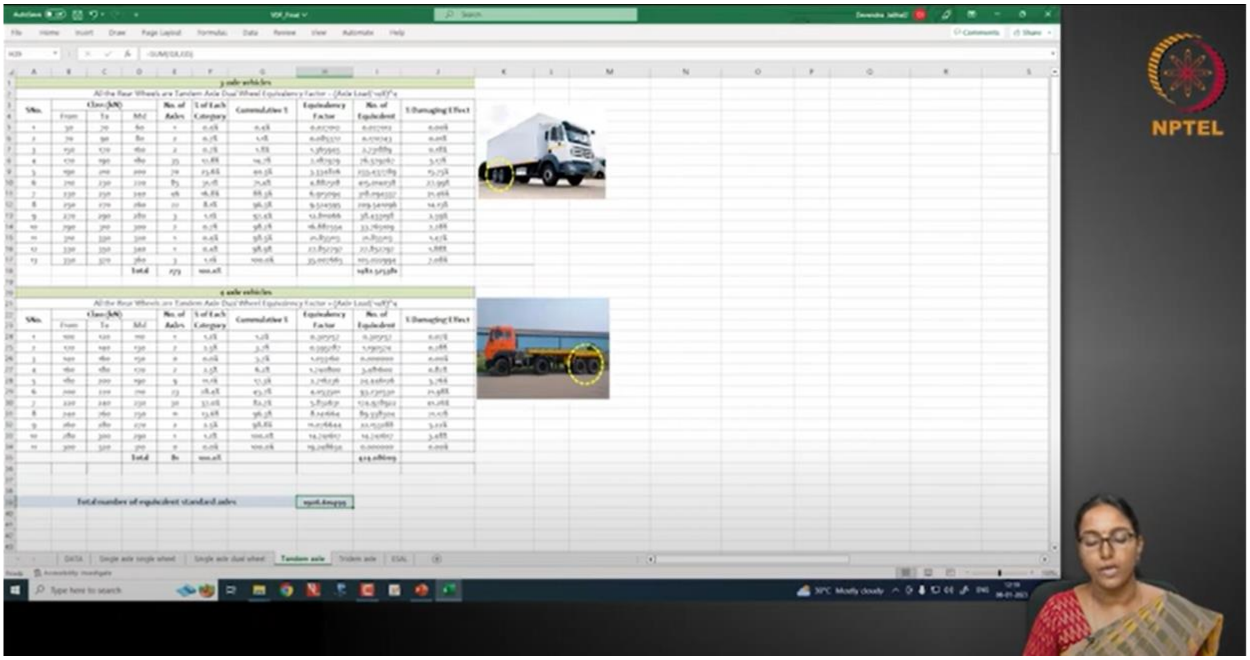

Now, moving on to the tandem axle, you had like 2 vehicle classes where there were tandem axles. Find the total equivalent standard axles for those classes.

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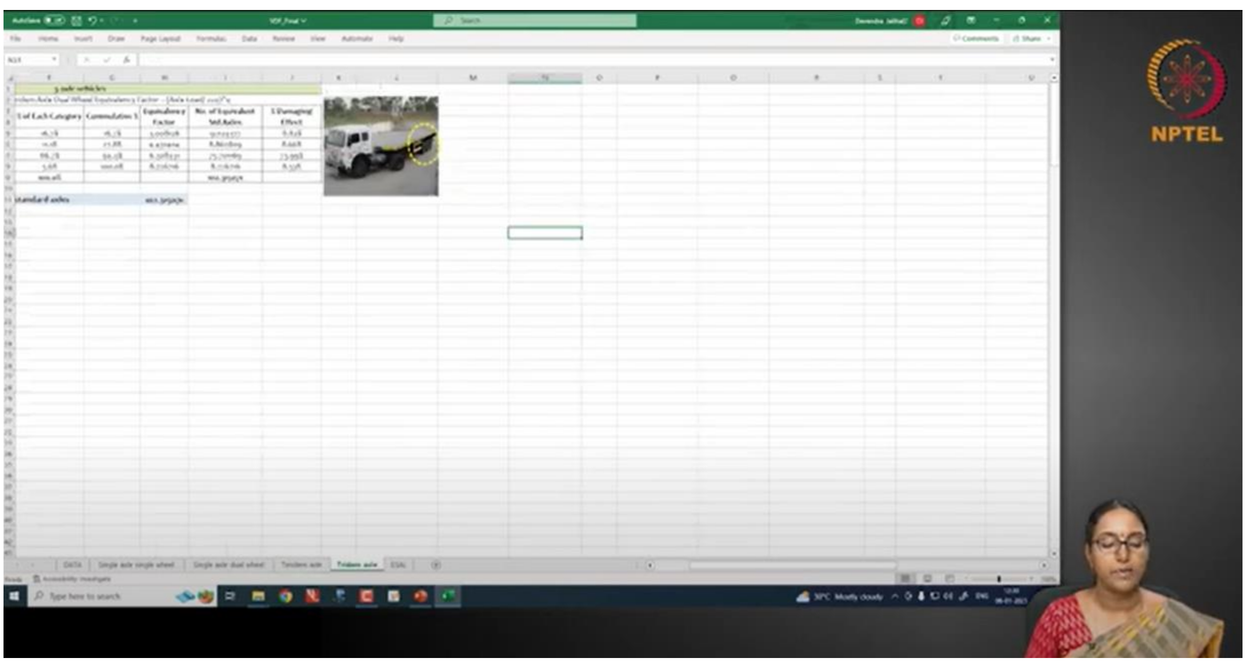

We had only one vehicle category where there were tridem axles. So, for that you will find what the damaging effect is. 102 are the total equivalent standard axles from this axle. Now, we have seen that you have computed the total equivalent standard axles for the single axle single wheels of all the categories of vehicles, which comes to 390. Then for the single axle dual wheel, it comes to 624. Then for the tandem axles from all the vehicle categories together, you get equivalent standard axles of 1906. And for the tridem axle, you get a value of 102. Now, let us see how the equivalent single axle loads or the design traffic can be estimated from this.

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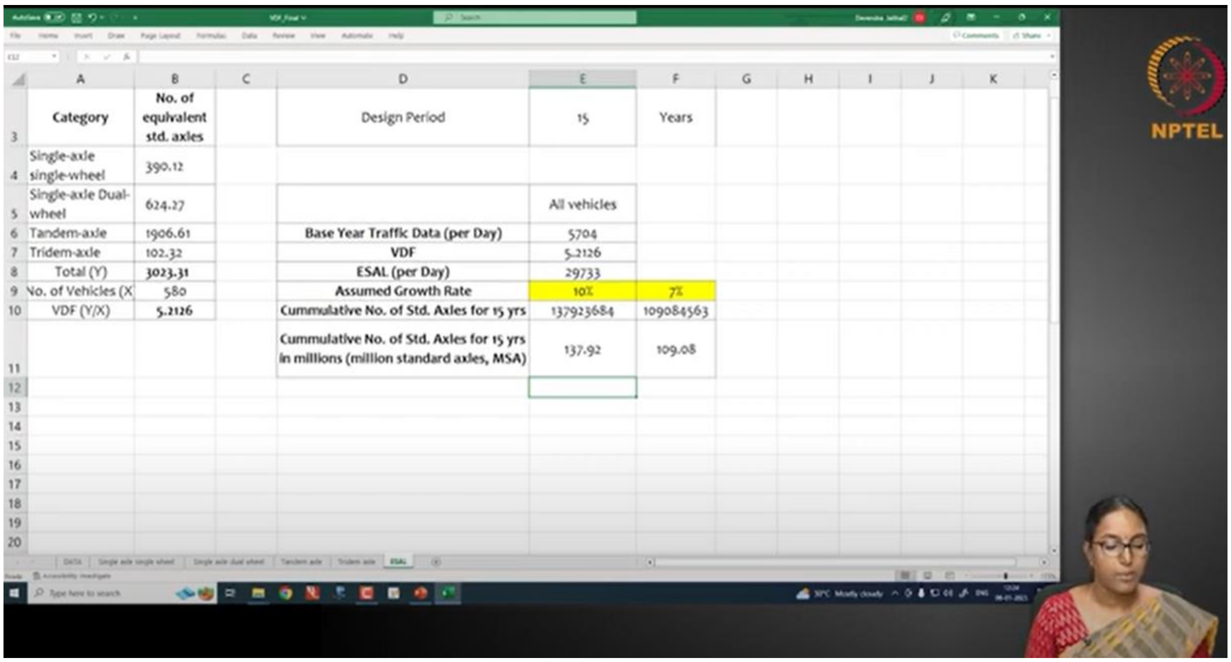

This is the total number of equivalent standard axles that we have computed for single axle, single axle dual, tandem axle and tridem axle. The total equivalent single axle loads for all the vehicles put together comes to 3023. Now, you have like 580 vehicles which are considered in this study. So, the total equivalent single axle loads divided by 580 will give you one vehicle damage factor which is 5.2126 for the all categories of vehicles put together. Now, let us use this VDF to find the design traffic. Like in the previous case, here also let us assume that there is a lane distribution factor of 0.4 and the design period is taken as 15. And you just need the total vehicle volume count which is 5704 in this case. Now, the ESALs per day can be computed as the traffic on the base year multiplied by the VDF.

Once you get the ESALs, now it has to be projected to the future. You cannot use different growth rates for the different classes of vehicles however, you have to choose only one growth rate for all the vehicles put together. Let us assume that the maximum of 10% is the growth rate and you apply the growth factor multiplied with the ESAL per day into 365 into the lane distribution factor to get the cumulative number of standard axles for 15 years. This is 137.9 million standard axles. Now, we have seen that the vehicle classes have different growth factors. Now, if I take a growth factor of 7 percentage instead of 10, you see that the design traffic comes down to 109. So, it is very important that you choose a appropriate annual growth rate if you are essentially going for one growth rate for the estimation of the design traffic, as in the case of this VDF method.