Analysis and Design of Bituminous Pavements

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Lecture - 14

Traffic analysis - ESWL Part 2

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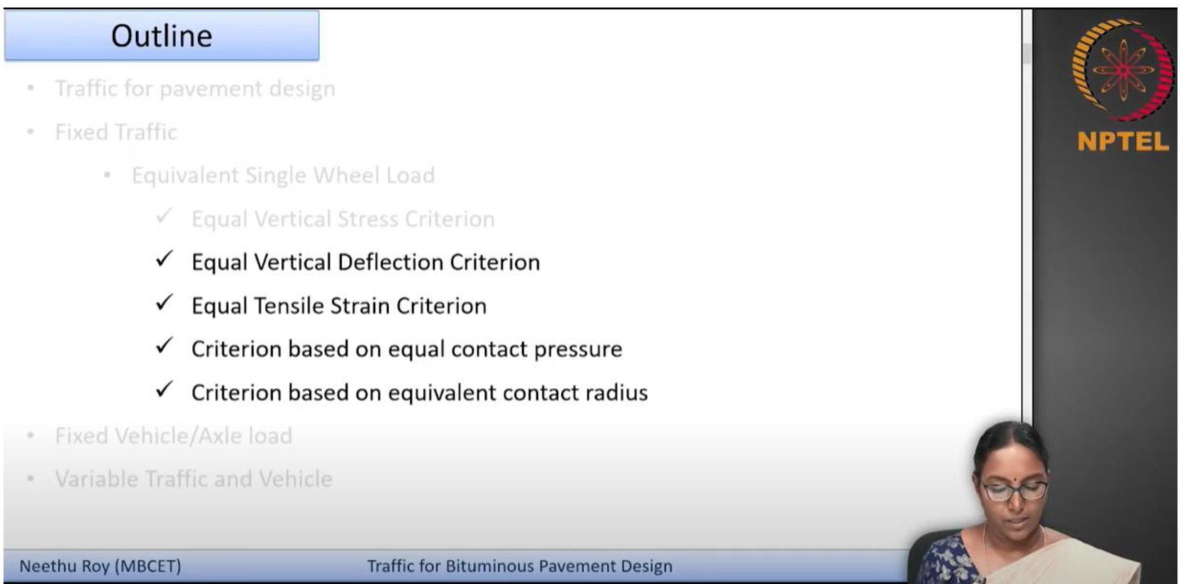

Now, we will continue with the other methods for the determination of equal and single wheel load.

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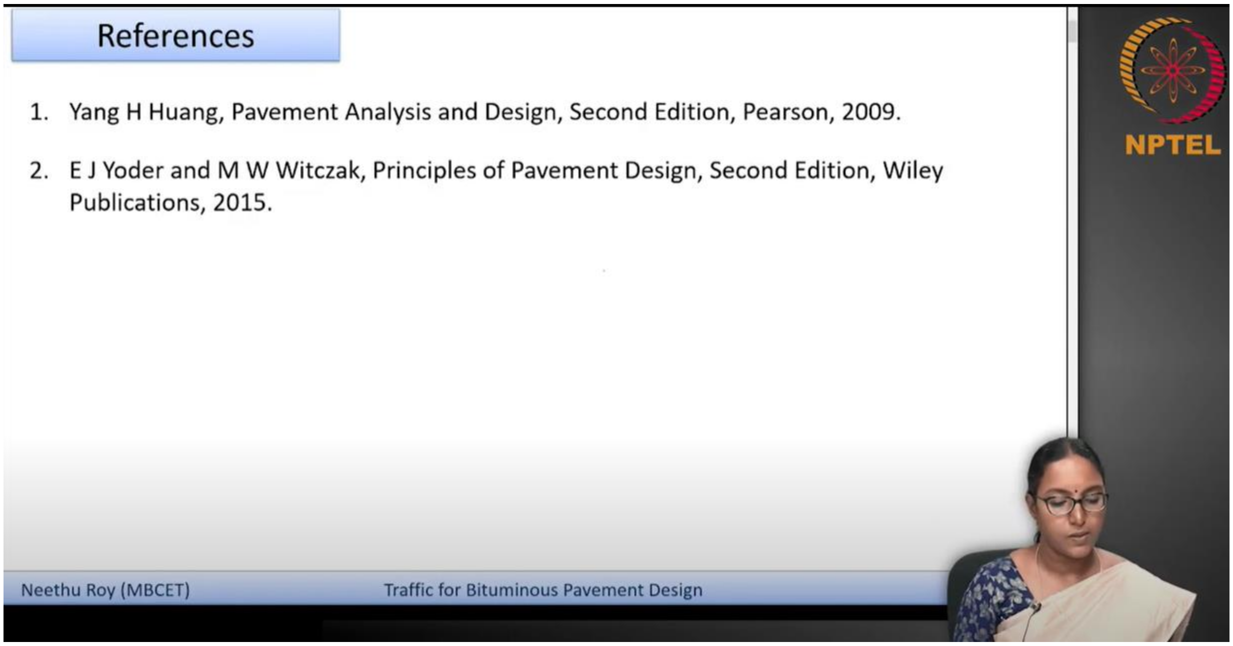

The references are Pavement Analysis and Design by Huang and also Principles of pavement design by Yoder and Witczak.

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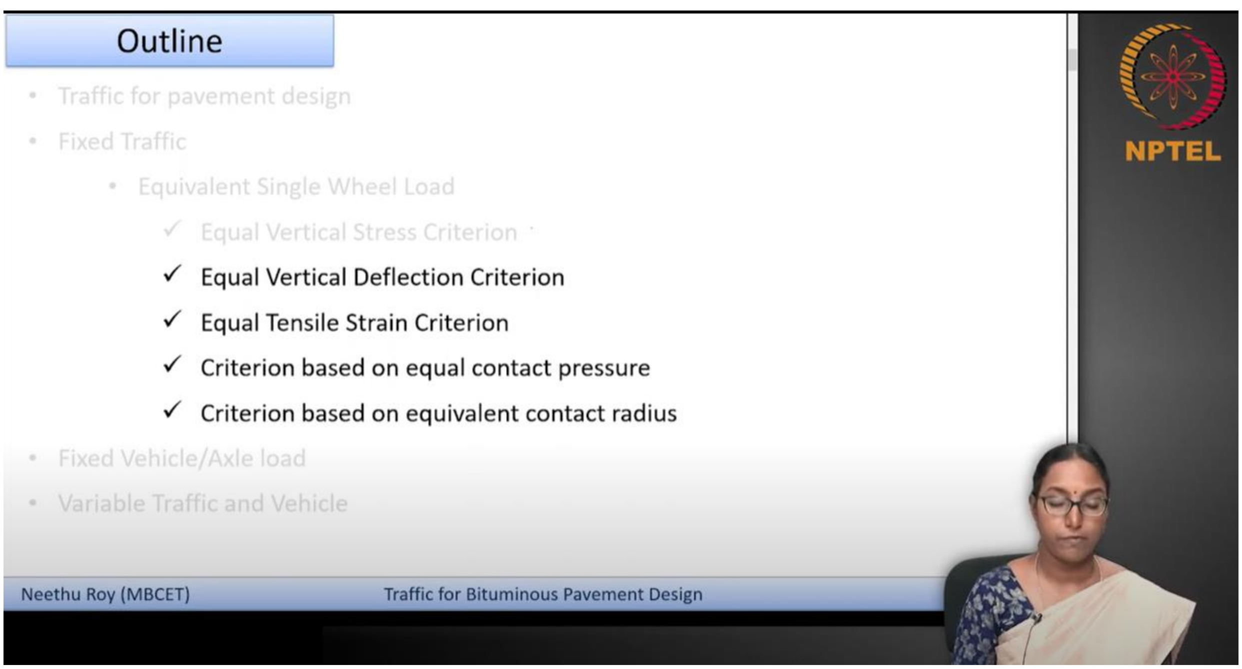

For the other four approaches, we have already seen the equal vertical stress criteria by Boyd and Foster, and Foster and Ahlvin. And then now we are going to discuss the approach by equal vertical deflection criteria, then equal tensile strain criteria, and then the criteria wherein an equal contact pressure or an equivalent contact radius is considered.

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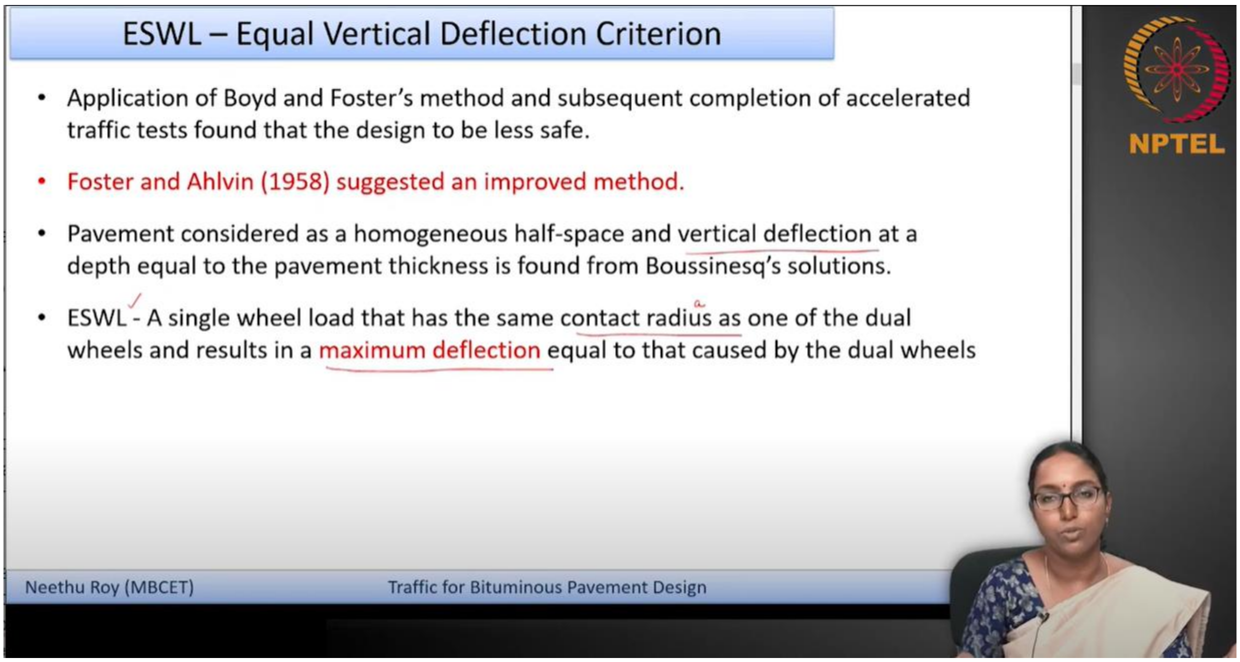

This is the third approach which is the equal vertical deflection criteria to get the equivalent single wheel load. So, with the application of the earlier methods or the Boyd and Foster method and subsequent completion of the accelerated traffic test, it is found that the design is found to be less safe. Foster and Ahlvin suggested an improved method wherein the pavement is considered as a homogeneous half space and the vertical deflection at a depth is equal to the pavement thickness found from the Boussinesq solutions. An equivalent single wheel load is considered as that single wheel load that has the same contact radius as that of the dual wheels and which will result in the maximum deflection equal to that caused by the dual wheel. So, here the maximum deflection at the bottom of the pavement layer is considered as the criteria for finding the equivalent single wheel load.

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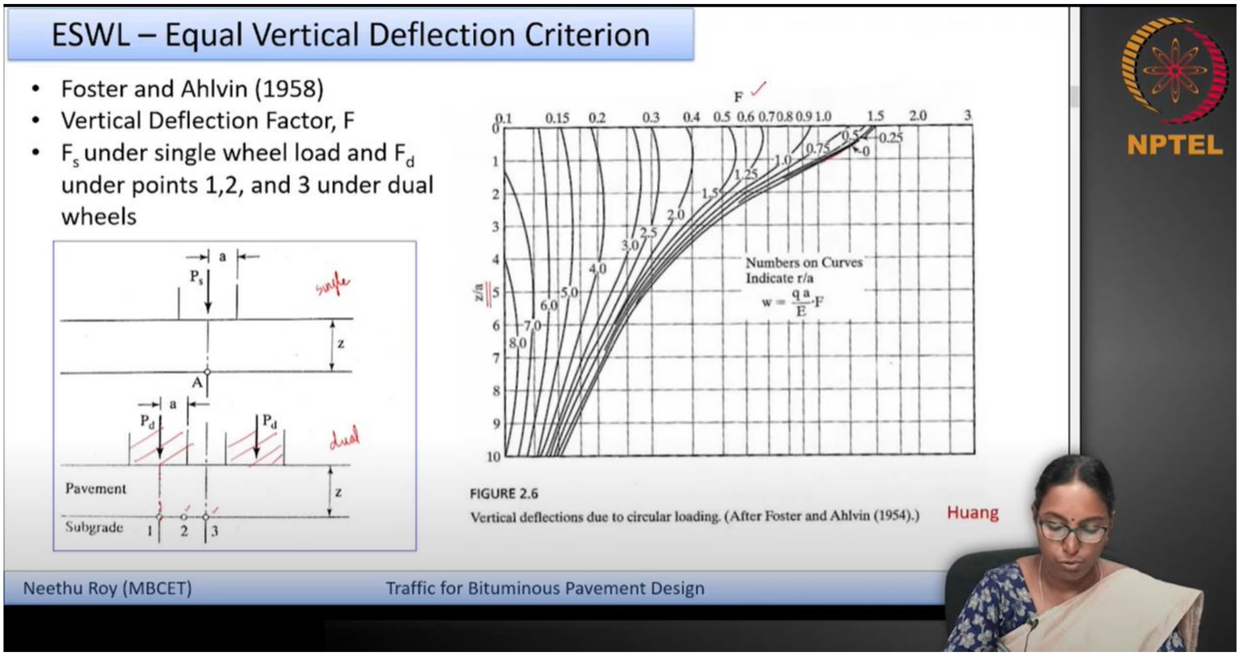

This is a chart again you are familiar with. This is the vertical deflection factor F for different depth as per Foster and Ahlvin. This is taken from Huang. So, you can get the vertical deflection factor for the single wheel as well as the dual wheel and from which the vertical deflections can be estimated and the expression for vertical deflection can be equated to find the equivalent single wheel load. In the case of the dual wheel, there could be 3 possible points where you can have the maximum vertical deflection which is point number 1 which is exactly at the middle of one wheel load or it could be point number 3 which is midway between the two wheel loads or point number 2 which is midway between 1 and 3.

So, you have to see where you get the maximum deflection factor at the points 1, 2 and 3 and the effect of two loads has to be superposed together that is the left wheel and the right wheel has to be superposed together to get the deflection factor at these 3 points and then find the maximum of this in the case of a dual wheel. And this has to be equated to that of a single wheel so that you can arrive at the single, equivalent single wheel load. So, let us see how we are equating these two values. So, as you can see here from the chart, you get the deflection factor F for different depths or z/a values and each of these curve is for a different r/a value. For r/a from 0 to 8, you have different charts, and once you get the deflection factor F, you can use the following equation to find the vertical deflection due to a circular loading of radius a and a contact pressure of q and in a pavement of modulus E.

$$w = \frac{qa}{E}F$$

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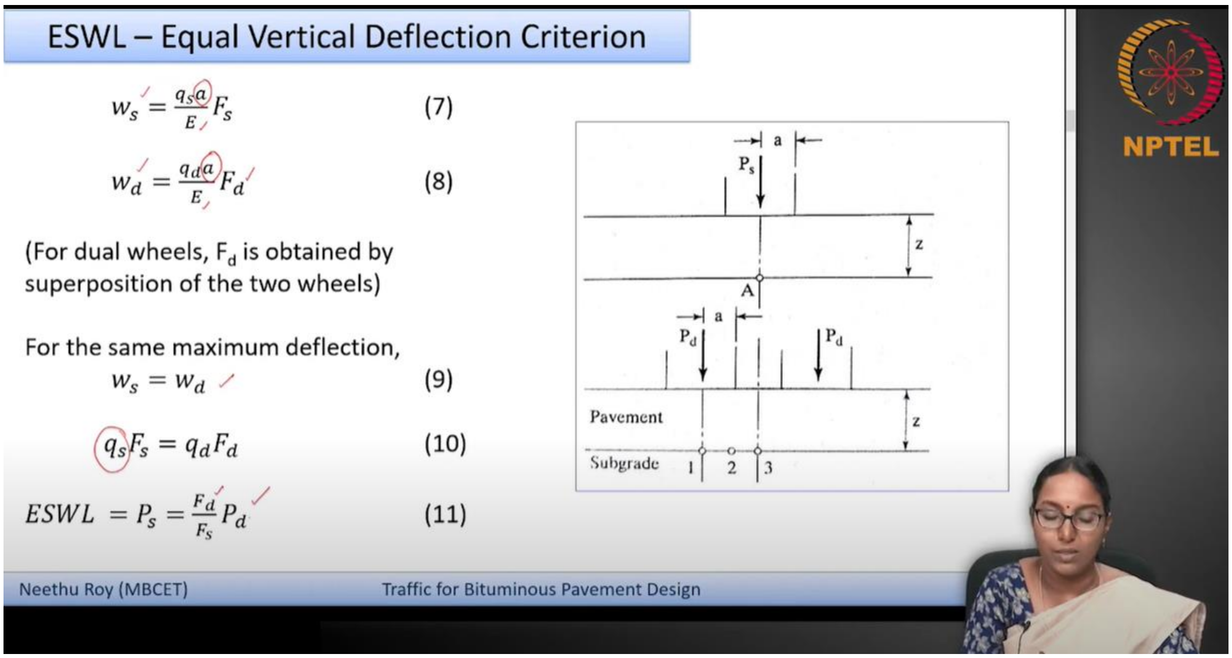

$$w_s = \frac{q_s a}{E} F_s$$

$$w_d = \frac{q_d a}{E} F_d$$

The vertical deflection due to a single wheel (w_s) can be computed using the above equation where F_s is the deflection factor due to the single wheel load. And in the case of a dual wheel, the deflection given by w_d is calculated using F_d, where F_d is the deflection factor for a dual wheel assembly. So, here the radius of contact of the dual wheel and the single wheel is kept the same as well as the pavement modulus is the same whereas the pressure indicated or the pressure imposed by the single wheel and the dual wheel is different which is denoted as q_s and q_d. Now, equating this maximum deflection as w_s is equal to w_d, that is the deflections are equated, you can note that $q_s F_s$ is equal to $q_d F_d$. Now, as the contact radius is the same, q_s is actually proportional to the load which is P.

$$P_s = \frac{F_d}{F_s} P_d$$

So, from here we note that F_d is the maximum deflection factor for the dual wheel assembly, F_s is the deflection factor for the single wheel and P_d is one of the dual wheel loads. So, multiplying with this ratio you get the equivalent single wheel load.

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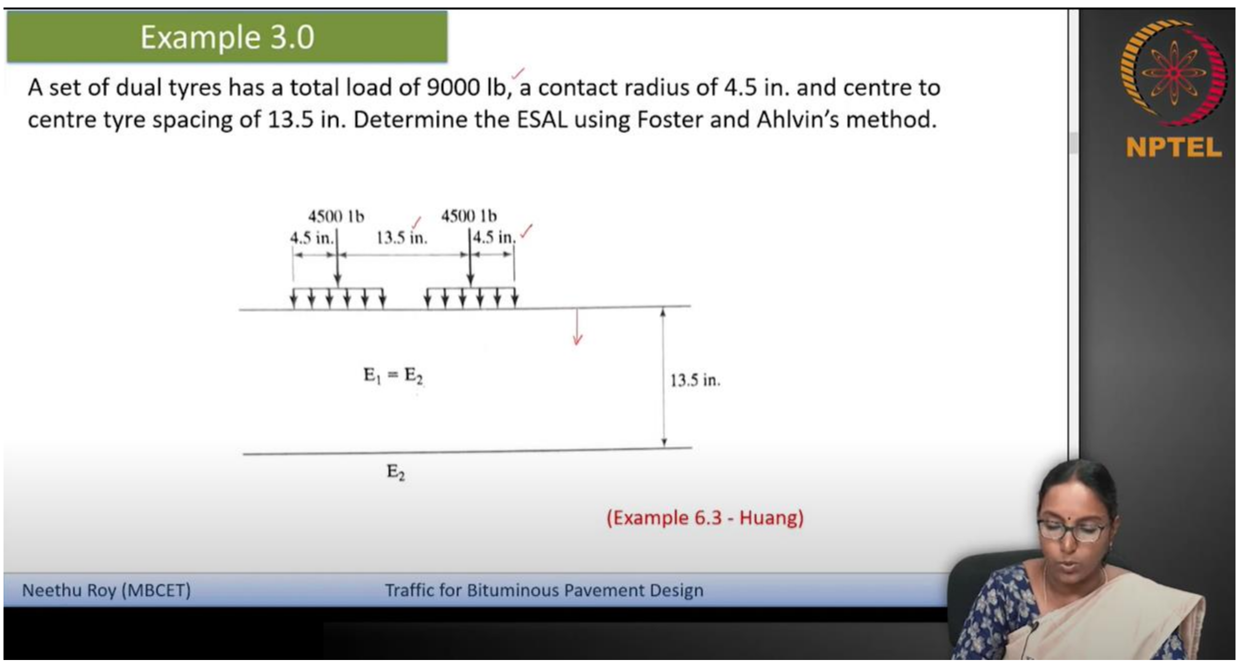

So, let us attempt the same question which we have discussed for the past two methods using this Foster and Ahlvin's method of equal vertical deflection criteria. So, a set of dual tires having a total load of 9000 lb and a contact radius of 4.5 inch and a center to center spacing of 13.5 inches is given here. Again, it is a homogeneous half space with $E_1 = E_2$. You are asked to find these equivalent single axle load for this dual wheel assembly based on the Foster and Ahlvin's method.

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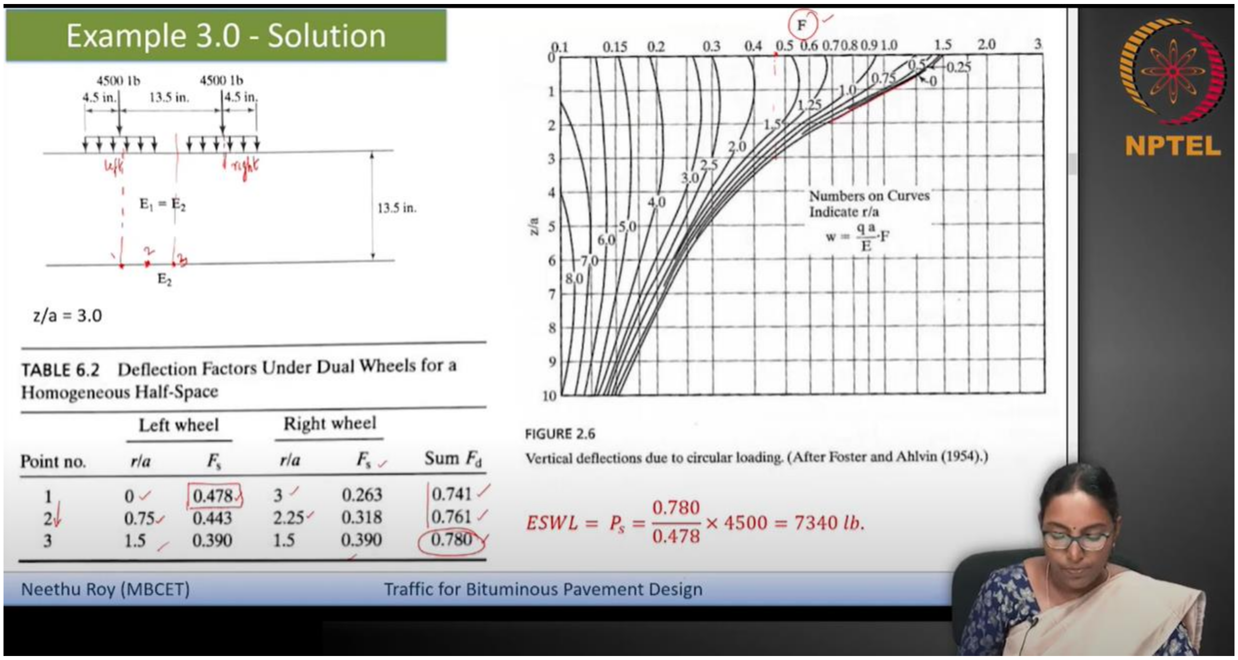

So, let us see how we do it with the Foster and Ahlvin chart. So, first of all, for the dual wheel assembly a table is written here. So, let us say this is the left wheel and this is the right wheel. So, the approach is exactly the same as what we have done for the previous one with σ_z. So, a similar approach is adopted here. So, you have a left wheel and a right wheel and you have to consider three points in the case of a dual wheel.

There are three points which is marked here as 1, 2 and 3. And first let us see when there is only a single wheel load. So, for the single wheel load, the point 1 itself will get the maximum deflection and r/a value for that point is 0 and z/a is 13.5/4.5 which is 3. So, for an r/a = 0 and z/a=3, you can note the F value from this chart. So, F value is directly there. So, we see let us see this is r/a of 0 plot and z/a of 3. So, it will come somewhere around here. So, this is this may be close to 0.48 as I said. So, this could be somewhere around 0.48. But since this is noted from computer analysis or using a kenlayer software, that is why it is written as 0.478. You can note whatever you note from this chart.

So, 0.48 or 0.478 is the deflection factor. Similarly, so this is the case of a single wheel load. Now you have the dual wheel load. For the dual wheel load let us see the left wheel value is the same. Now the right wheel value for an r/a value of 13.5/4.5 which will give you 3. So, for that r/a value, you get the F_s value. Similarly, consider point 2 for the left value. You see that r/a is 0.75. You read the F value from the chart which is 0.443. Again, you may get it as 0.44 only. Since this is noted in Huang from the computer analysis so that is why I have not taken the same chart here. So, this is 0.443. I am sorry you may get it as 0.44 from when you read from the charts, but since this is used this is computed using kenlayer or so. So for the second point here you can note that for the left wheel, the r/a is 0.75 and the right wheel the r by r/a is 2.25 and you can read the corresponding F values from the chart. So, you may read it as say 0.44, 0.32 etc, but since this is done using a computer program that is why they have arrived at this value of 0.443 and 318 and so on. So, this is taken from the Huang textbook. So, I have used the same table from the Huang textbook. So, you can read what you see here suppose it is 0.44 you can write it as 0.44 itself. So, you got the values at 0.2 likewise you can consider the 0.3 you get the values for the left wheel and the right wheel and the left wheel and the right wheel coefficients or the deflection factors to be summed up to get the total deflection factor F_d for the dual wheel. So, you see that at point number 1 your value is 0.741, and point number 2 has a Fd of 0.761 and point number 3 has a value of 0.78 of which the maximum value is 0.78. Now, the equivalent single wheel load is given by any one of the loads which is the P_d multiplied by the dual deflection factor divided by the single deflection factor. So, the single load deflection factor is 0.78 divided by 0.478 into 4500. So, you read that 7340 is the equivalent single wheel load based on this approach. It was the same question that we have discussed for the other approaches as well. So, you see that this closely matches the approach that we have discussed earlier.

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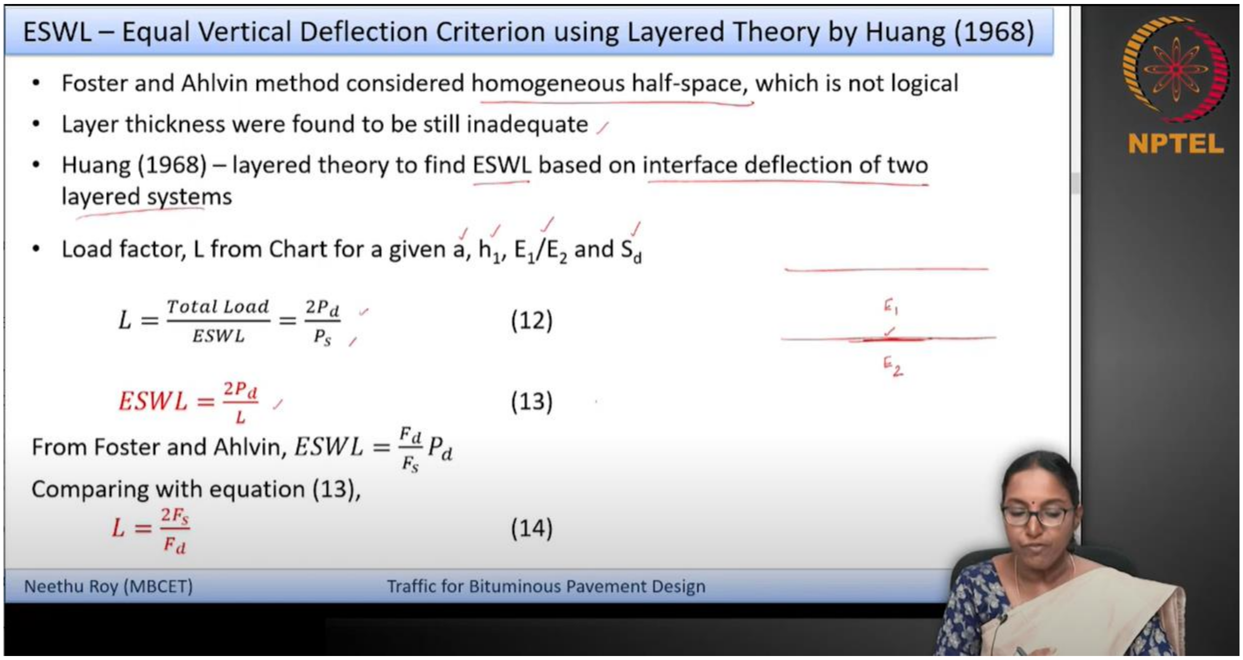

Now, the Foster and Ahlvin method that we discussed just now has considered a homogeneous half space that is the pavement has only one layer which is not logical because your subgrade and the pavement layer may have multiple layers. So, at least two layers are to be considered because you have subgrade and top pavement layer. So the approach that we have just discussed based on Foster and Ahlvin for using vertical deflection has considered that the pavement is a homogeneous half space that is it comprises of just one layer having a modulus of E which is not logical because the pavement structure should have at least one layer which is a pavement structure and at least two layers which is the pavement structure and the subgrade layers. But and also it was found that the layer thicknesses which were designed based on that approach was inadequate. So, Huang has considered the layer theory to find the equivalent single wheel load based on the interface deflection of two-layer system. So, you consider a two-layer system with E_1 is the top layer and E_2 is the bottom layer and the vertical deflection at the interface of these two layers is considered for finding the equivalent single wheel load.

Now to get this, you can use a load factor considered from a chart which is depending on various factors such as the contact radius, the thickness of the pavement, $\frac{E_1}{E_2}$ the modular ratio and the spacing between the dual wheels. And then the load factor is given by the total load divided by the single wheel load equivalent single wheel load or the equivalent single wheel load can be denoted as twice the total dual wheel load divided by the load factor.

$$\mathrm{ESWL} = \frac{2\,\mathrm{P_d}}{\mathrm{L}}$$

$$\mathrm{L} = \frac{2\mathrm{F_s}}{\mathrm{F_d}}$$

$$\mathrm{ESWL} = \frac{\mathrm{F_d P_d}}{\mathrm{F_s}}$$

Now from the Foster and Ahlvin equation, we know that equivalent single wheel load is the deflection factor for dual divided by the deflection factor for single into $\mathrm{P_d}$. Now comparing these two approaches, we see that the load factor can be written as twice the $\mathrm{F_s}$ deflection factor due to the single wheel divided by the deflection factor due to the dual wheel ($\mathrm{F_d}$)

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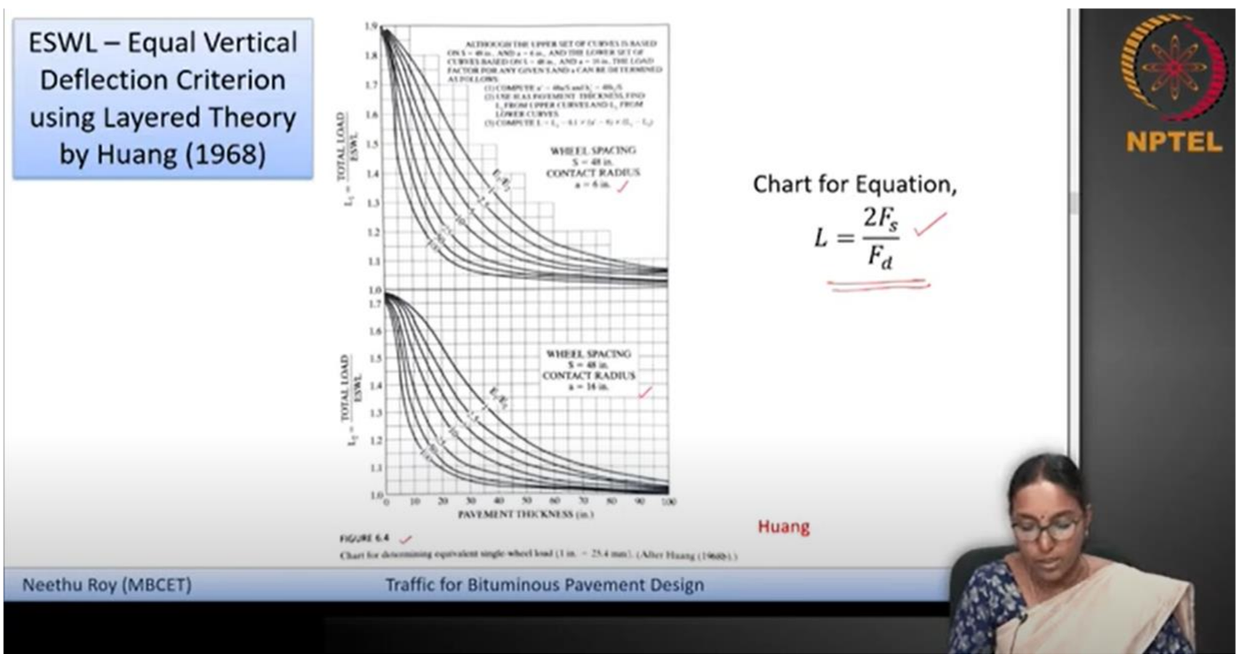

$$\mathrm{L} = \frac{2\mathrm{F_s}}{\mathrm{F_d}}$$

Now for this expression, either you can use the same charts to find the deflection factors and then use this but this may be very cumbersome. So what is done is that for this expression there is a chart which has been derived or chart that has been developed. So this chart is given in Figure 6.4 in Huang. So you see that this chart is for different $\frac{E_1}{E_2}$ values with two different contact radius. The first one is for a contact radius of 16 inches and the top one here is for a contact radius of 6 inches both drawn for a spacing of 48 inches.

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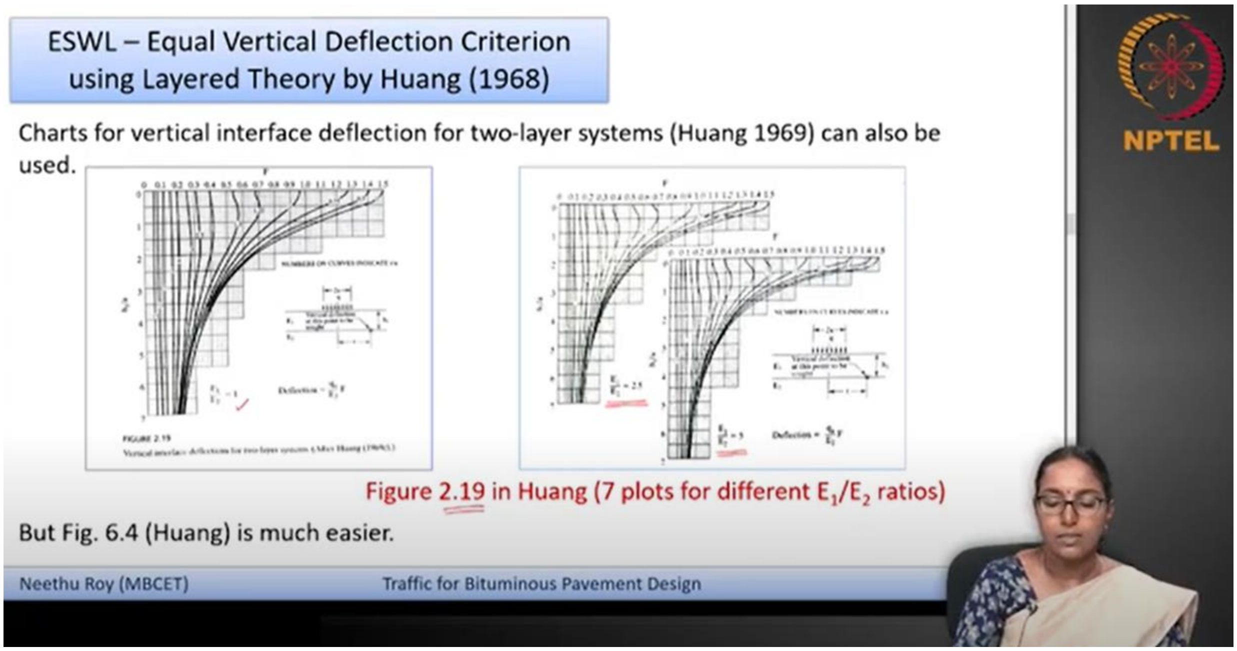

This is a chart that is developed to find the load factor. Instead of using this, you can use the vertical interface deflection for two layered systems given by Huang can be used. For example Figure 2.19 in the Huang textbook which is where there are 7 plots that are given for each one for a particular $\frac{E_1}{E_2}$ value. For example, I have shown some of them here. This is the vertical interface deflection for a two-layered system with $\frac{E_1}{E_2}$ of 1 and this is the vertical interface deflection value for $\frac{E_1}{E_2}$ of 2.25. This chart is for an $\frac{E_1}{E_2}$ of 5 and so on.

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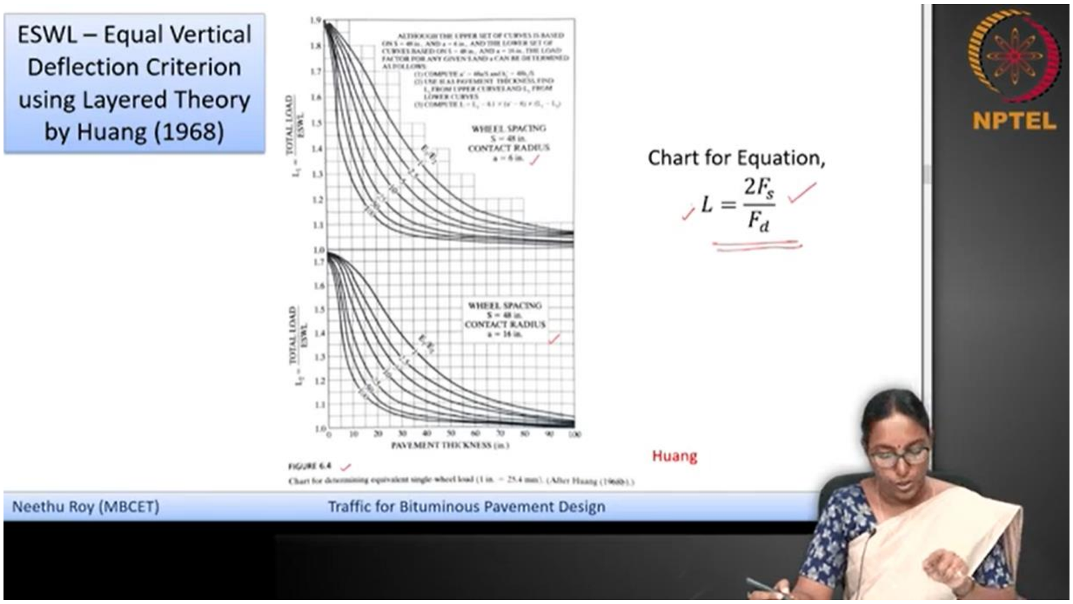

So either you can use these charts to find the deflection factors or you can use this load factor approach using the combined chart and get the load factor. This will be a simpler approach to use this chart given in figure 6.4.

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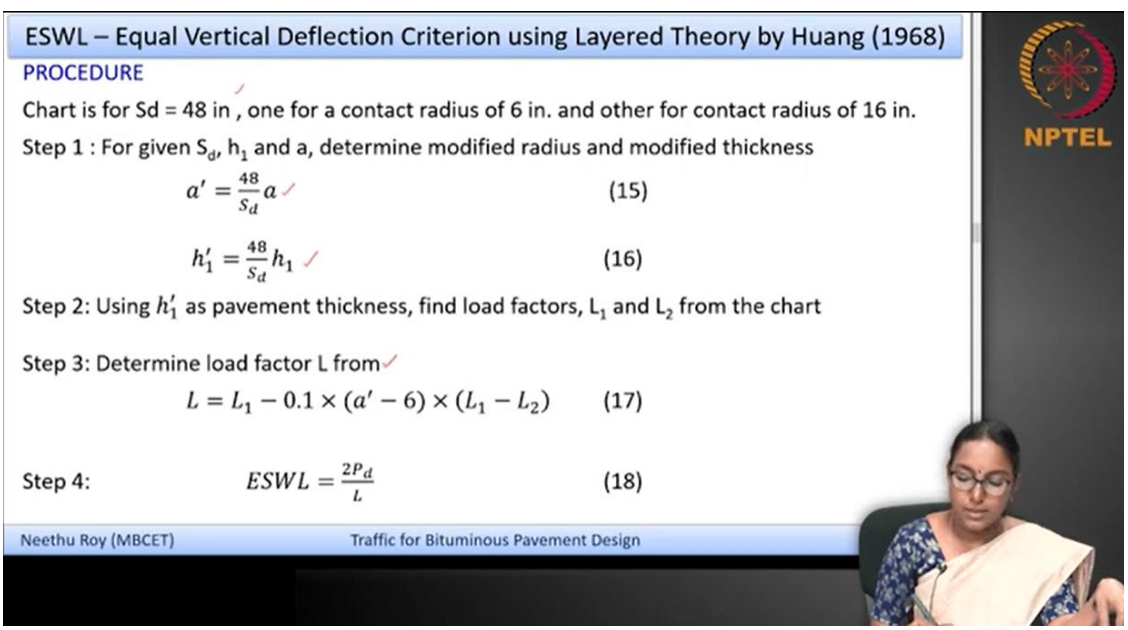

So the procedure is like this for S_d of 48 inch. The dual wheel spacing is 48 inches. The contact radius is equal to 6 inch and for another, it is equal to 16 inch. Accordingly they are denoted as L_1 and L_2 are the two load factors. Suppose in the question, you have a contact radius which is different from 6 inch or 16 inch or you have a spacing other than 48 inch, in that case you have to find the modified radius and a modified thickness as given here.

$$a' = \frac{48}{S_d} a$$

$$h_1' = \frac{48}{S_d} h_1$$

h_1' is equivalent pavement thickness and h_1 is the thickness of the original pavement.

If your question is with a different S_d value and a different contact radius, you have to find a modified radius as a' and a modified pavement thickness h_1'. So what you are trying to do is that this ratio of the spacing of the dual wheel and the pavement thickness is to be kept constant so that you can find an equivalent thickness so that the charts which are provided for 48 inch spacing can be utilized. So use this h_1' to read the load factors from the chart that is shown earlier. So you can get the load factors from L_1 and L_2. If your contact radius is not 6 and 16 inches, then what you have to do is that you have to interpolate the load factor for the given contact radius.

$$L = L_1 - 0.1 \times (a' - 6) \times (L_1 - L_2)$$

$$\text{ESWL} = \frac{2\ P_d}{L}$$

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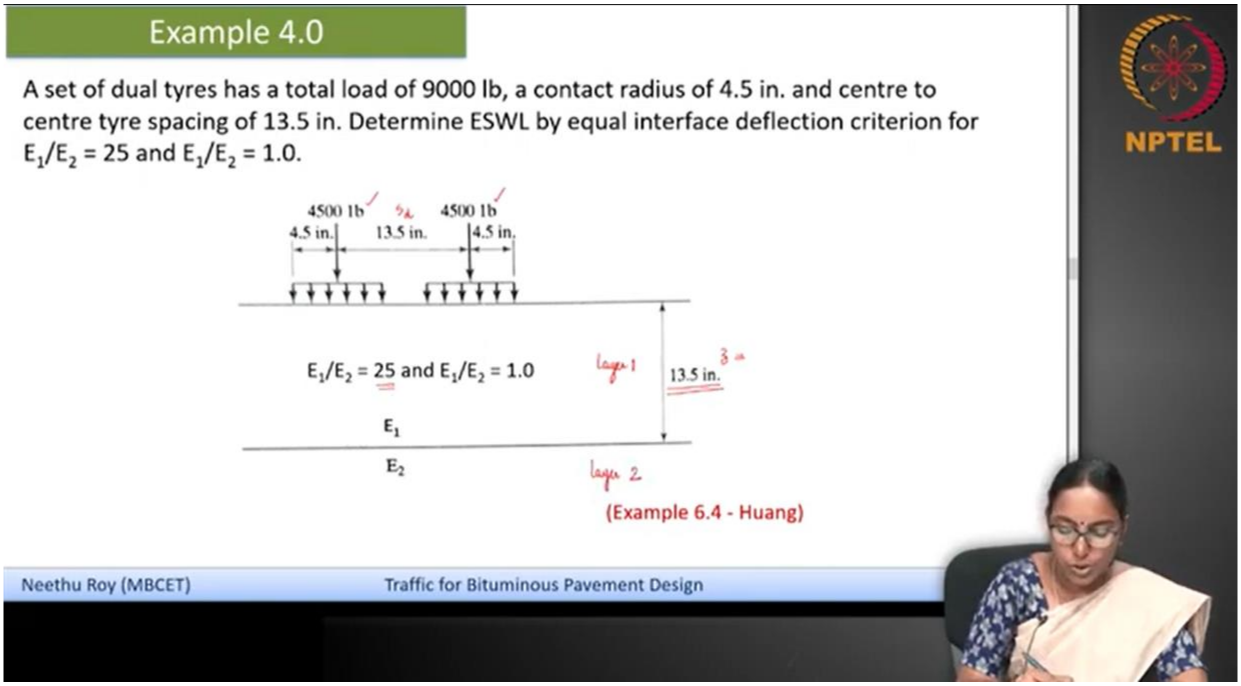

Let us work out the same problem again with this concept and see what will be the equivalent single wheel load. So as already discussed this is 4500 pounds and 4500 which is a total of 9000 pounds with a spacing of S_d spacing of 13.5 inch and you are asked to find the equivalent single wheel load when the pavement thickness is z is equal to 13.5 inch. And in this case, this is a two layer system and one is with $\frac{E_1}{E_2}$ value of 25. So E_1 is the modulus of layer 1. So this is the top layer or the pavement layer and this is the subgrade layer. So this is layer 2. So $\frac{E_1}{E_2}$ ratio is 25 and at the same time you are also asked to check whether it is a homogeneous half space that $\frac{E_1}{E_2}$ is equal to 1.

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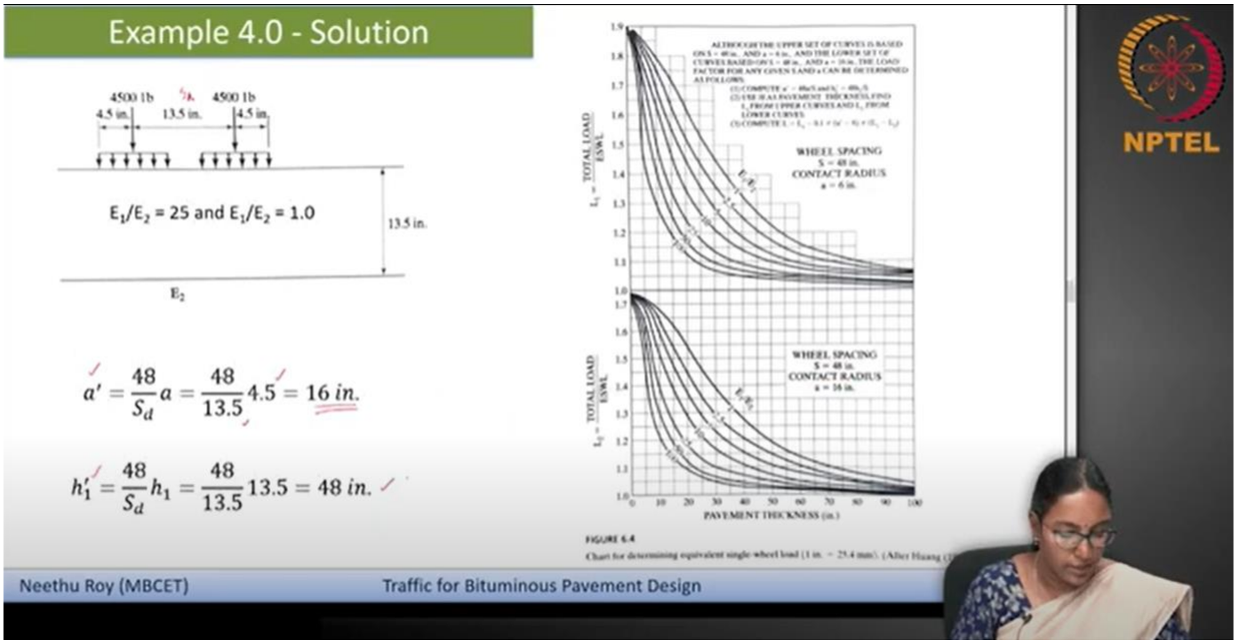

So let us use this approach. So first of all, what we have seen is that S_d is not equal to 48. So you cannot directly read from this chart.

$$a' = \frac{48}{S_d}a = 16 \text{ in}$$

$$h_1' = \frac{48}{S_d}h_1 = 48 \text{ in}$$

Now let us see the chart. Let us see if $\frac{E_1}{E_2}$ is equal to 25. So when we look at the chart, you see that the bottom chart is for a' is equal to 16.

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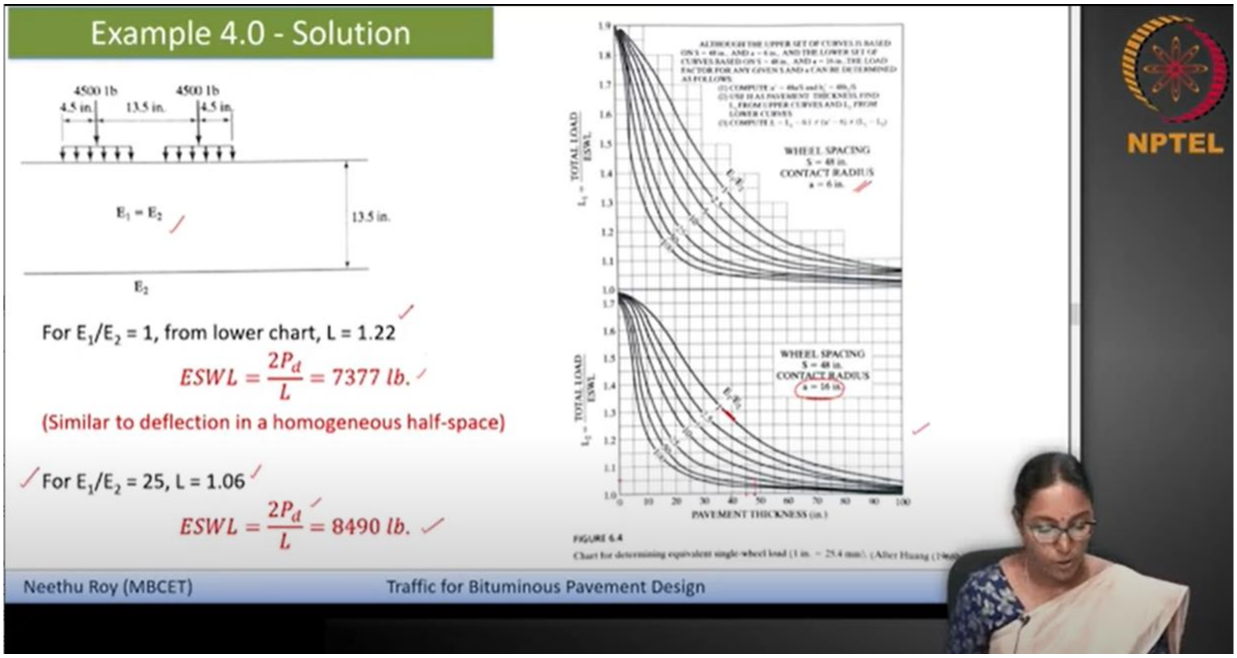

For h_1' of 48 inch and $\frac{E_1}{E_2}$ of 25, you can read from the chart that L is somewhere close to 1.05 or 1.06. So the L value is read from the bottom chart because it is for a is equal to 16 inch. So your a' here is 16 inches. So you got L as 1.06.

$$ESWL = \frac{2P_d}{L} = 7377 \text{ lb}$$

This is for a pavement structure with $\frac{E_1}{E_2}$ of 25. Now, for $\frac{E_1}{E_2}$ is equal to 1, you can read from the bottom chart that L is equal to 1.22. So if you find the equivalent single wheel load for a homogeneous half space, you got it as 7377 pounds. So this is similar to the deflection of the homogeneous half space that you have already determined which was close to 7400. So whether you use this chart or the homogeneous half space deflection criteria you will get a similar answer. So the idea here is to consider the layered system with different E values for the pavement and the subgrade.

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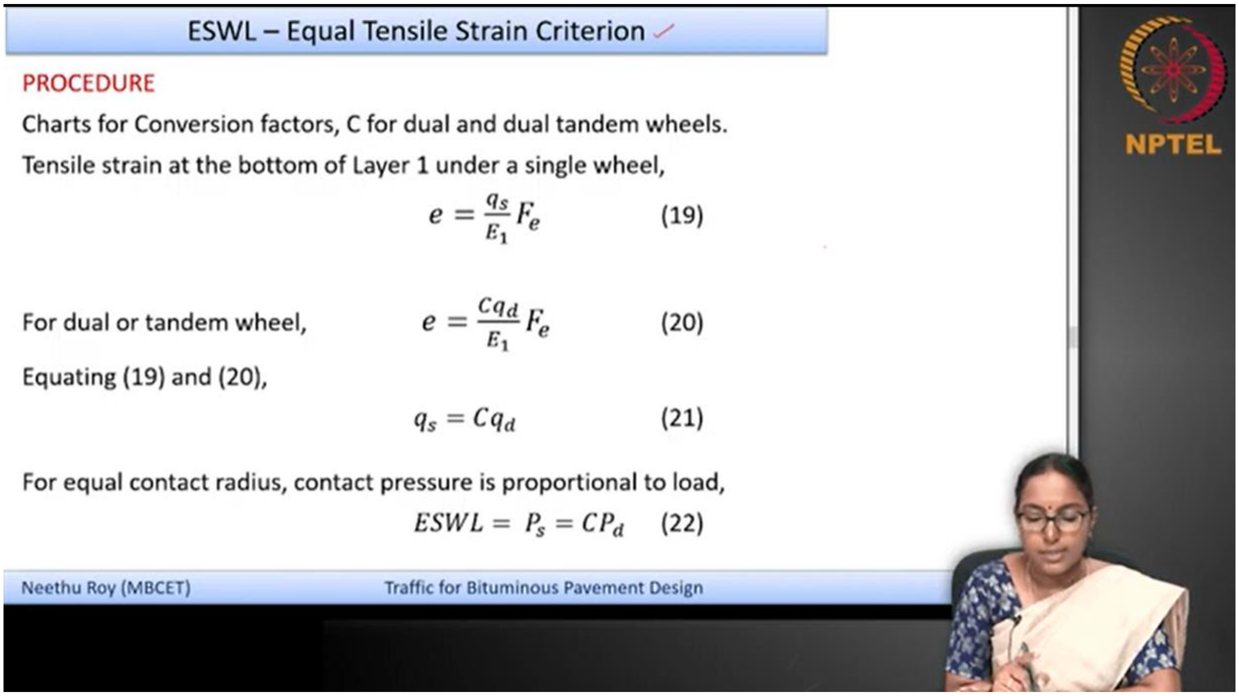

We have already discussed the criteria based on the vertical stress, then based on the deflection. Now the third one is, you are going to consider the tensile strain at the bottom of the pavement or the bottom of the bituminous layer. So you have already discussed how to determine the tensile strain at the bottom of the pavement layer or the bituminous layer wherein you have a chart available for finding the tensile strain for a single wheel and then there are conversion factors if there is a dual wheel or a dual tandem wheel. So the tensile strain at the bottom so was the chart from Huang Figure 2.21.

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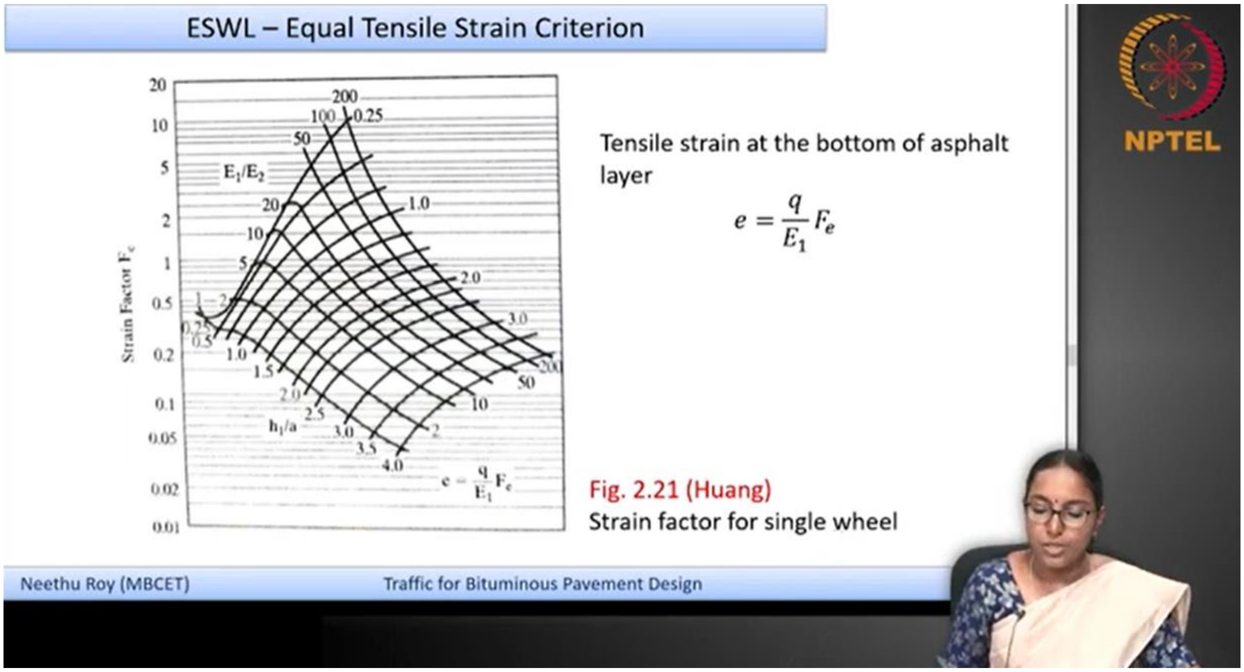

So the tensile strain for a single wheel load application is given as follows.

$$e = \frac{q}{E_1} F_e$$

Here, F_e is the strain factor that can be read from this and if your load has dual wheels or dual tandem wheels, there were conversion factors given so that the strain can be noted from this chart. Then, multiply it with the conversion factor to get the strains corresponding to a dual wheel. So this is how the tensile strain was computed from the charts.

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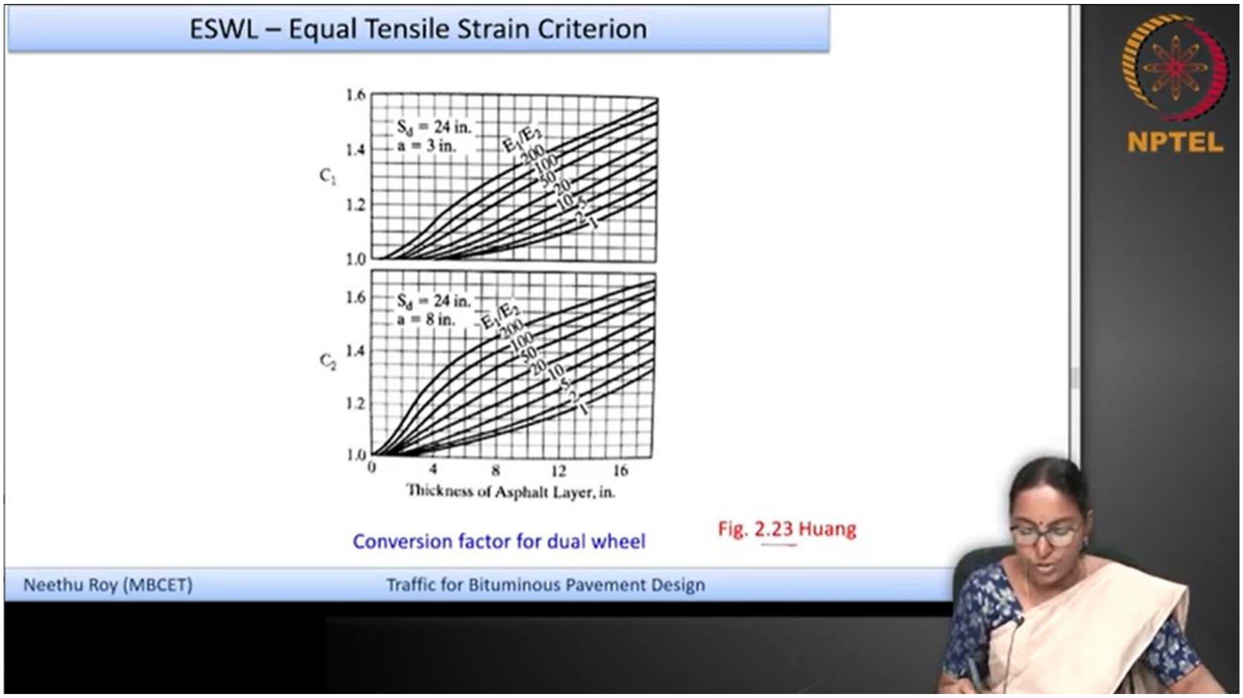

So you see here is the conversion factor for the dual wheel which was given in Huang in Figure 2.23. So these are the conversion factors for S_d spacing of 24 inches for two contact radius, one is for 3 inches and the other is for 8 inches, and if you get a different contact radius you have to interpolate from this. So this is already discussed by Professor Murali in his analysis of systems lecture.

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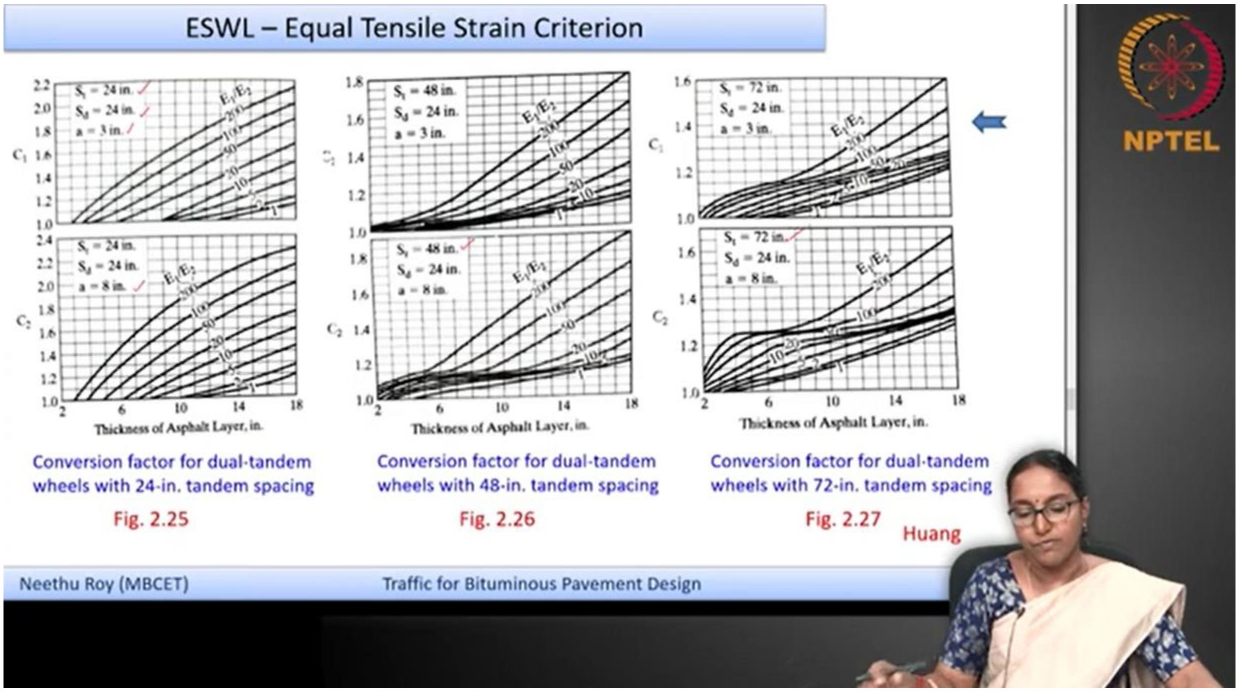

And these were the conversion factors for a dual tandem assembly. So this was a dual tandem conversion factor for a dual tandem assembly with a spacing of 24 inch. So this is the tandem spacing of 24 inch and the dual wheel spacing of 24 inch and a contact radius of 3 inch and the bottom one is for a contact radius of 8 inch. And the second conversion diagram was for a dual tandem wheel with 48 inch tandem spacing and the third one was with a conversion factor with a tandem spacing of 72 inch. So these were the conversion factors to find the tensile strain when you have dual tandem wheels.

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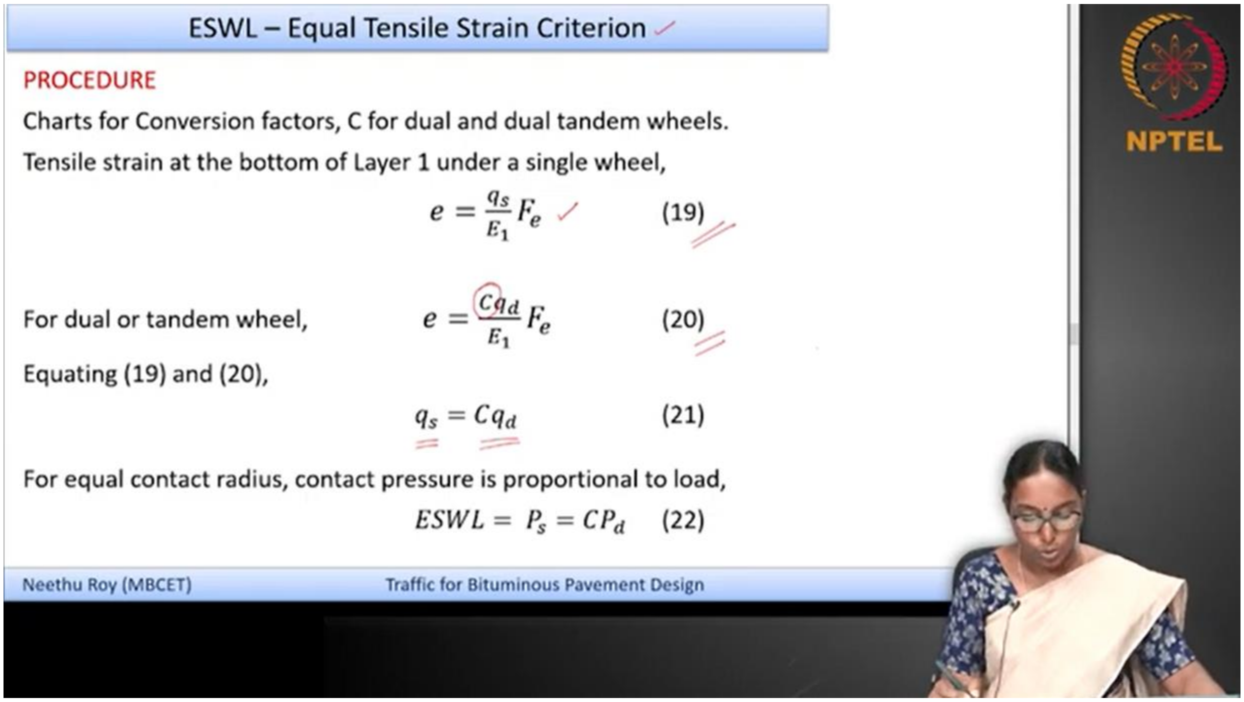

So as I mentioned, for the single wheel the strain is computed as follows.

$$e = \frac{q_s}{E_1} F_e$$

For dual or tandem wheel,

$$e = \frac{Cq_d}{E_1} F_e$$

For dual or tandem wheels, you find the conversion factor C from the chart and multiply it with the other factor to get the tensile strain. These are the two expressions to find the tensile strain due to a single wheel and a dual wheel. So the same approach can be used to find the equivalent single wheel load. So equating these two expressions or the strains, we see that q_s, the contact pressure in the single wheel is equal to Cq_d, the contact pressure in the dual wheel.

And since we are considering equal contact radius, your contact pressure is proportional to the load. Therefore, you can say that P_s is equal to C times P_d.

$$ESWL = P_s = 2P_d$$

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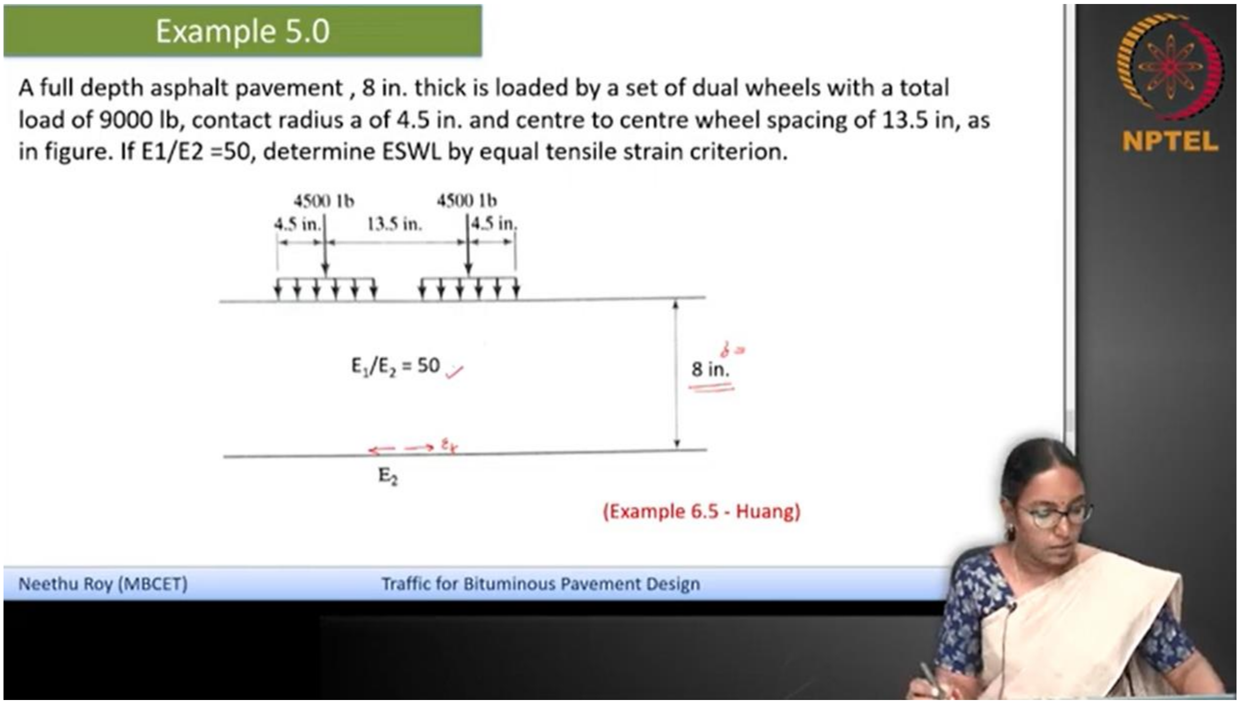

So let us work out one example to find the equivalent single wheel load based on the equal tensile strain criteria. But it is a similar question to what we have been discussing but the only thing is that the pavement thickness is changed to 8 inch than 13.5 inch. And the $\frac{E_1}{E_2}$ ratio is given as 50 here. So what you are finding going to see is what is the ε_t or the tensile strain at the bottom of this pavement layer and for the dual wheel and this strain is equated for the dual wheel assembly and to the equivalent single wheel load.

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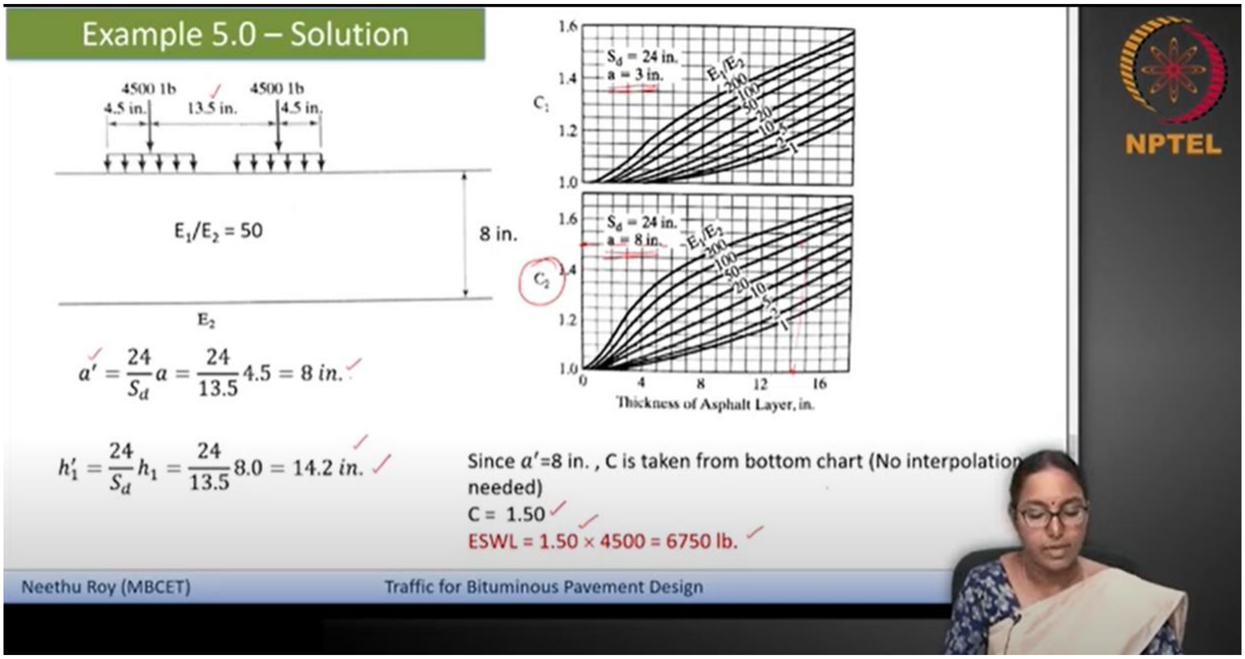

So first of all let us see what the spacing is. 13.5 is the spacing but since the spacing that is given in the strain computation is 24 inch, you have to convert it to find the dash and h1 dash. So this is already explained in the tensile strain computations.

$$a' = \frac{24}{S_d} a = 8 \text{ in}$$

$$h_1' = \frac{24}{S_d} h_1 = 14.2 \text{ in}$$

This conversion factor given for dual wheel is for a contact radius of 8 inch and for a contact radius of 3 inch. So in this case you got the a’ as 18. So you can directly read from this bottom chart, and you will get C. You do not have to interpolate it. So for the new h_1’ which is 14.2 and for $\frac{E_1}{E_2}$ of 50, you can read from this chart so that your value will come around 1.5. So the conversion factor for the tensile strain can be read from this chart for a dual wheel which is 1.5 and multiplying it with the one dual wheel or half of the dual wheel, which is P_d will give you the equivalent single wheel load.

$$C = 1.5$$

$$ESWL = C \times P_d = 1.5 \times 4500 = 6750 \text{ lb.}$$

The approach that we have discussed now is the tensile strain approach. You are considering that the tensile strain due to a dual wheel is equal to that due to the equivalent single wheel load and the conversion factors are already available in charts for computing the tensile strains due to a dual wheel and a dual tandem wheel.

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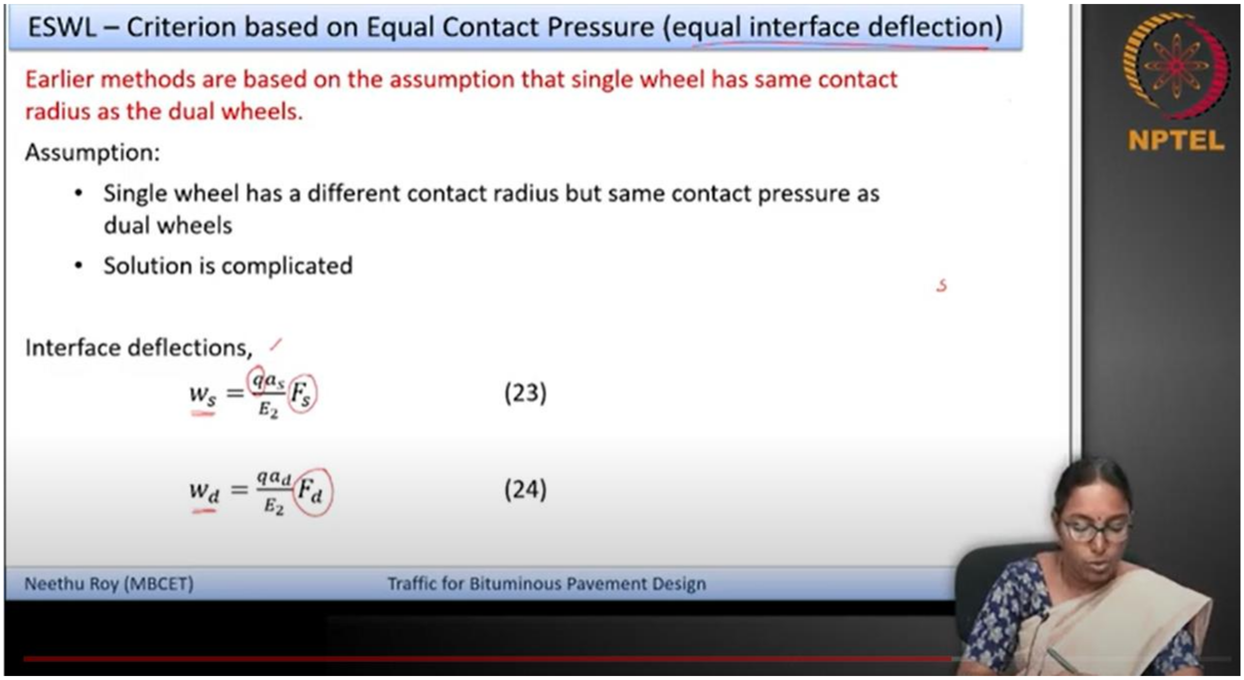

Now coming to the next approach wherein you consider equal contact pressure for the single as well as the dual. So the single and dual is having an equal contact pressure. So far, we have been discussing that the single as well as the dual wheel assembly have the same contact area. Now the assumption is that they have same contact pressure. Now problem with this method is that, it is slightly complicated to solve this. So moving on, the earlier methods that we have discussed based on the equal tensile strain or equal deflection or equal vertical stress are all based on the assumption that the single wheel, as well as the dual wheel both, have the same contact radius.

So the contact radius of the single wheel, as well as the equivalent single wheel load as well as the contact radius of the dual wheel assembly, is the same as what we have assumed. But in this approach, we are going to assume that both of them have equal contact pressure. So the radius will be different but the pressure due to the single wheel load will be the same as that of the pressure exerted due to the dual wheel. The problem with this method is, it is computationally difficult. So let us see again the criteria that is used for this approach is the equal interface deflection criteria.

So the interface deflection as we know is given by,

$$w_s = \frac{q_s a_s}{E} F_s$$

$$w_d = \frac{q_d a_d}{E} F_d$$

In this case, I have taken q as constant. w_s is deflection due to the single wheel and w_d is deflection due to the dual wheel and F_s is the deflection factor for the single wheel and deflection factor for the dual wheel is given as F_d. So in this, the q is taken as constant whereas the area the radius of contact a_s and a_d are different.

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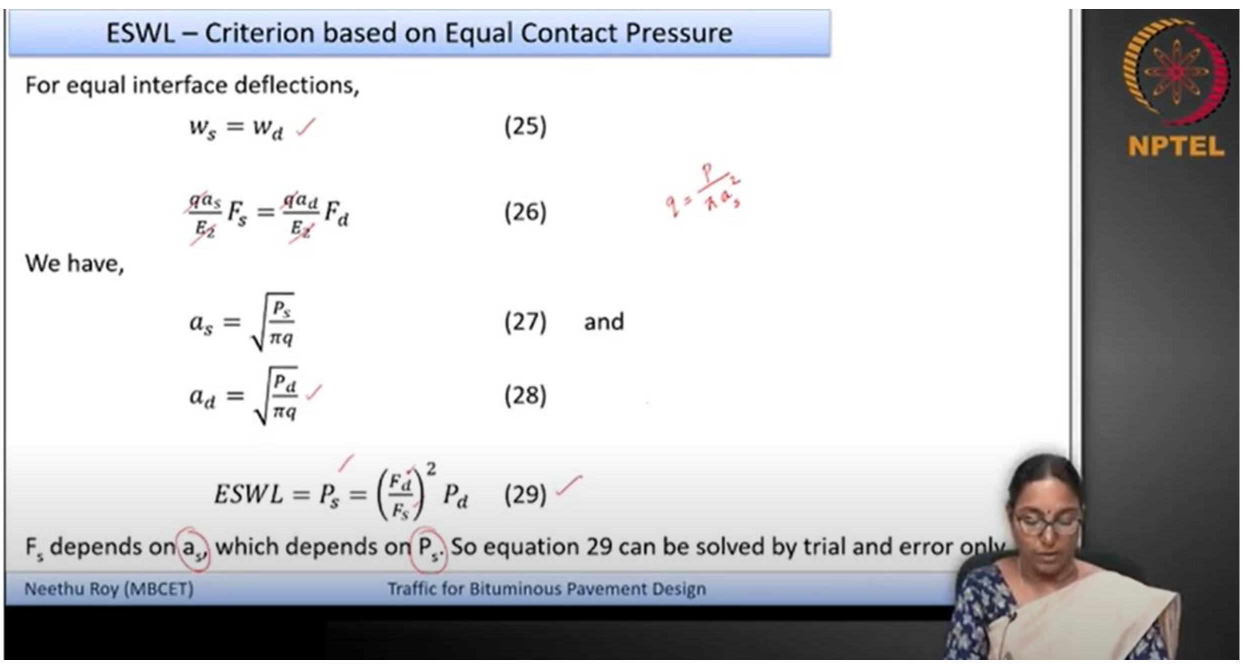

Now equating the deflection due to single and the dual wheel,

$$w_s = w_d$$

$$\frac{qa_s}{E_2} F_s = \frac{qa_d}{E_2} F_d$$

We can remove E_2 and q. Then, we will get the following.

$$a_s F_s = a_d F_d$$

$$a_d = \sqrt{\frac{P_s}{\pi q}}$$

$$a_s = \sqrt{\frac{P_s}{\pi q}}$$

a_s is the radius of the single wheel assembly and similarly a_d is the radius of the dual wheel assembly.

Now from the above expressions, we know that P_s is given by the following.

$$ESWL = P_s = \left(\frac{F_d}{F_s}\right)^2 P_d$$

If you get the dual wheel factor and the deflection factor for the dual wheel and the deflection factor for the single wheel, you can solve the above equation. But the problem is that for the single wheel, the deflection factor depends upon a_s but this depends upon P_s because if you have to get the radius of contact of the single wheel, you need to know what equivalent single wheel load is. So, this can be solved only by trial and error.

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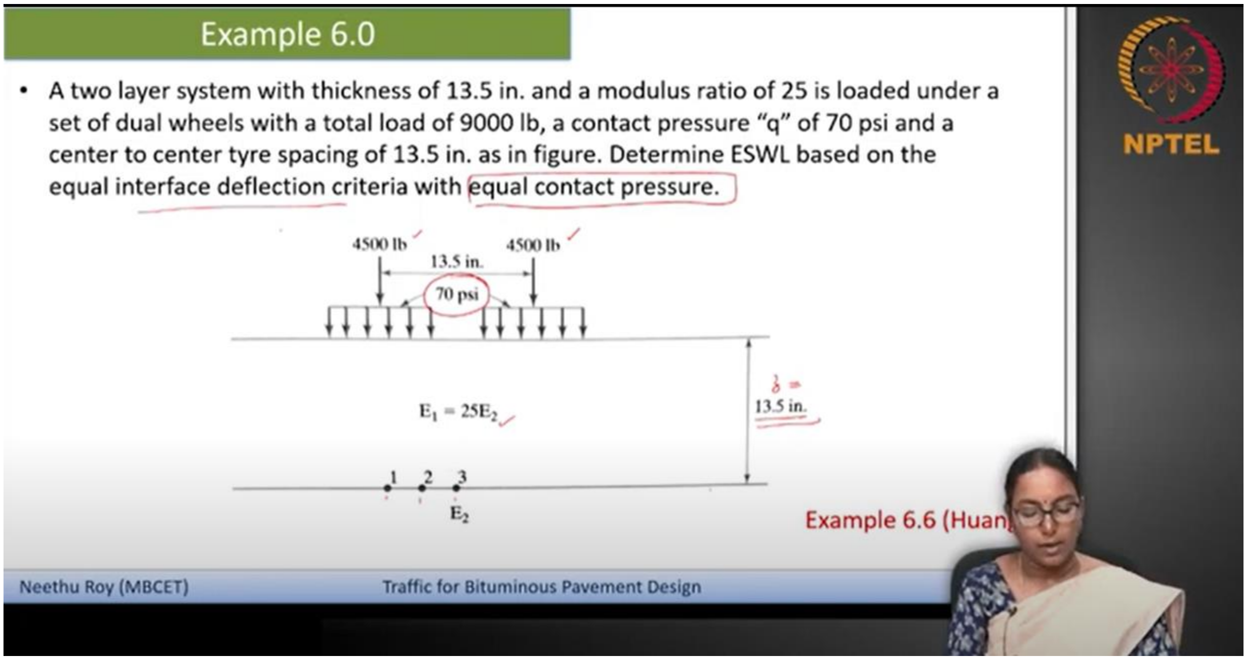

Let us try to solve the same question with $\frac{E_1}{E_2}$ ratio of 25 based on equal interface deflection criteria but with equal contact pressure. So, in this question, as you see here, there are 2 loads 4500 are dual wheel loads with a spacing of 13.5 inches and they have the same contact pressure of 70 psi. And you are asked to find the equivalent single wheel load for a pavement depth of z = 13.5 inch and again since you have dual wheels the deflection is the equal interface deflection criteria. So, the deflections at 3 points are to be noted in the case of a dual wheel and then you have to get the maximum deflection factor in any of these 3 points and that vector has to be taken.

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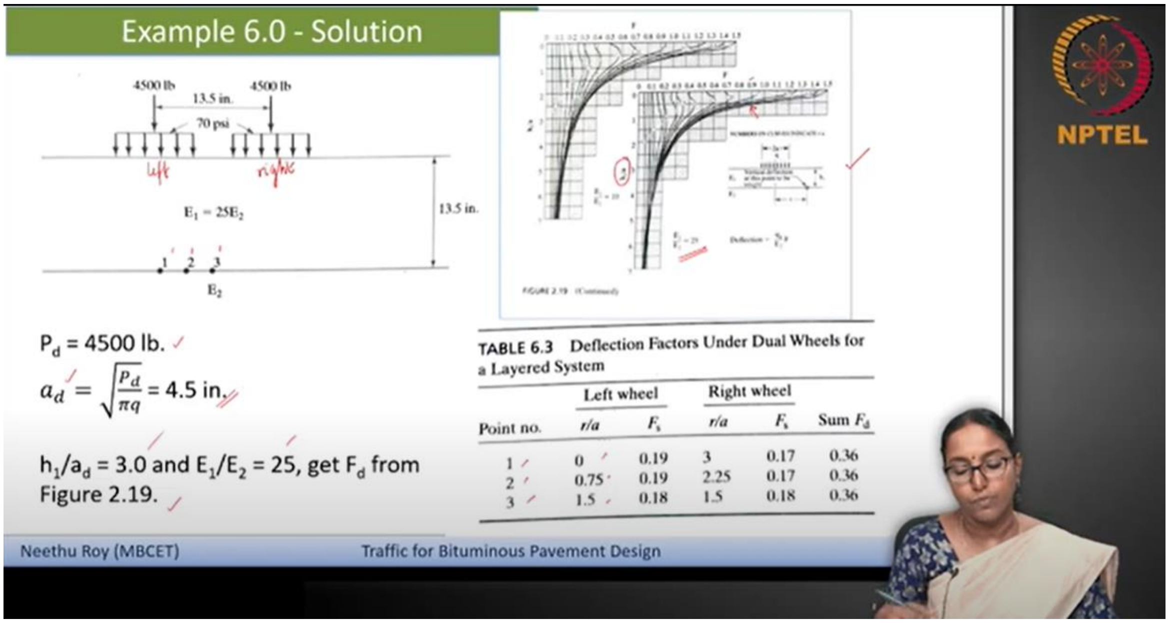

So, this is the interface deflection factor from the Figure 2.19 for different $\frac{E_1}{E_2}$. So, you have this $\frac{E_1}{E_2}$ equal to 25. So, I have taken that plot here. So, P_d that is one of the loads is 4500 for which the load is known to you. The radius of contact (a_d) is calculated as follows.

$$a_d = \sqrt{\frac{P_d}{\pi q}} = 4.5 \text{ in.}$$

So, in the case of a dual wheel, the radius of contact is 4.5 inch. Now let us take for the dual wheels. So, $\frac{h_1}{a_d}$ is 3, $\frac{E_1}{E_2}$ = 25. You can get F_d from Figure 2.19. Now for the dual wheels you have to note the different points. So, you have considered point number 1, point number 2, and point 3. This is the left wheel and this is the right wheel. As we have already discussed, these are the r/a values, and again for the various r/a values from this chart, and for the given $\frac{h_1}{a_d}$ values, you can get the F values. To use this chart for a single wheel load, you need this $\frac{h_1}{a}$ value but a is the radius of the single wheel which is unknown. Since we do not know the equivalent single wheel load we do not know the radius as well.

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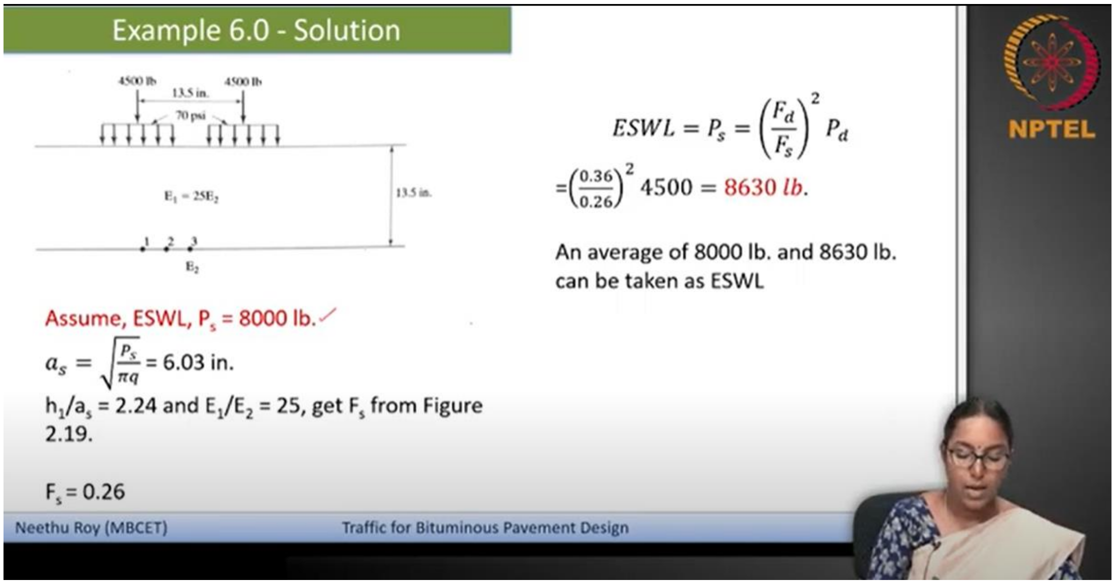

So, what you do is that you assume an equivalent single wheel load. Since the total load is 9000 pounds we assume that the equivalent single wheel load is 8000 pounds.

$$a_s = \sqrt{\frac{P_s}{\pi q}} = 6.03 \text{ in.}$$

Now you can note that for an $\frac{h_1}{a_s}$ of 2.24 and $\frac{E_1}{E_2}$ of 25, you can get the F_s value from this chart.

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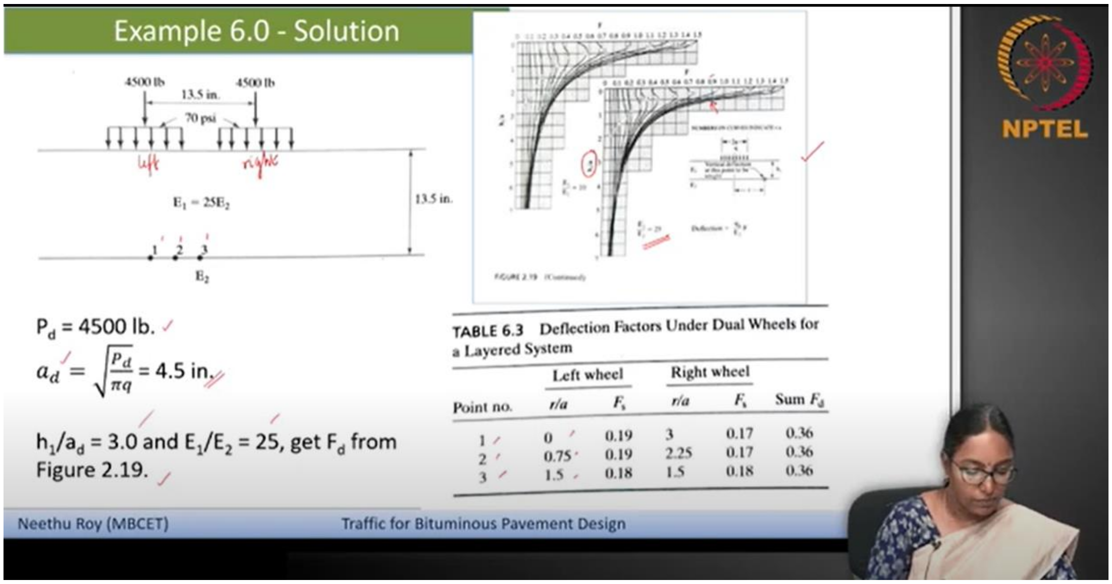

So, the Fs value for the single wheel is noted from the chart as 0.26 whereas for the dual wheel, you summed for the left wheel and the right wheel and you got it as 0.36, 0.36 and 0.36 for all the three points. So, the deflections are the deflection values are constant you know the same for all three values so the maximum is 0.36 of course.

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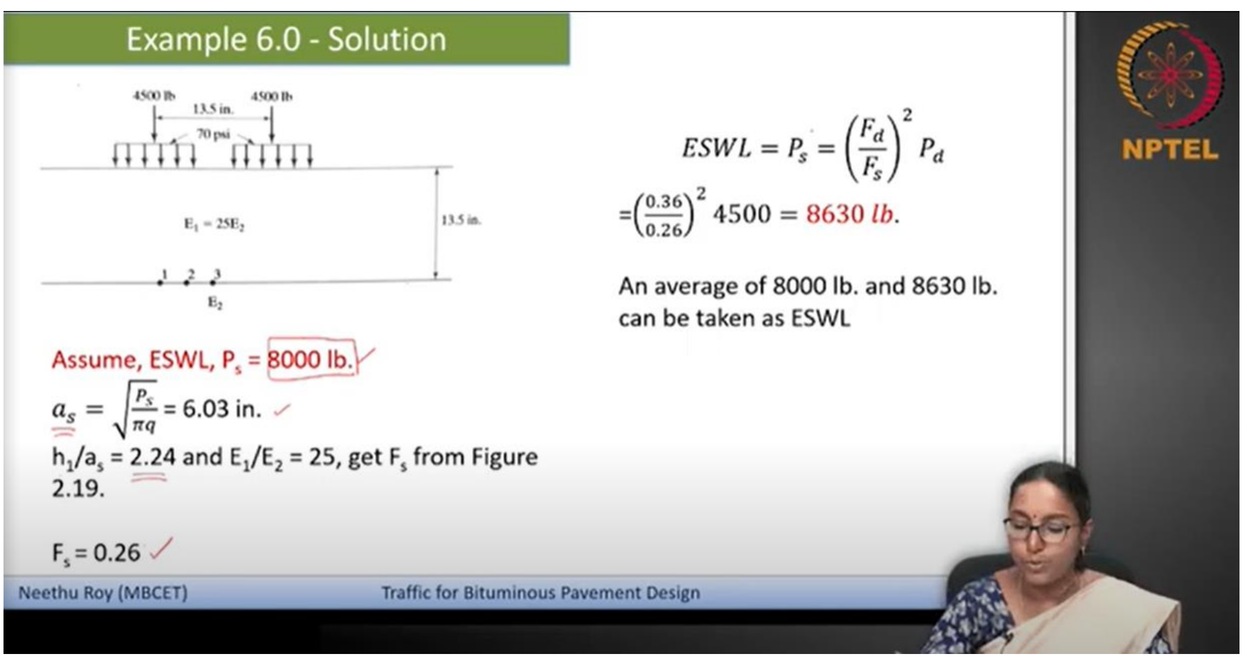

So, F_d for the dual wheel assembly is 0.36 and the F_s for the assumed equivalent single wheel load of 8000 is 0.26.

$$\mathrm{ESWL} = P_s = \left(\frac{F_d}{F_s}\right)^2 P_d$$

Now the equivalent single wheel load is 8630. So, you have assumed a value of 8000 pounds, and by trial, you determined what the equivalent single wheel load is and you got it as 8630. Now if you want, you can slightly increase the P_s value and again do this iteration and see what the ESWL is. But since you are reading from a chart, more accuracy may not be possible. So, what you can do is you can take an average value of 8000 and 8630 as the equivalent single wheel load. So, this is a trial and error approach wherein you have assumed that both of the wheel loads have or the equivalent single wheel load and the dual wheel are having different contact radius but they are having the same contact pressure.

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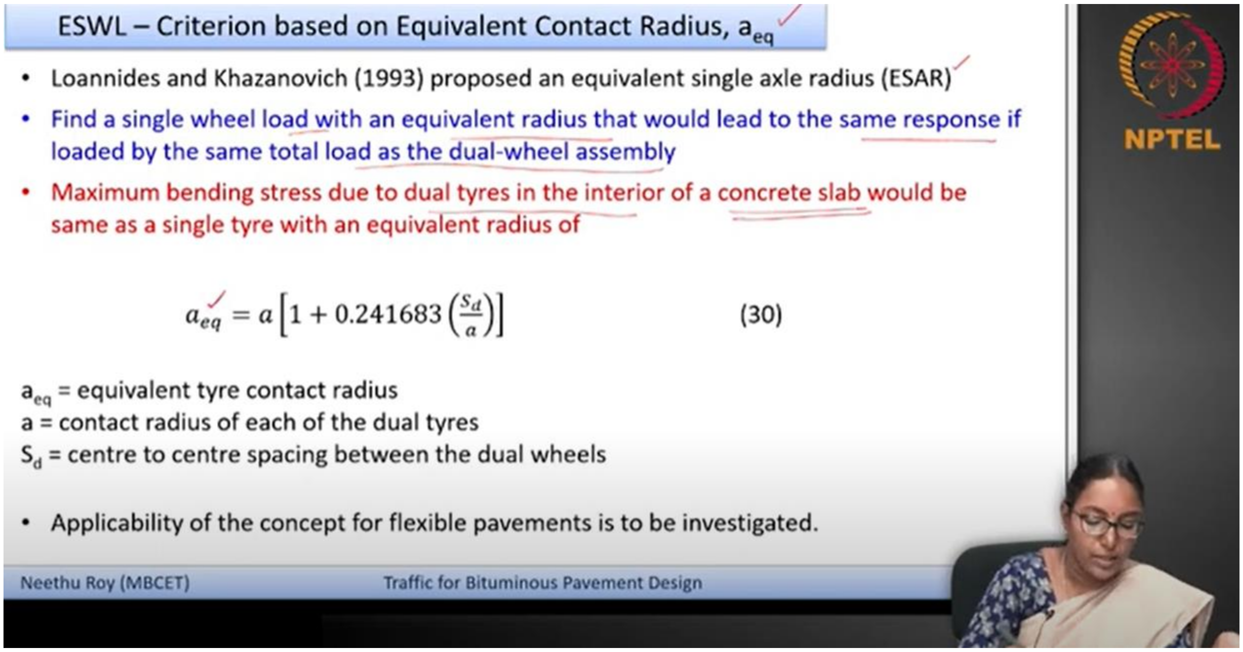

Now this is the last approach which is based on an equivalent contact radius. It is called ESAR, Equivalent Single Axle Radial. Now what you are going to find is a single wheel load with an equivalent radius that would lead to the same response if loaded by the same total load as a dual wheel assembly. So, what you are trying to keep constant here is that the dual wheel load as that of the sum of the two wheel loads which is say in the previous example it is 9000 pounds. So, if we load the same 9000 pounds what is it equivalent radius which will give you the same response?

So, you are not going to find the equivalent single wheel load but you are going to find an equivalent radius that will produce the same effect. Now this empirical equation is derived for maximum bending stress due to a dual tire in the interior of a concrete slab.

$$a_{eq} = a\left[1 + 0.241683\left(\frac{S_d}{a}\right)\right]$$

a_{eq} is the equivalent tire contact radius and a is the contact radius of each of the given dual tires and S_d is the center to center spacing of the wheels. So, this approach can be used for a concrete slab so wherein the usage of this for a flexible pavement is yet to be investigated. So, to summarize what we have discussed in these two lectures is how to convert a dual wheel assembly into a single equivalent single wheel load.

So, we have used different criteria such as the same vertical stress or same deflection, or same tensile strain with equal contact radius and the other approach wherein you have considered that the contact radius is different but the contact pressure is the same. So, likewise, you have converted dual wheel assembly to a single equivalent single wheel load. Thank you.