Advanced Design of Steel Structures
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Lecture - 54
Design check for LTB - 2

Friends, welcome to the 54th lecture of the course Advanced Steel Design. We are now continuing to discuss about the Lateral Torsional Buckling. In this lecture, we will learn how to do design check for lateral torsional buckling. Now, if you look into the international code as well as Indian code and see how these codes handle the design for members against lateral torsional buckling.

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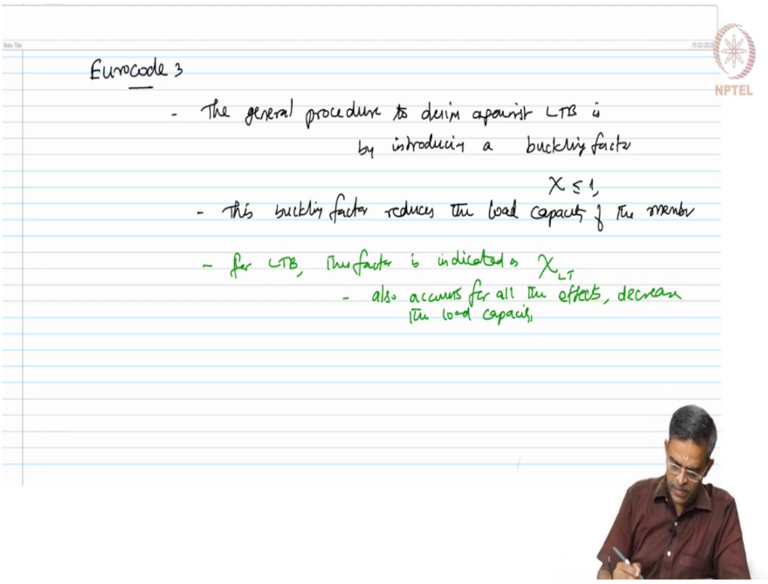

For example, we will discuss first with Eurocode 3. The general procedure is described in this code. So, the general procedure to design against LTB is by introducing a buckling factor. And, if this buckling factor psi is less than or equal to 1 considered to be, so now, this buckling factor reduces the capacity of the member. To be specific, when I am using this check for lateral torsional buckling; so, I should say for lateral torsional buckling, this factor is indicated as psi LT.

So, LT stands for lateral torsional bucking. Remember, this factor also accounts for all the effects which can decrease the load capacity. We have seen many factors which affects the capacity of the member under buckling. So, this factor psi LT will address all those concerned parameters which will contribute to decrease in load capacity or the moment carrying capacity of the member under buckling.

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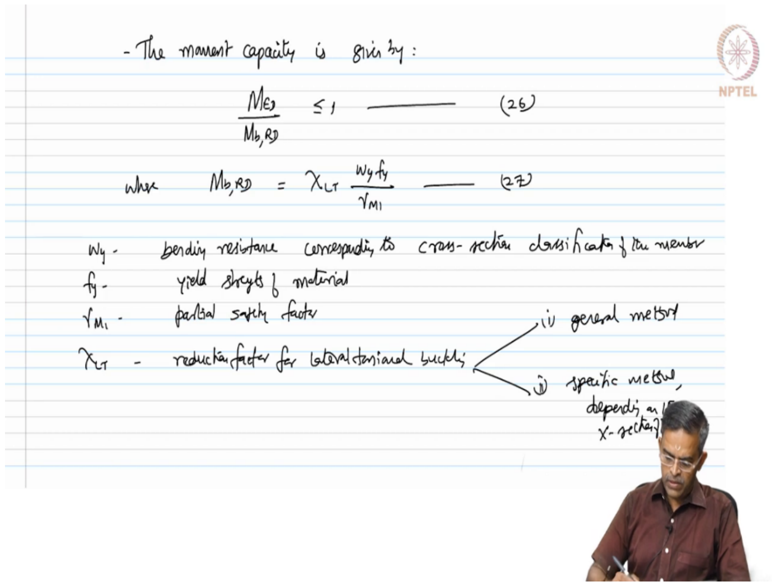

Now, the moment capacity is given by the following equation, M_{ED} /Mb R D is less than or equal to 1, call this equation number 26. Because I am doing the continuation what we had in the previous lectures, were M b R D is actually given by the factor of psi LT which is W y f y by gamma M 1, equation number 27. Now, let us see W y is a bending resistance corresponding to the cross-sectional classification of the member. I think we all know even the cross section is classified, according to the section being used.

And of course, f y is the yield strength of the material, gamma M 1 is the partial safety factor and psi LT is a reduction factor for lateral torsional buckling. Now, this reduction factor can be calculated by two methods. One you can have a general method and you can have an specific method to calculate psi LT. We will see both, specific method depends depending on the cross section of the member. There are two procedures available in the literature.

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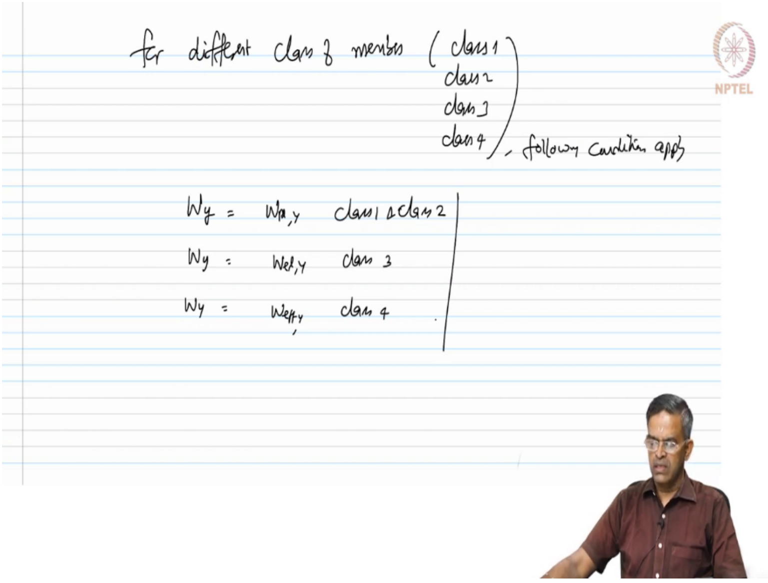

Now, for different class of members certain conditions also apply varying from class 1, class 2, class 3 and class 4 of the members, following conditions also apply. Let us see what they are, W y will be W pl, y for class 1 and 2, W y is taken as W el, y for class 3 and W y is W effective y for class 4. This is as per the advice of the Eurocode. Now, Eurocode also gives us a table for correction factors of moment gradient conditions.

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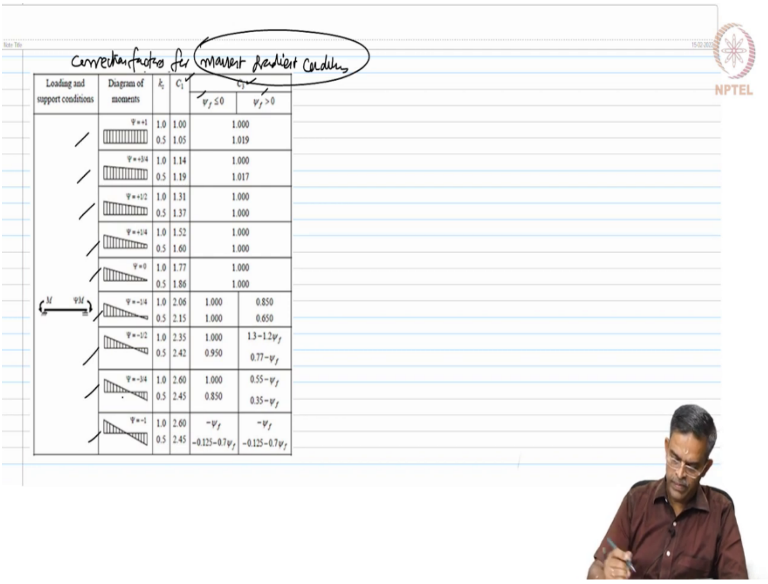

So, this is actually the correction factor for moment gradient conditions given by the code. One can see different types of possible bending moment distribution and you can also look into the factors C 1 and C 3 depending upon psi f less than or more than 0, for different loading conditions. We will use; we will be using this correction factor when you do a problem. Now, let us discuss the general method.

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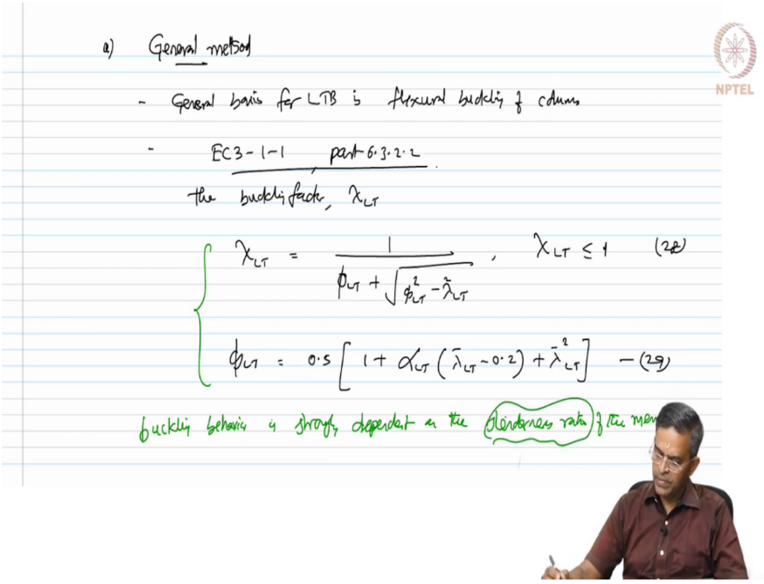

As we just now said the code suggests two alternate methods to check the stability design of the beams under bending. The designer can choose any method appropriate to the specification as recommended by the local codes, both follow a similar procedure. The general method recommended for lateral torsional buckling of beams is given based on the flexural buckling of columns. So, the general basis for LTB is flexural buckling of columns. The parameters are derived for the behavior of members of the bending.

So, Eurocode part 3-1-1, part 6.3.2.2 is what we are specifically referring to. This specific factor gives the buckling factor. This is given by the equation as written from the code, 1 by phi LT of square root of squares of phi square LT - lambda square LT for psi LT less than 1 because 3 28 , where phi LT, LT stands for Lateral Torsional bucking is 0.5 times of 1 + alpha LT of lambda LT - 0.2 + lambda bar square LT, equation 29.

So, one can very easily write a note here, looking at these two equations one can say the buckling behavior is strongly dependent on the slenderness ratio of the member.

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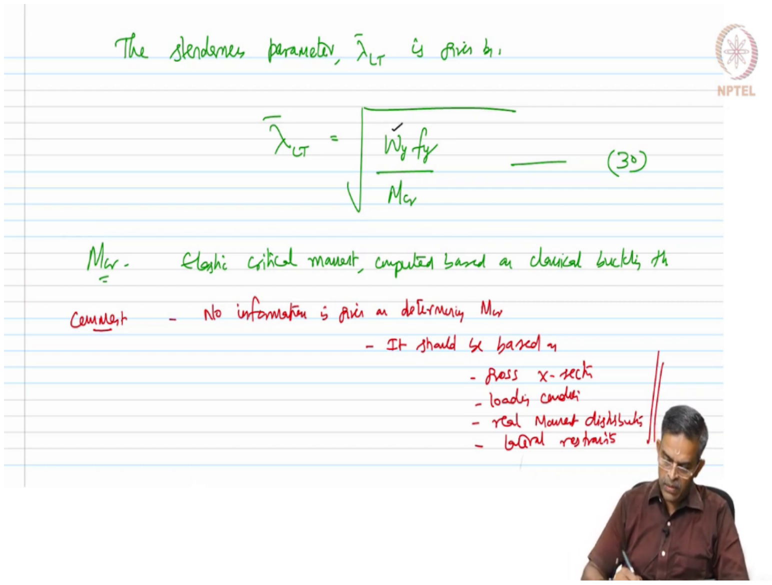

The slenderness parameter psi LT is given by the following equation, sorry not psi LT lambda bar LT. So, lambda bar LT is given by √Wy fy/ Mcr. I think we know all these terms earlier; we have been discussing this. For example, we know M c r is the elastic critical moment based on classical buckling theory. We can also recollect that this M c r accounts for the critical moment effect, imperfections, and residual stresses.

There are correction factors know, three factors which we were discussed in the last lecture. There is one important comment which we like to make here. The comment is the code does not provide any information on determining M c r. But, it states that it should be based on the gross cross section, the loading condition, real moment distribution and lateral restraints used to control the lateral torsional buckling.

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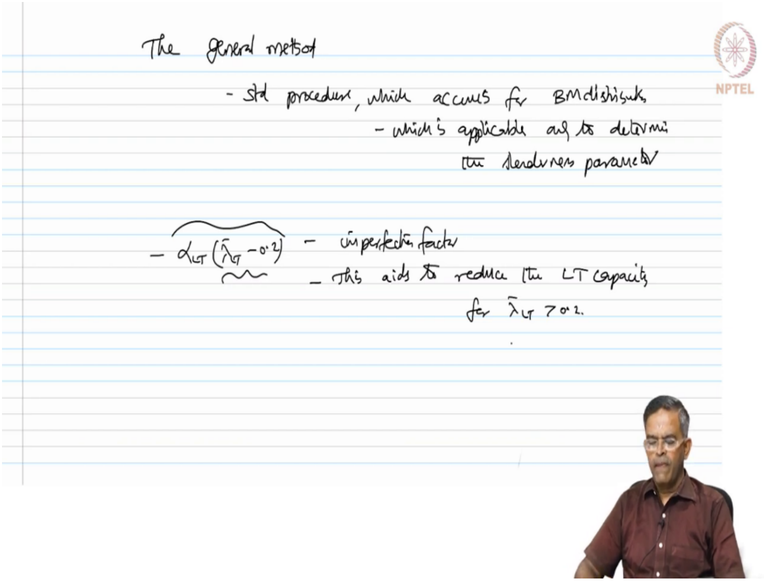

So, we can also make another comment on this procedure, that the general method is a standard procedure which accounts for the bending moment distribution which is applicable only to determine the slenderness parameter. How can I say that? The slenderness parameter depends on W y and we have seen a table which talks about the moment gradient conditions for different moment distributions. So, we can very well say that the general method is concerned about the moment distribution pattern and the boundary conditions as applicable determine the slenderness parameter.

Now, alpha LT which is called the imperfection factor, in fact, we should say not alpha LT, we should say alpha LT into lambda LT - 0.2, I mean that is the whole factor here. This accounts for imperfection factor. This aids to reduce the LT capacity , for lambda bar LT greater than 0.2 , that is why it is - point. So, in simple terms the lateral torsional buckling curves will have a plateau length of 0.2 are only applicable under this condition.

We have also seen the table which gives me the bending moment distribution and the corresponding factors for that which can be used in parallel to the lateral torsional buckling curves which will be using them in the analysis.

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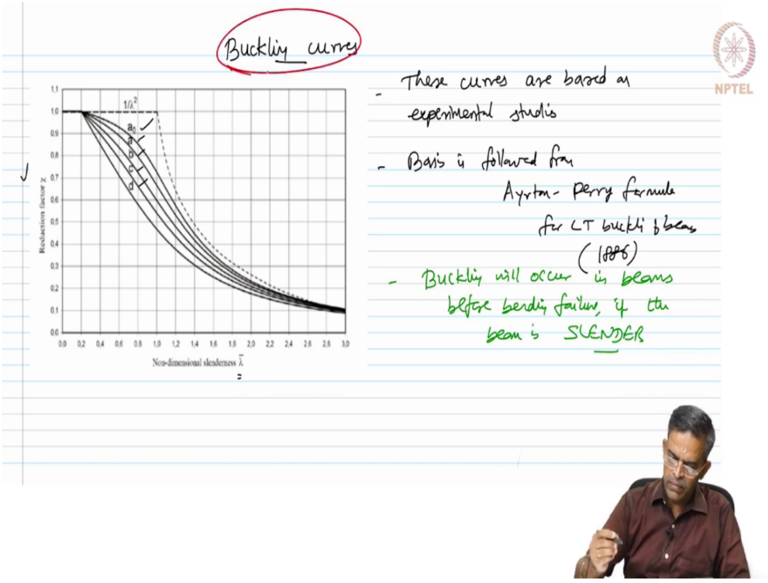

Then, we will talk about the buckling curves, because that is a part of the general method.

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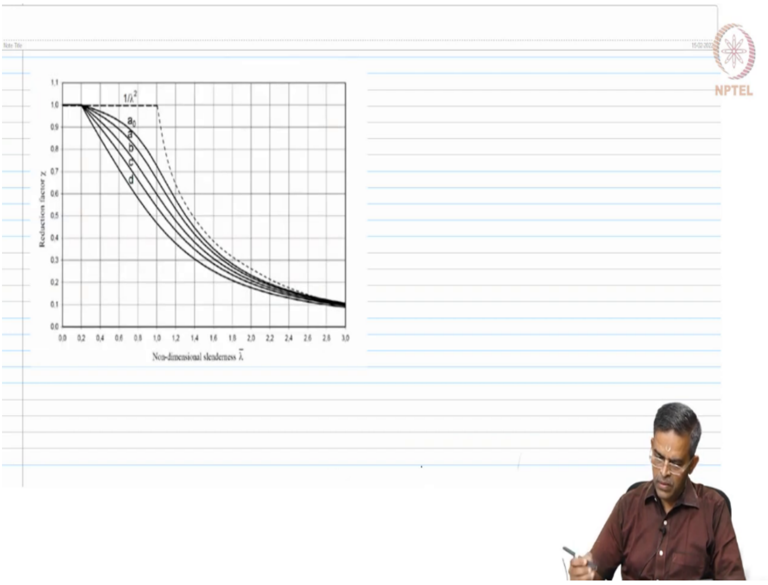

I will copy this figure and put it here. The one what you see on the screen is a non-dimensional lambda bar which accounts for the reduction factor. It is a buckling curve given for different designation as a, b, c, d and a naught curve. Now, these curves are based on; these curves are based on experimental studies conducted to investigate the beam under bending. Lateral torsional buckling curves applicable different cross sections were developed subsequently right.

So, it has got a basis of the basis is followed from Ayrton Perry formula for lateral torsional buckling of beams. This was developed much early in 1886. So, this states very interesting condition that buckling will occur in beams before bending failure, if the beam is slender. So, buckling failure preludes the bending failure. So, therefore, in doing this analysis, the buckling factor becomes a very important parameter.

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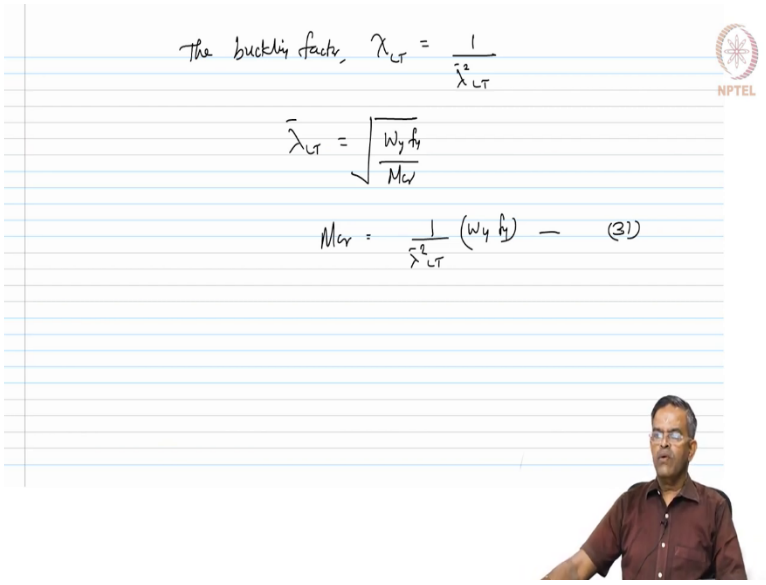

So, the buckling factor which is psi LT is equal to 1 by lambda bar square LT, where lambda bar LT is given by W y f y by M c r. So, from this we can say M c r is 1 by lambda bar square LT of W y f y, can you say that? We call equation number 31. Now, we can see in this curve there are different grades like a naught, a, b, c, d. They are different choice of buckling curves which depends on the cross section, type of steel quality and manufacturing method. Let us have how do they vary. Let us see that.

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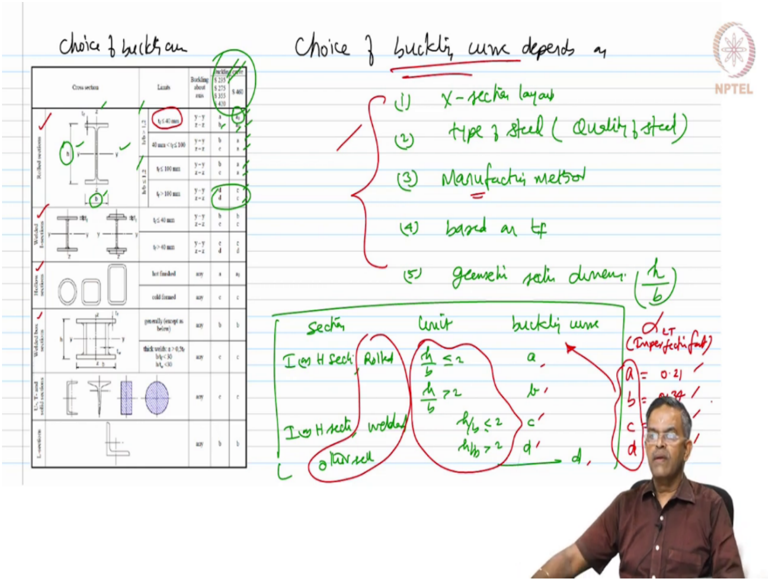

Please look at this table. The choice of buckling curve depends on this is choice of buckling curve. How can you say this choice of buckling curve? I will just show you, you can see here there are varieties of curves being recommended, buckling curves. It depends on various parameters. Number 1, it depends on the cross-sectional layout, 2, it depends on type of steel.

To be very specific, Eurocode puts us quality of steel, S 235, S 275, S 355 and so on , you can see here. It also of course, depends on manufacturing method. If you carefully look at this code, the values of the choice of curve depends on whether it is manufactured in the standard procedure, whether it is welded I section that is built up section, if it is an hollow section or a box section and so on.

So, depends upon how you manufacture, how do you fabricate the choice of curve is different, number 1. Number 2, it also limits the thickness of the flange. You may wonder why flanges thickness is limited. We already know flange governs buckling, is it not; thickness governs buckling, we already saw that in the three parameter formulae in the last lecture about e_{cr} M_{cr}.

So, we got that value and understood how it is. Also remember friends, if it is buckling about major then the curve choice is different, it buckles about minor then the curve choice is different. Of course, these curves are close to each other for a larger value of lambda, but still there is a variation. And, these are all depend on experimental finding.

Furthermore friends, there is also a ratio of the geometric section dimension that is depending upon h by b, h is the overall depth of the section, b is the overall breadth; depending upon h by d h by b for the section you also have different curves. So, that is very interesting to see how they are classified well in detail in the code. Furthermore friends, in a short summary we can say that if it is an let us say type of section, limit value and the recommended buckling curve.

If you look at this summary very quickly from this table for I or H sections which are rolled, if h by b is less than or equal to 2, we can look for a, if h by b is more than 2, look for buckling curve b. If it is welded, then if h by b is less than 2 equal to 2, look for curve c. If it is more than 2, you can look for curve d. For all other sections, you only use curve d. These are all the recommended buckling curves as per the code, as a summary extracted from the table what you see on the left side.

Furthermore, for every buckling curve, one has also recommended the imperfection factor alpha LT called imperfection factor. So, for a curve this factor is 0.21, for using b buckling curve it is 0.34, for c curve it is 0.49 and for d curve it is 0.76. These are all type of buckling curves. Having said this, if the theoretical buckling factor is plotted for different values, the relationship is actually given as you see in figure 324 ; as you see in this figure it is plotted. The corresponding limited values are also given in the table as you see here.

There is a curve what we have; this is the curve what we have. This is the curve what we have and there is a table recommended by the code. And, the buckling curve depends on various parameters and depending upon the type of manufacturing and the section limitations, we have recommended certain curves by the code whose imperfection factor is also given. So, now we can say very clearly some summary, very quick observation on this.

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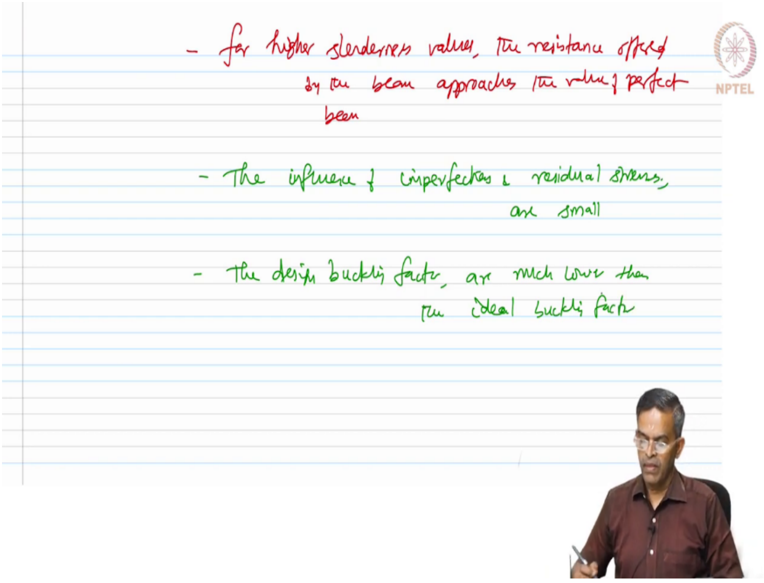

For higher slenderness values, the resistance offered by the beam approaches the value of perfect beam. Furthermore, it is also seen the influence of imperfection and residual stresses, though they are considered in the buckling curves they are small. Furthermore, the design buckling factor are much lower than the ideal buckling factor. So, it gives me a conservative design of this general approach.

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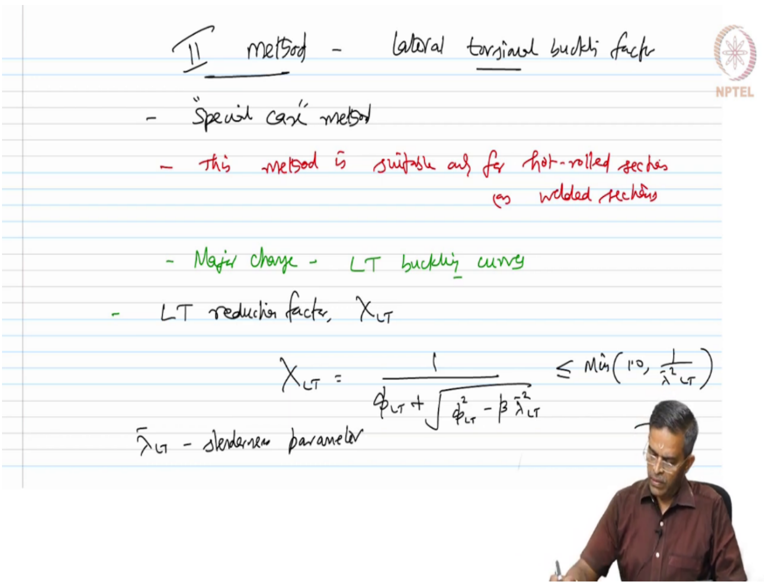

There is another method by which we can use, this is second method. The second method is useful to calculate the lateral torsional buckling factor. Let us quickly see how this method works. This is referred as a special case method in the code. This method is applicable for beams with hot rolled an equivalent welded section only. Now, what is the variation? The major change is reflected in the lateral torsional buckling curves.

So, according to this method, the lateral torsional buckling reduction factor which is psi LT is given by 1 by phi LT + squares of phi LT square - beta lambda bar square of LT subject to a value which is minimum of 1 by lambda bar square LT; equation 32, where lambda bar LT is the slenderness parameter.

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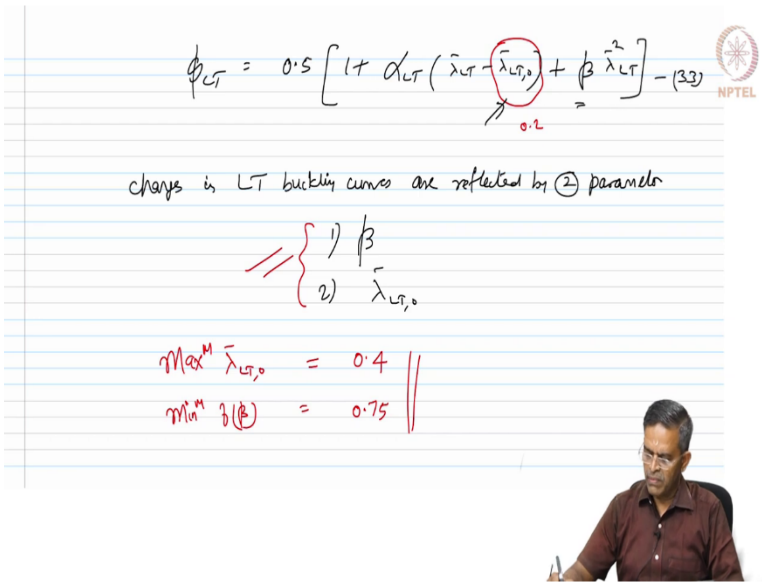

Further, phi LT can be computed using this expression 1 + alpha LT of lambda bar LT - lambda bar LT at 0 + beta lambda bar square. If you look back the previous equation, you would remember and recollect immediately that this was flattening of 0.2 earlier. So, that is now changed significantly by the alternate method as I am discussing now. We call equation number 33 is it not, yeah 33.

So, now considering these two equations 32 and 33, the shape of the lateral torsional buckling curves significantly changed compared to the general method. Now, the changes are reflected, changes in the LT buckling curves are reflected by two parameters. One parameter is referred as beta which is seen here. The other parameter is alpha bar sorry lambda bar LT coma 0 which is indicated here.

So, now the code also imposes a maximum limit for lambda bar LT naught. The maximum limit imposed by the code is 0.4. Therefore, designers do not have to count on reduction factor for lateral torsional buckling, if lambda bar LT is less than 0 and 4 is the slenderness range. And, there is a minimum value of beta, recommended by the code which is 0.75.

So, friends as we now understand the lateral torsional buckling curves are significantly modified by the second method compared to the general method. The second method is called a special case method which is significantly different from the general method because, of these two parameters and the limits are given here.

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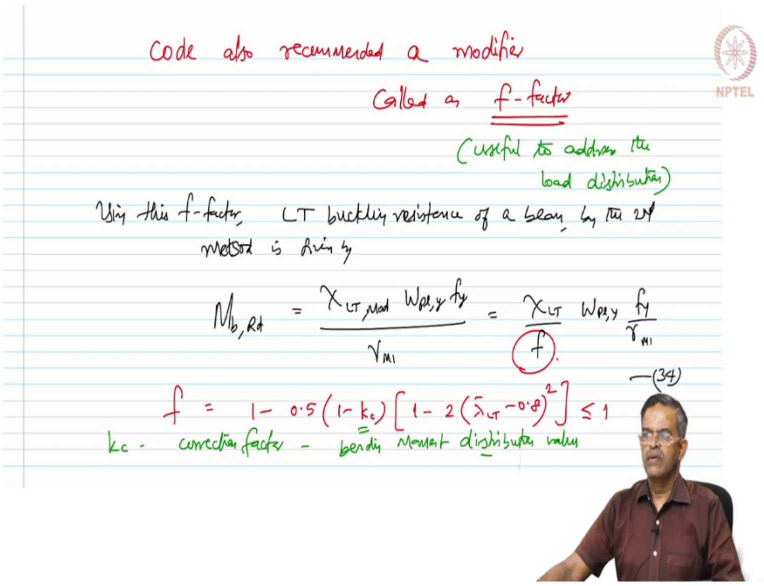

In addition to this, Eurocode also proposed a modifier called as f factor method, code also recommended a modifier called as f factor. Now, this f factor is useful to address the load distribution, because you see in the general method the bending moment distribution was addressed by a tabular value depending upon thickness of the flange, method of manufacturing, all those things were there.

So, the second method that is also taken care of by a factor called f factor. So, now using this f factor, the lateral torsional buckling resistance of a beam by the second method is given by M b R d, which is psi LT modify W p l, y f y by gamma M 1 which is given by psi LT by f, W p l, y f y by gamma M 1; call equation 34 right, yeah 34. Now, in this equation you will notice there is a factor f.

This factor is given by 1 - 0.5 times of 1 - k c of 1 - twice of lambda bar for LT - 0.8 the whole square and this is limited to 1. It is a reduction factor. In this, k c is called correction factor. What does it correct? It corrects the bending moment distribution value, depending upon the bending moment distribution pattern this factor is recommended. So, now let us see how this factor looks like in the code.

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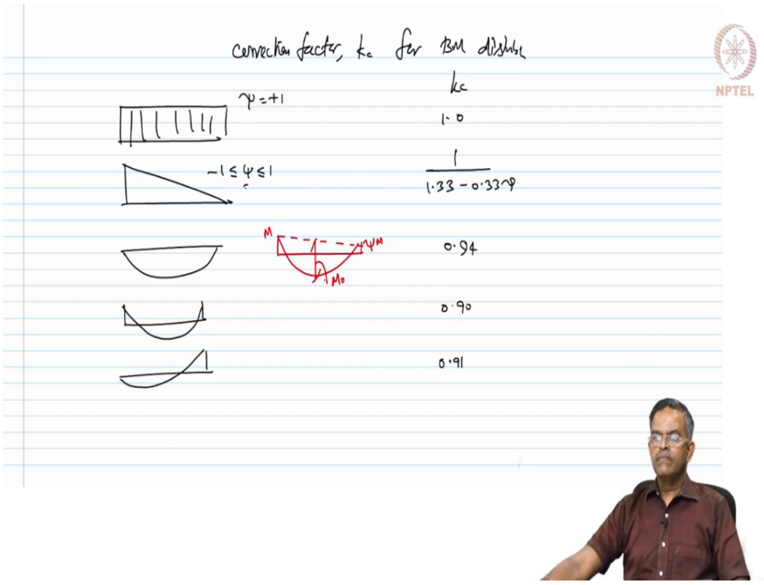

For various types of bending moment distribution, let us say the correction factor k c for BM distribution. So, we say if it is uniform, where this is + 1 k c is 1.0. If it is triangular varying from - 1 to + 1, then k c is given by 1 by 1.33 - 0.33 psi. If it is distribution of this order 0.94, if it is distribution of this order which can be a fixed beam 0.9, if it is eccentric on overhang is 0.91.

So, now psi is a factor, how do you work out this factor? If I have the fixed end moments of this order and span moment of this order, if we call this as M and this as psi M. So, psi is a fact is a factor and this is my maximum M naught.

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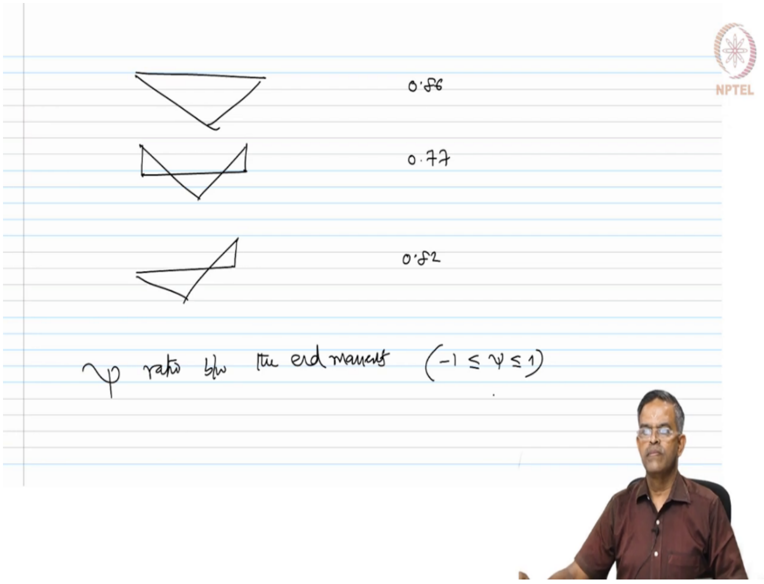

So, if we have a triangular distribution, then k is 0.86, if you have a distribution of this order which is linear 0.77. These are all for point loads, I think you can recollect the bending moment diagrams very easily related to the type of load. We can say here psi is a ratio between the end moments, that is what we have written there. It can vary anywhere from - 1 to + 1, it is a ratio between the end moments.

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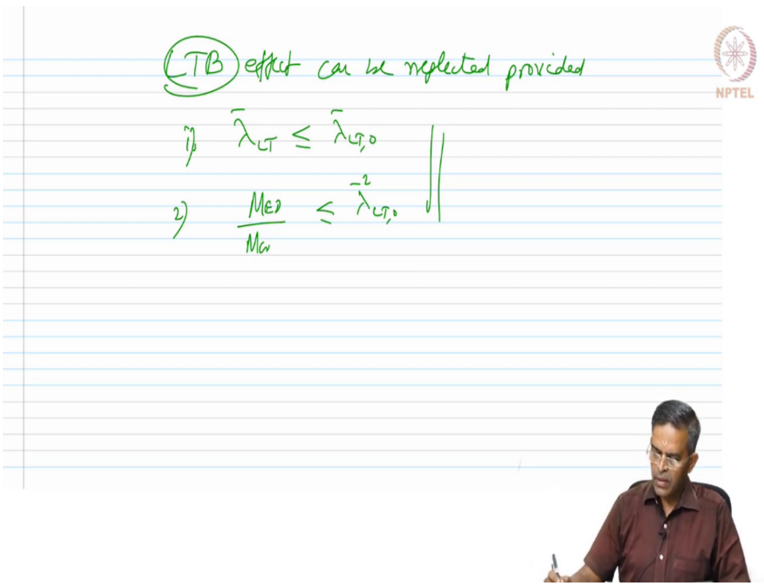

Now, code also advises very interestingly a statement; lateral torsional buckling effect can be neglected provided lambda bar LT is lesser than lambda bar LT 0 and M ED by M c r is lesser than equal to lambda bar square LT 0. If this condition is satisfied, then you can neglect the lateral torsional effect in the design. Now, the buckling curves are also having different designations.

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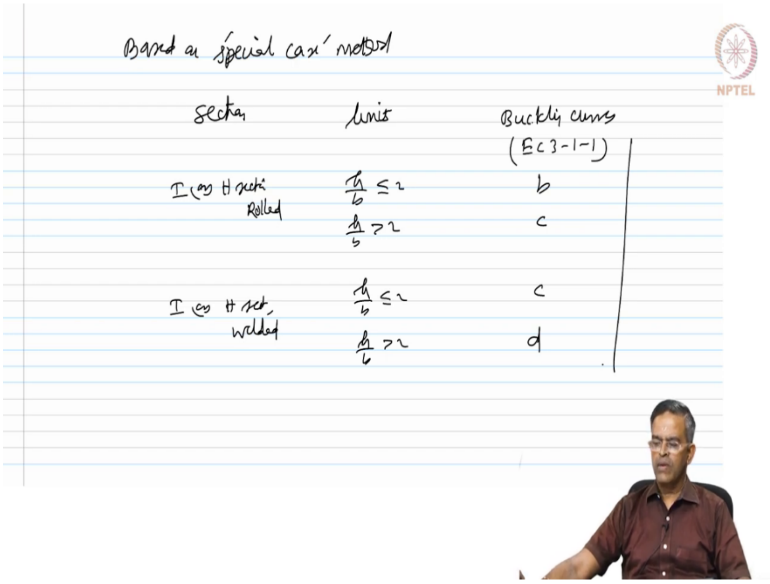

Based on the special method depending upon the type of section and depending upon the limits, the buckling curves are also recommended, and this is available in EC 1-1. For I or H sections which is rolled, if h by b is less than or greater than 2, then I can use b or c. For I or H section, which is welled, that is built up section, if h by b is less than or more than 2, I can use c or d curve. This is recommended by the code, when you start using the second method, special case method.

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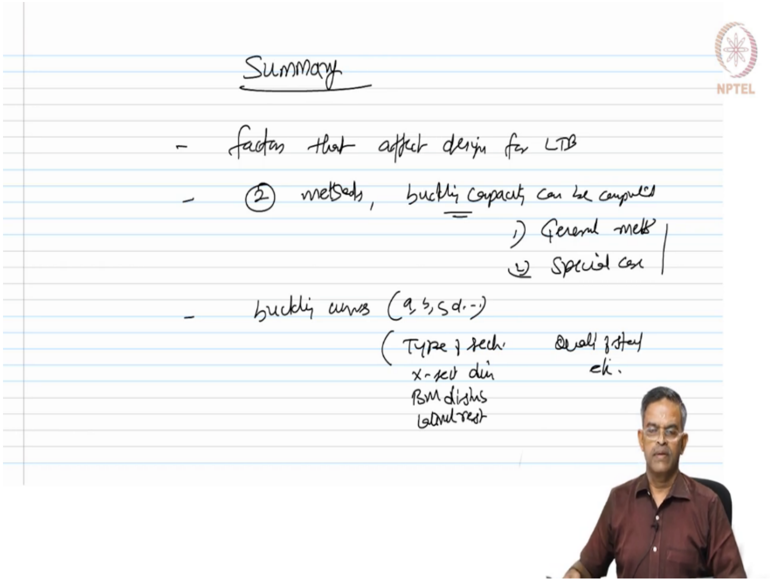

So, friends in this lecture, we learnt what are the factors that affect design for lateral torsional buckling. 2 methods by which the buckling capacity can be computed which is one is a general method; one is the specific case or special case method. We have also seen there are different buckling curves which as a, b, c, d etcetera which can be selected to compute the buckling capacity depending upon the type of section, the sectional dimensions, bending moment distribution, type of lateral restraints and quality of steel etcetera.

So, in the next lecture, we will take up a design example and solve this using Eurocode as well as Indian code and illustrate step by step the decision procedure to design or check the beam against lateral torsional buckling.

Thank you very much. Have a good day.