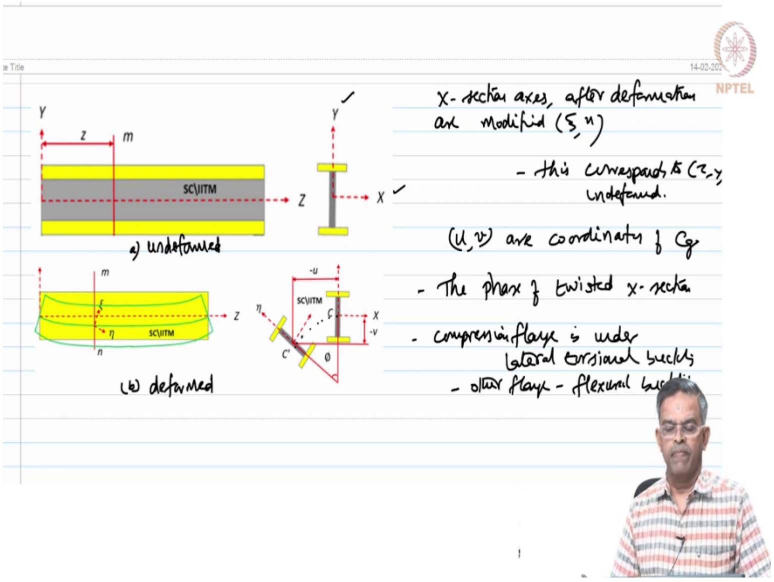
Advanced Design of Steel Structures
Dr. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Lecture - 52
Lateral torsional buckling

Friends, welcome to the 52nd lecture on Advanced Steel Design. We are going to continue to discuss the Lateral torsional buckling. In the last lecture we explain independently how do we get lateral, torsional and why it is called as buckling. Let us recapture the last figure, what we drew for an undeformed and deformed geometry which I have drawn on the screen now.

(Refer Slide Time: 01:00)

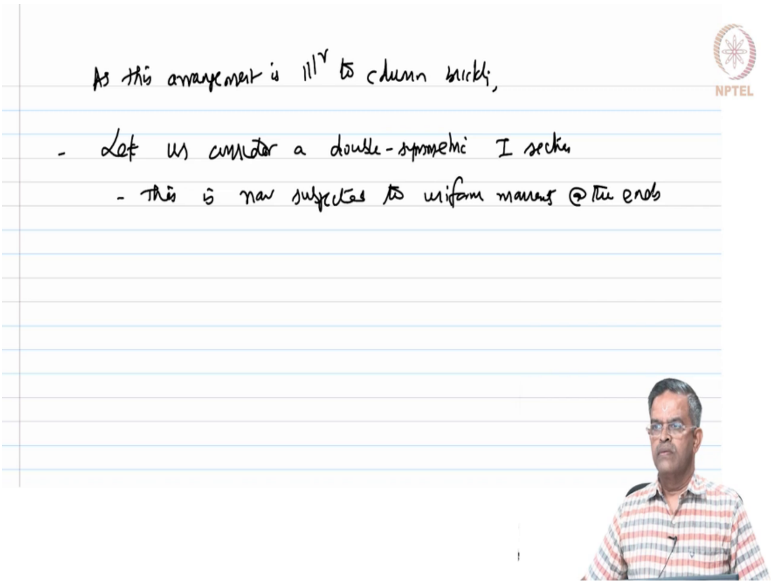


So, this is my undeformed geometry. And, the second figure what you see is the deformed geometry. So, we are considering a simply supported beam, as loaded. The cross-section axis are now modified, the cross-section axis after deformation are modified as ζ, η axis as you see in the figure and this corresponds to Z, Y axis which is undeformed,. Let us also understand that u and v are coordinates of the C g of the section which will now designate the new position after twisting.

Now, having said this, let us look at the deformed geometry where the C g point is shifted to C prime and the rotation is ϕ. So, now, let u and v are marked as - u and - v because you know the positive X and positive Y are in the other direction as you see here. So; obviously, C dash is displaced in the negative coordinates of X and Y respectively as u and v as shown in the figure.

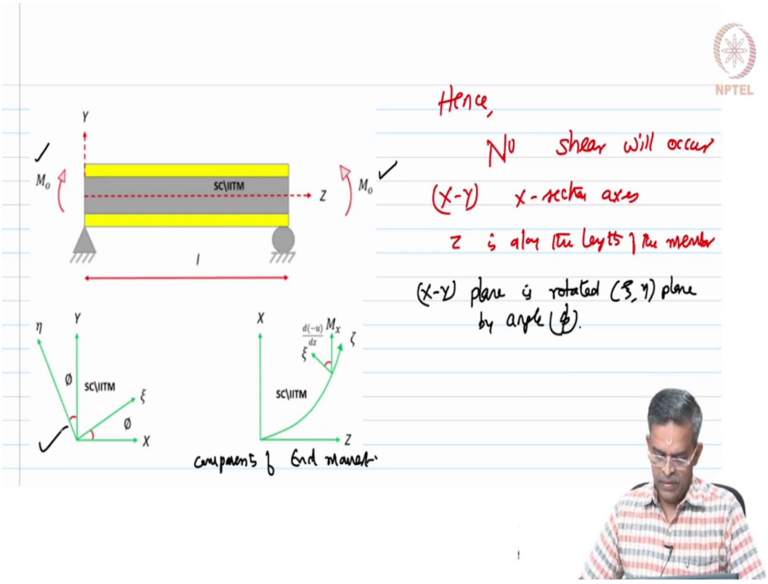
Now, the twisted cross-section, the phase of the twisted cross-section, signifies the flange under flexural bending; while the compression flange is under lateral torsional buckling. You know it's a simply supported beam we can very well see from the figure that the compression flange is under lateral torsional buckling. Whereas the other flange is under flexural buckling. Now friends, this arrangement is like the column buckling.

(Refer Slide Time: 04:36)



Therefore so, elastic buckling equation can be derived for a simply supported beam. Now, let us consider a double-symmetric I section. This is now subjected to uniform moments at the ends.

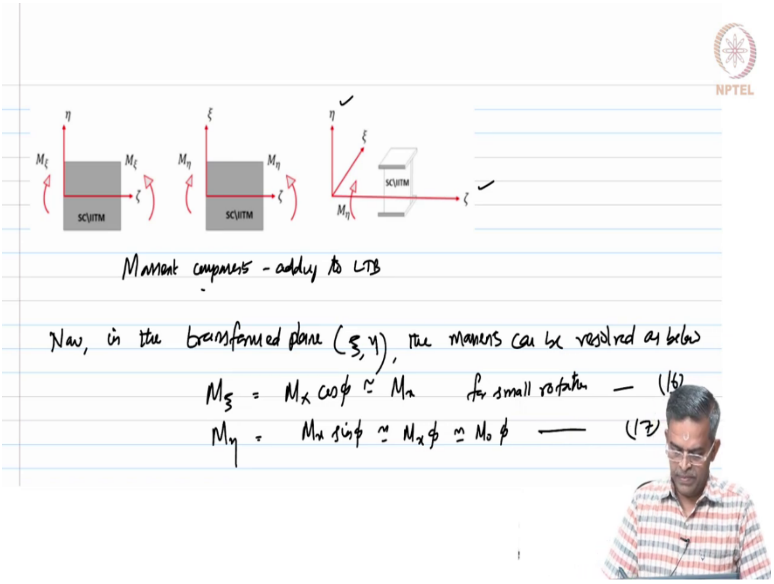
(Refer Slide Time: 05:50)



So, let us see this figure, it is subjected to uniform moments at the ends M0. under such arrangement no shear will happen. No shear will occur. So, the X-Y cross-sections cross-section axis and the Z-axis or marked as shown in the figure. So, X-Y is the cross-section axis and Z is along the length of the member. Now, let us look into the bottom figure where I am marking the components of the end moment.

So, these are the components of the end moment. When you look at the figure showing the components of the end moment, one can very well see the X-Y plane is rotated to ζ, η plane by an angle ϕ, correct. See here. Now, when I try to mark the moment components which will account for lateral torsional buckling so, these are the moment components.

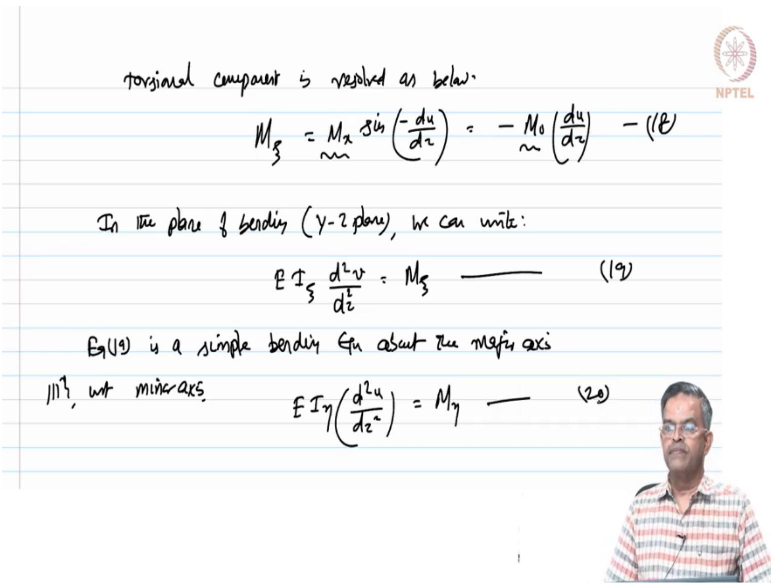
(Refer Slide Time: 08:03)



So, now, I can say what are the components of the moments, which will add up to LTB? So, these are the components of the moment which will add up LTB, where you can see that Mζ and Mη both are adding together to form the moment about η, ζ axis which is inclined at an angle ϕ to the original X-Y axis,. So, now, in the transformed plane, what is the transformed plane? I should say ζ, η. The moments can be resolved as follows. So, M ζ will be equal to M X cos ϕ which is approximately equal to M x for small rotations as a continuity we mark this equation number 16.

Similarly, M η will be M x sin ϕ which will be approximately equal to M x of ϕ which can also be said as M_0 of ϕ, ok, that is what the original moment we applied equation number 17.

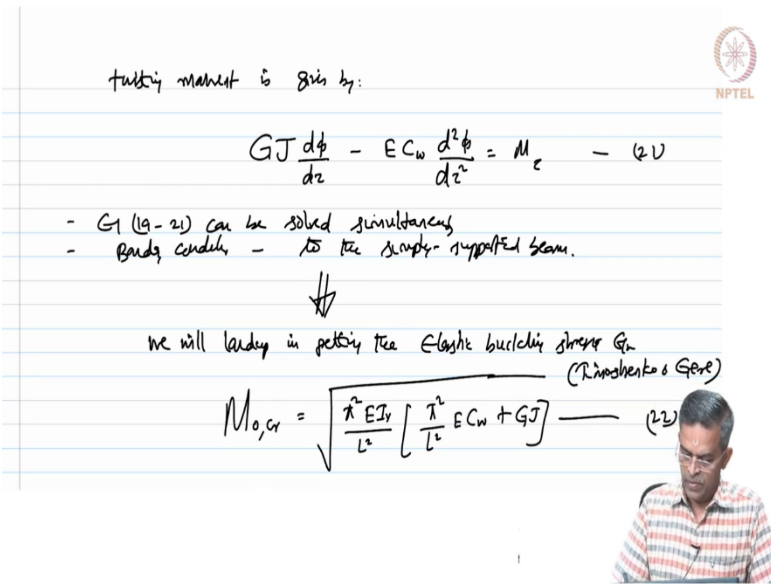
(Refer Slide Time: 10:07)



Now, the torsional component is resolved as below. Will be given by M x sin (- du/dz); as z is the axis along the length of the member which came you know said as – M_0 du/dz equation number 18. So, one can very well notice here, M x replaces M0 because M0 is the end moment acting about the X-X plane. Now, in the plane of bending which is the Y-Z plane we can now write E I ζ d^2v by dz^2 will be M ζ equation 19.

Equation 19 is a simple bending equation about the major axis. This is written in consensus with the general equation with respect to axis the beam. Similarly, with respect to minor axis, we can say E I η d^2u by dz^2 will be M η, ok, we call equation number 20.

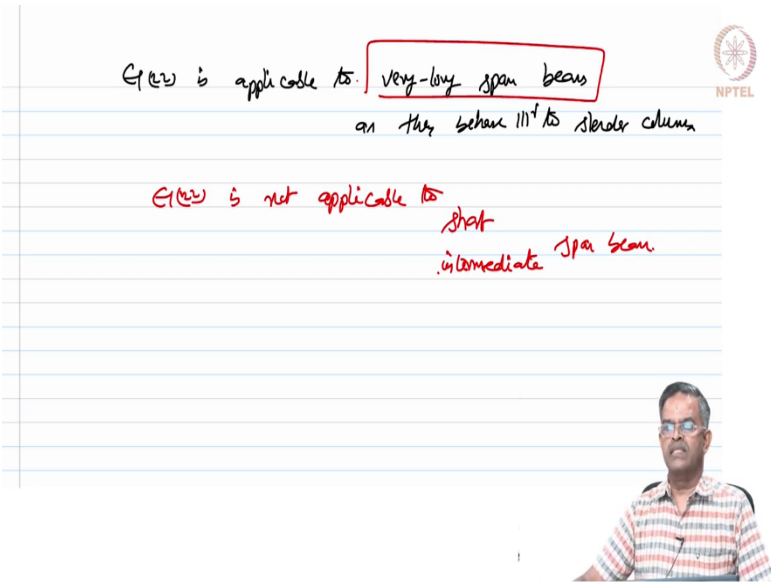
(Refer Slide Time: 12:47)



Now, the twisting moment is given by G J d ϕ by dz - E C w $d^2\phi$ by dz^2 is $M\tau$ this is equation 21. Now, we can solve all these three equations. So, equations 19 to 21 can be solved simultaneously. And, we can apply respective boundary conditions for the simply supported beam the boundary conditions will be applicable to the simply supported beam.

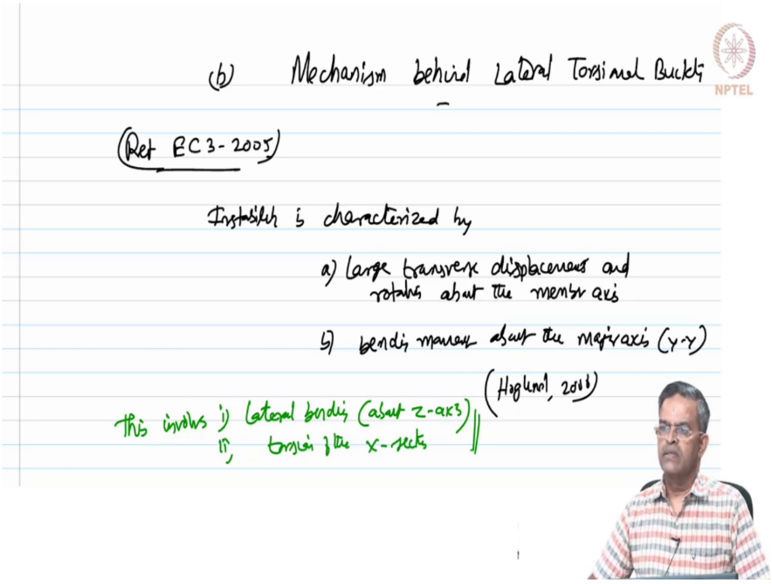
So, what do we get? We get the governing equation for elastic buckling strength. This was given by Timoshenko and Gere, which is M_0, cr is square root of π square E I Y by L square of π square by L square E C w + G J. We call this equation as 22 which is the classical elastic buckling strength equation. This is applicable to very long span beams which is similar to slender columns.

(Refer Slide Time: 15:32)



Equation 22 is applicable to very long span beams and as they behave similar to slender columns; short and intermediate span beams will not be applicable or governed by equation 22. So, we can say equation 22 is not applicable to short and intermediate span beams. So, friends, the elastic buckling strength equation which is governing the lateral torsional buckling is applicable to long span beams. Now, let us see what the mechanism behind lateral torsion is buckling as explained by Eurocode.

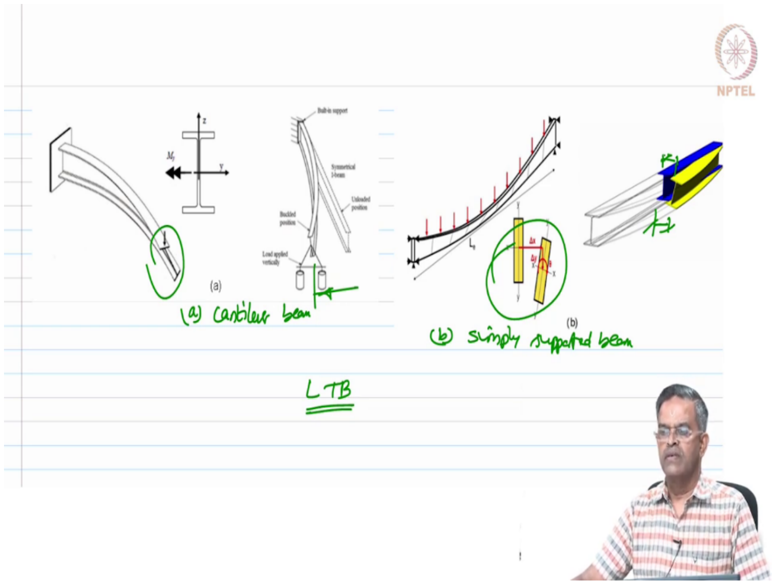
(Refer Slide Time: 16:49)



Let us refer Eurocode, EC3-2005; according to this Eurocode 3, instability is characterized by large transverse displacements and rotation about the member axis, under bending moment about the major axis. So, now according to this, instability is characterized by a, large transverse displacements, and rotation about the member axis. Further bending moment about the major axis, as per our figure it will be Y-Y axis, is it not.

This very clearly explained by Hoglend in 2006. This instability phenomena involves lateral bending and torsion of the cross-section. So, this involves 2 aspects; i, lateral bending above Z-Z axis, Z-axis is the length of the member axis, please understand that. ii, torsion of the cross-section, ok these 2 are there. We will try to represent this graphically as you see here.

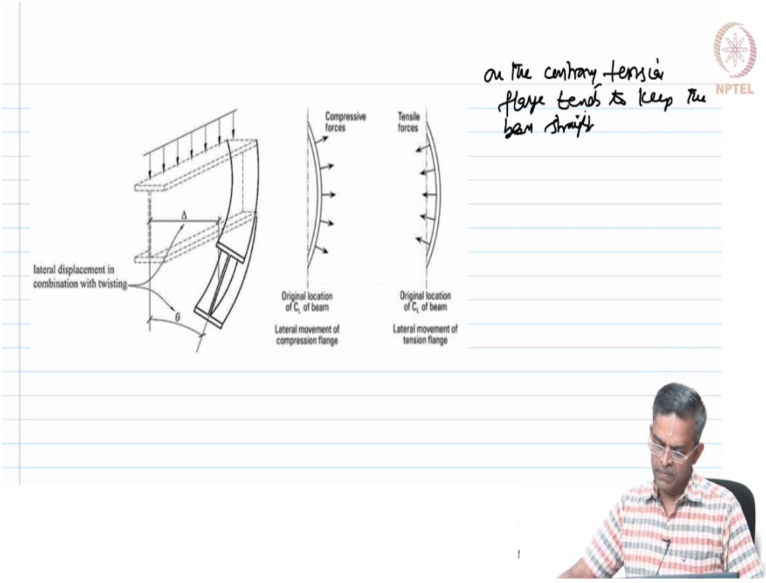
(Refer Slide Time: 19:25)



So, graphically the lateral torsional buckling is expressed this is an LTB. Of course, this represents cantilever beam and the right-hand side figure represents LTB for a simply supported beam. Now, in both these figures one can see that the beam is subjected to constantly increased loading in the major axis bending. If the beam is slender, it may buckle before the section capacity is fully utilized. This buckling involves both lateral deflection this buckling involves both lateral deflection and twisting this involves both lateral deflection and twisting.

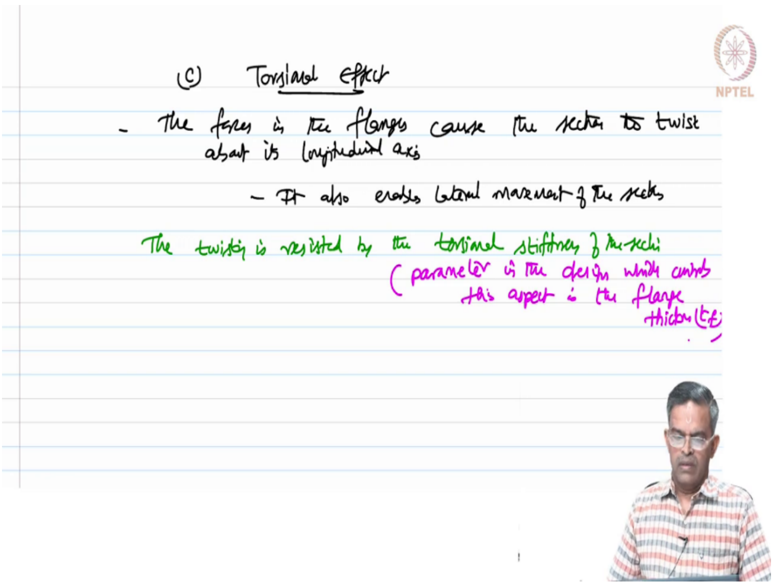
This is what we call as lateral torsional buckling. The vertically applied load the vertically applied load in both cases induces compression and tension in the flanges of the beam. It causes deflection of the compression flange and enables laterally swaying away from the original position. You can see the compression flange is swaying away compression flange is swaying away from the original position; we call these phenomena as lateral torsional buckling. On the contrast, the tension flange tends to keep the beam straight.

(Refer Slide Time: 21:32)



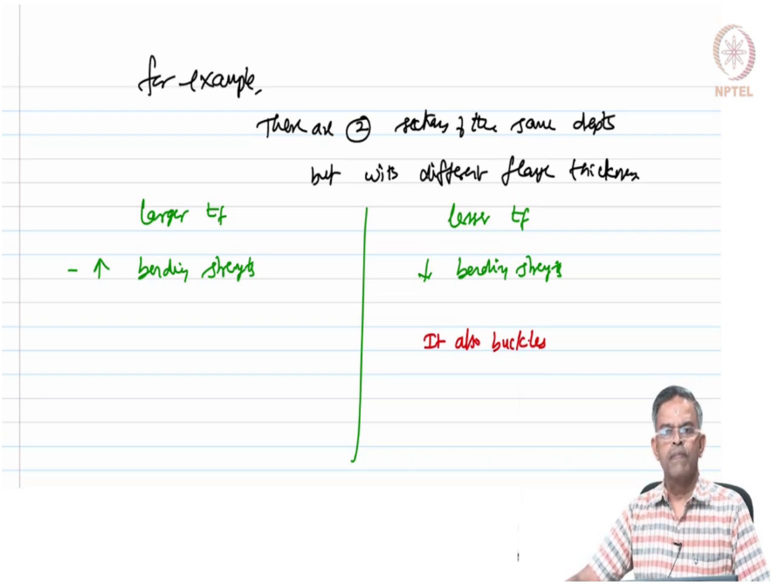
Look at figure 16. On the contrary, tension flange tends to keep the beam straight. This lateral bending of the section creates restoring forces that oppose the moment because the section tends to remain straight. These actions generate lateral forces which sometimes are not adequate to prevent the section from lateral deflection and that is what we call as resistance against lateral torsional buckling which we can see from this figure.

(Refer Slide Time: 22:39)



Let us see, what is the torsional effect under such situation. Now, the forces in the flanges, cause the section to twist cause the cross-section to twist above its longitudinal axis. It also enables lateral deflection that is what you see in the previous figure. Now, the twisting is resisted by the torsional stiffness of the section. Now, what is the parameter in the design which will control this? The parameter in the design, which controls this aspect is the flange thickness. Let us say for example, we have 2 sections of the same depth.

(Refer Slide Time: 24:35)



For example, there are 2 sections of the same depth, but with different flange thickness. Now, let us say larger t f, lesser t f thickness of the flange. The larger t f shows high bending strength. This shows lesser bending strength. If the span is very long then the beam becomes unstable, even for the small magnitude of the load compared to short span beams and if the beam is the same length, but different cross-sections are imagined then beams with slender cross-section buckle.

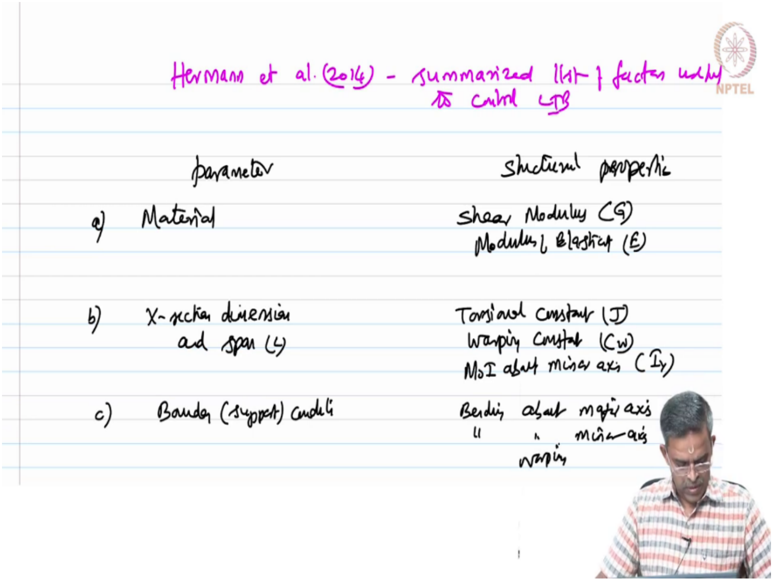
So, it is a very classical example where, if the thickness of the flange is not sufficient enough to restrain or offer enough torsional resistance the section or the beam will fail by lateral torsional buckling.

(Refer Slide Time: 26:21)

This is a photograph of a bridge girder failure under LTB. One can very well see the twisting of the cross-section and the thickness of the flange is phenomenally lesser which cannot sustain or offer enough torsional rigidity to this. So, now in controlling LTB, let us say what are the factors in the design. 1, Of course the beam span; if it is too long then it is dangerous. 2, The cross-sectional shape.

So, friends even to control LTB we are anyway aiming at form dominance. We are looking for the effective cross-sectional shape for controlling LTB. So, now there are various factors which can contribute to control LTB, Hermann et al. 2014 gave a very interesting list.

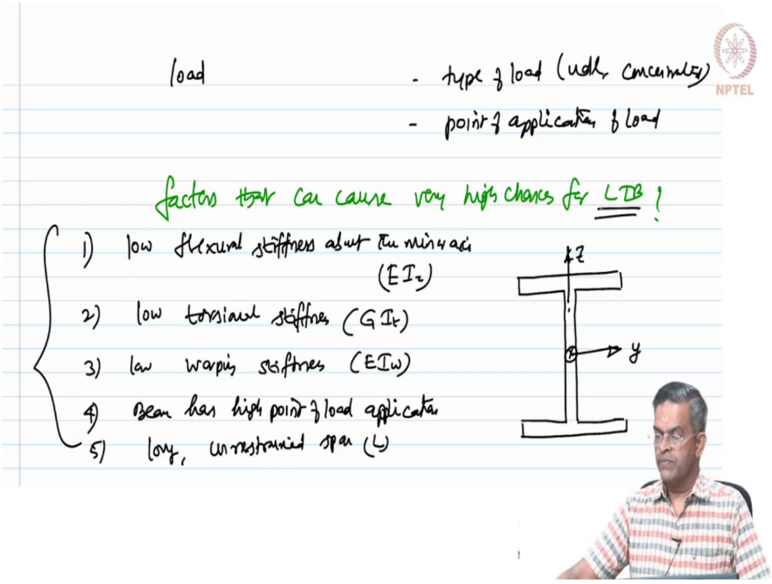
(Refer Slide Time: 28:05)



Summarized list of factors useful to control lateral torsional buckling, let us see what they are. Let us see one by one. Let us say the parameter and structural properties. Let us start with material properties. So, you can material can be useful in controlling or offering resistance with high shear modulus and with high modulus of elasticity. So, it can offer you a very high G and E value. Then, the next parameter is the cross-sectional dimensions and span.

So, now, the structural properties governed by this will be torsional constant, warping constant and moment of inertia about the minor axis. Let us say I Y. The third factor which contributes to LTB is the boundary conditions or I should say support conditions. When you look at the support conditions, they can contribute, or they can initiate bending about major axis. They can also sometimes initiate bending about minor axis. They can also cause warping of the cross-section.

(Refer Slide Time: 30:49)

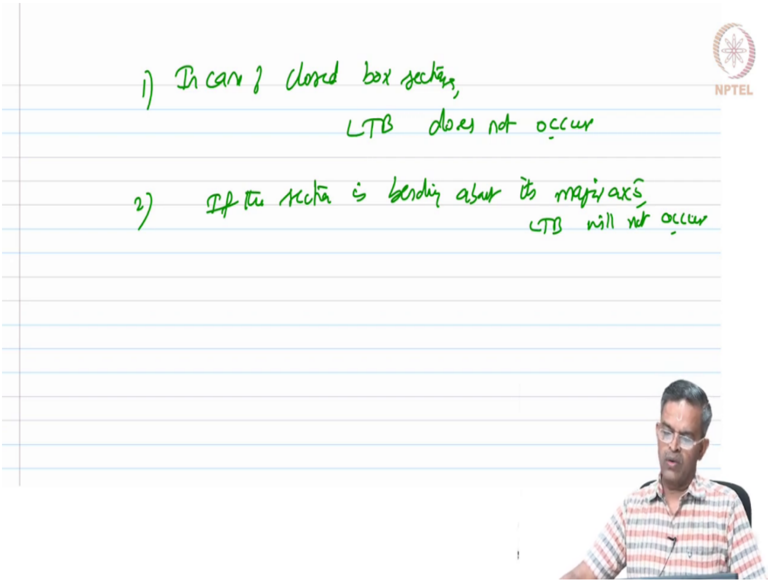


The fourth factor is a load. So, depending upon the type of load, whether it is uniform distributed load, whether it is concentrated load etcetera one can also result in lateral torsional buckling. The next is the point of application of load where the load is applied along the length of the member and along the breadth of the member. So, these factors are very useful in designing the beam to control the lateral torsional buckling and that can be avoided.

Now, if you ask me a question, what will be the factors that intuit very high lateral torsional buckling? Let us ask this question. What are the factors that can cause very high chances for lateral torsional buckling? Ok, very simple. There are about five factors. We will take an example of an I section. This means central axis C g; we call this as y let us say this as z.

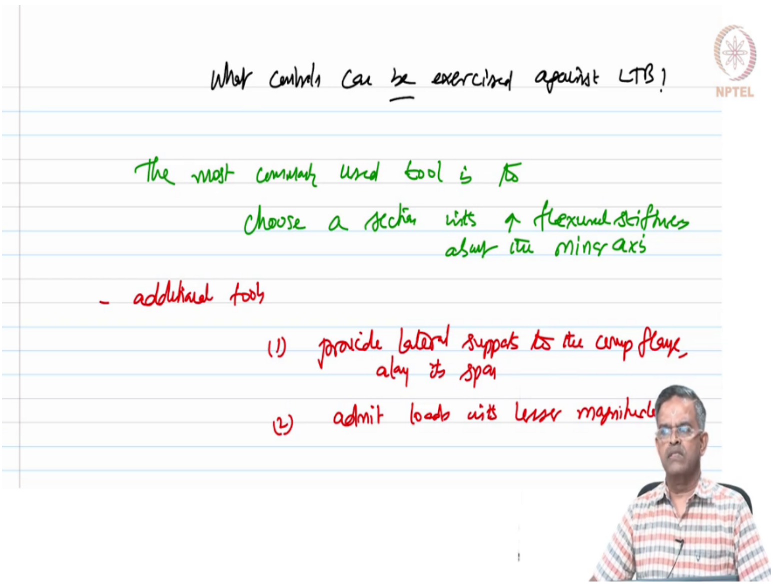
So, if the section has low flexural stiffness, about the minor axis that is if E I z is very small it can cause LTB; if the section has low torsional stiffness that is G I t. If the section has low warping stiffness which is E I w; if the beam has high point of load application, load is applied on some other plane which is at a different elevation from the beam the last point is the beam has got very long unrestrained span. So, these are the factors which will cause very high chances for lateral torsional bucking.

(Refer Slide Time: 34:30)



So, further friends it is also interesting to see that in case closed box sections LTB does not occur, number 1. Number 2, if the section is bending about its major axis, then LTB will not occur. These are the conditions where LTB does not occur. Now, the question comes, what precautions, what design controls we can exercise to prevent LTB in the design.

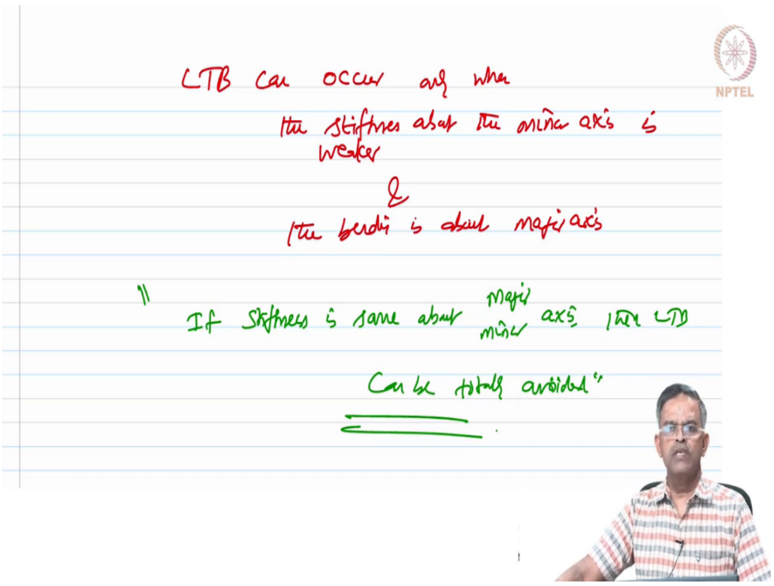
(Refer Slide Time: 35:34)



So, what controls can be exercised against lateral torsional buckling? For preventing lateral torsional buckling, the control factors what we discussed in the previous slide are very interesting and very useful. For example, one of the most used techniques is to choose a cross-section with high flexural stiffness about the weaker axis. So, the most used tool is to choose a section with high flexural stiffness about the minor axis.

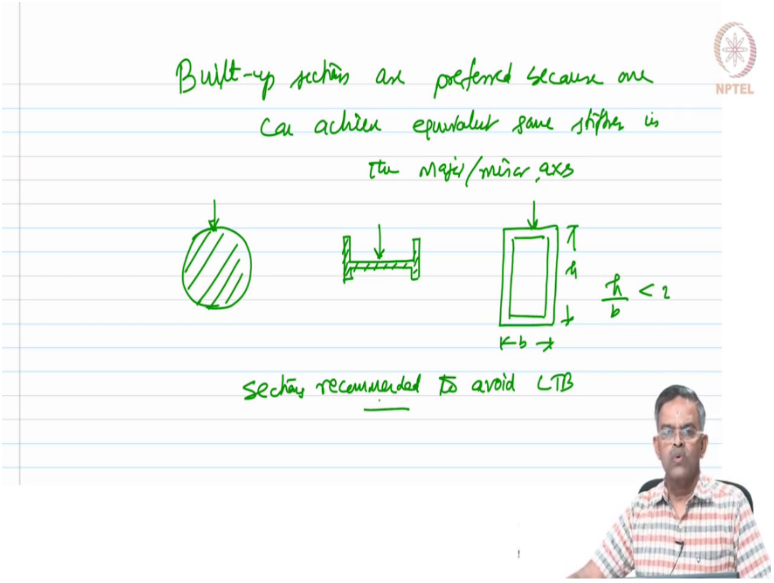
Alternatively, admitting the load with the lesser magnitude or providing lateral restraints for the compression flange can also prevent LTB. They can also control LTB. Lateral torsion buckling is only possible in major axis bending when the corresponding minor axis about the corresponding stiffness about the minor axis is weak.

(Refer Slide Time: 37:50)



So, the control point is, LTB can occur only when the stiffness about the minor axis is weak and the bending is about major axis. If the structural stiffness is same over both the axis, then LTB can be avoided completely; that is a very interesting statement we have. If stiffness is same about both major and minor axis, then LTB can be totally avoided. So, that is a very interesting and simple tool to control LTB in the design itself. Now, offshore structures being strategic importance, the top side of these platforms are designed within ultimate care and generally they are designed as a built-up section.

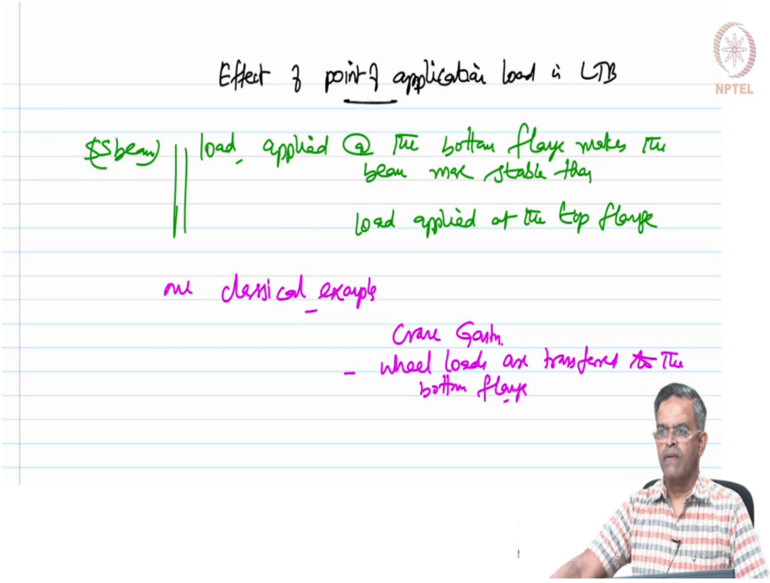
(Refer Slide Time: 39:33)



So, that is one of the important reason. So, built-up sections are preferred; because one can achieve equivalent same stiffness in the major and minor axis it is possible with built up sections only its possible. Now, what are the possible type of sections we have. Let us draw them, solid circular sections. If you have an I section, the loading is here then it is, ok; if you have a box section, the loading is applied here and if this is b and if this is h we need a condition that h by b should be less than or equal to 2.

So, these are all the sections recommended to avoid lateral torsional buckling. Now, we discussed also an important factor saying the point of application of load can also cause LTB.

(Refer Slide Time: 41:37)

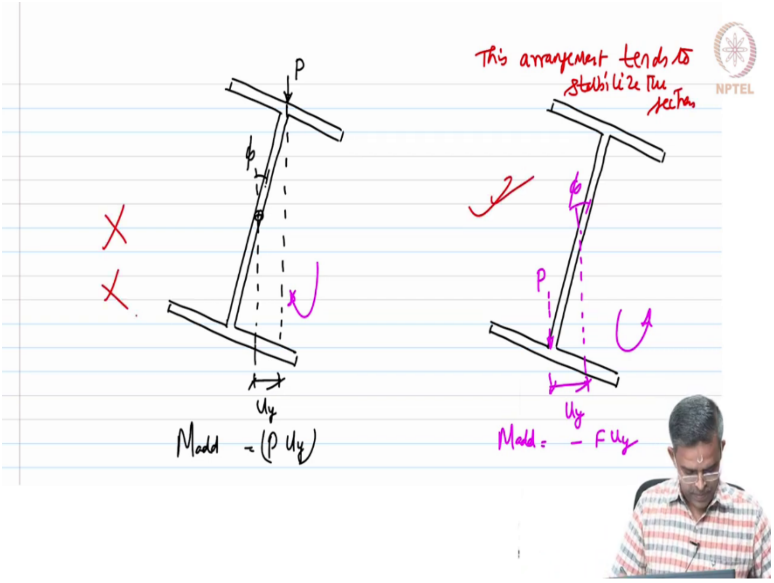


Let us now discuss, what is the effect of point of application of load in LTB. The loads even with lesser magnitude can minimize the chances of occurrence of LTB. Therefore, when the load is applied at the bottom flange, it causes a beam considerably more stable than the load applied on the top flange. So, load applied at the bottom flange makes the beam more stable than the load applied at the top flange. We are talking about simply supported beam.

One classical example to prove this is the crane gantry. Please, look at the crane gantry girders; you will observe that the wheel loads are transferred to the bottom flange. You can notice that whenever you go to any heavy industrial system, please see the crane gantries are designed in such a manner the wheel loads will always rest on the bottom flange and not on the top flange.

This is possibly only due to the reason that when the load does not contribute to any restraining effects. The event of LTB the beam deflects when the load above the centre of twist generates twisting moment. So, let us explain this graphically like this.

(Refer Slide Time: 44:03)

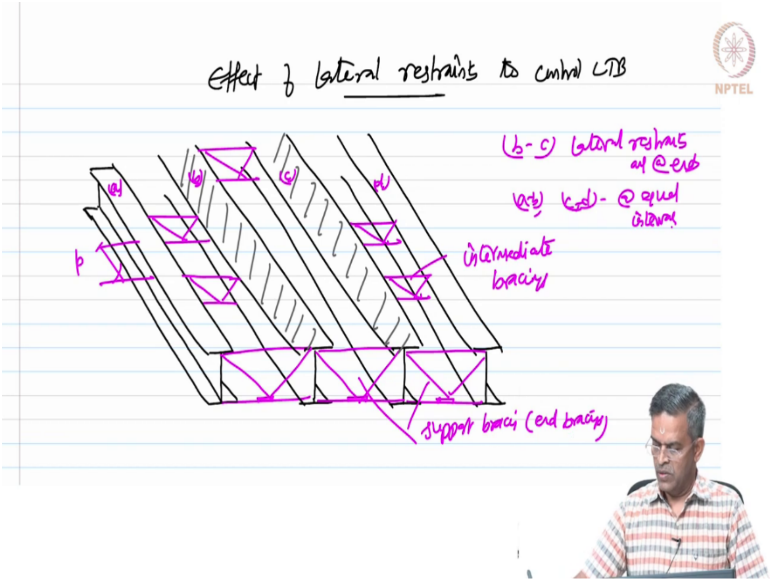


Let us say, if you have a section let us copy the same figure here. When a load is applied here, there is a line of action of the load. So, C g let us say this is U y and we call this shift as ϕ. This is the load P. So, the additional moment caused in this case will be the load P into U y.

Imagine that the load same is applied at the bottom flange, its applied here and is the same shift let us say this is U y and the rotation is same the additional moment caused in this case is - F into U y, ok; because this is causing an anticlockwise moment whereas, this is causing a clockwise moment.

So, point of application of load can also cause interestingly the lateral torsional moment. So, one can see from this figure when the load is applied in the bottom flange, it tends to stabilize a section. So, it is better; this is not better. Having said this, let us see what the effect of lateral restraints on lateral torsional buckling will.

(Refer Slide Time: 47:15)

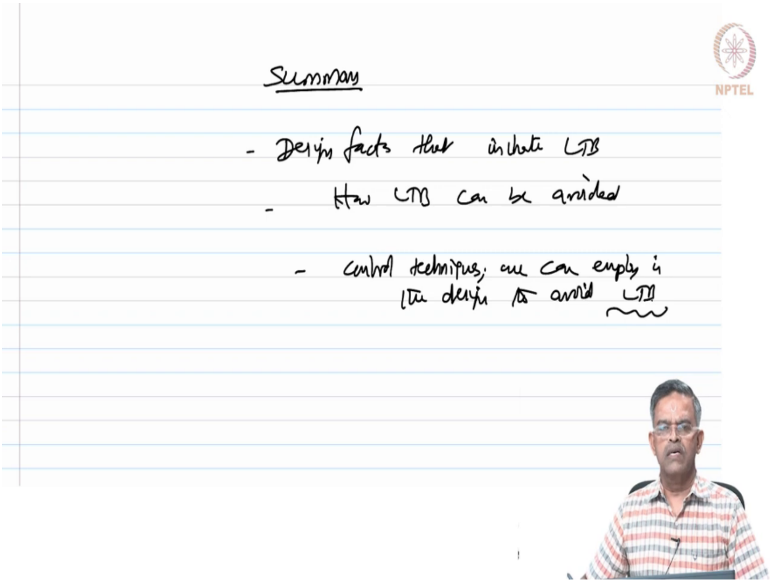


These are design parameters, design aspects. So, very interestingly friends if you have an I section. Let us say, so I can we simply say, there can be similar I sections like this which are arranged in parallel arrangement like this. We are talking about lateral restraint offered to the system these are all primary beams. What we can do is we can put lateral restraints in this direction. At intermittent gaps, let us say I can put this is one beam which we have here. This is another this is another beam we have here, there is another beam.

So, we can put the lateral restraints between these two at equal gaps. Similarly, between, these two at equal gaps and so on and between beams b and c only at the ends. So, between b and c we have lateral restraints only at the ends between a-b, c-d we have at equal intervals. So, I can provide the lateral restraints along the length of the beam at equal intervals that becomes a spacing of this lateral restraint they are called intermediate bracings. And, these are called support bracings or sometimes called end bracings.

Now, one can also find out, what are the possible buckling modes we have with lateral restraints to avoid lateral torsional buckling.

(Refer Slide Time: 51:35)



So, friends we will discuss that in the next lecture. So, in this lecture we learnt about, what are the design factors that initiate LTB, how LTB can be avoided, what are the control techniques one can employ in the design to avoid lateral torsional buckling. Apart from understanding, why do we call this bending as lateral torsional buckling. We will see more details in the next lecture. We will also work out an example design example of LTB, using Indian code and one international code to illustrate the design of LTB, against LTB.

Thank you very much and have a good day bye.