Course on Design of Steel Structures
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Mod 10 Lecture 46
Failure Modes of Flexural Members

Now, I am going to discuss about different aspects of failure modes of the flexural members. We know in case of RCC structure the failure modes are basically the failure due to bending sue to shear and due to deflection, which is the basically is a serviceability criteria; however in case of steel structure as the structural sections are mainly hot rolled sections where the it is not like a rectangular section or like a compact section. Therefore, some other type of failure may also occur. What are the other type of failure that is the local buckling of the cross section like local buckling of the web and failure of the flange, because of low thickness compared to its width, also lateral torsional buckling also come into picture. So such type of failures may arise in case of steel structure.

Therefore, when we are going to design a flexural member with respect to steel we have to consider not only the bending shear or deflection, we have to consider other (())(1:39) of failures and design criteria has to be satisfied from those points of view so that the local failure may be restricted.

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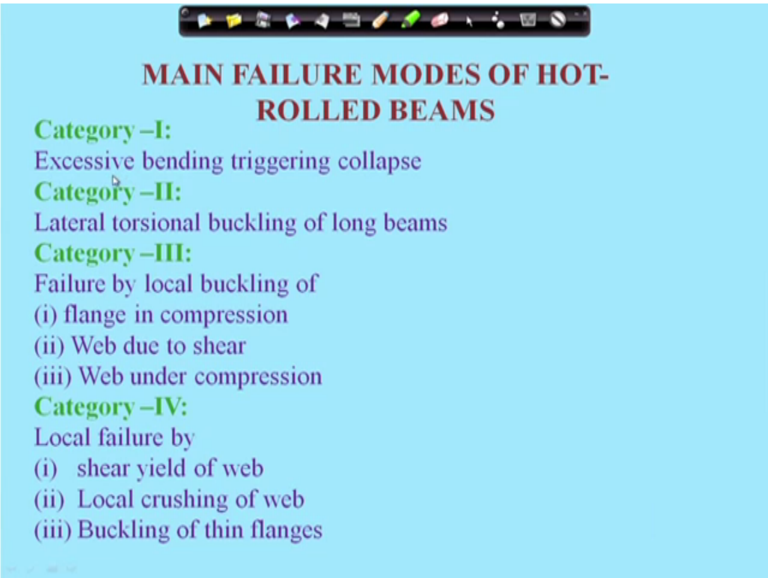

So first let us come to what are the types of failures we come across. First is the excessive bending triggering collapse, because we see that when the excess.

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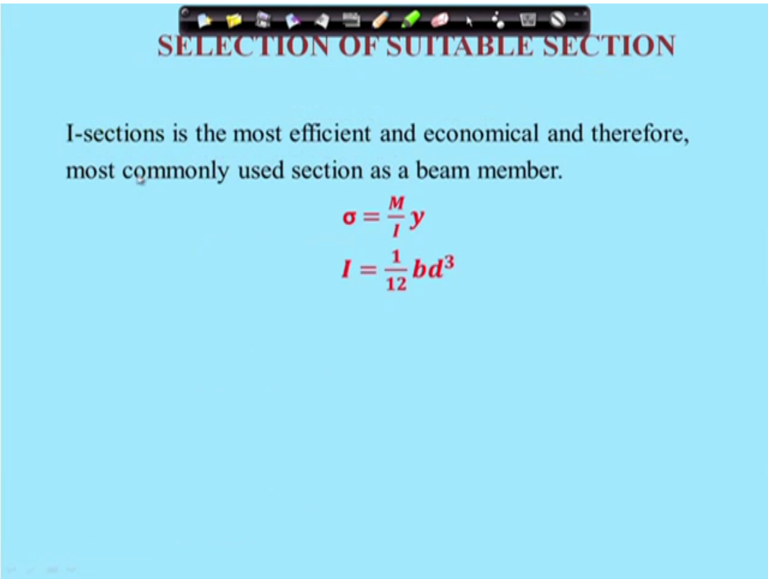

When we see the if the load is quite high or the length is quite high then the bending moment will be maximum means will be huge at next span (())(2:30) in general; however it may differ considering the support condition and loading condition as well. So because of the excessive bending moment the collapse may occur due to bending. So this is happening, in case of RCC structure also, it happens.

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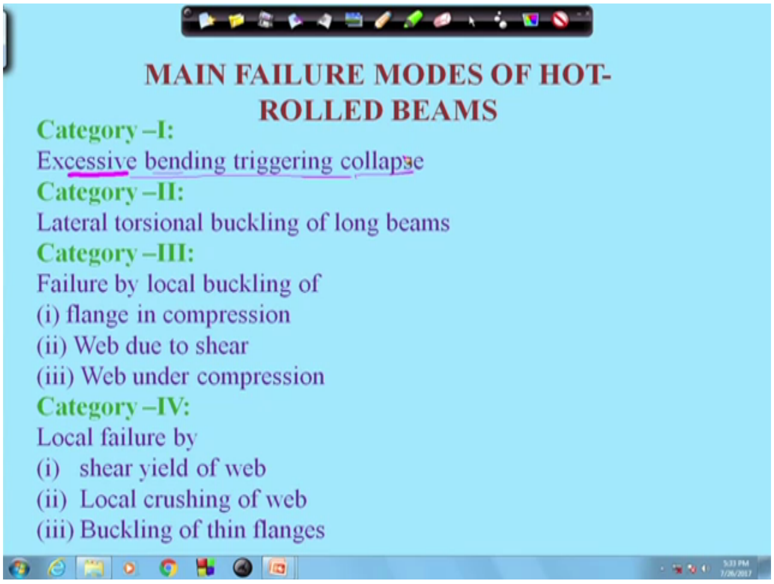

It looks like this, say the bending failure will come into picture and this is a basic failure mode and in this case, the beam is prevented from lateral buckling and the component elements are list compact so that they do not buckle locally. So such (())(3:14) beams will collapse due to plastic information. This is one type of failure which is called category one.

Then another type of failure will be come into picture, which is called lateral torsional buckling, which is an important failure criteria for steel for steel flexural member. So lateral torsional buckling comes in picture when the beam is quite long.

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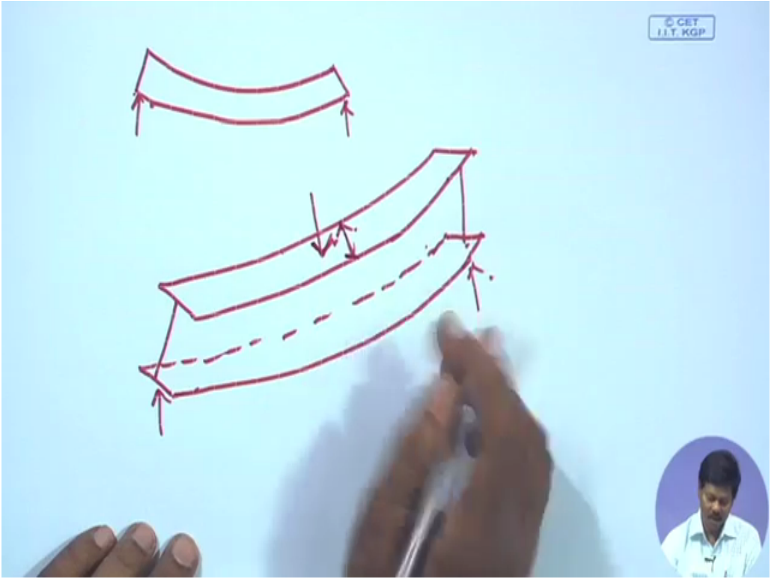

Say for example, if an I section with having long length then it fails due to lateral torsional buckling. So here if load is acting in this and support conditions are there then it may buckle laterally and this lateral buckling occurs due to combination of lateral deflection and twist. The proportion of the beam support conditions and the load applied on it are the certain factors which effect on the failure due to lateral torsional buckling, say for example, if the load is not (())(4:42) treatments along its width then in some cases, means the twisting may come into picture, because of the torsional moment across the section and because of that lateral torsional buckling will come into picture.

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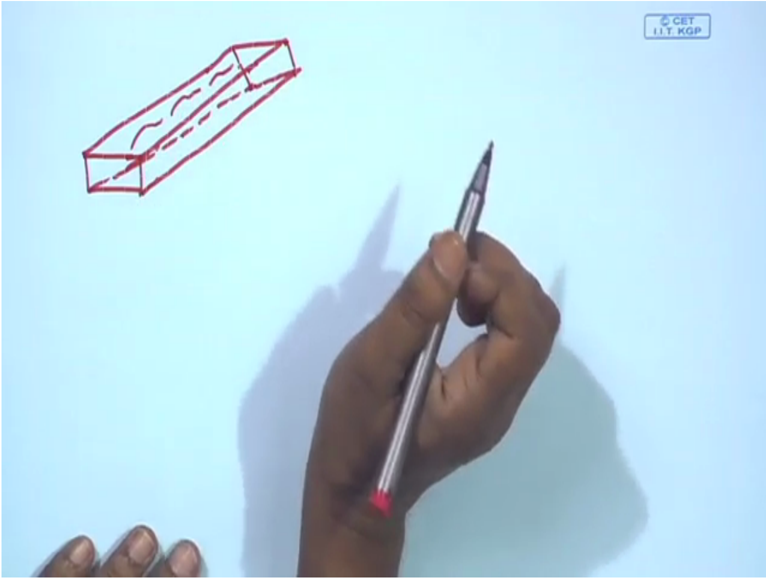

Next another is the local buckling, which is in category 3 that is failure by local buckling. Here, failure means flange in compression, means flange failure due to compression, web due to shear and web under compression. These are the certain mode of failure which come into this category, say for example, if we have a box section, then it may fail in its flange, say this block section. Now so unlikely the hot rolled section which are generally stocky (())(6:00) fabricated box sections may require flange stiffening to train pre-(())(6:05) immature collapse. So it may fail due to compression of the flange. So maybe we need flange stiffening to (())(6:14) such type of failure.

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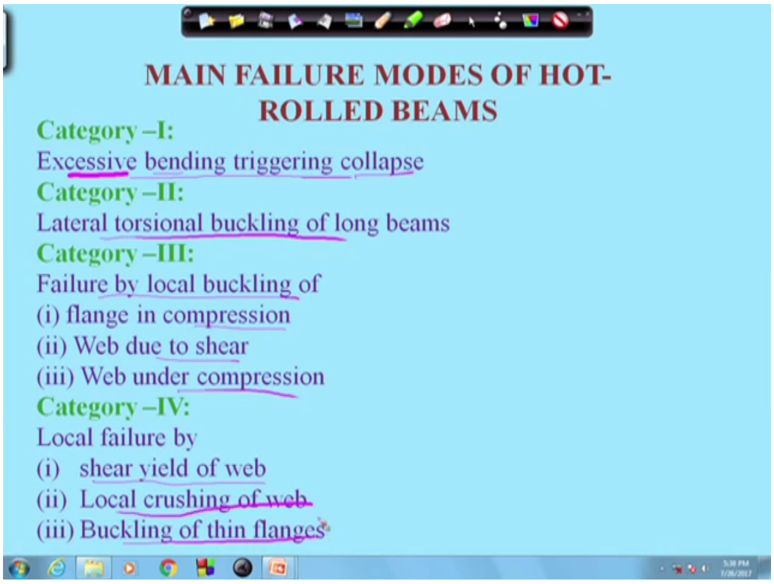

Also, it fails due to web due to shear and also web under compression it may fail.

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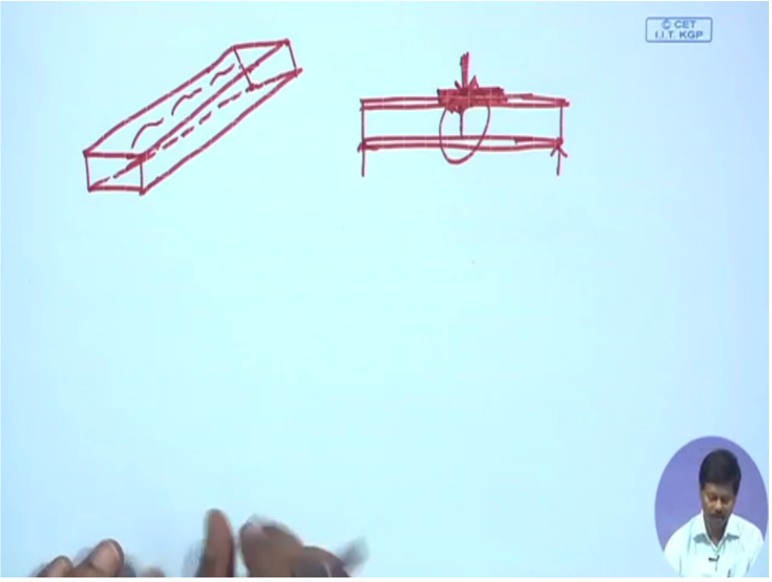

Web under compression means say for example, if we have a member under concentrated load then such type of members may fail, at this point means at the point of application of concentrated load if the load is heavy, because load cannot disperse (())(6:51) throughout it section. So therefore the failure may come into picture due to compression due to concentrated load and this can be overcome by the use of additional bearing plate, which will disperse the load, additional bearing plate we can provide here and through that we can disperse the load and we can overcome the such type of failure.

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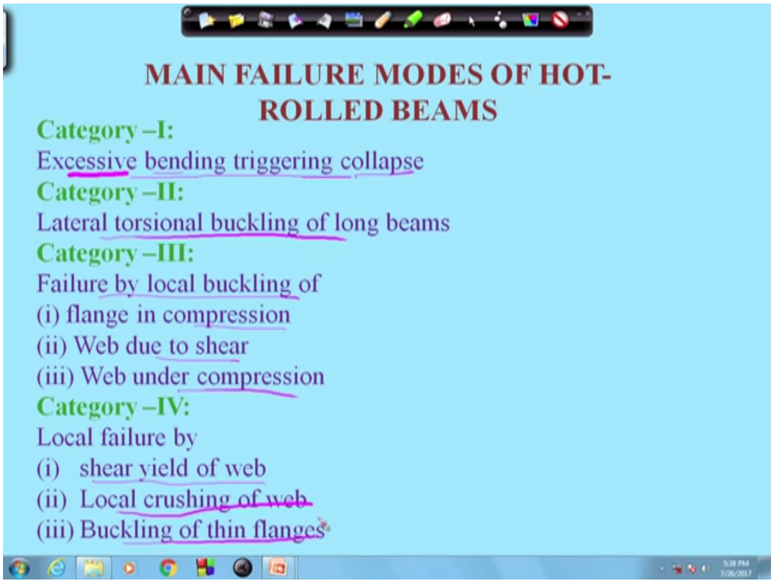

Another failure is category 4, which are mainly the shear yield of web, so this when you want then local crushing of web and buckling of thin flange.

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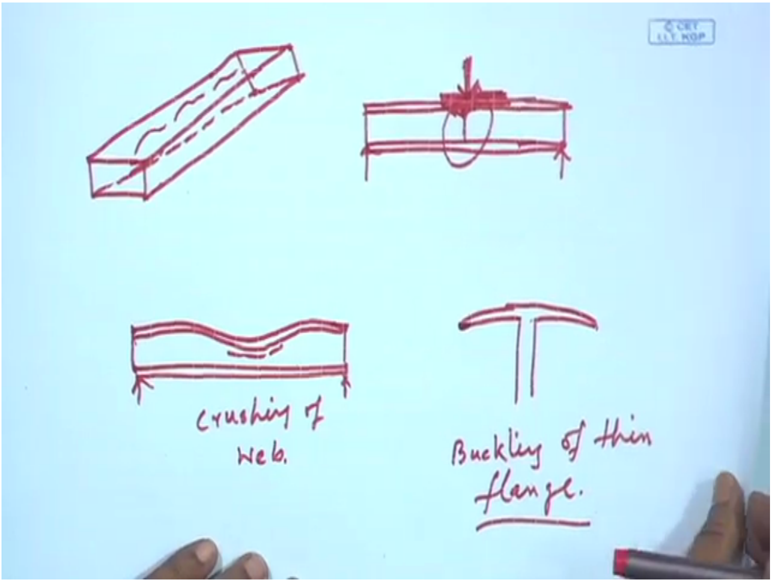

So local crushing of web means if we have a section and if it is under concentrated load then it may fail due to local crushing like this. So this may fail like this, because of crushing of the web. This is called crushing of web and another is bucking of thin flange, say sometime the flange with this quite high compare to its thickness.

So therefore it may buckle due to the very thin flange width, say for example like this, say if flange width is very thin compared to its thickness compared to its width then such type of buckling may come into picture which is called buckling of thin flange**.** So this is also means this type of failure may also happen; however this type of failure may overcome, if we use additional plate at the flange by welding so that the B by T ratio means width to thickness ratio can be increased. Therefore, means and thus we can avoid the flange buckling failure. So this is one type of buckling failure which can be also avoided by the use of additional plate. Now what is the most suitable section?

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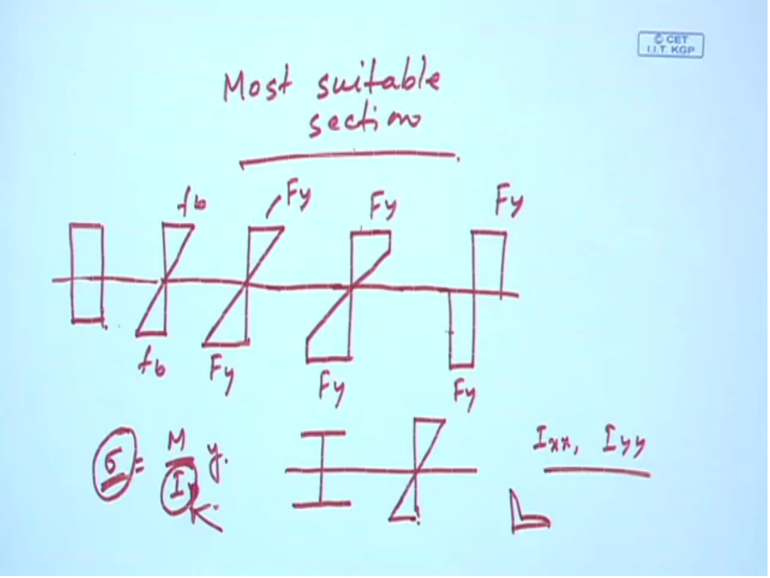

Most suitable section for beam most suitable section for this we have to see certain things, we have to know what is a stress diagram along the cross section, say for example, if we see rectangular section then we know initially it fails means its stress develops like this. This is called bending stress Fb and if the load is going to increase then after certain period the bending stress will reach to its yield stress. So maximum stress which is called yield stress, it will reach up to that. So after further increase of the load, it will start formation of plastic inch (())(10:34).

So plasticity will develop, so the sections will undergoes under plastic deformation, right. So here we will see that after development of yield stress Fy, it is developing across the depth of the section and after certain time, it will develop fully plastic, right. Fully plasticity will be developed. So basically plastic moment is the moment which will carry means which will produce the full plasticity member cross section and create the plastic in. So this is how we can calculate the plastic moment as well.

Now we know sigma the stress develop is M by I into **M by I into** y, right. So if we can increase the, I value then the development of stress at the extreme fiber can be reduced. So from the experiment we can see that, if I section like sections are provided then compared to its cross sectional area or requirement of material, its moment of inertia is quite high. Therefore, with light-weight, we can achieve high amount of moment of inertia and as a result we can reduce a major amount of stress as a result, if we **if we** see different type of section we will see that if we consider I section then it will be the most suitable section, because of the I value, the moment of inertia value is high compared to its weight or the cross section area.

Now another thing that in case of I section, it is symmetry in nature means Ixx, Iyy we can consider and it is symmetric in nature, but if we use channel section or angle section then unsymmetric bending will come into picture for which, we have to again consider the stress how it is developing, because of unsymmetrical bending,. So in fact in earlier lecture we have shown that why the channel sections and angle section are not suitable in most of the cases and in case of high load or large length we have seen that if we use I section then, because of the increase amount of moment of inertia we can reduce the deflection as well as you can reduce the stress due to bending. Therefore, we generally choose I section most preferably.

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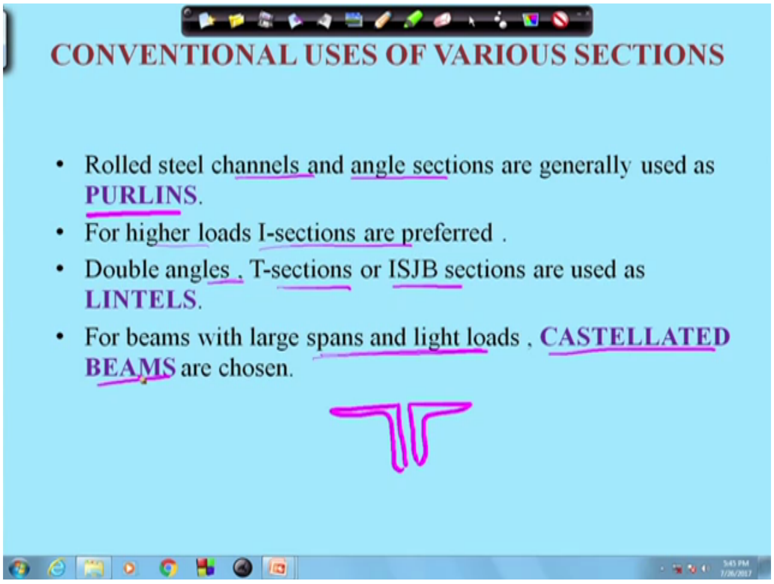

Now coming to conventional use of various sections, we know that we generally use channel or angle section, in case of PURLIN. Generally PURLINS are taking light lode. So load is coming less, so for such type of member we use either angle section or channel section and I as told for high load, I sections are preferred and in case of LINTEL, generally double angle double angle means in this way we provide, this is one angle this is another angle we provide.

Double angle T sections or sometimes also ISJB sections are used and for large spans and light loads means where the deflection may come huge, so for that we have to increase the I value, so to increase the I value we have seen earlier that CASTELLATED BEAM if we use we can increase the I value, because depth we to (())(14:58) increase without increasing the material among. So for light loads and large span, one can use the CASTELLATED BEAM which will be economic.

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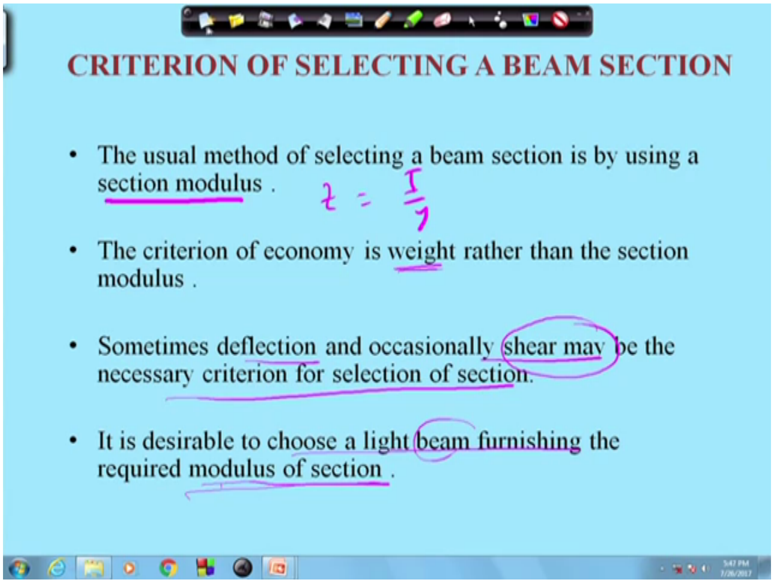

And these are few criteria to select a beam section, the first is the usual method of selecting a beam section is by using a section modulus Z, Z means I by Y right, because we know M by Z is equal to the sigma. So the main criteria should be the section modulus and the criterion of economy is weight rather than section modulus, because sometimes, we can see if the section modulus is high means weight may be less also or may be high also.

So but if we consider the economic consideration point of view then you choose the lighter weight; however that may not be achieved always. Therefore, we have to see the section modulus that section whether section modulus is also high or not that means lighter weight and high section modulus will be the preferable one and sometimes deflection and occasionally shear may be the necessary criteria for selection of section. This is very rare, when we have to consider the deflection criteria where deflection is quite high and we have to (())(16:35) two deflection and for such type of things we may have to go for castellated beams and sometimes shear may be the guiding criteria, so for that also we have to consider corresponding section.

And it is desirable to choose a light beam furnishing the required modulus of section what I was telling that always we will try to choose a light beam section and which we will have required section modulus. So if we have a similar section modulus of different kind of section then among those, we will try to find out the lighter one.

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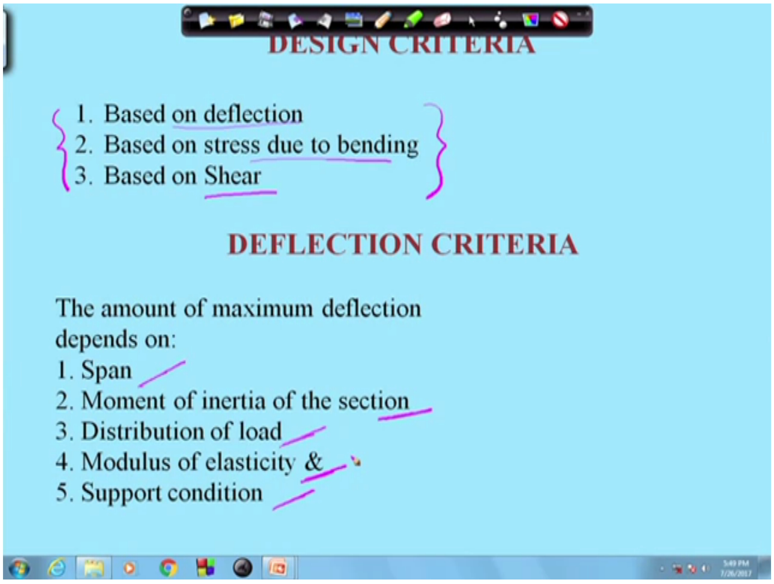

An primarily design criteria will be based on these three criteria that is, one is the based on deflection, based on stress due to bending and due to shear and in case of RC structure we have seen that these are the 3 major criteria for which the beam is designed and in case of steel structure also the primary criteria will be these three, one is deflection, another is stress due to bending and another is shear; however other criteria has to be fulfilled like the torsional buckling, local buckling then the web buckling, flange buckling. So those things we will also has to be taken care, right. Then web crippling also will come into picture, which has to be overcome through the by providing certain measure means may be baring (()) (18:15) we have to provide or we have to take certain measurement so that the web crippling can be avoided, right.

Now when coming to deflection criteria, the maximum deflection we known depends on span, the span length, what is the span length then moment of inertia of the section and then the load means load and load distribution and modulus of elasticity and support condition. So these are the five factors on which, the maximum deflection depends. So depending on that we will try to find out what is the maximum deflection coming into the member and what is the limiting deflection, depending on those we have to decide the section size.

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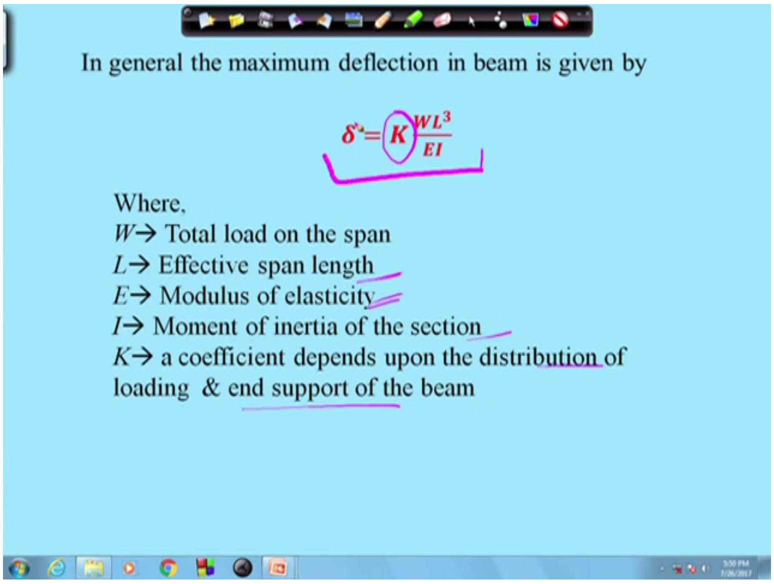

So in general the maximum deflection can be writurn as like this. The delta is equal to K into WL cube by EI where W is the total load on the span and L is the effective span length, E is the modulus of elasticity, I is the moment of inertia of the section and K is a coefficient, which depends upon the distribution of loading and end support. So K varies for different end supports and loading condition. So we can find out the maximum deflection depending on this support condition and the loading criteria, according to that we can find out the maximum deflection and we have to check whether it is exceeding the limiting deflection or not.

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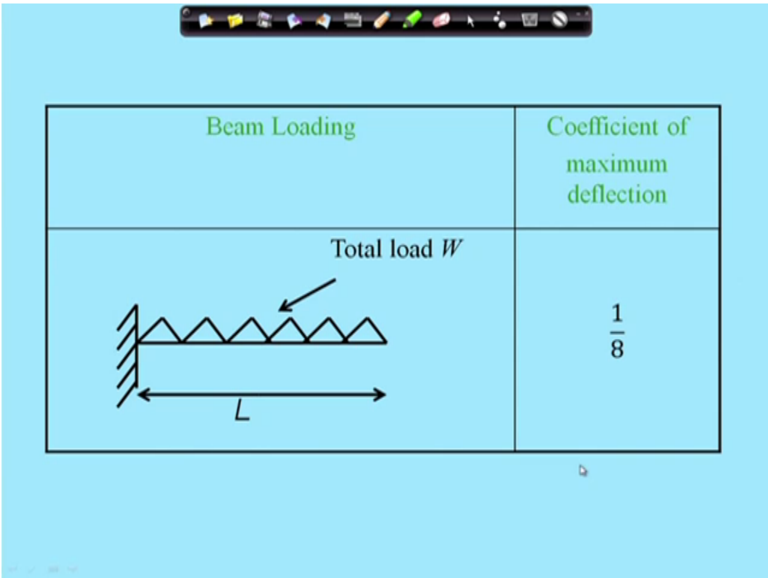

Say for example, we can see here that if a simply supported beam carrying a UDL load then the maximum deflection we can find out at 5 by 384 W will keep by EI okay. So K value the coefficient K, KWL cube by EI, K value will be 5 by 384. So in case of simply supported beam carrying UDL, we can find out the maximum coefficient for deflection is 5 by 384. Similarly, we will see very quickly some of the coefficient of maximum deflection for some other cases, say for cantilever beam having UDL load, K value will be 1 by 8.

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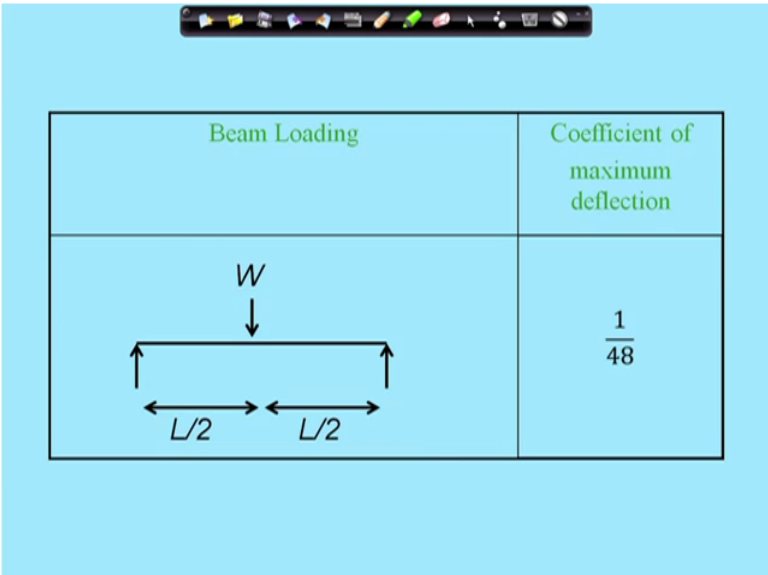

Similarly, for simply supported beam having concentrated load at the mid-point, in such cases, the coefficient of maximum deflection will be 1 by 48.

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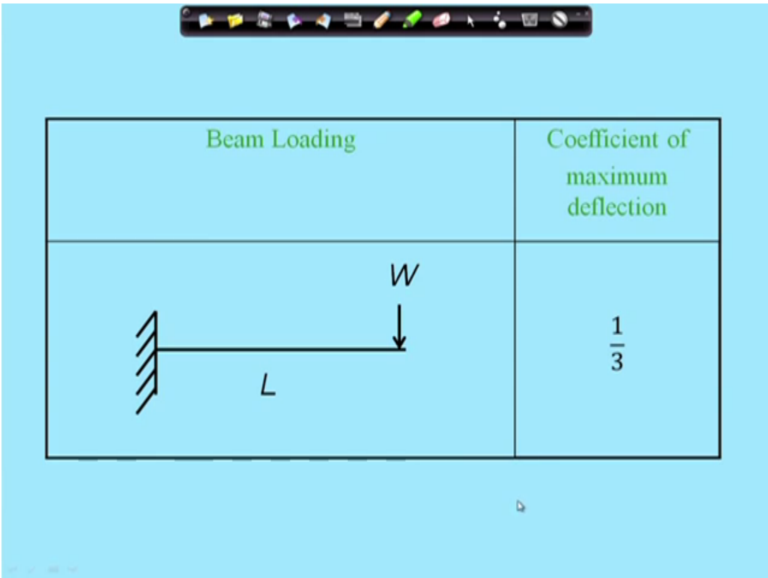

Say cantilever beam having concentrated load at the end, coefficient of maximum deflection will be 1 by 3.

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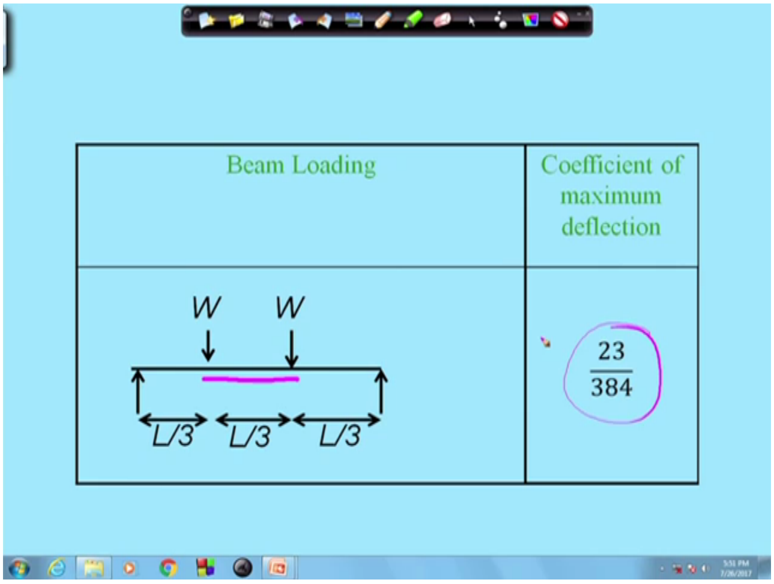

If we have a beam loading with 2 **2** concentrated load at a distance of L by 3 L by 3 then the coefficient of maximum deflection can be 23 by 384.

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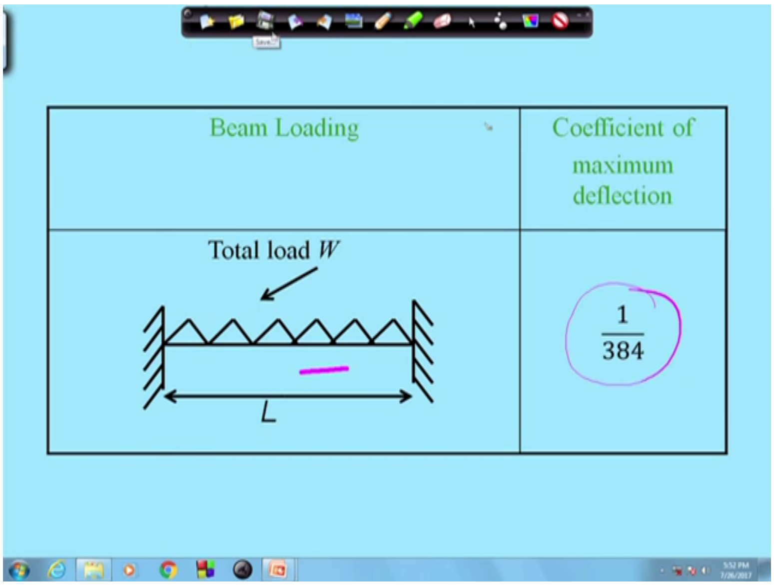

So either we have to remember this coefficient or we have to evaluate this, right, say for example in this case, when a continuous beam means fixed **fixed** beam having UDL load then the maximum deflection coefficient will be 1 by 348, right.

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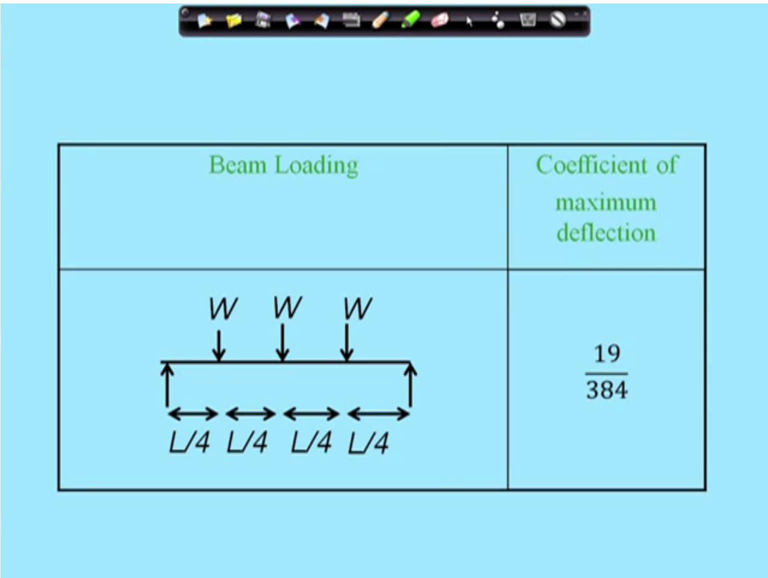

Similarly, if we go to next case beam having 3 concentrated load at a L by 4 distance then coefficient of maximum deflection will be 19 by 384.

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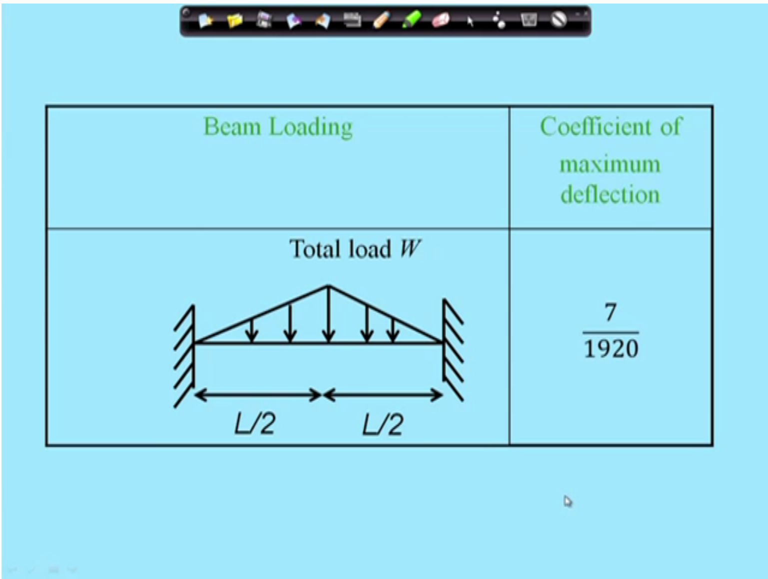

Then if it is a triangular load then the coefficient will be 7 by 1920.

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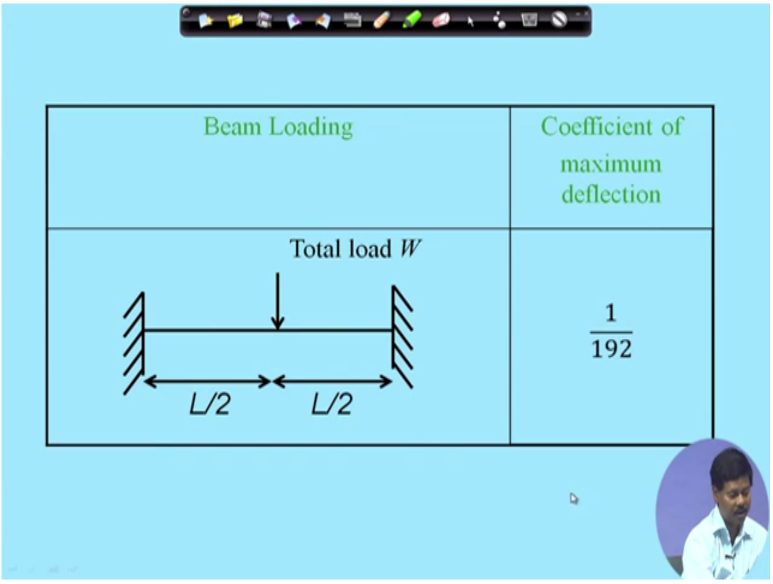

And if it is a fixed beam having concentrated load at the mid span then it will be 1 by 192.

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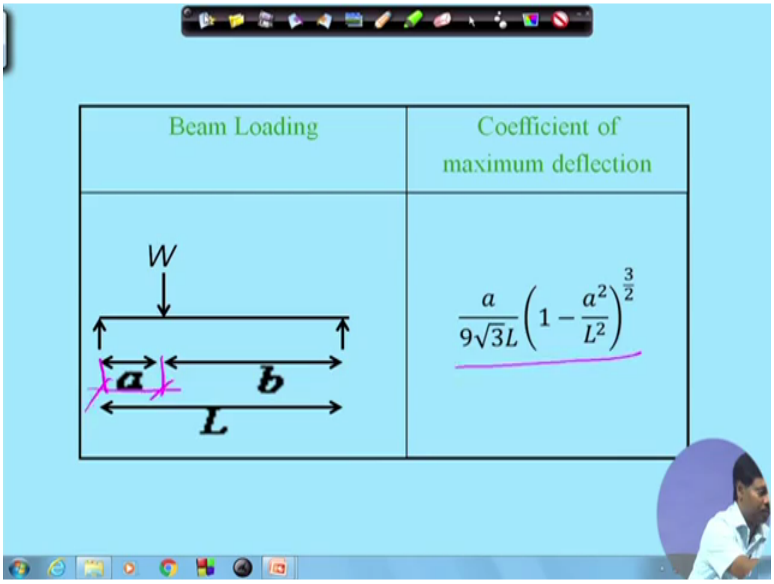

Similarly, if we achieve (())(22:32) the certain supported beam having a load at a distance of a from one side then its coefficient of maximum deflection can be written in this form, a by 9 root 3 L into 1 minus a square by L square whole to the power 3 by 2, where this is a, right. So **so** for such type of loading, we can generalize the value of maximum deflection coefficient as a by 9 root 3 L into 1 minus a square by L square whole to the power 3 by2.

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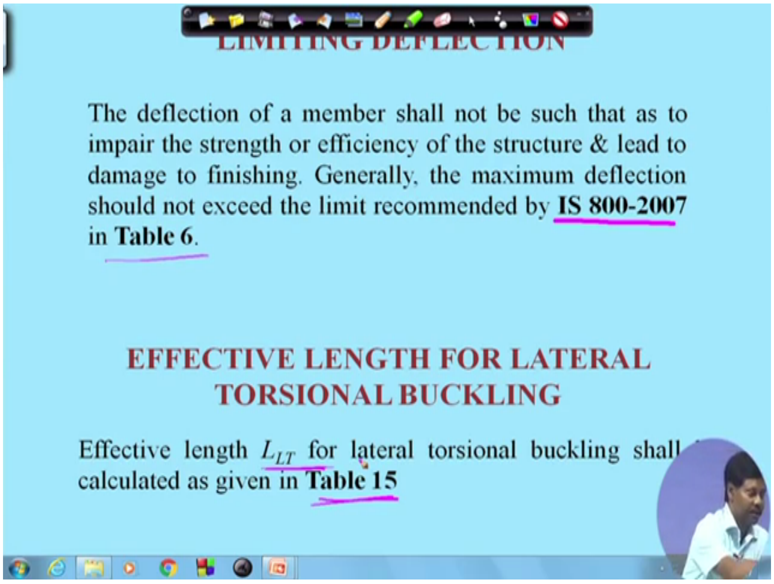

Now limiting deflection, so limiting deflection can be found from the IS code, from few slides, what we have seen, I could show that what is the maximum deflection coming for different loading conditions and different support conditions. So maximum deflection we can find out and we can find out the limiting deflection from table 6 of IS 800-2007 table 6 and the maximum deflection should not exceed the limiting deflection which are given in table 6 of IS 800-2007.

Here, you will find out the different type of deflection coefficient has been told for different criteria, right say for example, if it is under dead load light load what will the maximum deflection criteria means what will be the maximum deflection limit, so those thing those are given in the table 6 from which you can find out and effective length for lateral torsional buckling can be found from table 15. Effect length for lateral torsional buckling will be required for calculation of designed bending moment, right. So for that the effective length Llt for lateral buckling we can calculate as given in table 15.

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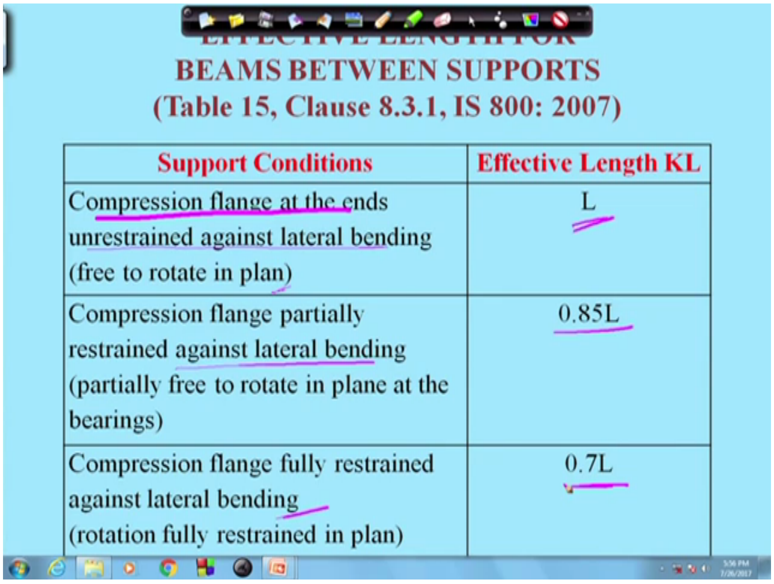

So few of them just I am showing here, which are given in table 15 and in clause 8.3.1 also, it is discussed, say for example, if the support condition is like this as compression flange at the ends unrestrained against lateral bending that means free to rotate in plan. So for such cases effective length will be K into L, right and compression flange partially restrained against lateral bending that will be 0.85L and compression flange, fully restrained against lateral bending the effective length will be 07L. So this is how the effective length can be calculated, which are given in table 15 for different support conditions, the value of effective length are given either L or 0.5L or 0.7L.

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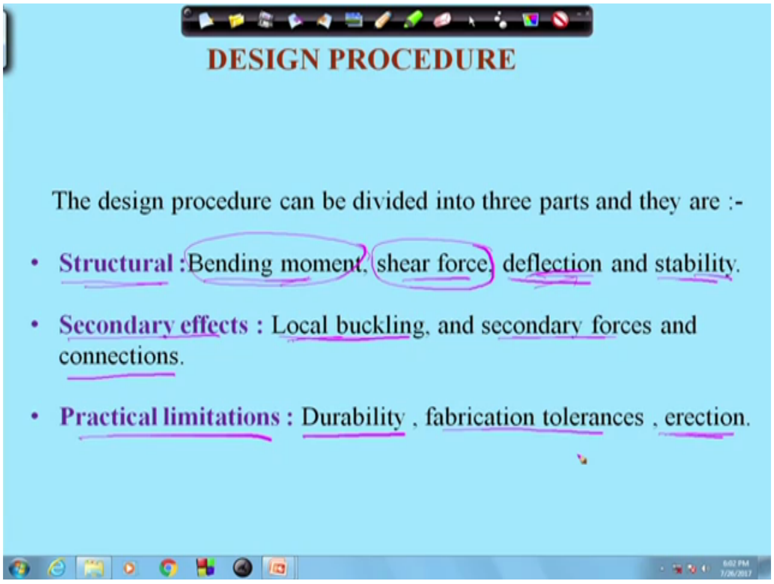

So in today's lecture, the last thing we like to discuss is about the design procedure. So design procedure can be divided into 3 parts, one is structural; another is secondary effect and practical limitations. So basically the design of the member will be done due to bending moment, due to shear force, due to deflection and due to stability. First is the bending moment. So first we will see, what is the maximum bending moment coming into the member and for that what will be the size of the section whether, it is capable of carrying, this much bending moment or not. Then we will check whether the developed shear force will be able to carried by the section. If the design shear force is more than the **the** external shear force then it is fine otherwise we have to increase the section size to withstand the shear force coming from the load.

Then we will see, the deflection, the maximum deflection can be calculated for the given load and the section and we will check whether the maximum deflection is exceeding the limiting deflection. If it is exceeding the limiting deflection then we have to increase the section size and we have to redo all the things, otherwise we can go ahead. Another is stability; stability like lateral torsional buckling may come into picture. So from that point of view also we have to consider whether the structure is safe or not. So these are the structural aspects which has to be taken care for design.

Another is the local buckling. So local buckling means buckling of the web crippling of the web or the buckling of the flange, because of thin flange, flange may also buckle. So these are the some secondary effects, which has to be also taken care and we have to check whether it is safe against local buckling, against secondary forces or not and also we have to check the connections whether it is okay or not and then we will go to the practical limitations. Practical limitations means we have to consider the durability, fabrication tolerances and erection strategy means erection strategy means we have to see that the given section which are coming is possible to erect properly or not that we have to see and we have to make a erection strategy so that the given sections can be erected properly in the site. So this is how one can design the section.

So in today's lecture in short if we say that main thing what we have discussed is the failure criteria of the member and what are the type of failure may come into picture and because of that failure how to take care means how to take care that design that will be discussed in next class, right.

So in today's class basically we have discussed the failure criteria and the what is the maximum displacement coming into the section for different loading conditions and boundary conditions. What is the practical limitations of the deflection as per the coder permissions and what is the effective length of the member due to lateral torsional buckling? Those have been seen how to calculate through the code and design procedure also has been discussed where we have to consider the structural criteria. Then the secondary effects and local buckling and then the erection, durability etc. So these are few things which we have to keep in mind for designing flexural member. In next class we will discuss about the design procedure of the flexural member, considering all this design failure criteria, right, okay. So todays lecture is over okay, thank you.