Course on Design of Steel Structures
Professor Damodar Maity
Department of Civil Engineering
Indian Institute of Technology Kharagpur
Lecture 21
Module 5
Design Strength of Tension Member

Hello today I am going to discuss about the codal provisions for calculation of design strength of members under axial tension. So as I told in last class that design strength calculation will be calculated on three criteria one is the due to gross yielding of the section and due to rapture and due to clock shear. And the strength calculations will be done one the basis of these three criteria and the minimum of these three will be the design strength of the tension member.

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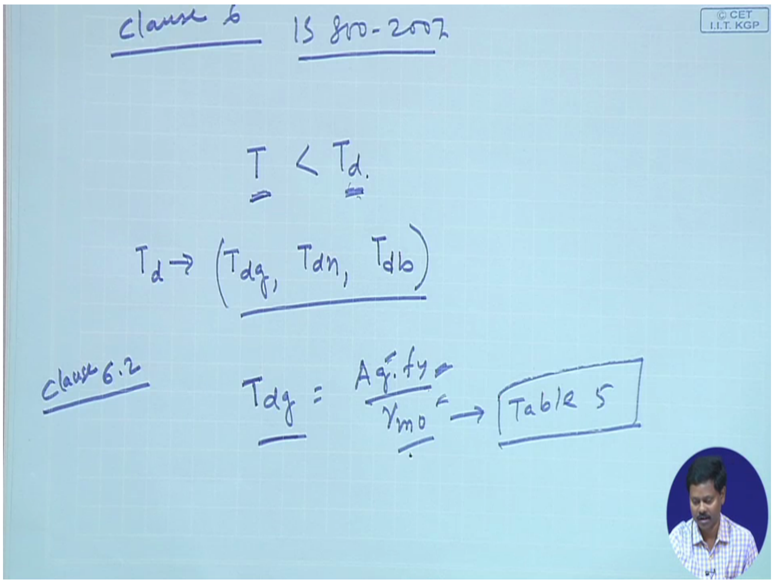

So coming to the codal provisions if we see that in clause 6, we will go we will get the design strength calculation of tension member clause 6 of IS: 800-2007. So details you can find out from this and in clause 6.1 it is told that the factor design tension T should satisfy the requirement of this Td where Td is the design strength of the member under axial tension and Td will be the least of these three, one is the yielding of gross section Tdg, then rapture of critical section Tdn and then block shear failure Tdb.

So on the basis of these three the Td will be decided. So Td will be the least of these three and that Td has to be less than the factor tensile force coming into the member. So coming to clause 6.2 if we see clause 6.2 we will see that the gross yielding strength the design strength due to gross yielding Tdg can be calculated as Ag into fy by gamma m0, we can calculate from this where fy is the yield stress of the material and Ag is the gross area of the cross section and gamma m0 is the partial safety factor and this we can find out from table 5 of the IS code from table 5 the partial safety factor the material has been given. So Ag fy by gamma m0, if we calculate this value we can find out the design strength due to gross yielding.

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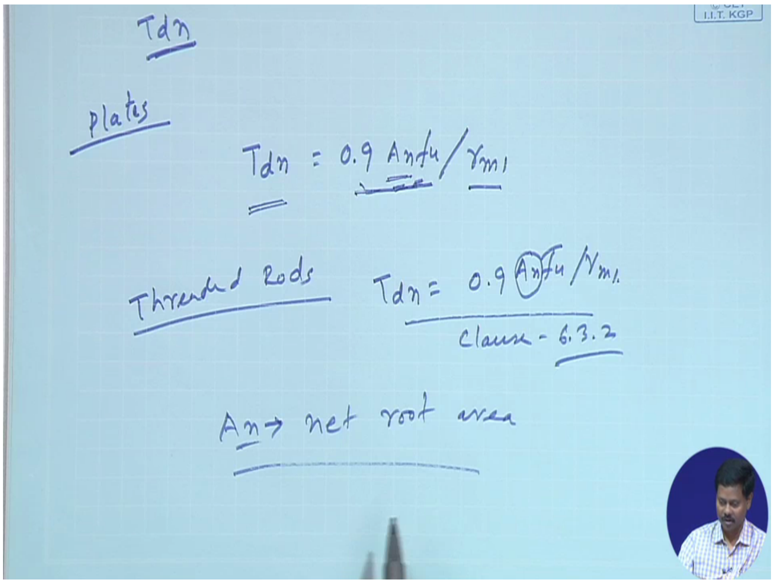

And similarly I can find out design strength due to rapture of critical section rapture of critical section Tdn we will try to find out design strength due to rapture of critical section. So this can be found this is given in clause 6.3 and in clause 6.3.1 you will get about plates design strength in tension of a plate. So that is calculated Tdn is equal to 0.9 Anfu by gamma m1. Here function is the ultimate stress of material and An is the net area of the cross section and gamma 1 is the partial safety factor of failure in tension at ultimate stress, right.

So the design strength due to rapture of critical section of plate can be found from this formula that is Tdn is equal to 0.9 Anfu by gamma m1, right. Now this is true for plate, so for plate in earlier lectures we have seen that how to calculate the net area of the plate net area of the plate means about the critical section what will be the net area net effective area of the plate that we have seen how to calculate. So this net area will be required to find out the rapture strength of the section, so here this net area will be required.

Now in threaded rods in case of threaded rod also this this will be same formula we can use that is Tdn will be is equal to 0.9 Anfu by gamma m1, so this is also same in clause 6.3.2 it is given clause 6.3.2 it is given where An here An in case of threaded rod it will be the net root area of the threaded section An will be the the difference with plate is that here An will be the net root area area of the threaded section, right. So this is how we can calculate the design strength of threaded rod.

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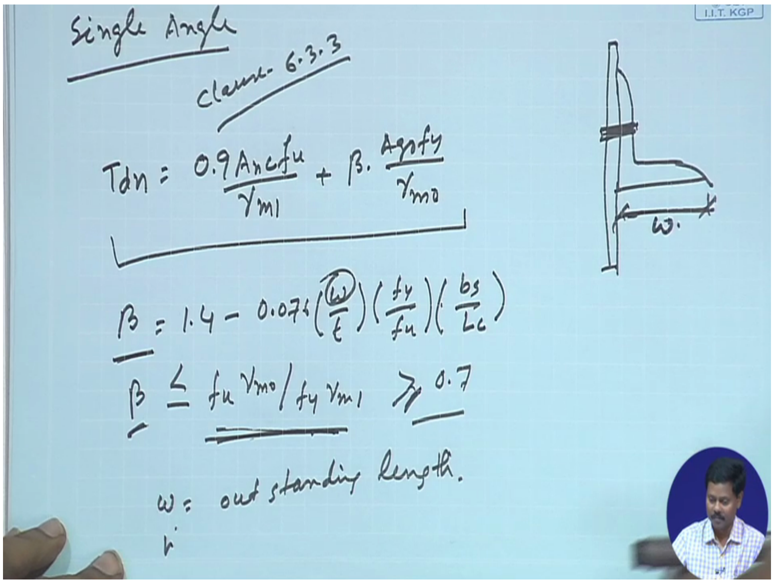

Similarly for angle section say for single angle, now in case of single angle as I told that if it is connected with some gusset plate, or some other plates, or some other members then if it is connected with this then shear lag effect will be going to be occur because this portion is not connected therefore we have to calculate the Tdn value taking care of the shear lag effect.

So this Tdn value can be calculated from this formula 0.9 Ancfu by gamma m1 plus beta into Agofy by gamma m0, right and this you can find out in clause 6.3.3 of IS: 800-2007 in clause 6.3.3 you can find out this value where the rapture strength of angle is effected by the shear lag and that shear lag effect has been taken into consideration in this formula.

Here beta is a factor which can be calculated from this formula that is 1.4 minus 0.076 into w by t into fy by fu into bs by Lc, right and this should be less than or equal to this beta should be less than or equal to fu gamma m0 by fy gamma m1 and should be greater than or equal to 0.7.

So beta should vary from this value to this value means it should be greater than 0.7 and it should be less than this and that means beta we have to calculate and we have to check with this value whether it is coming under this condition or not if not then we have to consider the remaining value.

Now this w w is basically outstanding length outstanding length of the section that means this is in this case this is w, this w when we are going to consider this w will be the outstanding length in this case, right.

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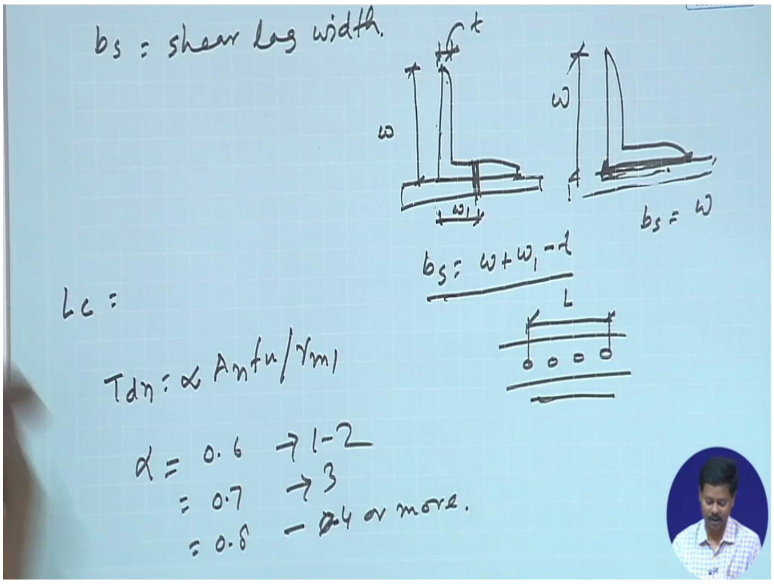

So next is the bs bs is the shear lag width so bs we can find out here it is shear lag width, how to calculate say you will get details in figure 6 of IS: 800-2007, I am just representing that graph here and the figure here that is if a angle say it is connected with a plate with the bolt connection then this is as I told that outstanding lag is the w outstanding lag width and this we can consider as w1, then this bs will be here bs will be w plus w1 minus t t is the thickness of the angle this is t, right.

So when angle with single lag connection then bs can be calculated from this shear lag width bs will be w plus w1 minus t but if it is connected with weld connections then connected with weld connections means basically it will be connected here and here means throughout right. So here we can calculate bs as simply w, because it is connected upto this right. So bs is the outstanding lag width and the width which are not connected from outstanding lag width site right so w plus w1.

And Lc Lc is the length of n connection that is the distance between the outermost bolt that means if it is connected with bolts then this this will be the Lc the distance between outermost bolt in the n joint, measure along the load direction or length of the weld along the load direction. So this is how the Lc can be calculated.

And at the beginning we may not find out because we may not know that the all the details, so for preliminary sizing we can calculate Tdn as this formula from this formula also we can calculate approximately it will be like this alpha into Anfu by gamma m1, where alpha is a factor which can be consider as 0.6 for 2 number 1 or 2 bolts 1 to 2 bolts, alpha is equal to 0.6 and 0.7 for 3 bolts and 0.8 for more than 3 bolts means 4 or greater than or equal to 4 means 4 or more, right.

So for preliminary sizing one can find out Tdn as alpha into Anfu by gamma m1, where An is the net area of the cross section and alpha is the factor which we can take 0.6 if 1 to 2 bolts are there and it is 0.7 if it is 3 bolts and it is 0.8 if we can if we take 4 or more bolts.

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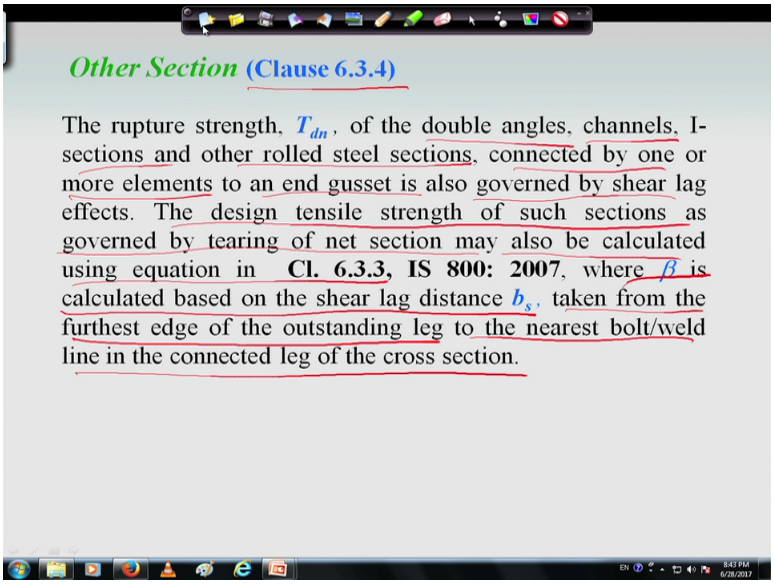

For other section other sections we can see here which is given here that is written in clause 6.3.4 which I have represented here that is the rapture strength Tdn of the double angle because earlier we have calculated for single angle, for double angle channels I-sections and other rolled steel sections connected by one or more elements to analysis end gusset is also governed by shear lag effect.

The design tensile strength of such sections as governed by tearing of net section may also be calculated using (equation 6.) equation in clause 6.3.3, right where beta is the is calculated based on the shear lag distance bs, and bs is taken from the furthest edge of the outstanding leg to the nearest bolt or weld line in the connected leg of the cross section. So for rapture strength calculation other than the single angle section we can use this clause that is clause 6.3.4.

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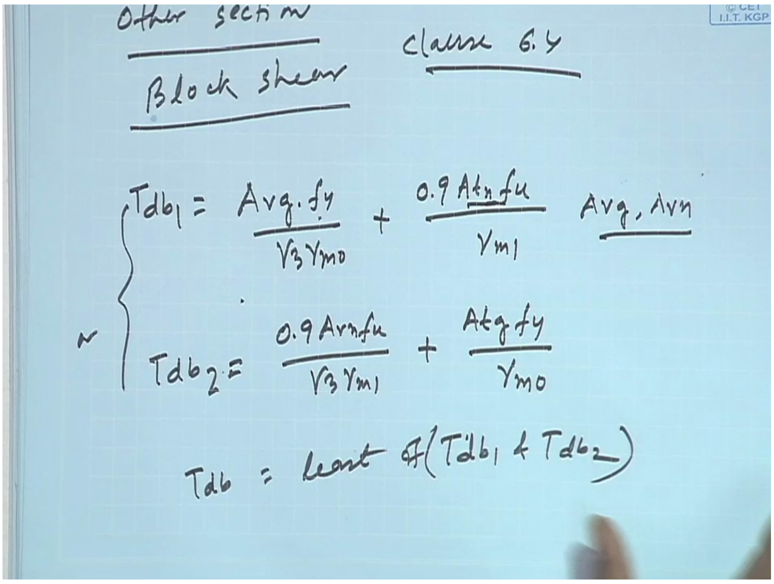

Then we will come to block shear design strength due to block shear, right. So the block shear we can calculate from clause 6.4 of the IS code, it is given in clause 6.4. The block shear strength Tdb can be calculated from this formula that is Tdb is equal to Avg into fy by root 3 gamma m0 plus 0.9Atn into fu by gamma m1 or Tdb also may be this is because of tension fracture and shear yield, if shear means due to shear yield and tension fracture the block shear can be calculated or tension yield and shear fracture also we can calculate that will be 0.9Avnfu by root 3 gamma m1 plus Atgfy by gamma m0.

So block shear can be calculated due to tension fracture and shear yield or tension yield and shear fracture whichever is less means Tdb1 and Tdb2 we can calculate and Tdb will be least of least of these two Tdb1 and Tdb2, right. So this is how we can calculate. Now what are the parameters means this Avg and Avn what are this, now we have to know.

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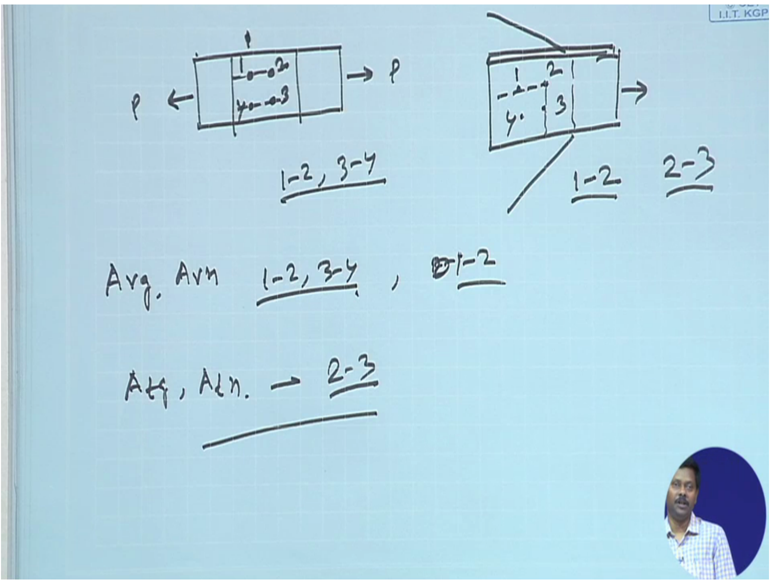

So to know this let us draw a picture which I am reproducing from figure 7 of IS: 800-2007 from figure 7 it is given if we see if a plate are connected with some bolt connections say like this and if axial force are in this direction then we can see that this I can write 1, this bolt 1 1, 2, this is 3, this is 4 and also let us come to the angle section if we can see this angle section is connected to a plate and under tensile force and bolt are connected in this way so it can we can see 1, 2, 3, 4, ok.

Now Avg and Avn, Avg is the minimum gross area and (Av) is the Avn is the net area in shear along bolt line parallel to external force that means along line 1-2 and 3-4 and here along 1-2, right. So Avg and Avn will be the minimum gross and net area in shear along bolt line parallel to external force, right.

Similarly Atg and Atn will be the minimum gross and net area in tension t for tension from the bolt hole to the toe of the angle that means along 2-3 perpendicular to the line of the force respectively, right. So this will be along 2-3 then perpendicular to the force and this will be along 1-2 or 3-4 and in case of angle along 1-2. So this is how we can calculate the Avg, Avn, Atg and Atn and fu and fy are as usual meaning fu is the ultimate strength of the plate and fy is the yield strength of the plate.

Now for weld connections Tdb can be checked for welded connections by taking analysis appropriate section in the member around the end weld and this which can shear of as a block. So this weld connections also we can use means we can calculate the Tdb value for weld connection as well.

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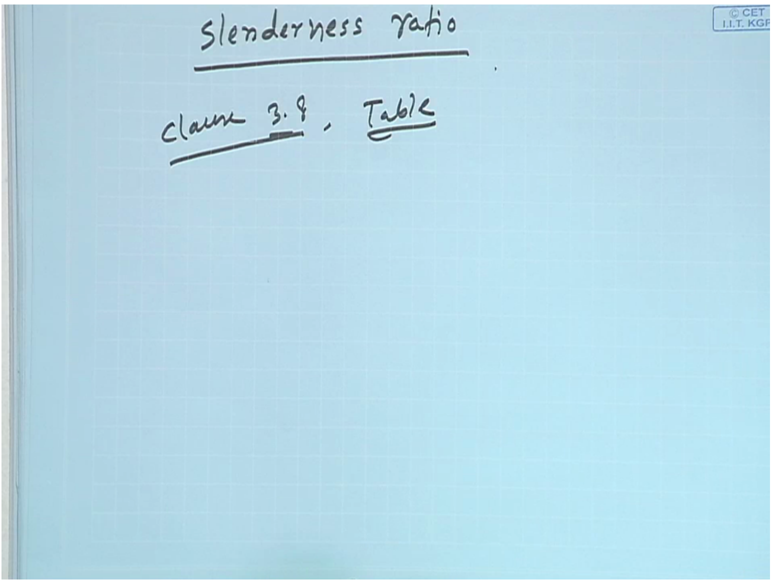

Now another things we have to check that is slenderness ratio slenderness ratio theoretically there should not be any upper limit of the slenderness ratio because it is under tension if it is compression then there is a chance of buckling so for that we have to consider the limiting value of slenderness ratio but in this case theoretically we should not, but we consider certain slenderness ratio from serviceability point of view, right limitation is necessary because to prevent undesirable vibration and (())(21:05) movement.

So this is given with this limitation limited values means permissible values are given in clause 3.8 clause 3.8 of or table 3 in the IS code table 3 in clause 3.8 the permissible value of slenderness ratio are given, right. So why we are providing slenderness ratio means in case of tension member because to make sure that vibration is not going to be more from limit state of serviceability point of view, we have to take care means we have to restrict certain slenderness ratio so that the excessive deformation can be restricted, also sometimes the member get reverse load means which was means due to wind and earthquake if reverse effect may happen.

So in that case slenderness ratio will be a big factor means will come into picture that is why IS code has provided certain permissible value with respect to slenderness ratio. (I am just changing the).

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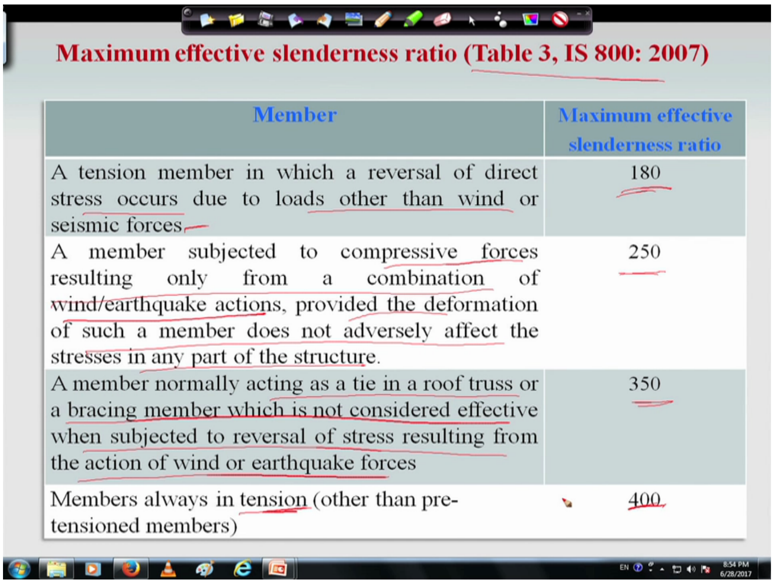

Member	Maximum effective slenderness ratio
A tension member in which a reversal of direct stress occurs due to loads other than wind or seismic forces	180
A member subjected to compressive forces resulting only from a combination of wind/earthquake actions, provided the deformation of such a member does not adversely affect the stresses in any part of the structure.	250
A member normally acting as a tie in a roof truss or a bracing member which is not considered effective when subjected to reversal of stress resulting from the action of wind or earthquake forces	350
Members always in tension (other than pre-tensioned members)	400

So the slenderness value slenderness ratio value are given in table 3 of IS: 800-2007, if we see that we will see that when the tension member has reversal of direct stress due to loads other than wind and seismic it is 180 180, right.

Whereas when a member subjected to compressive forces resulting only from a combination of wind and earthquake actions, provided the deformation of such a member does not adversely affect the stresses in any part of the structure. In that case the permissible value of slenderness ratio is 250.

And if a member normally acting as a tie in a roof truss or a bracing member which is not considered effective when subjected to reversal of stress resulting from the action of wind or earthquake we can consider as 350.

And when members are always in tension other than pre-tensioned members we can consider as 400. So this is how the IS code has provided certain limit on maximum effective slenderness ratio, so that has to be keep in mind.

So that means when we are going to design a tension member not only we have to find out the strength point of view the section is shape but also we have to find out whether it is under the permissible limit of slenderness ratio or not, so both the things we have to see.

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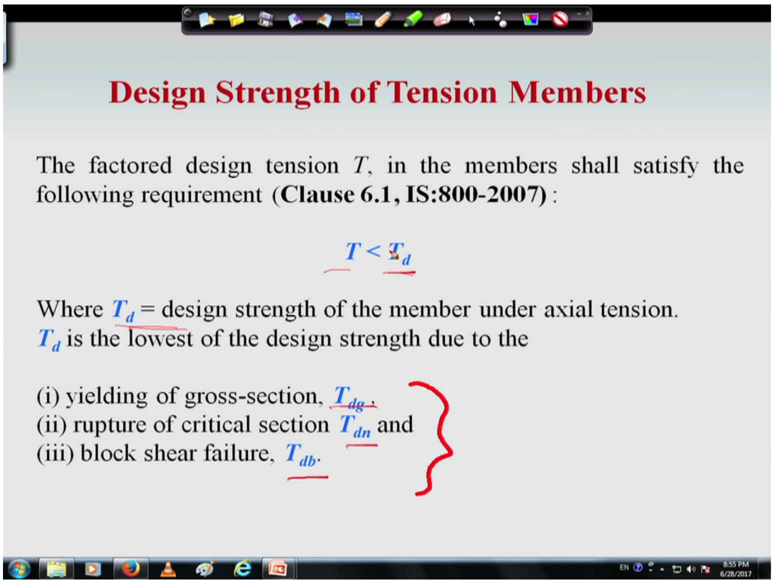

So if I see quickly the design strength calculation for tension member we have to see that these three criteria we have to calculate one is yielding of gross section, then rapture of critical section and block shear failure and the least of these three will be the design strength of member and which should be means the factor design tension should be less than that design strength.

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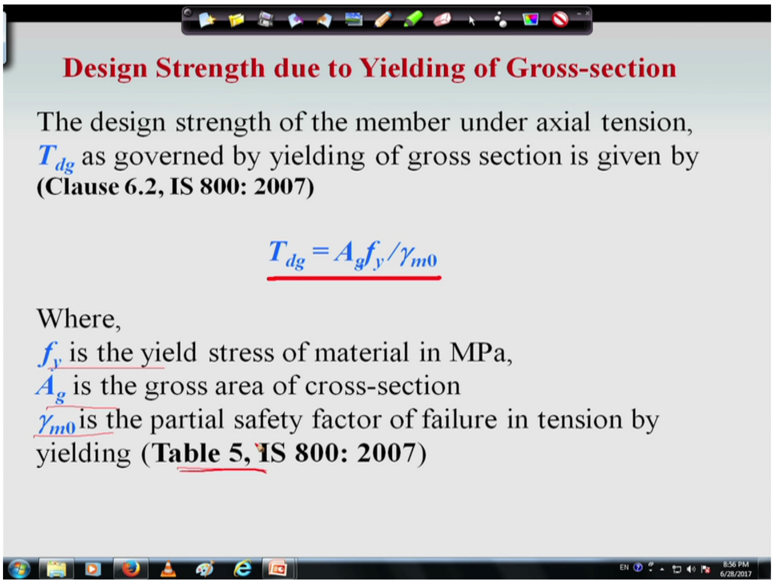

So to find out this we have to calculate the design strength due to yielding of gross section, that we can calculate this is the Tdg is equal to Agfy by gamma m0. Now Ag is the gross area of the section and fy is the yield stress of material and gamma m0 is the partial safety factor and this gamma m0 value we can find out from table 5, right. So this is how we can find out the design strength due to yielding of gross section.

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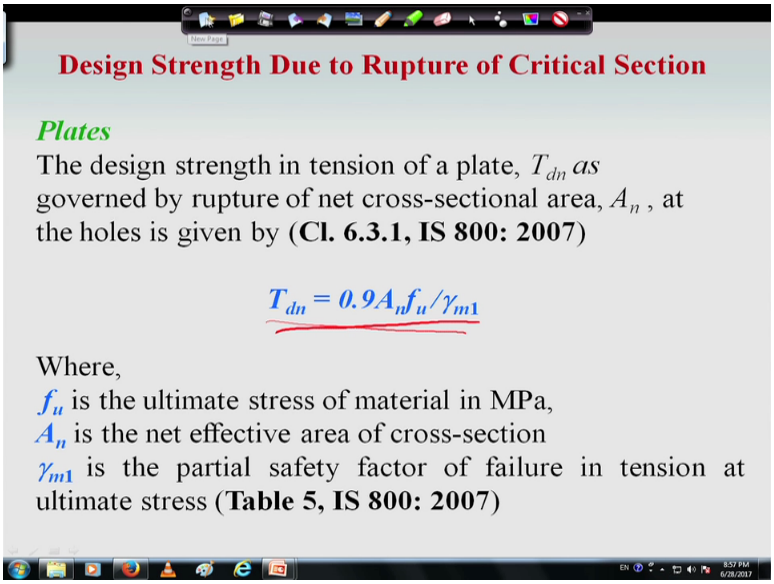

Then design strength due to rapture of critical section if we see we can find out that Tdn is equal to 0.9Anfu by gamma m1, where fu is the ultimate stress of material and An is the net effective area of the cross section and gamma m1 is a partial safety factor. So for plate simply we can find out Tdn as 0.9Anfu by gamma m1.

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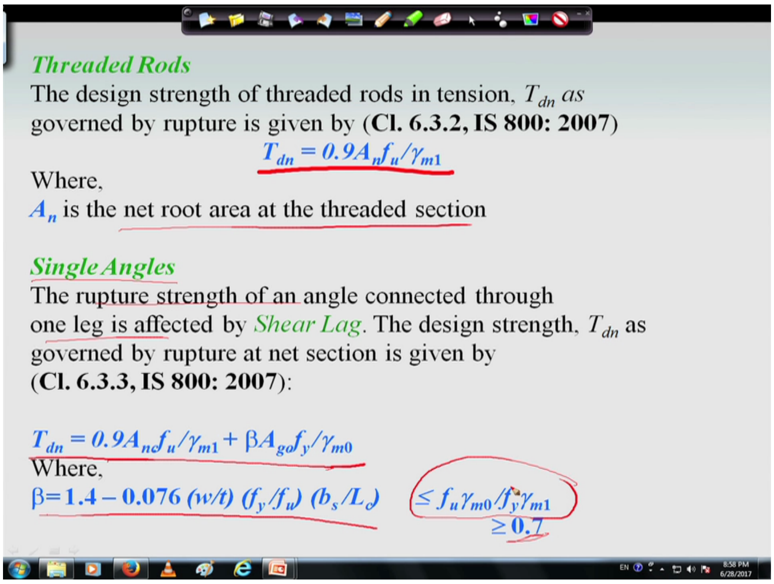

But in case of angle we have to consider the shear lag effect when before going to angle first we will see how to calculate the Tdn value of threaded rods. So in case of threaded rod formula is same only the An will be the net root area net root area of the threaded section. So while calculating the net area of the section we have to calculate net root area of the threaded section in case of threaded rod.

And if we have a single angle connection means if the angle is connected with a plate then the rapture strength of that angle which is connected through one leg can be found from this because if it is connected through one leg then shear lag effect will be will come into picture, so that has to be taken care.

So Tdn as we see will be 0.9Ancfu by gamma m1 plus beta into Agofy by gamma m0 and beta can be calculated from this formula that is 1.4 minus 0.076 into (w by t)(fy by fu) and (bs by Lc) and the beta value should not exceed this value that is fu gamma m0 by fy gamma m1 and should not be less than means it should be should not be less than (0.07) 0.7.

So this is how we can find out the design strength of angle due to rapture and while calculating we need to know what is the bs the shear lag width and Lc. So these two we have to know.

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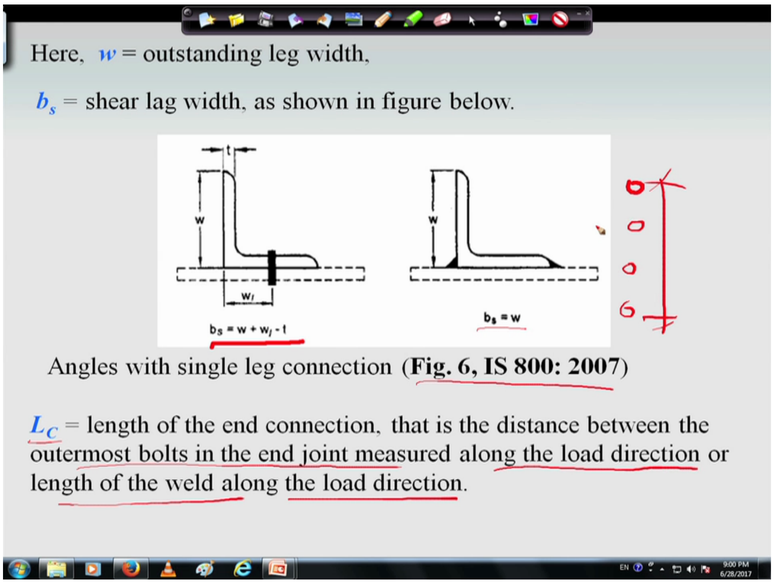

So if we see here that the bs value can be calculated as bs is equal to w plus w1 minus t, if it is connected with bolt and if it is connected with one leg with weld then bs is equal to simply w. So this is given in figure 6 of IS: 800-2007 from which directly I am showing here and Lc will be the length of end connection that is the distance between the outermost bolts in the end joint measured along the load direction or length of the weld along the load direction. So this is how I can find out the Lc.

So in case of bolt connections it will be if we have bolt like this so end to end connection the distance between end to end bolt and along the load direction and if it is weld simply length of the weld along load directions means we have to find out the length of the weld along load direction, this is how we can calculate.

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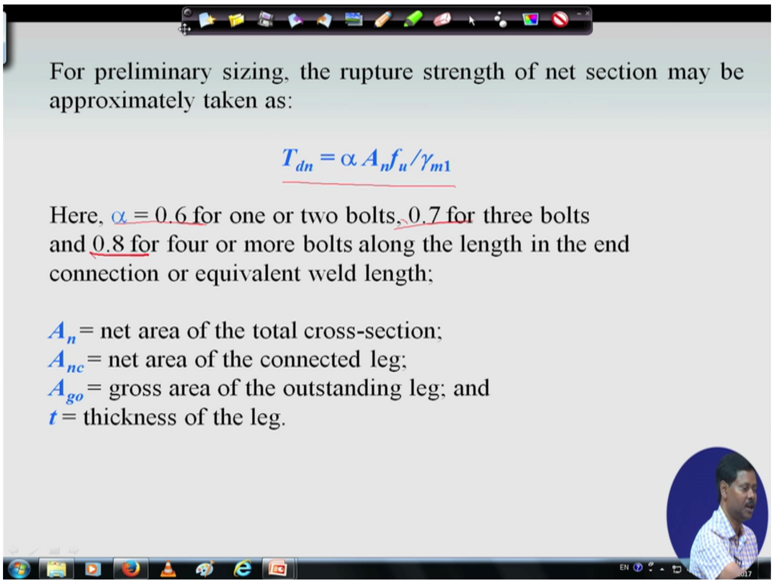

And for preliminary sizing we can find out the rapture strength approximately as this Tdn is equal to alpha into Anfu by gamma m1 and this alpha value has been given in the code as 0.6 for one or two bolts, 0.7 for three bolts and 0.8 for four or more bolts along the length in the end connection, so this is how we can approximately find the Tdn value.

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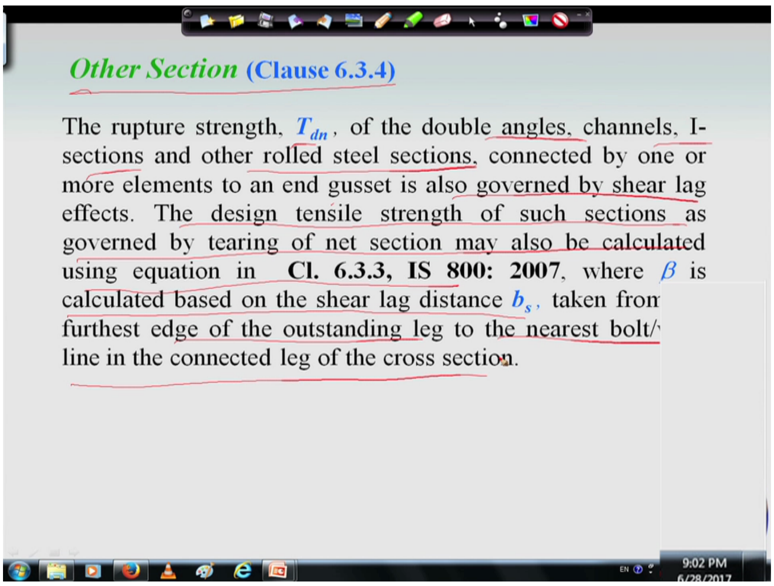

And for other sections the codal provisions sorry codal provisions are given in clause 6.3.4 where it is mentioned that the rapture strength Tdn of the double angle channel I-sections and other rolled steel sections, connected by one or more elements to an end gusset is also governed by shear lag. So the design tensile strength of such sections as governed by tearing of net section may also be calculated using equation given in clause 6.3.3. Here beta is the calculated based on the shear lag distance bs, which we have calculated earlier we have seen taken from the furthest edge of the outstanding leg to the nearest bolt or weld line in the connected leg of the cross section. So this is what clause 6.3.4 describes, so for other sections we have to keep in mind for calculating the Tdn value.

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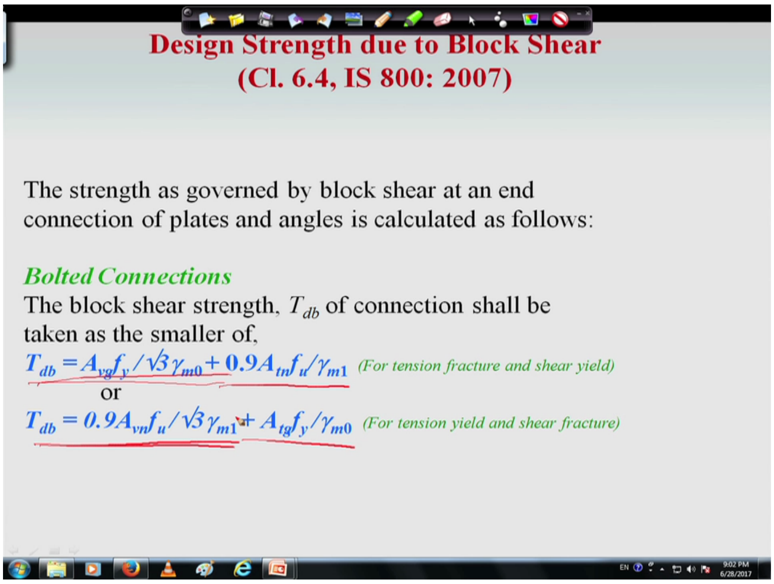

And another factor we have to consider that is block shear. So the strength as governed by block shear at the end connection of plates are this that is Tdb is equal to Avgfy by root 3 gamma m0 plus 0.9Atnfu by gamma m1, or Tdb is equal to 0.9Avnfu by root 3 gamma m1 plus Atgfy by gamma m0. This is for tension fracture and yield shear yield and this is for tension yield and shear fracture. So least of these two will be the strength due to block shear failure.

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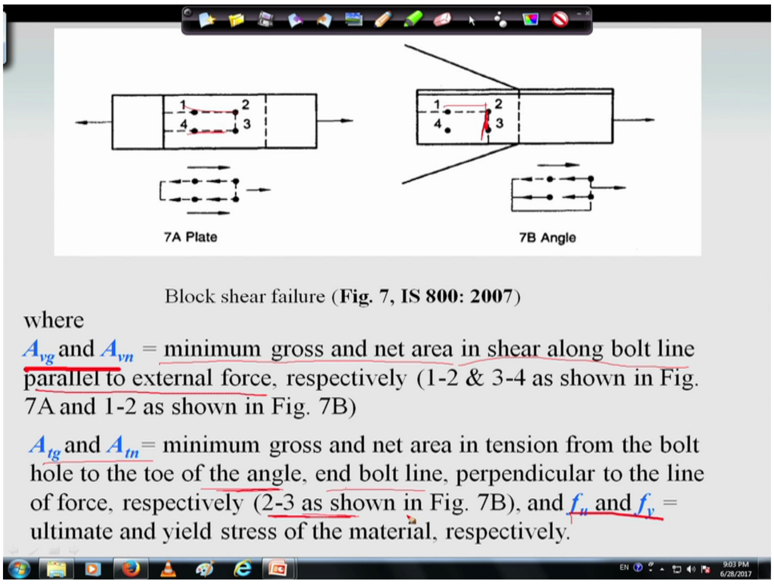

Now while calculating block shear failure we have to know the Avg and Avn value how to calculate this is given in the code in figure 7 it is mentioned that this will be the minimum gross and net area in shear along bolt line parallel to the external force, that means 1-2 and 3-4 in plate and 1-2 in angle.

And Atg and Atn will be the minimum gross and net area in tension from the bolt hole to the toe of the angle bolt hole to the toe of the angle, that means the end bolt line perpendicular to the line of force respectively that means 2-3 as shown in figure so this is right and fu and fy are has the usual meaning. So this is how we can calculate Avg, Avn, Atg, Atn and then the block shear Tdb.

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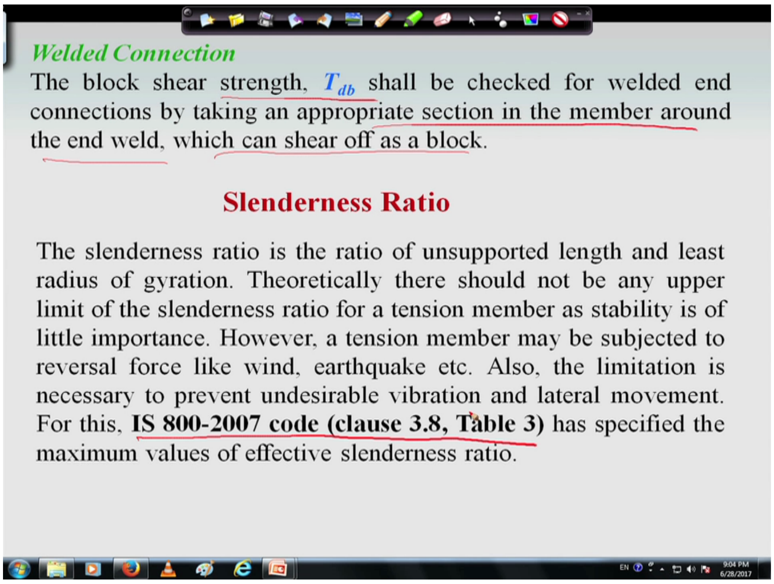

In case of weld connection the codal provisions says that the block shear strength Tdb shall be checked for welded end connections by taking an appropriate section in the member around the end weld, which can shear off as a block so that we have to take care. And in case of slenderness ratio the maximum (())(33:27) slenderness ratio are given in table 3 of IS: 800-2007 and in clause 3.8 it is mentioned.

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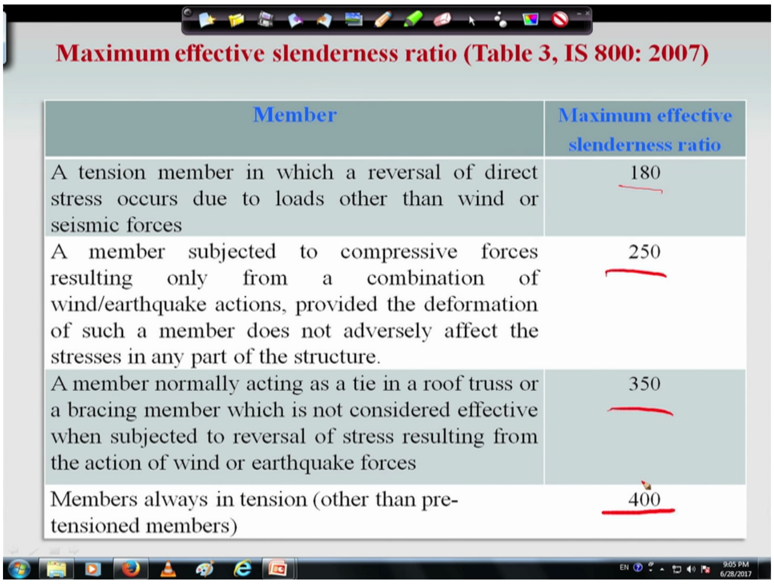

Maximum effective slenderness ratio (Table 3, IS 800: 2007)

Member	Maximum effective slenderness ratio
A tension member in which a reversal of direct stress occurs due to loads other than wind or seismic forces	180
A member subjected to compressive forces resulting only from a combination of wind/earthquake actions, provided the deformation of such a member does not adversely affect the stresses in any part of the structure.	250
A member normally acting as a tie in a roof truss or a bracing member which is not considered effective when subjected to reversal of stress resulting from the action of wind or earthquake forces	350
Members always in tension (other than pre-tensioned members)	400

So that also I am showing that is given here that maximum effective slenderness ratio slenderness ratio means L by R where R is the minimum radius of (())(33:56) and L is the effective length. So we can calculate the effective slenderness ratio and from that we have to check that which condition it is coming, then accordingly the maximum limiting value has to be checked whether it is ok or not.

So this is how one can calculate the particular section capacity, design capacity and check whether that section is (())(34:31) the slenderness ratio means ratio the codal provisions of the slenderness ratio or not, right.

So in todays lecture if we see that in short we can say that how to calculate the design strength of a member under axial load, axial tension that we have gone through and also we have seen that what will be the maximum permissible effective slenderness ratio of the member for different loading case. So considering all this we can next design the things, right thank you very much.