Course on Design of Steel Structures
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Lecture 36
Module 8
Lacing Systems

Hello today I am going to discuss about the lacing systems, lacing systems are used basically to keep the built up sections throughout its length we can equidistance that means the built up section whatever we used throughout its length we need to tie them to make them parallel and to make them equidistant and to make them act as a monolithically, so that as a whole the built up section works.

So for that we may use lacing which are basically some inclined member between the two compressive means vertical members or may be batten system, batten system is basically it is a horizontal plate which are connected with the two main members these are called batten members. But today we will be discussing about the lacing member which are basically the inclined members and these lacing members are used when means when compressive loads are acting or the eccentricity is there specially for eccentric loading we prefer lacing system.

Now for lacing system the lacing members are generally plate flat plate it may be, it may be angle section, it may be light channel section, or may be circular section means tubular section, so in different way we can provide.

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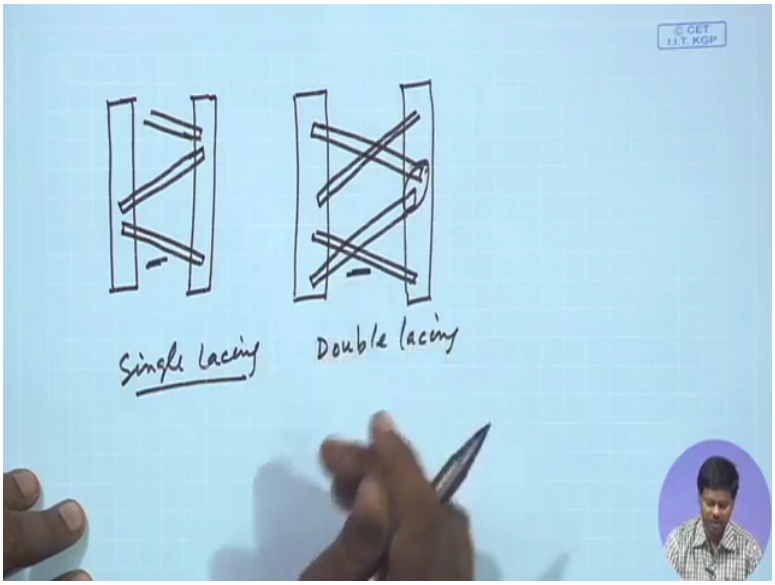

Now in case of lacing member again we can consider two type of lacing member, say this is one member have been provided, this is one compression member, this is another compression member which are used for built up section and we are providing lacing.

So we can provide as a single lacing this is called single lacing system or we can provide double lacing also, in case of double lacing it will be like this, right. So in different way we can connect of course may be separately we can connect, may be this can be connected together. So this is called double lacing, so when we will be designing we have to first decide whether we are going for single lacing or double lacing because accordingly the force on lacing member will come into picture that has to be taken care.

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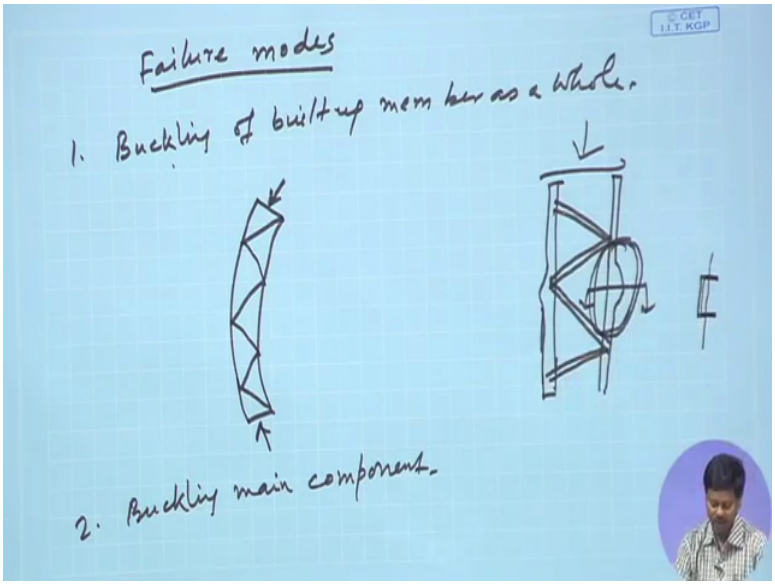

Now when we will be going for designing of a lacing we need to know what are the failure modes failure modes of the lattice member. So what type of failure may happen that we will first see and accordingly we will try to develop a design methodology so that the failure can be arrested. So in case of one is buckling of built up member as a whole buckling of built up member as a whole that means if as a whole, if column is very slender then it may buckle like this, right it may buckle like this under if column is very slender and if axial load is much high then the buckling may happen in this way, so this is one means one way it may fail.

Another way it may fail that buckling of main component buckling of main component buckling of main component means may be we are providing say a compression member here and we are providing a compression member may be here and we are providing certain lacing system, right. So what we could see if the loading whatever it is coming for that if the member is not able to carry that much load due to buckling means excessive buckling then it may fail the main component because say if we see the cross section the main components if we use channel section the minimum radius of gyration will be about y-y, so the failure will happen about this section. So as a local failure this can arise buckling of main component.

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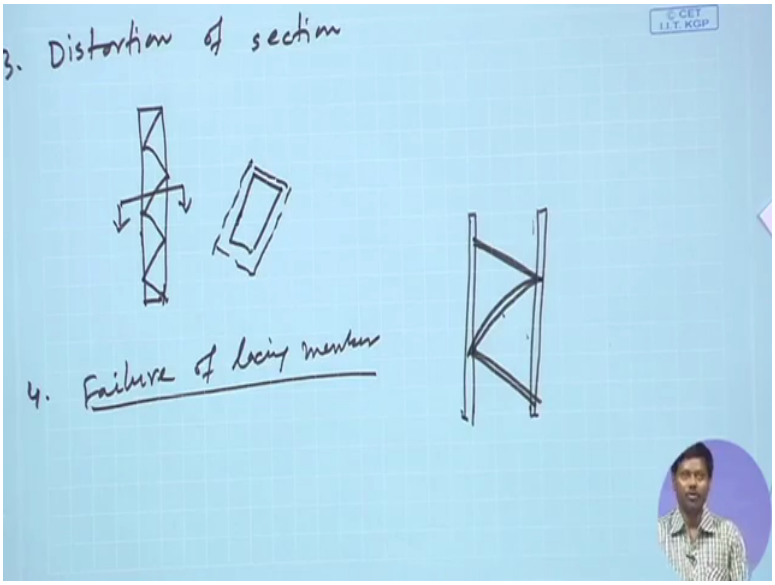

Then another way of failure is the distortion of the section the section may distort, say for example say this is a built up section where lacing has been provided. Now if we see if distortion happens it will be something like this, so due to distortion the failure may happen which has to be taken care.

Another failure is this is number 3, number 4 is the failure of lacing member means lacing member whatever we are providing that has to be also taken care. Say for example if we provide two built up sections with the lacing say if its width is less compared to its length then it may buckle like this, say a member may buckle like this, right so this is called failure of lacing member. So 4 type of failure may come into picture.

Now what we need to do is that we will design the lacing system in such a way that that it will arrest the failure of local buckling, it will arrest the failure of lacing system and it will take care the failure of member as a whole means globally and also distortion.

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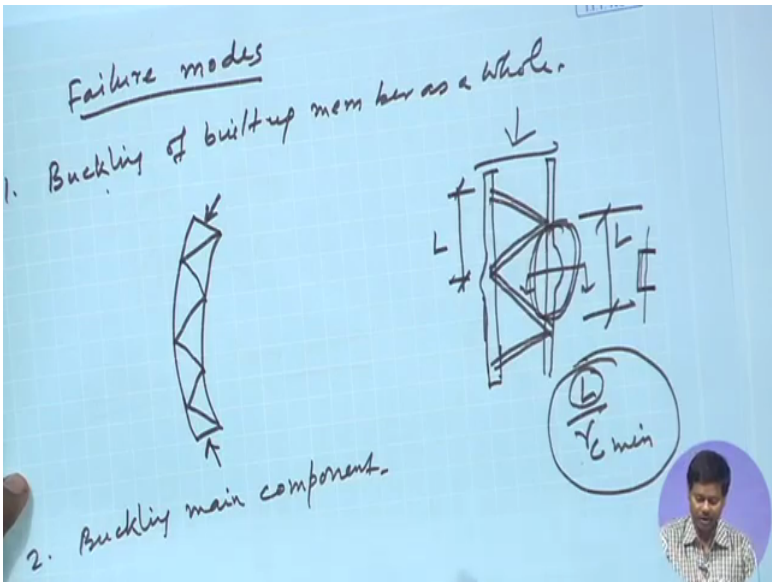

So what we have to consider since for example how do we consider the say this one say this is called L, so L L by rc rc minimum means L by rc minimum, so radius of gyration should be limited because otherwise this may fail, so some restriction should we should provide the slenderness ratio is restricted and to restrict the slenderness ratio we have to restrict the length that means spacing between two lacing has to be decided.

So from failure of local buckling we can find out what should be the maximum distance between two lacing L, so this is what we have to decide.

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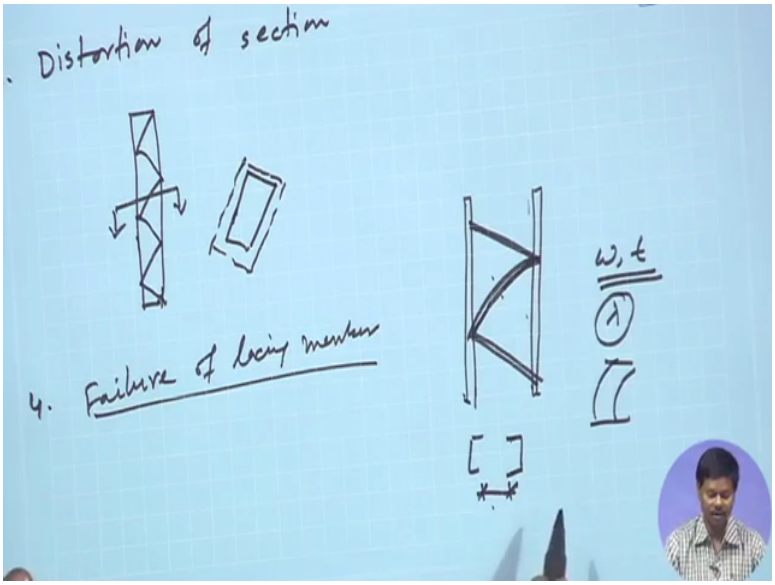

Another thing is when the failure of lacing member happens say for example for this that means the lacing cross section is not sufficient to take the slenderness means to take the load that is why it is buckling. Therefore the what should be the width of the lacing member, what should be the thickness of the lacing member that has to be decided from which the slenderness ratio has to be calculated, so that also we need to take care.

Next is the failure as a globally it may failure so if global failure happens that means we have to see that if we have to two sections we are providing then we need to take the section spacing in such a way that we are under the limit of the slenderness ratio that means the slenderness ratio of the built up section should not exceed the limiting value that has also to be decided, right.

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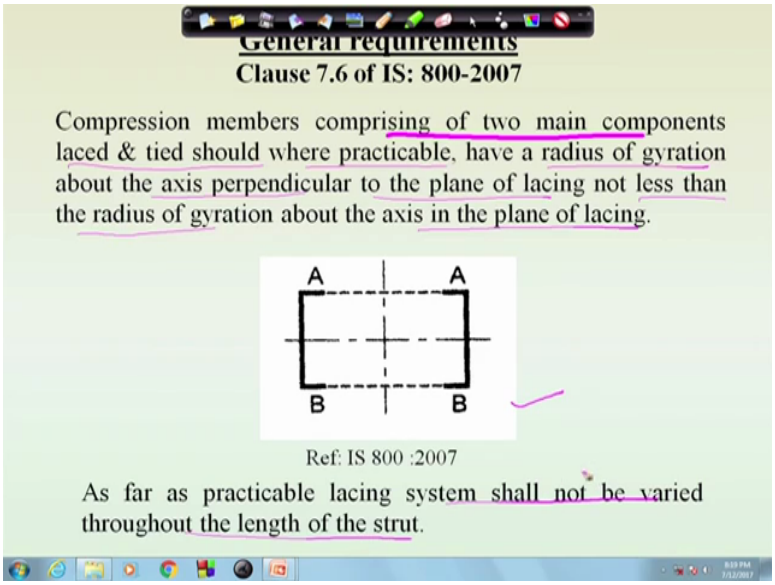

So now coming to the general requirements which has been given in the code, this is given in clause 7.6 of IS: 800-2007. Here it says that the compression member comprising of two main components laced and tied should where practicable, have a radius of gyration about the axis perpendicular to the plane of lacing not less than the radius of gyration about the axis in the plane of lacing. So this has to be taken care. Therefore that as far as practicable lacing system shall not be varied throughout the length of the strut that means the lacing system, the lacing spacing and lacing dimension those things should not be varied along its length that also has been mentioned in the code.

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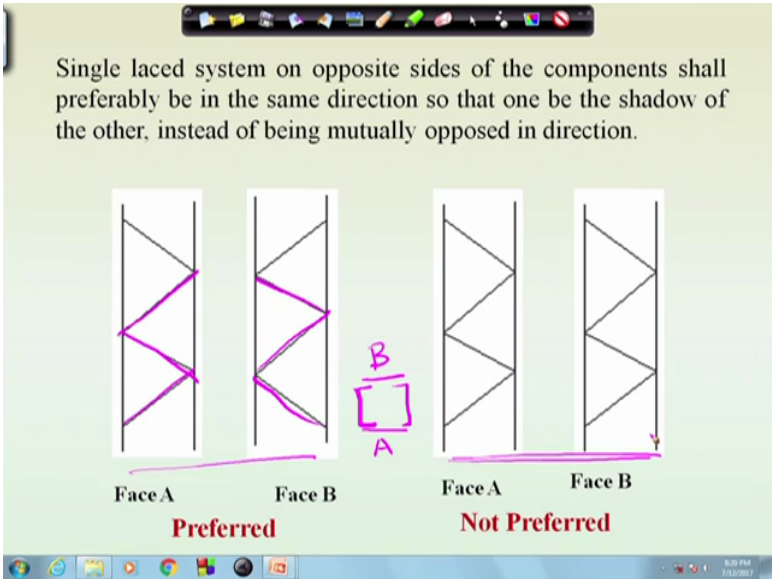

Now coming to the single lacing system we have say for example we have a channel section say toe to toe, now we will be providing lacing here and we will be providing lacing here, this is say call face A and this is face B, right. Now the prefer orientation should be like this that means one should be the shadow of the other, if this is provided in this way then the other in other direction it should be provided in this way so it should be the mirror image of that, right it should not be means such type of orientation are not preferred.

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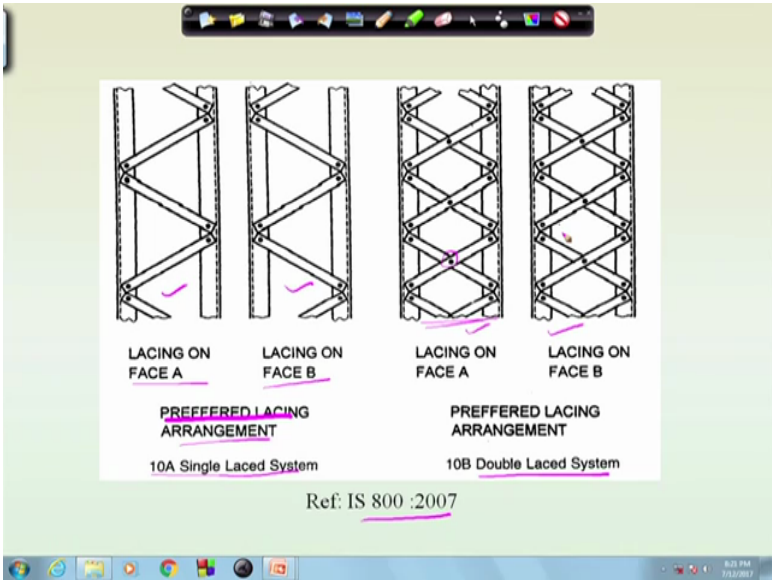

So this is also mentioned in the code, we can see here that the preferred lacing arrangement lacing on face A and lacing on face B has been made. So one is shadow of the others and this is given in the IS: 800-2007 figure number 10A and in figure 10B double lacing system how the prefer lacing has been should be that has given also mentioned here that when double lacing systems are there means it is preferable that you make a bolt connection here that means you tie it then it will be much more effective and the face A and face B should be in this way so that the arrangement will be means as per codal provision the facing means lacing on face A and face B should be like this that means similar, identical to each face.

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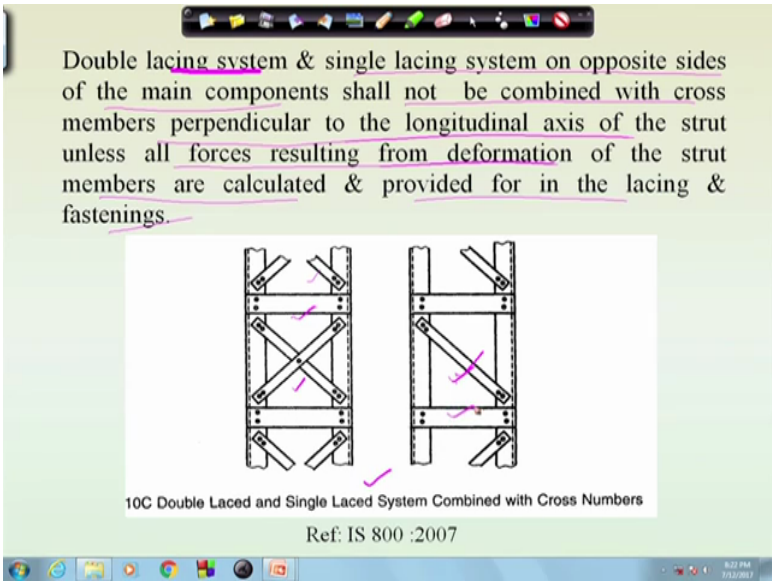

Then another things is told in the code which are mentioned in the code is that double lacing system and single lacing system on opposite sides of the main components shall not be combined with cross members perpendicular to the longitudinal axis of the strut unless all forces resulting from deformation of the strut members are calculated and provided for in the lacing and fastening.

So this is what in the code it is told, also we should keep in mind that when we are providing lacing and means with combined cross member then in such way one can provide. Say double lacing system then cross member, double lacing system then cross member like this or if we use single lacing system one inclined member that is which is called lacing then one cross member like this it is preferred.

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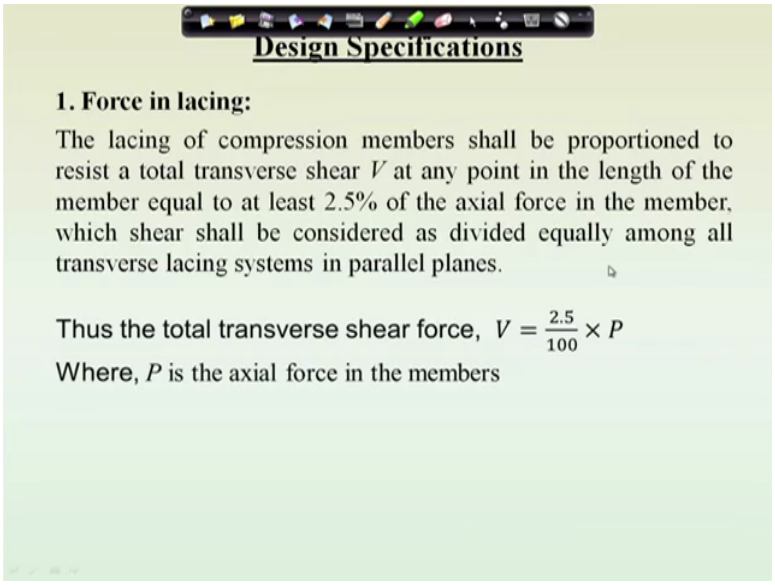

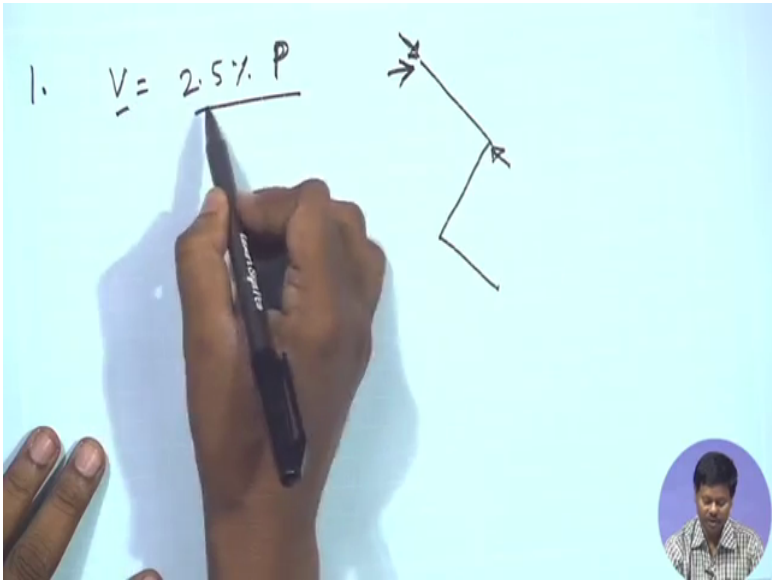

Now coming to design specification design in design specification first it is told that the total transverse shear force V will be the 2.5 percent of the compressive force P, because in lacing when we are going to design a lacing, lacing will be undergoing some compression in one member in other member it will be tension and that means some forces will be acting here that force will come from the transverse shear force and that transverse shear force is calculated from the axial compressive force and in codal provision it is told that the transverse shear force should be 2.5 percent of the compressive force.

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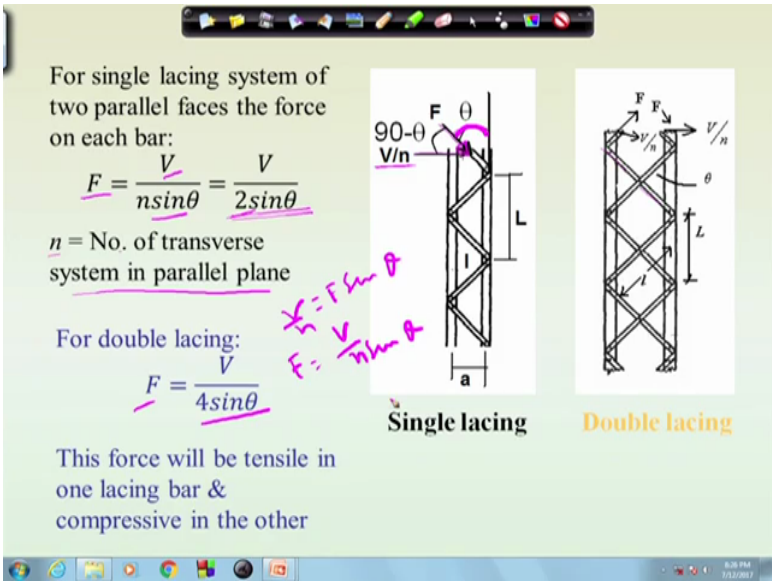

Next if we distribute the load means force on the lacing we can see here that for a single lacing system if we see that we know that this is the in angle of inclination we can consider as theta with the vertical angle and the total transverse shear force it V then in each face it will be V by n because in two face it may have in two face or number of face may be increased, so depending on the number of face the shear force in each cases will be V by n, right and if this is V by n and if the force acting on the lacing is F then we can find out F sin theta means V is equal to F this will be F cos theta and this will be F sin theta that means F is equal to V by n that means F will become V by n sin theta, right.

So F will become V by n sin theta and if number of parallel plane is two for single lacing it is generally 2, so V by 2 sin theta, here n is the number of transverse system in parallel plane. Now for double lacing it will again divided by 2, because it will be distributed in 2 cases, so F will become V by 4 sin theta, now as I told that this force will be tensile in one bar and compressive in other bar.

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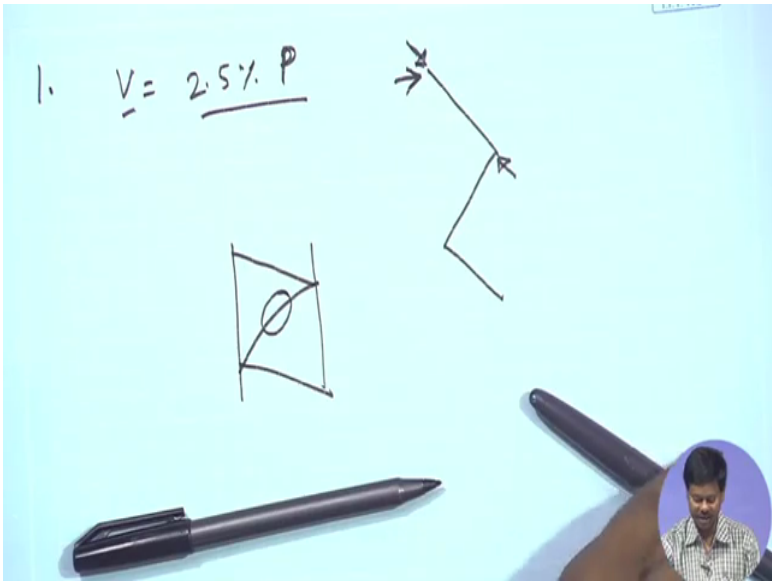

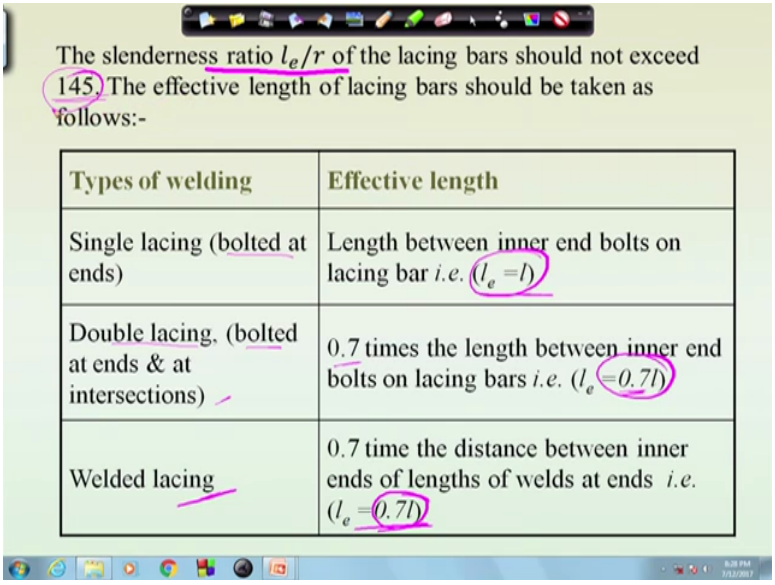

Now as I told the lacing member may buckle locally this lacing member may buckle, right so the code has provided certain restriction which is given in tabular form here that the what will be the effective length and what will be the slenderness, the slenderness ratio it is telling that the le by r of the lacing bar should not exceed by 145 that means as per the codal provision we have to make the dimension of a lacing system in such a way that le by r should not become more than 145, so that has to be mentioned.

And to calculate le the effective length that has been also discussed in the code that is in case of single lacing with bolted end le will be l that means l is the length between inner and end bolts of lacing bar, so le will be l and for double lacing bolted at ends and intersections it will be 7l where l is the length between inner ends of bolts, right and for welding lacing also it

will be 0.7l. So the effective length for different cases has been defined in the code which is shown here in single lacing it will be le is equal to l, in double lacing it will be 0.7l and in welded case also it will be 0.7l and the slenderness ratio should not exceed 145.

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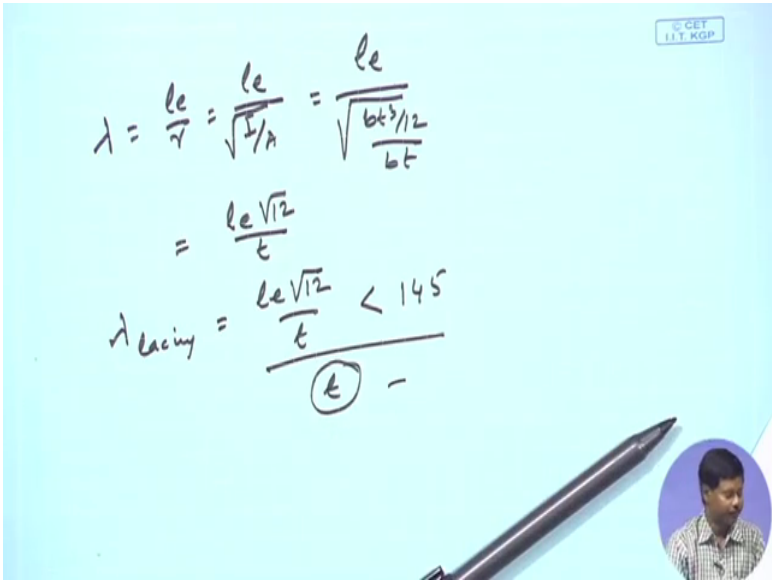

Now if we use flat bars then what should be the restriction means lambda lacing how do we calculate. So lambda as we know le by r, right so le by r if we calculate this will become le by I by A square root of I by A that will become le by square root of I by A means bt cube by 12 by bt, this will be so finally it will be le into root of r 12 by t, right. So lambda lacing means lacing in the means slenderness ratio of the lacing bar should be le into root of r 12 by t and should be less than 145, so this is how from here we can find out the value of t, thickness of t also can be found from here, right.

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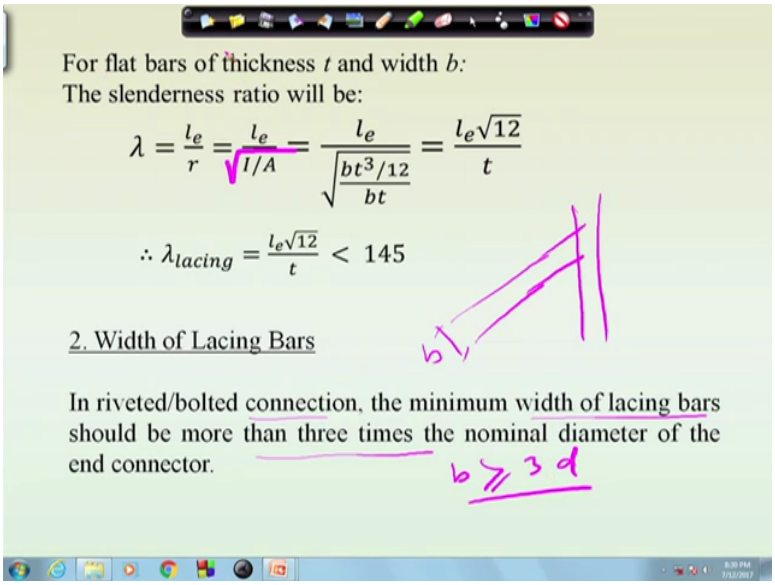

Then the ya okay r here it will be I by A root of r I by A, now width of lacing bar now how do we find out the width of lacing bar width of lacing bar means what will be the width of this if lacing bars are provided. So width of lacing bar if we say V then in bolted and riveted connection the minimum width of lacing bars should be more than 3 times the nominal diameter of the end connector that means b should be more than or equal to 3 into d the width should be minimum 3 times d, d is the diameter of the bolt or rivet.

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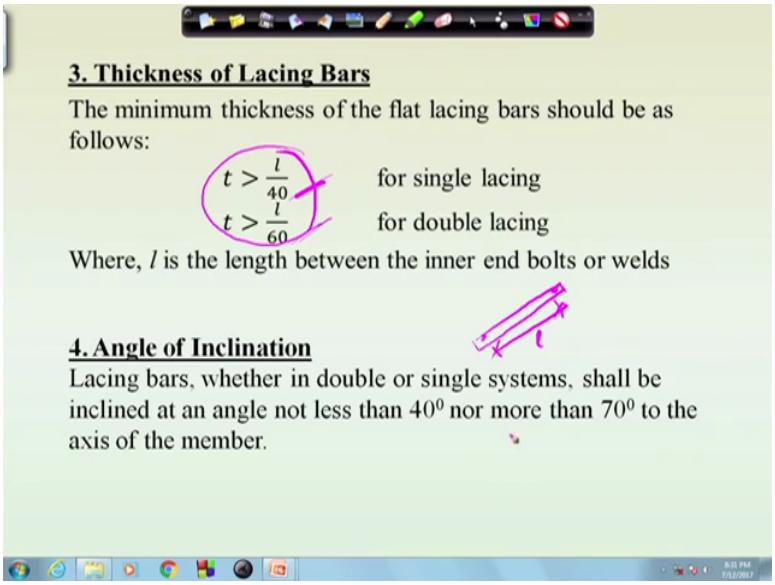

Then coming to thickness, thickness either we can find out from that the slenderness ratio value or at the beginning we can find out the thickness from this criteria and we can check for slenderness ratio. So in case of single lacing it is suggested that t should be greater than or

equal to l by 40 and for double lacing t should be greater than l by 60, where l is the length between the inner end bolts that means if this is lacing bar then if this is bolt then this will be the length, right.

So the minimum thickness of the lacing bar can be found from these criteria for single lacing it will be l by 40 and for double lacing it will be more than l by 60.

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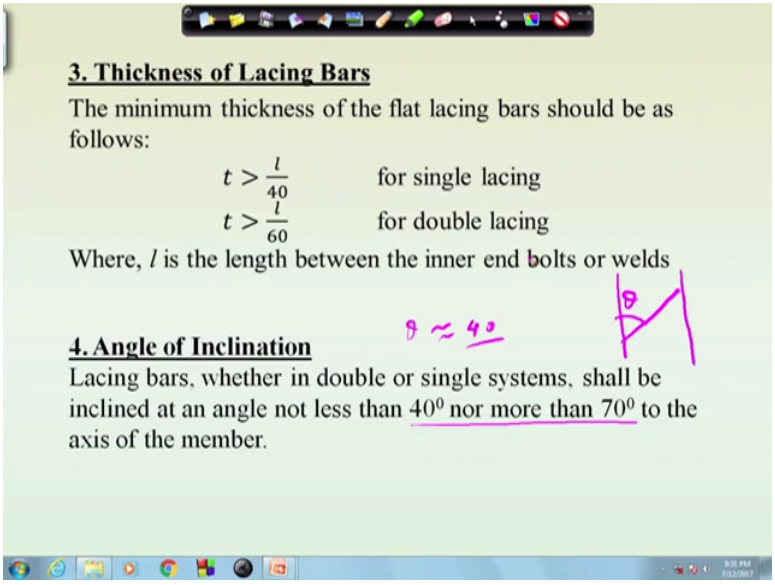

Then another important thing we have to find out means we have to decide that is the angle of inclination of the lacing bar how do we decide that can be decided means as codal provision says it should be between 40 to 70 degree, right if we have a lacing here then the angle of inclination with the vertical member should be between 40 to 70 degree. However it is from the experience it is seen that it this lacing system will be effective if theta becomes more or less 40 means near to 40, 40 or 45 if we consider means basically 35 to 45 then it will be much effective.

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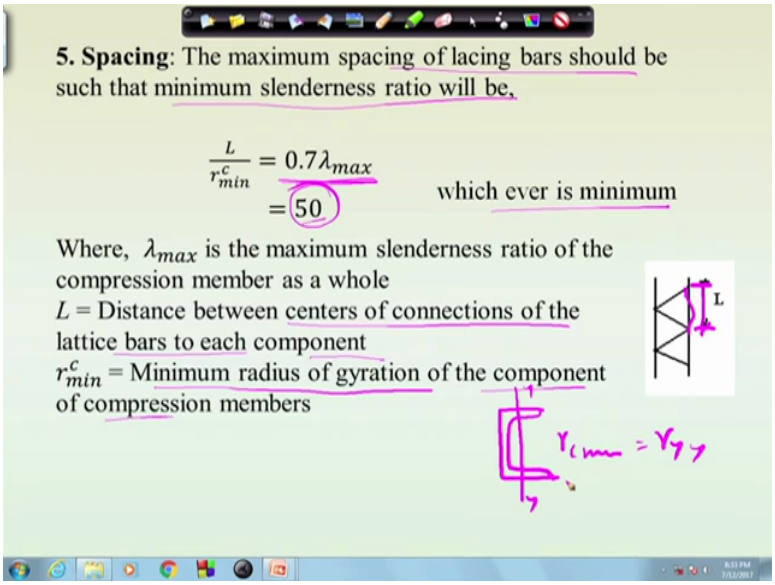

Then spacing, spacing means the distance between two lacing member which is called spacing at L and this spacing because this may buckle like this locally so to take care this buckling the codal provision has told that the maximum spacing of lacing bar should be such that minimum slenderness ratio should be 0.7 lambda max or 50 which is minimum. So in any case it should not exceed 50 and it may be 0.7 lambda max as well. So spacing of the lacing bar has to be this to take care the local buckling of the column, right.

Here L is the distance between center of connections of the lattice bars to each component. Now what is rc minimum, rc minimum is the minimum radius of gyration of the component of compression member that means if we use say if we use say channel section then rc minimum will be the ryy, rc minimum will be ryy, right.

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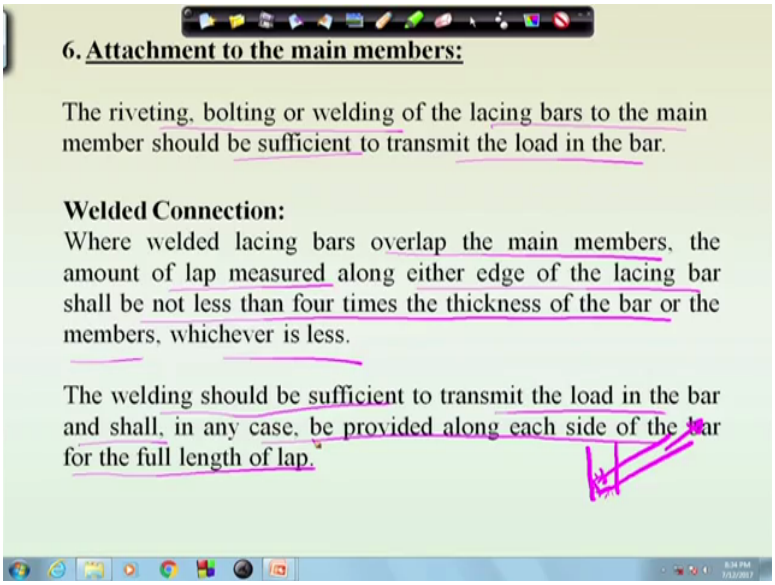

Then attachment to main member, now we need to find out certain number of bolts or welding dimensions for attachment of lacing to the main component, right so that will be dependent on the what is the force coming in this lacing member depending on that the number of bolt will be decided or if we use weld connection the length of weld connection, size of weld connection should be decided.

So the codal provision says that the riveting, bolting or welding of the lacing bars to the main member should be sufficient to transmit the load in the bar. Then in case of weld connection it is told that where welded lacing bars overlap the main members, the amount of lap measured along either edge of the lacing bar shall be not less than the four times the thickness of the bar or the members whichever is less.

And the welding should be sufficient to transmit the load in the bar and shall in any case we provided along each side of the bar for the full length of lap, so this is what we have to remember in case of weld connection. And for bolt connection we have to provide means we have to find out the strength and number of bolts.

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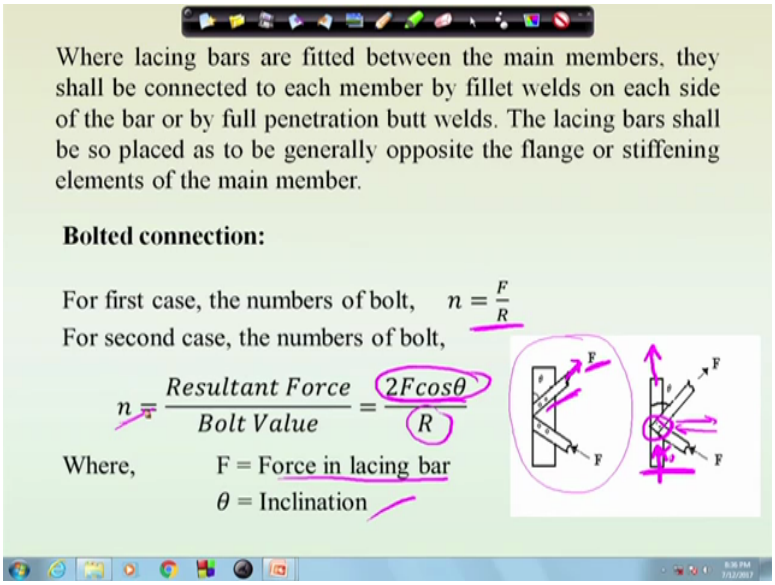

So in case of such member means such type of connection where where connections are made separately then the number of bolts can be decided as F by R, where R is the bolt value, right and F is the force on the lacing member. So if we know the force on lacing member then we can find out the number of bolts required for this, so this is how we can calculate.

But for second case in this case we can see that the both the members are acting on this bolt, right so the resultant force we have to find out in this resultant force will be if we see this the resultant force will be F cos theta plus F cos theta, right this is theta so 2F cos theta will come into picture and this is F sin theta and this is F sin theta which is nullifying, so 2F cos theta will be the resultant force and bolt value if we consider R then 2F cos theta by R, right where theta is the angle of inclination and F is the force in the lacing bar.

So if we find out the force in lacing bar then we can find out the number of bolt required to connect the lacing bar with the main plate and this depends on what type of connections we are going to consider whether it is separately connecting or it is overlapped two lacings are overlapped and acting as a double shear. So here also you can see that the bolt value of this case and bolt value of this case will be different, because here the bolt value will be under single shear and here the bolt value will be under double shear, so accordingly the bolt value has to be calculated.

So these are the things we have to remember when we will be going to design a lacing member so in short if we say that lacing members are designed or the entire built up sections are designed on the basis of failure criteria, failure of the member as a whole. So we have to

restrict the radius of gyration so that failure does not occur, failure of the main member locally that also we have to provide the lacing spacing that L capital L in such a way that L by rc minimum should not exceed certain value, right.

Then again there will be a chance of failure of the lacing member itself due to heavy force or due to slenderness, so that also has to be taken care we have to see what is the strength carrying capacity of the lacing member and we have to see what is the radius of gyration and what is the slenderness ratio is coming and we have to restrict within the maximum slenderness ratio which are permissible means within the permissible slenderness ratio, this is what we have to do.

Also we have to find out a suitable arrangement of bolt or weld connection for attaching the lacing system into the main members if we use bolt connection then again we have to see whether we are connecting the lacing member separately or we are overlapping that accordingly the forces will be calculated and then the number of bolts will be calculated and in fact if we see the force on the lacing member is quite less and generally number of bolts become 1 to 2 in maximum case we will see 1 and sometimes we will see 2 that is sufficient. So through work out example we will also confirm this, okay.

So this is what today we have discussed and in next class we will discuss about the steps whatever we have discussed today how to design step wise means in a systemic manner that will be discussed and then a work out example will be done, thank you.