Course on Design of Steel Structures
Professor Damodar Maity
Department of Civil Engineering
Indian Institute of Technology Kharagpur
Lecture 37
Module 8
Design of Lacing Systems

Now I am going to discuss about the design of lacing system, now in earlier lecture we have shown what are the force coming on the lacing and what are the failure modes are coming for lacing system for the built up member and how to calculate the number of bolts, how to calculate the thickness of the lacing, width of the lacing and how to decide the spacing of the lacing bar, what should be the length of the lacing bar all these things have been discussed but for designing we have to make a systemic way so that step by step we can design.

So first I will discuss the steps which can be used for design of a lacing system it is a very lengthy process so we should remember the steps chronologically so that we can design systematically a lacing system entirely and after discussion of the steps we will discuss about the one software has been developed by my students I will discuss how a software can be developed and how the lacing systems can be designed, right and if time permits we will go through one example partly, okay.

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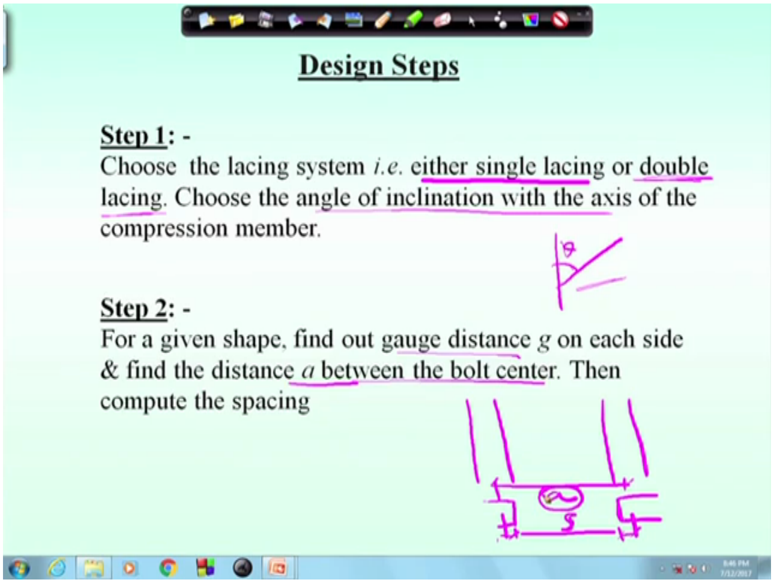

So let us come to the design steps, so first what we will do we will choose a lacing system means either we will choose a single lacing or double lacing that we have to first decide because the design procedure will be entirely changed for single lacing and double lacing because the (number) depending on the single lacing or double lacing the force acting on the member will be different and accordingly the force on the sorry the number of bolts, the dimension of the lacing system will be changed.

Similarly if single lacing if we provide what will be the radius of gyration and what will be the slenderness ratio and for double lacing what will be the slenderness ratio that also will be calculated in different way. So if we decide first the lacing system whether it is single lacing or double lacing then it will be better to proceed further. Next is we have to decide a angle of inclination with the axis of the compression member, angle of inclination means the this angle theta.

So as we told earlier that theta should vary from 40 to 70 degree and generally we try to keep theta from 40 to 45 degree to get maximum efficiency of the lacing system. Then once we decide the lacing system and its angle of inclination then we can find out the gauge distance and the distance between two members means if we see if this is a channel section facing back to back then we can find out the this is gauge distance if this is gauge and this is S then we can find out the distance between these two from gauge to gauge that is a. So find the distance a between the bolt center that is that can be found and for a given shape we know what is the gauge distance on each side, right and also already we have decided what should be the spacing so that Ixx and Iyy become same.

So that has already been decided and the size of the section has also been decided whether it is channel section or I section that also has been decided and whether it will be channel section back to back or toe to toe that has also been decided earlier. So according to that we can find out the value of a which is the distance between bolt center.

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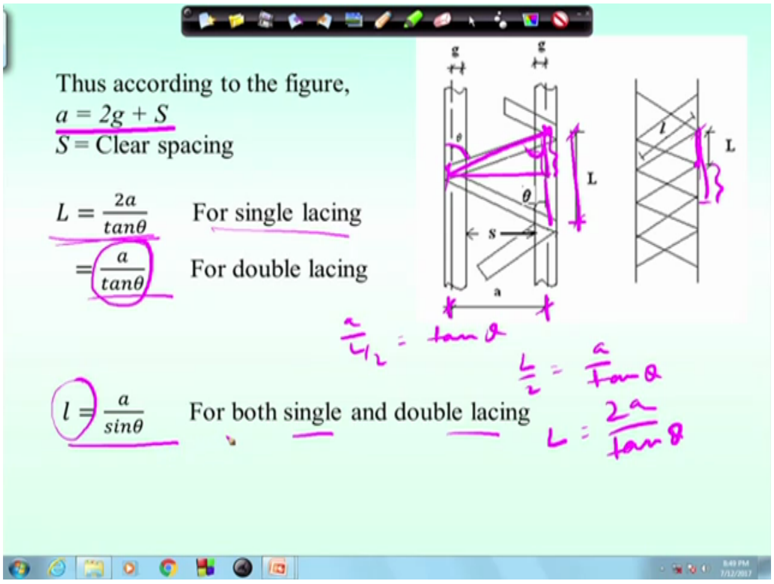

Next is so a will become basically S plus 2g, where S is the clear distance and g is the gauge distance. Now we have to find out the length length of length between two lacing, so which is called spacing clear spacing sorry spacing between two lacing, right. So how do we find out the length length means this one, so we know this value a, a means the distance between bolts so if we know a then we can find out the value of this, right.

If this is theta this will be theta, right and this will be if this is theta then a by L by 2 will become tan theta, so L by 2 will become a by tan theta that means L will become 2a by tan theta, right. So L the length between two lacing members can be found for single system as 2a by tan theta, where this is L by 2 and this is L by 2. So L can be found for single lacing, similarly for double lacing it will be simply this L not this one total, total is for single lacing and this is for double lacing, right. So for double lacing system it will be a by tan theta, so this is how the spacing between two lacing can be found.

Then another we have to find that is the length, length of the member, length of the lacing. So length of the lacing also we can find out because we know if this is theta a sin theta will be the L, so L I can make a by sin theta. So in case of single lacing or double lacing the length of lacing can be found from this geometry that is a by sin theta this is how we can find out.

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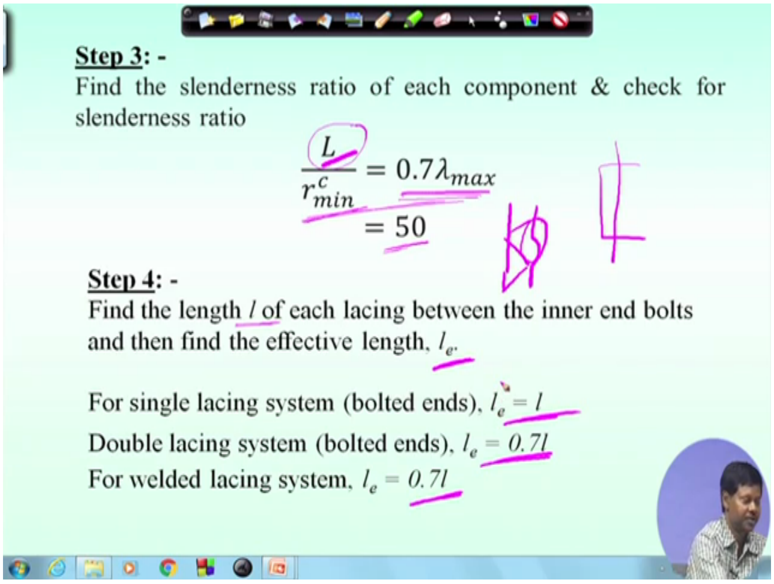

Next in step 3 we can find out the slenderness ratio of each component and check for slenderness ratio. So we know we now know the L so and rc minimum we we know rc minimum about this direction the individual radius of gyration of the section the minimum radius of gyration of the individual section. So L by rc minimum and it should be minimum of this 50 or 0.7 lambda max that we have to check, right if it is not then we can what we can do we can either reduce the length length of spacing by changing the angle of inclination or we can change the section size, right.

So this is what we have to do so that the local buckling of the member can be arrested local buckling of the member can happen and that can be taken care by providing this restriction, right.

In step 4, so once we find out the length of each lacing then I can find out the effective length. Now effective length will be either 7 if it is single lacing system with bolt end, if it is double lacing system it will be 0.7l and if it is welded system it will be 0.7l. So we could find we can find the effective length of the lacing member in step 4.

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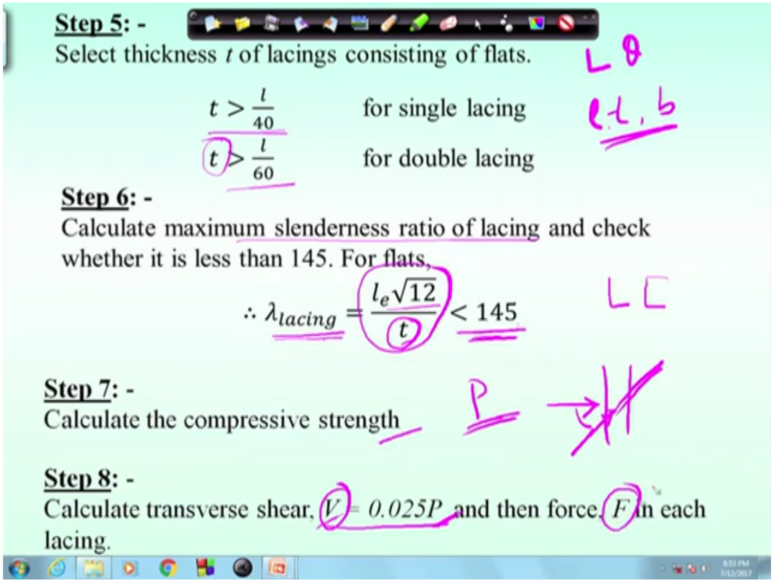

Now in step 5, we can find out the thickness of the lacing, so in for lacing member we need to know length, then thickness and width these are the three things we need to know already we knew the spacing between lacing member and angle of inclination, right theta. So the thickness can be found from this that t should be (less than) greater than l by 40, where l is the length of the lacing member and this is true for single lacing and for double lacing it would be greater than l by 60. So from this I can find out a suitable thickness of the lacing system.

Now we have to check for slenderness ratio, so we can find out the maximum slenderness ratio of the lacing system and generally lacing systems in case of lacing system, lacing members are either flat plate or may be angles angle or may be channel, right. In case of flat plate we have calculated already in earlier classes that lambda lacing will be le into root 12 by t, so it should be less than 145.

So for flat plate lambda can be found from simply this formula that is le root 12 by t and we have to check it should be less than 145. Now if it is not less than 145 what we can do we can increase the thickness of the lacing, if we increase the thickness of the lacing, then lambda lacing will be reduced and the we can means we can make the lambda lacing below 145, right.

So in step 7 we will calculate the compressive strength compressive strength of the member we can calculate. Then in step 8 we can calculate V, so in step 7 compressive strength means the P the total compressive force whatever it is coming on the member that we can find and then the transverse shear V is 2.5 percent of P, so that can be calculated, right and then after finding out the transverse shear we can find out the force in lacing because transverse shear if it works like this and if lacing is like this then what will be the force on this component that can be found, right.

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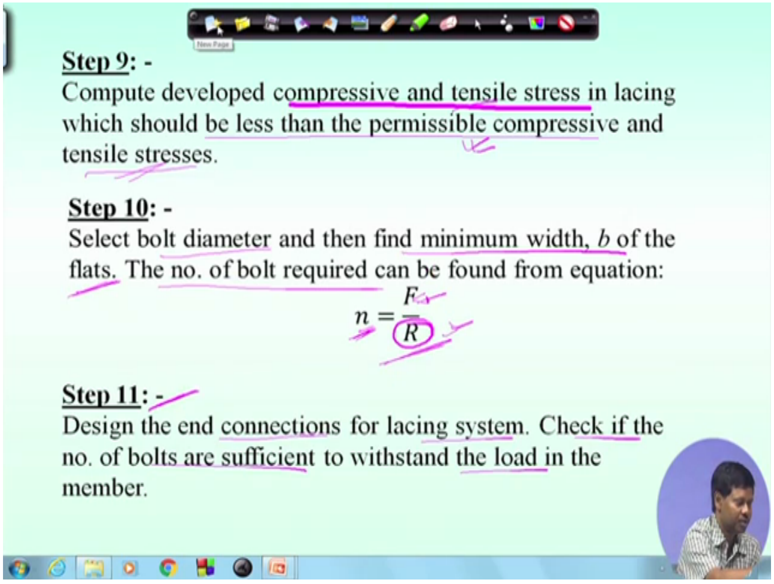

Now coming to step 9, we can find out the compressive stress and tensile stress of the lacing system and we have to check that this compressive stress and tensile stress is less than the permissible compressive and tensile stress. So we know permissible compressive stress of the lacing member fcd value, right for a particular radius of for a particular slenderness ratio and for a particular grade of steel and also we can find out the tensile stress on the permissible tensile stress and the developed compressive stress and tensile stress also can be found and we have to check whether it is less than or not.

If it is not less than that then we have to increase the section size, section size means either we have to increase the thickness or width of the flat plate or if we use angle section then we have to increase the section, right once it is done we can go for connection. So if we use bolt connection then we have to choose a suitable bolt diameter and we have to find a find the minimum width, b of the flat plate, right.

So b can be found from the bolt diameter the 3b 3d will be the minimum flat width and then number of bolts required also can be found that will be simply n is equal to F by R and F is the force on that on that on that member, member means lacing member, right. So number of bolts can be found from the bolt value so before finding out the number of bolt we have to find out the bolt value R and depending on the spacing and means pitch distance and edge distance and whether it is single shear or double shear R will be calculated so once R is calculated we can find out the number of bolt.

Now in step 11 we will design the end connections for the lacing system that means we check for the number of bolts whether it is sufficient or not to withstand the load and if we go for weld connection we will check whether the length of weld connection is sufficient or not to withstand that load and this length of the weld will be decided on the basis of weld strength and the force acting on the lacing member depending on that the lacing welding size and welding length will be decided. So this is what the steps we have to follow to find out the to find out the lacing dimensions and its configuration, right.

So 11 steps means we have discussed here we have to chronologically follow these steps more or less and then we have to find out one by one and finally we have to find out what should be the final angle of inclination of the lacing, what is the lacing size, what is the spacing and what is the number of bolt or length of weld and size this is what final output we have to make.

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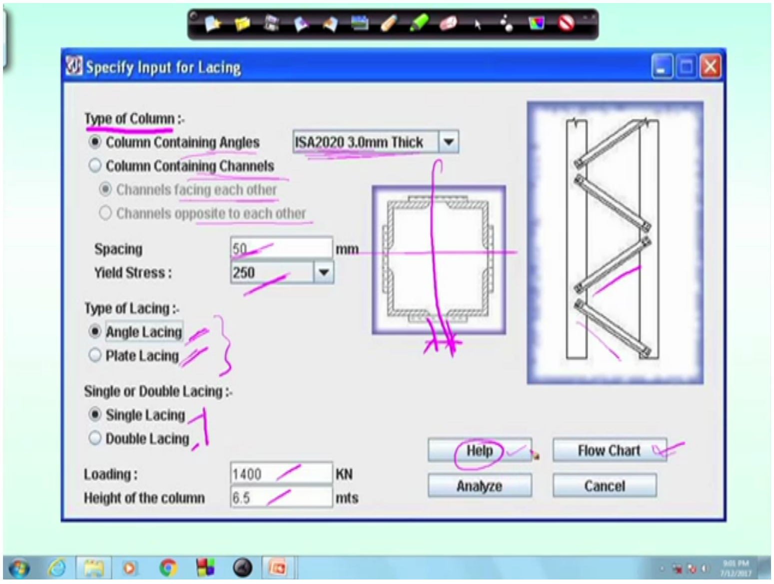

Now this is a sample software of root we have shown here, in fact one of my student has developed this software where the lacing member can be designed. Now the most important part of this is that how to make a GUI to take the input. Say I am giving showing this example to give an idea about how to develop a GUI means how it should look and how user friendly one can make a GUI so that a user can use this and find out the design means design and can find out the dimensions of the lacings and its design details.

Now suppose first if we come to the type of column, now this few options have been incorporated in the program, one is column containing angle means it may be box section or some other section and column containing channel, okay and channel will be facing each other means facing toe to toe or channel back to back. So these are the options we have.

Now if we click on column containing angle then this will this popup button will come where we can find out a particular section and these sections are taken from means these sections and their properties have been taken from SP: 6 from SP: 6 the different section size has been taken and their properties which have stored in the library of the software and then when we are clicking a particular size of the section its properties will be taken.

Now then the spacing has to be decided because spacing will be decided on the basis of Ixx is equal to Iyy on that basis we have to decide spacing, so the spacing will be provided here and yield stress of steel we have to provide we have to select yield stress of steel and then whether we are going for angle lacing or flat plate that also we can decide. So these options also are incorporate in the software that we can provide not only plate means flat plate but also we can provide angle lacing.

And then another options we have created that is whether it is single lacing or double lacing because if we go for single lacing then it looks like that and then accordingly the calculation shall be done and if it is double lacing then its calculation will be different. Then we have to go to the load what is the compressive load is coming and what is the height of column that has to be defined.

And here you see we have given a help button, in help button if you click then will get the all the design criteria means what are the design steps and how design has been done the theory has been provided here. And in flowchart the how step by step it has been progressed that has been shown in this flowchart. And if we click in analyze then it will go for analysis of the system.

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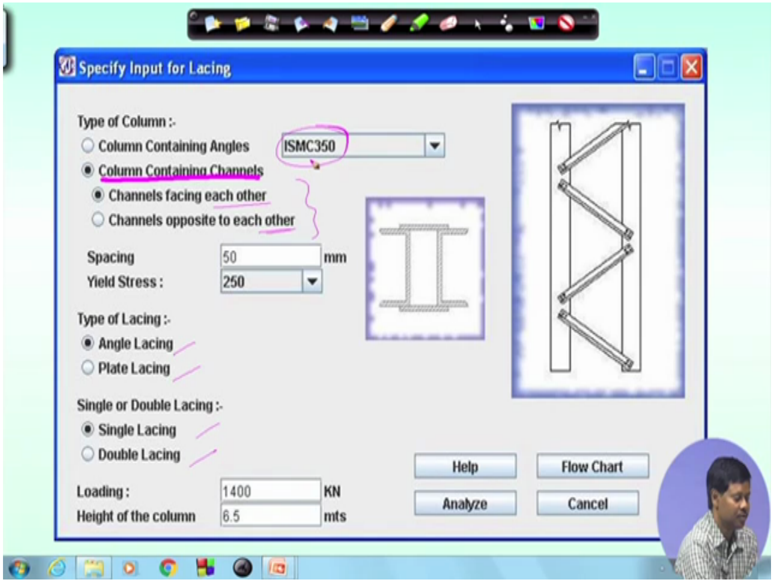

So here you see if we select the column containing channel then there are two options we have the channel facing each other and channel opposite to each other, right. So that will be taken care and others will be similarly we can consider say angle section or plate section for lacing system then single system single lacing or double lacing all these things will be similar, only thing is when column containing channel so all the channel properties means all the properties of the channel sections as given in the IS SP: 6 will be taken.

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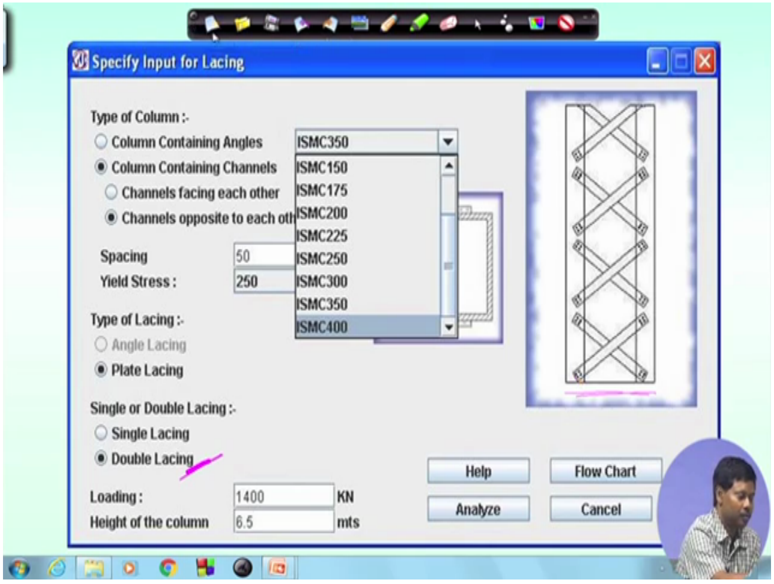

Here channel opposite to each other has been consider, here another option has been consider that is if we consider double lacing system then how the orientation will be done that has been shown here. So the program can take care the design of double lacing system as well, right.

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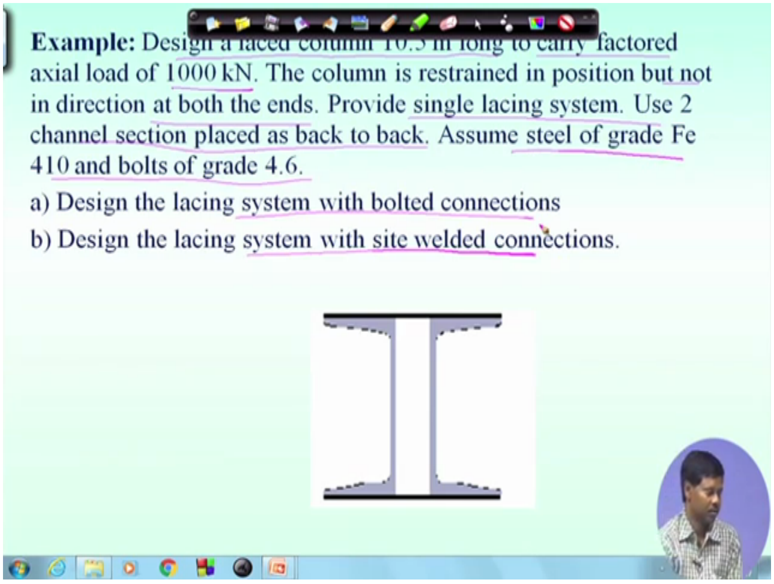

Now we will go through one example so the design steps whatever we have discussed will be followed in this design example and in this design example the previous example has been consider, previous example means in lecture 35 we have considered a certain section means against a certain load and length of the column and then we have considered that (IS) ISMC 300 section and back to back with 184 millimetre spacing that has been decided, so on that basis we will try to find out the details of lacing.

So coming to the example if we see that design a design a laced column 10.5 meter long to carry a factor axial load of 1000 kilonewton. The column is restrained in position but not in direction at both ends. Provide single lacing system. Use 2 channel section placed as back to back. Assume steel of grade Fe410 bolts and bolts of 4.6 grade. Design the lacing system with bolt connection and design the lacing system with site weld connection, so for 2 cases we will consider.

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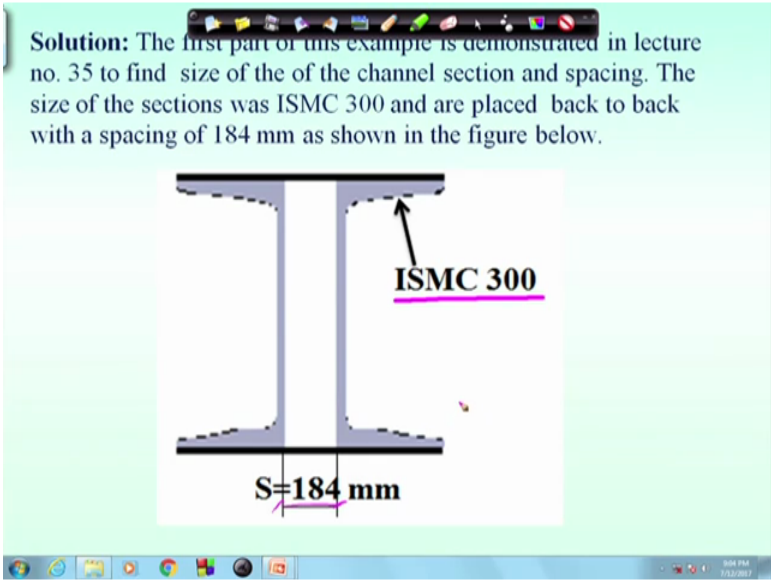

So if we recall the design example provided in lecture 35 we can see that we obtained ISMC 300 channel section and having a spacing between these two as 184 and channels were placed back to back. So this is what already we have calculated. Now we will calculate the forces coming on lacing and the dimensions of lacing.

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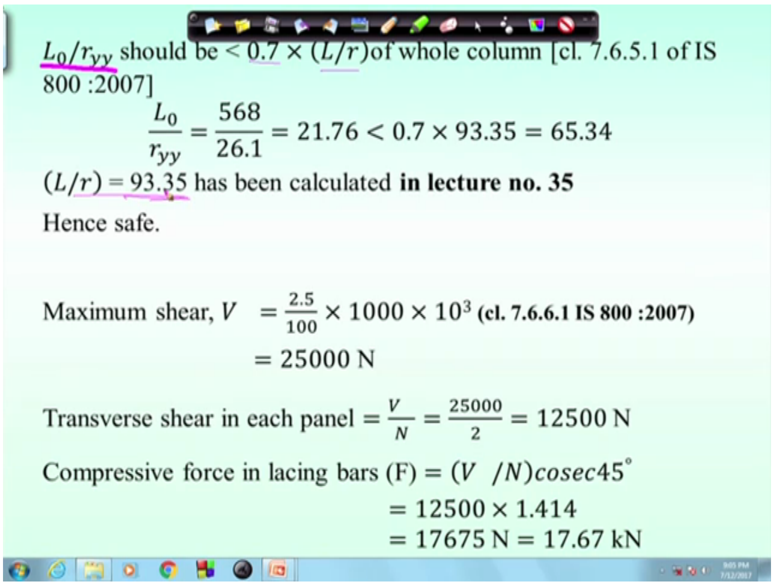

So if we come to that first what we can find out we can find out what should be the L by r right and this L by r should be less than 0.7 into L by r, right. Now this L by r already has been calculated as 93.35, right and L0.

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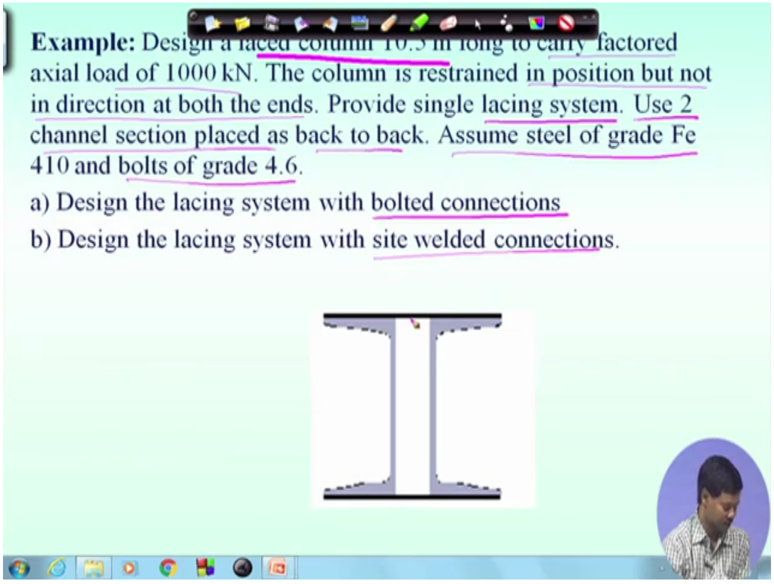

So for design of lacing we have consider this example that is a design of laced column of 10.5 meter long to carry a factor load of 1000 kilonewton and the column is restrained in position but not in direction at both ends. And provide single lacing system this has been told. And use 2 channel section placed as back to back. And assume the steel of grade Fe410 and bolts of grade 4.6. And design the lacing system with bolted connections and design the lacing system with welded connections, right. So basically this is the example which has been done earlier in lecture (33) 35.

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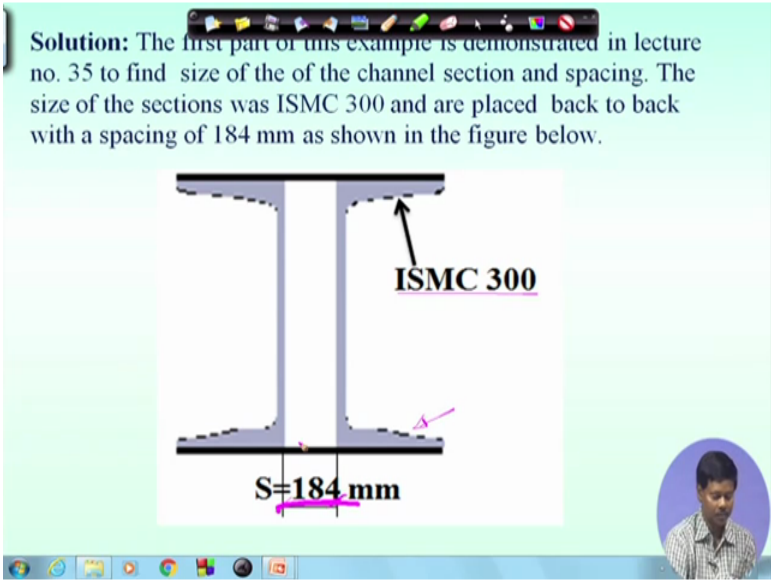

So same example has been considered here and in lecture 35 we have seen that how to calculate the spacing between two members and how to decide the section size that has been discussed in lecture 35 and and we have seen that ISMC 300 section is sufficient to take care the load the given and 184 millimetre spacing is sufficient, so this is what earlier we have calculated.

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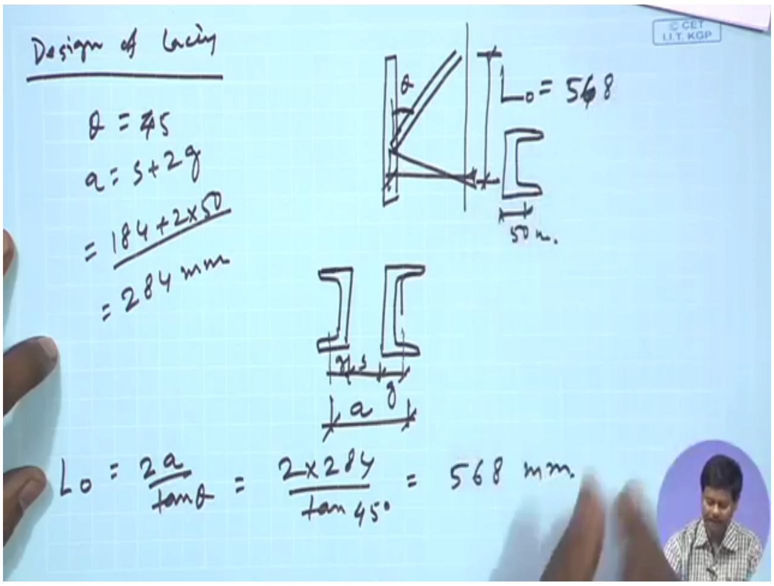

Now we will come to the design of lacing system, so coming to design of lacing first we will find out the angle of lacing. So what should be the angle of lacing, so that has to be decided, right. So so in first step we have seen that we have to assume the angle of lacing, so here we can assume say angle of lacing theta as 45 degree, right and for this channel section the gauge distance was given in SP: 6 it is 50 mm, right.

So the distance between bolt to bolt means because the channel sections are placed like this back to back it was placed, so distance between two bolts can be found now this is S and this is the bolt distance this is g and this is g. So distance between the bolt center to center of the bolt which is called a in general this a we can find out as S plus 2g, so that will become 184 plus 2 into 50, right so this is what we will find out that has been 284 millimetre, right.

Now once we find out a, we can find out the spacing between lacing L because we know the angle of inclination we know a, right so we can find out the spacing between lacing bar, so L0 will become 2a by tan theta, right so 2 into a is 284 by tan 45 degree, right. So this is becoming 568 millimetre. So L or L0 means spacing between two lacing this has been now decided as 568 millimetre, right.

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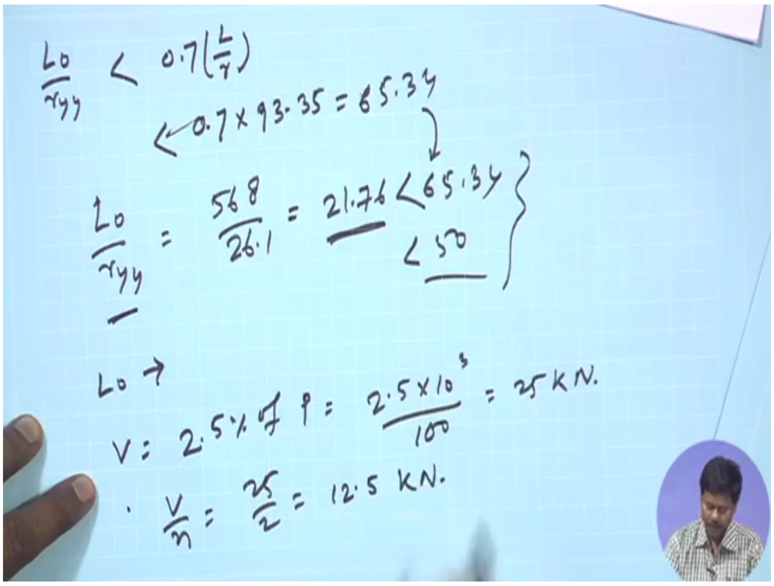

So once this is done, we can find out L0 by ryy, okay so L0 by ryy should be less than 0.7 L by r, okay. This L by r was calculated earlier as 93.35 that means 0.7 into 93.35, so this is becoming 65.34, right. So L by r now we can find out as L0 by ryy we can find out as L0 is 568 and ryy is 26.1, right so this is becoming 21.76 and this should be less than 0.7 L by (ry) r so that is 65.34 or it should be less than 50, right. So as we found L0 by ryy as 21.76 which is less than this so the spacing between two lacing member is okay, so L0 is okay, right.

Now we will find out the maximum shear V as we know maximum shear will be 2.5 percent of the compressive load. So we can find out 2.5 into 10 cube by 100, so 25 kilonewton, right. Now in each panel transverse shear will come in each panel as V by n that will be 25 by 2, that will be 12.5 kilonewton, right.

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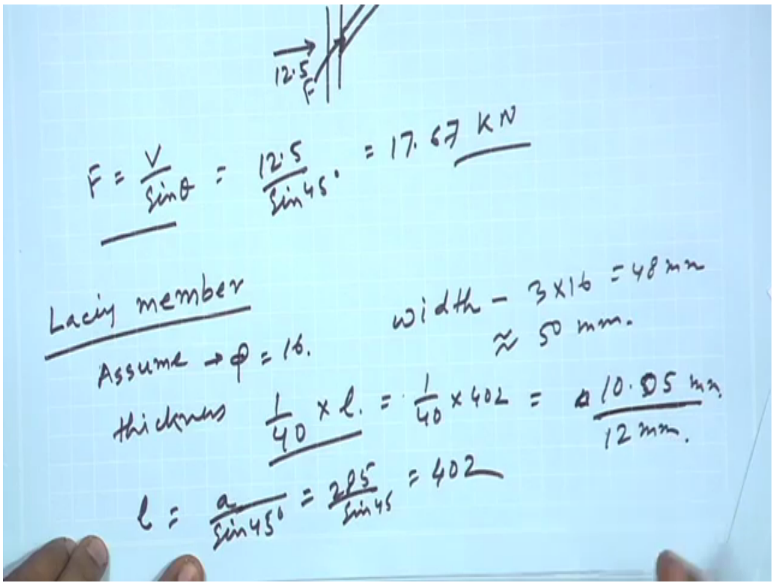

Now we have to find out the force compressive force in lacing bar, so V we are getting 12.5 kilonewton and we have to now find out the force on this force, right. So this we can find out this force as V by sin theta, right so V we got 12.5 by sin theta is sin 45 degree so this is coming 17.67 kilonewton, so compressive force in lacing bar we can find out this.

Now the size of lacing flat we can find out we can choose lacing member as a flat plate if we choose that then we have to decide the thickness and width of the lacing member as well as the length of the lacing member. So to find out the thickness of the lacing member we have to find out the length and also to find out the width of the lacing member we know that it should be dependent on the diameter of bolt.

So we can assume some diameter of bolt say diameter of bolt as 16 mm, so width of minimum width as per the clause 7.6.2 minimum width will be 3 into 16, okay 48 mm that means we can provide say 50 mm width. And thickness thickness we know that will be for single lacing system it will be 1 by 40 into length between two plate. Now length between two plate we have to find out.

Now length between two plate can be found as we calculated length as a by sin 45 degree, if we go back to earlier lecture we can see that length can be found a by sin 45 degree that this is coming a is 284 by sin 45, so it is coming 402. So thickness will become 1 by 40 into 402, right so that is coming (10 point) 10.05 millimetre. So the thickness we can consider as 1a 2 mm because minimum is 10.05 mm. So thickness of the plate can be decided from this.

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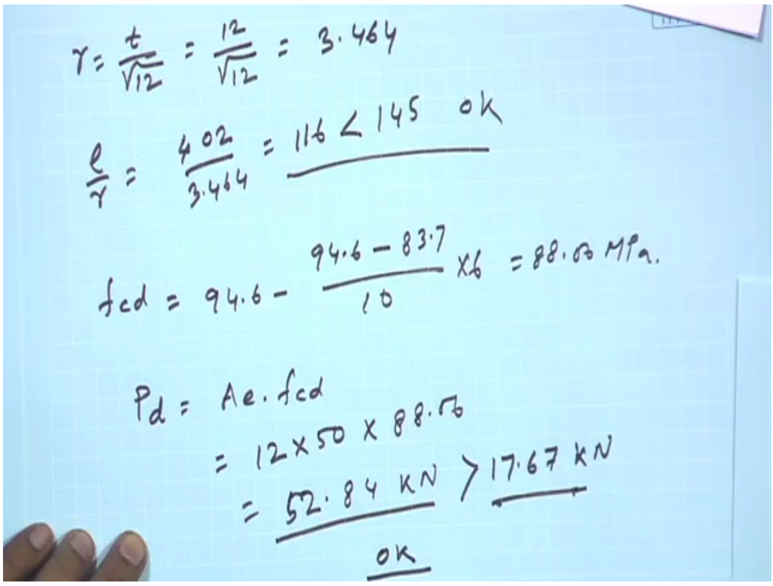

Now r we know that t by root 12 for flat plate so that we can find out as thickness we have considered 12, so we can find out r the minimum radius of gyration with 3.464, right. So l by r we can find out l was calculated as 402 and r was calculated as 3.464 okay. So this is 116 and is less than 145, so it is okay, right. So from slenderness ratio point of view this is okay.

Now we will find out the compressive stress fcd fcd of the member can be found because slenderness ratio is given. Now from table 9c we can find fcd as 94.6 minus 94.6 is the fcd value corresponding to 110 and 83.7 is corresponding to 120 by 10 into 6, so 88.06 MPa fcd value.

Now once we find fcd value we can find out the design compressive strength, design compressive strength Pd we know Ae into fcd. So Ae is the cross-sectional area of the flat plate which is b into t into fcd value is 88.06, so this is coming 52.84 kilonewton. So design strength of the compressive the lacing member is 52.84 kilonewton which is greater than the axial compression force on lacing member that is 17.67 which was calculated earlier. So this is how we can check that the design strength is more than the actual force coming on the lacing member, so the size of the lacing member is okay.

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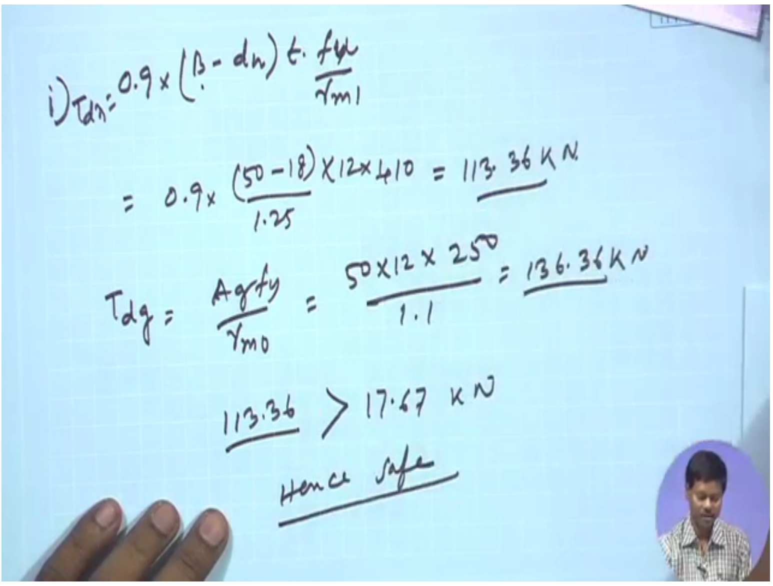

Now we can find out the tensile strength as per clause 6.2 and 6.3.1 we can find out the tensile strength as first we will find out due to rapture of the critical section that is 0.9 into B minus dh into t into fu by gamma m1. So that will be so Tdn we can say Tdn will be 0.9 into 50 minus 18 by gamma m1 is 1.25 into t is 12, fu is 410, so this is coming 113.36 kilonewton, right.

And the strength due to gross yielding Tdg we know we can find out Agfy by gamma m0, so Ag is 50 into 12 into fy is 250, gamma m0 is 1.1, so 136.36, right. So the design tensile strength will be minimum of these two which is 113.36 kilonewton and this is more than the axial tension or compression coming on the lacing bar that is 17.67, so hence safe, right. So this is how we can find out, right.

So for todays lecture as we do not have much time, so we can conclude here and before concluding again if I repeat the steps whatever we have done in the workout example is first we have found means we have assumed first what is the angle of inclination and according to that we have found the distance between bolt that a, then we have found the spacing between the lacing member, then we found the lacing dimension that is thickness, width and length from the geometry and from the design criteria, then we found the compressive strength design compressive strength of the lacing bar and design tensile strength of the lacing bar and we have seen that the design compressive strength and design tensile strength is more than the actual force coming on the axial force coming on the lacing bar.

Now the lacing bar we will means if one lacing bar is in compression, another lacing bar will be in tension. So for both the cases the magnitude of the force will be same that means for compressive force and tensile force will be same for the same lacing bar. And this is what we have checked and also we have checked the minimum slenderness ratio means the (permi) which is means the slenderness ratio of the column member means it is less than the permissible slenderness ratio. Also we have checked the slenderness ratio of the lacing member is under the permissible limit of the lacing member permissible limit of the slenderness ratio. So these are the checks we have done, next what we will do we will go for connections details, right okay.