Course on Design of Steel Structures
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Lecture 52
Module 11
Design of Laterally Unsupported Beams

Hello today I am going to discuss about the design steps for Laterally Unsupported Beams. In fact in last lecture we have discussed how to calculate the Lateral Torsional Buckling moment and what will be the lateral torsional buckling stress and then we have found how to calculate the design bending stress due to lateral torsional buckling. Today with the based on the last days lecture we will follow certain design steps and after that we will go through one example.

Now in design steps basically we will try to find out first a appropriate section based on the approximate section modulus and then we will check whether the assumed section is safe against the design bending against the bending forces coming on to the member then we will check for shear whether it is safe or not, then we will go for checking deflection, web buckling and web crippling.

So one by one we will check for the design basis criteria means design of the beam when we are going to do we will check one by one criteria like deflection, shear, then web buckling and web crippling.

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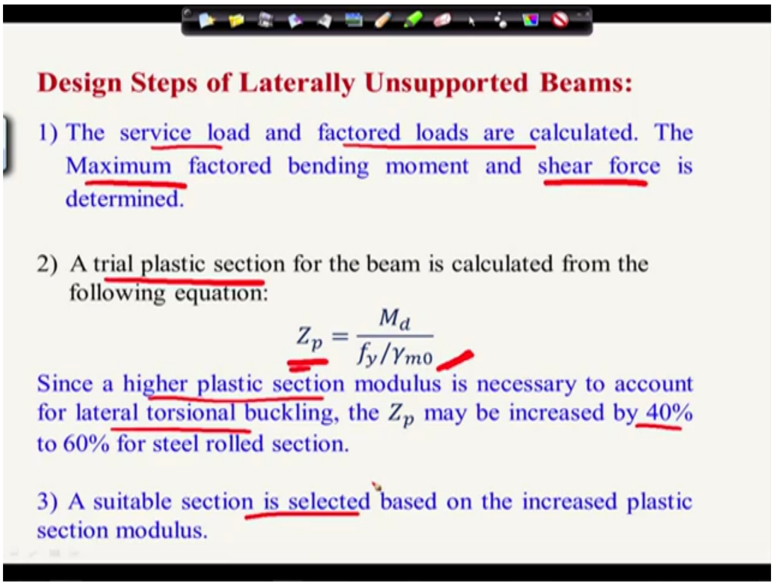

So coming to design steps first we will calculate what will be the service load acting on the beam. So once we calculate the service load then we can find out the factored load also, right. So factored load after calculation of factored load we can find out the factored maximum bending moment and shear force, so factored shear force and bending moment we can calculate on the basis of some load factor as per the different load.

Say for example whether it is dead load or live load or it is wind load or systematic load basis on that we will multiply certain factor and we will try to find out the maximum bending moment and shear force under that factored load. After that we can start with a trial plastic section modulus means we can find out a plastic section modulus based on this formula that Zp is equal to Md by fy by gamma m0. Remember this is considered for means considering the section to be laterally supported.

But in case of laterally unsupported beam a major amount of stress is reduced due to lateral torsional buckling. So the section modulus whatever coming here will not be sufficient we have to increase substantially. So that the chosen section is safe against this bending moment due to lateral torsional buckling. So what we can do we will choose a higher plastic section modulus which is necessary to account for lateral torsional buckling. So what we can do we can approximately increase 40 to 60 percent of the section size means plastic section modulus.

So what we will do actually we do not know exactly what percentage of increasement implement is there means is required. So we can try with 40 percent or 50 percent, however means basically it is a trial and error process, so finally we have to do the trial trial method and we have to find out the actual requirement, there is no basis that this much percentage if you increase then your section will be safe. So once we go through one example we well experience how to increase the section size and how to get the appropriate section.

So after finding an appropriate section what we can means section modulus we can choose a suitable section means based on that plastic section modulus. So section may be I section, may be channel section means based on the requirement we can choose a certain section.

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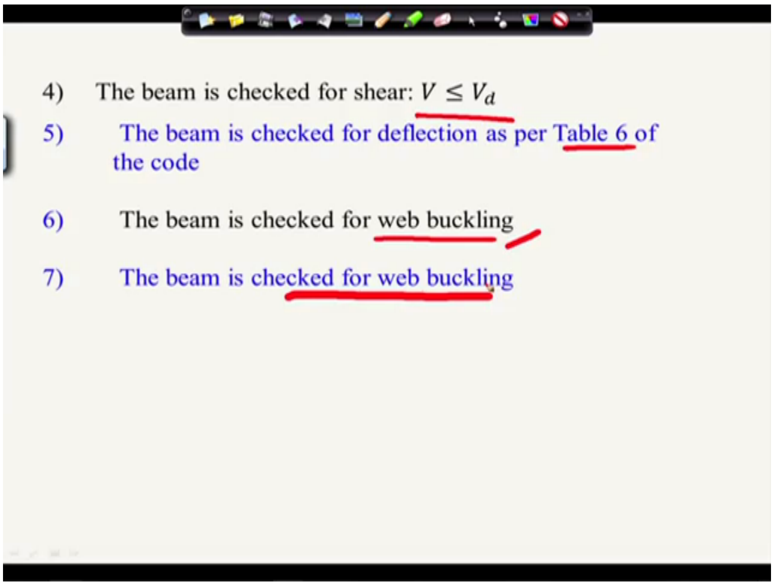

And then with that section we will check whether the section is capable of taking that much moment due to lateral torsional buckling or not, if that is fine then we can go to step 4, where we have to check the beam for shear, right. So we will check for shear if the design shear stress is more than the the shear force coming on to the beam then it is fine or we have to increase the again we have to increase the section size to take care the shear.

In step 5, we will check for deflection as per Table 6 the limiting deflection is given and we know what is the maximum deflection on that particular beam means considering the loading condition and support condition. So based on the loading condition and support condition we can find out the maximum deflection on that particular beam and we will check whether the maximum deflection is exceeding the limit permissible limit or not. If maximum deflection is exceeding the permissible limit then again we have to increase the section size to accommodate this otherwise if it is not then the section is safe from serviceability point of view then what you can do we can go for next step.

Next step is the web buckling, so we know the beam may be the beam web may buckle due to the consistent load acting on the member or at the support. So we have to check the web buckling and if the buckling strength is more than the force coming on that particular place then it is fine otherwise we have to increase the section size or we can increase the bearing length, if we increase the bearing length then also we can increase the buckling strength then we can keep it safe once it is done then again we will go for web crippling, so web crippling also we have to check on the basis of certain bearing so if the web crippling strength is more than the strength at the means acting force at the support then we can means we can say this section is safe otherwise we have to redesign. So this is the process which we have to follow to design a laterally unsupported beam.

So the process is basically a trial and error process, where we will start the means we will start with a certain section on certain basis then the section has to be checked against bending moment, shear force, lateral web buckling, web crippling and deflection. So if all the checks are done and it is passing then the section whichever is chosen is fine otherwise you have to redesign, this is the process.

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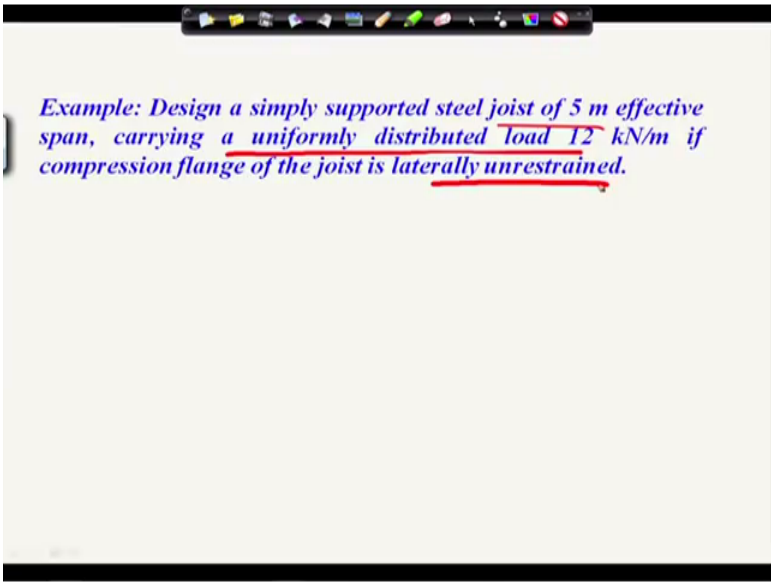

So following this process now we will go through one example then it will be clear to us. So let us go through this example which is given here that is design a simply supported steel joist of 5 meter effective span carrying a uniformly distributed load of 12 kilonewton, if compression flange of the joist is laterally unrested. So here effective length of the beam is 5 meter and the load on the beam is taken as 12 kilonewton which is basically dead load and imposed load, right.

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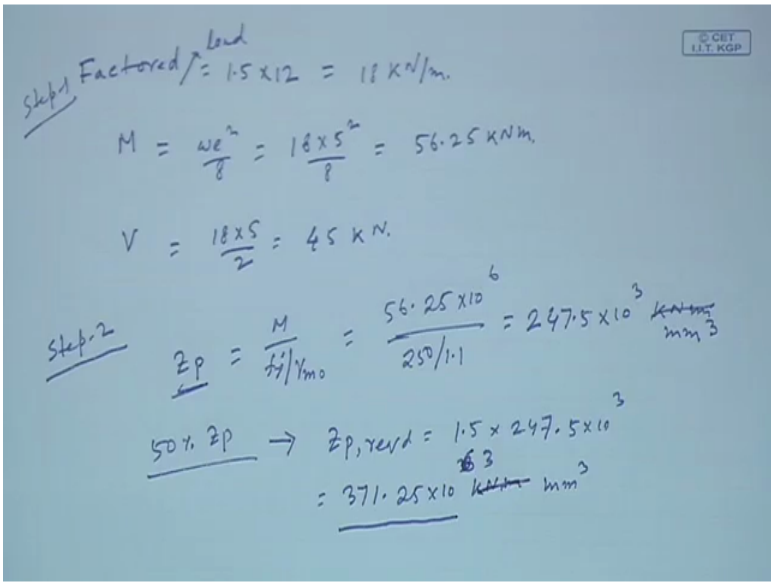

So what we can do we can find out the maximum bending moment, so for finding out maximum bending moment we have to find out the factored load, so factored load what we can find is that 1.5 times the load on beam. So factored load will be load will be 18 kilonewton per meter on the beam. Then we can find out maximum bending moment maximum bending moment will be wl square by 8 at the (())(9:37) because it is simply supported beam therefore we can find out maximum bending moment as w into 8 into l is 5 5 meter was the span length by 8, so it is coming 56.25 kilonewton meter.

Similarly maximum shear force V can be found as wl by 2, so 18 into l is 5 by 2 therefore we can find out as 45 kilonewton. Now so this is step 1, in step 2 we can find out a trial section. So to find out then initial section what we can find out we can find out a approximate section based on the section modulus, so Zp we can find out that is M by fy by gamma m0 so M we have calculated as 56.25 and fy we have calculated as means we know fy as 250 and gamma m0 as 1.1 therefore the section modulus plastic section modulus required is 247.5 into 10 cube.

Now this section modulus has been calculated considering the beam as laterally supported. So in case of laterally unsupported beam we have to multiply certain means we have to increase with certain percentage to get a an appropriate section modulus, right because in case of laterally unsupported beam lateral torsional buckling will come into picture and because of that the permissible stress bending compressible stress will be reduced to some extent. So to accommodate that we need to increase the plastic section modulus so that we can get the required section which will be same.

So if so in case in this case we can increase 50 percent of the Zp means Zp we can increase upto say 50 percent. Then the Zp required will be will be 1.5 times of calculated Zp, so this is becoming 371.25 into 10 cube kilonewton meter sorry 10 to the 6 sorry 10 cube not kilonewton Zp, so Zp will be millimetre cube sorry this will be millimetre cube, right Zp we are. So plastic section modulus of the section we found as 371.25 into 10 cube millimetre cube, right.

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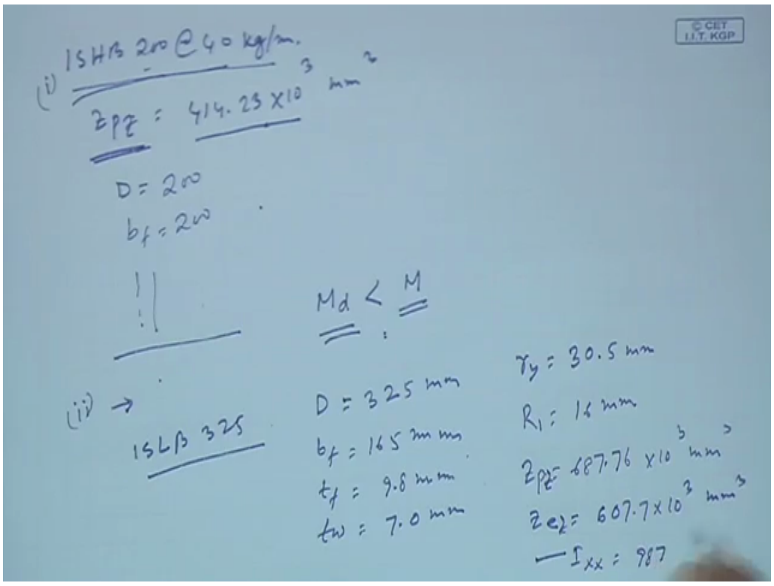

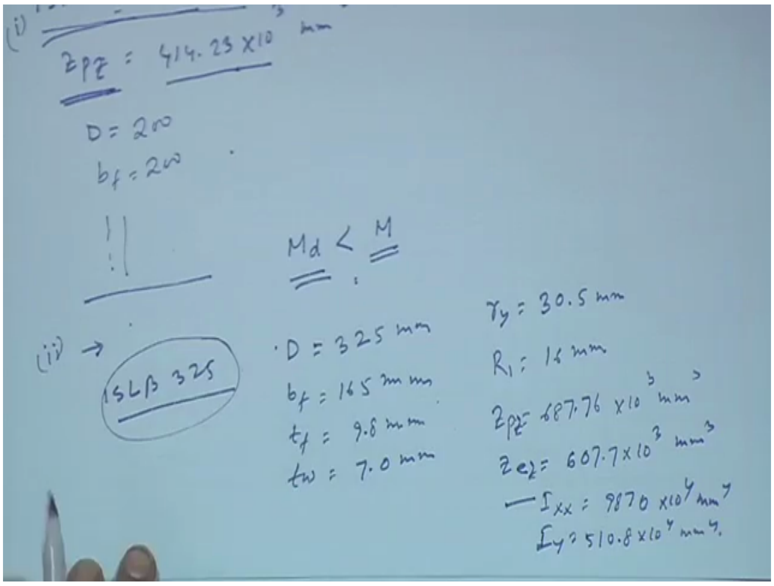

So now looking into the code that is IS: 800-2007 we can see that ISHB 200 at 40 Kg per meter if we consider its Zpz is coming as 414.23, right into 10 cube millimetre cube. So the Zpz we can provide which is higher than the required one. So if we select ISHB 200 at 40 Kg per meter then we can try with this because this is higher than the required one.

So here we can find out the properties of the section like what is the D value say 200 mm, then bf we can find out 200 mm like this we can find out all the properties. Now after finding the all properties from the code then we can try to find out the actual bending stress coming into the member. So the actual bending stress coming into the member can be calculated based on this trial section. Now I am not going into details of this calculation because of shortage of time.

So if we calculate this then we can see the required bending strength Md will be less than the M whatever we have, right. So design bending strength for this section will come less than the maximum bending moment acting on the member so what we need we need to increase the section size. So what we have to do we have to so first we have consider ISHB 200 then again we can consider some higher section where Zpz value will be more than this, so in this way we have to go on increasing and we have to check whether this is okay or not and because of shortage of time I am not going to check all the steps what I am going to do I am going to find out the final section.

So after increasing the size of the section we could see that ISLB 325 section will become same, so this calculation I will go into details. So for ISLB 325 section we can find out the relevant properties from IS code that is D is 325 meter and bf is 165 millimetre, then tf is coming 9.8 millimetre, tw is coming 7 millimetre, then we can find out ry the minimum radius of gyration is coming 30.5 millimetre, root radius R1 is given as 16 mm and Zpz is 687.76 into 10 cube millimetre cube.

Similarly the elastic section modulus Ze Zez we can find from the SP 6 as 607.7 into 10 cube, right and then Ixx, Iyy we can find out, right. Say Ixx is equal to 9870 into 10 to the 4 millimetre to the 4 and Iy is equal to 510.8 into 10 to 4 millimetre to the 4, right. So relevant properties of these sections are found from the code.

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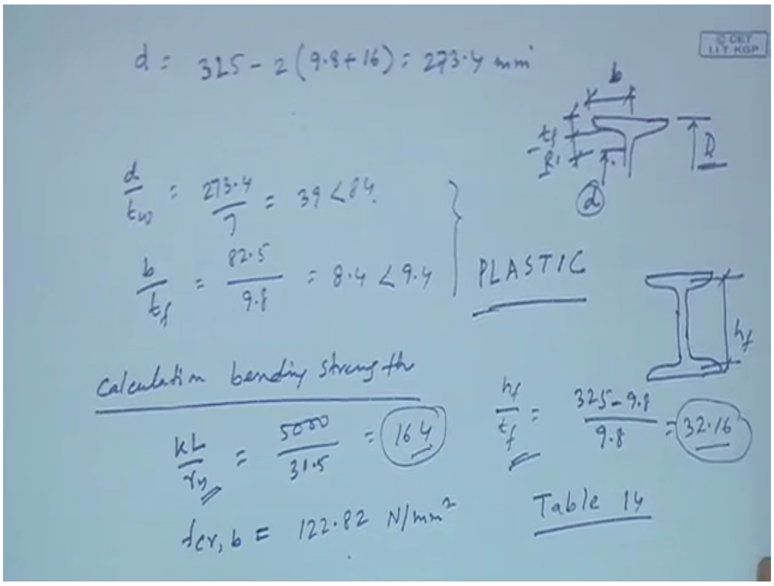

And then we can find out the effective depth d as capital D 325 minus 2 into tf thickness of flange is 9.8 plus 16 will be the root radius so this will become 273.4 millimetre. So if we see the section it will be like this so from here it will be D and small d will be from here, right and that is this is tf and this is R1, right so small d will be capital D minus 2 into tf plus R1, so from this we can calculate the effective depth.

Then we can find out the ratio d by tw as 273.4 by 7, so this is becoming 39 which is less than 84 and also b by tf b by tf will be this will be (bf) b that means bf by 2, okay. So bf we have 165 so b will be 82.5 then thickness of flange is 9.8 this is becoming 8.4 which is less than 9.4, so from this we can classify the section as plastic so the section is plastic, right so accordingly we can find out the bending moment value in lateral stress, okay.

Now we need to calculate the bending strength, so for this step calculation of bending strength either we can find out the bending strength from the formulas which were given in the code and we have discussed earlier or we can find out from table from table directly also we can find out that will be KL by ry will be as it is as simply supported beam so KL will be 5000 and ry was given as 30.5, so KL by ry ratio is coming 164, right.

And hf by tf hf by tf means if we draw this then the value of hf will be center to center distance of the flange, so this will become hf so hf will be D minus means 325 minus hf that will be sorry tf tf is 9.8 by tf 9.8, so hf by tf ratio we are getting as 32.16, right. So corresponding to value of KL by ry as 164 and hf by tf as 32.16 we can find out fcr,b so elastical buckling fcr,b we can find out from table 14 as 122.82 remember this has been obtained by interpolation of the data given in table 14, okay in IS: 800-2007. So in table 14 for different values of KL by ry and hf by tf the fcr,b value is given so from that we can interpolate and we can find out the fcr,b value corresponding to 164 and 32.16.

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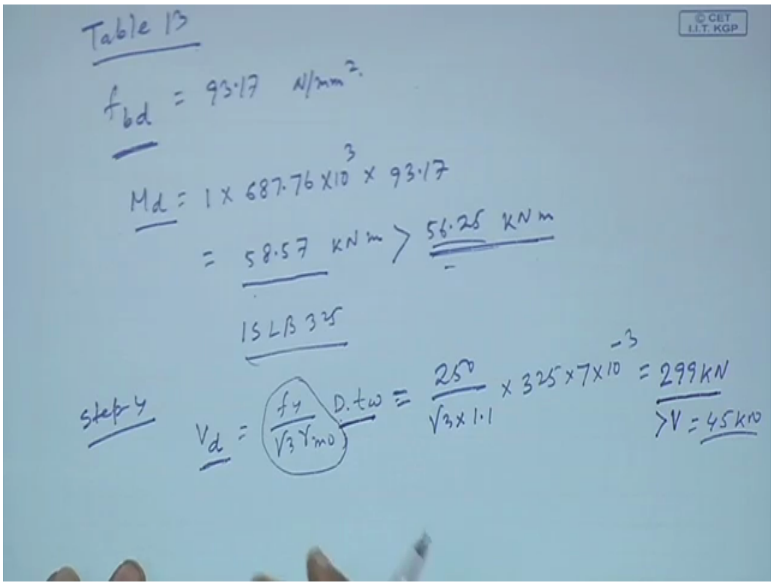

So for this fcr,b value again using table 13 corresponding to this fcr,b value and fy we can find out fbd value as the design bending stress as 93.17 newton per millimetre square, right. So fbd value we could find out. Now for plastic section Md we can find out plastic section for plastic section it will be 1 into Zp was 687.76 into 10 cube into fbd is 93.17 so this we are getting 58.57 kilonewton meter which is greater than 56.25 kilonewton meter which was the maximum bending moment on the beam.

So maximum bending moment on the beam due to factored load is 56.25 and the design bending strength of the member we are getting 58.57 that means just it is becoming safe from flexural point of view, so from flexural point of view what we could see that the atleast we have to use this section this is the minimum section which we used to use that is ISLB 325, right. So with this section we could achieve the strength as 58.57 which is just more than the actual bending moment coming into the beam, right.

Now what we will do in step 4 we will go for checking of shear, right. So to check the shear we need to find out the design shear strength Vd that will be we know fy by root 3 gamma m0 into D into tw, right. Because shear will be carried by the web so area of the web is D into tw and fy by root 3 gamma m0 is the shear stress allowable shear stress fy by root 3 gamma m0.

So from this if we put the value then I can get the value of design shear strength Vd, now here D is 325 into tw is 7 and to make it kilonewton we can multiple with 10 to the minus 3 which is becoming 299 kilonewton. So design shear strength of the beam is coming 299 kilonewton kilonewton which is greater than the maximum shear force at the support which is 45 kilonewton which we have calculated earlier, 45 kilonewton is the maximum shear force due to factored load and the design shear strength is coming 299 kilonewton, therefore the beam is safe against shear force. So against shear the beam is safe.

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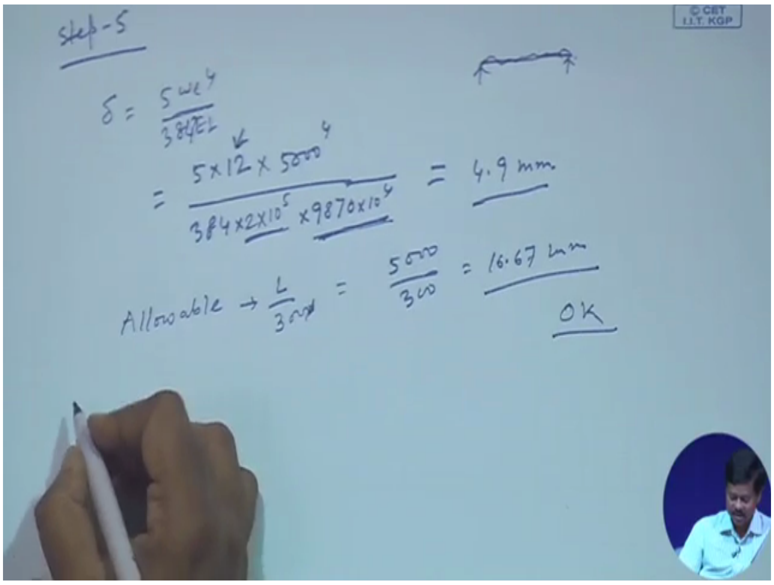

So what we can do now we can we have to next step check for deflection. So in next step we will check the deflection on the basis of maximum deflection which is 5 into wl to the power 4 by 384EI because we know for a simply supported beam with udl load the maximum deflection comes as 5 by 384 into wl to the power 4 by wl to the power 4 by EI. So if we put those value w is the udl load that is 12 here you remember that we are taking the service load not the factored load because deflection will check against the actual load the service load, right.

So into l is 5 meter so 5000 millimetre by 384 EI, E we have 2 into 10 to the power 5 because in case of steel we generally consider 2 into 10 to the power 5 and I was found earlier which is 9870 into 10 to d power 4 for ISLB 325, right for ISLB 325 section Ixx or Izz was consider as this. So after calculating this value we can find out delta as delta as 4.9 millimetre and allowable deflection allowable deflection will be L by 300 300 so that will be 5000 by 300 it is 16.67, so allowable deflection is 16.67 and maximum deflection is coming this which is less than the allowable one so it is okay. So from deflection point of view the chosen section is fine.

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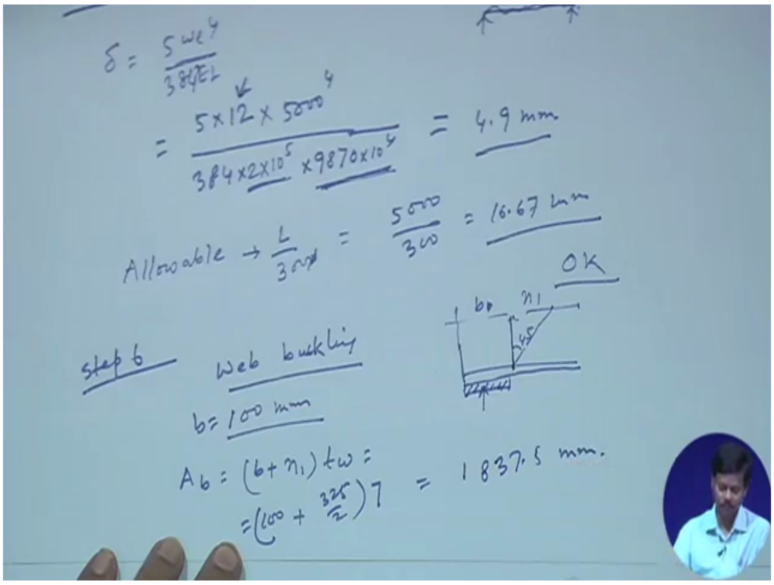

Now we will go to step 6, in step 6 what we will do we will check for web buckling, right so web buckling and web crippling we have to check. So in case of web buckling we will try to find out the web buckling area so for that we have to find out the bearing length, right. Now as nothing is given so we can consider bearing length as say 100 mm if we provide 100 mm bearing length then I can find out the cross-sectional area of web buckling that is Ab is equal to b plus n1 into tw. So here we can find out b as 100, right then n1 now n1 we know that it is (())(28:11) 45 degree.

So if we recall that if we have a support here and if we provide a bearing of this then it will (())(28:24) upto neutral axis, right. So with the 45 degree angle so this will be n1 and this is b so b plus n1 so n1 will become D by 2, right so n1 will be 325 by 2 into tw tw was taken as 7, so I can find out the cross-sectional area for the web buckling that is 1837.5 millimetre, right.

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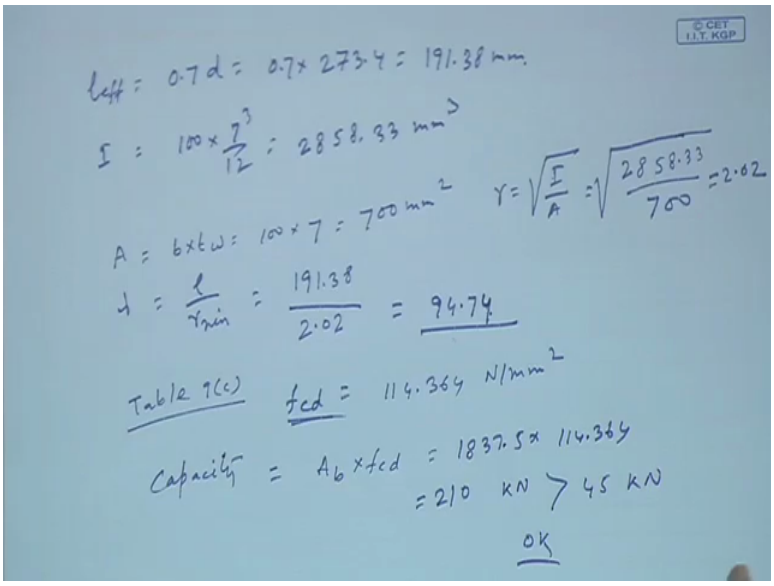

Now we have to find out the effective length of the web so effective length of the web we know that is 0.7 into d that is 0.7 into d we have calculated earlier that is 273.4 so that is coming 191.38 millimetre and moment of inertia will be Bd cube by 12 so 100 into tw is 7 cube by 12, so 2858.33 millimetre cube, right.

So now we can find out the area area will be b into tw, so 100 into tw is 7 so 700 millimetre square, right. And lambda we can find out l effective by r minimum l by r minimum, so l effective we know that is 191.38, right and r minimum, r is basically I by A so I we have calculated 2858.33 cross-sectional area is 700, so this is becoming 2.02, right. So r minimum is 2.02 therefore the lambda we got 94.74, right.

So now from now we know this will be buckling class c, so from table 9c we can find out the value from table 9c we can find out fcd value corresponding to lambda is equal to 94.74 and fy is equal to 250 as 114.364 newton per millimetre square. So design compressive stress fcd for the web is coming 114.364 newton per millimetre square. So the capacity of the section the web buckling capacity of the section will be Ab into fcd, so Ab is 1837.5 into fcd value is 114.364 that is coming 210 kilonewton which is greater than 45 kilonewton, so it is okay that means from web buckling point of view also the section is safe.

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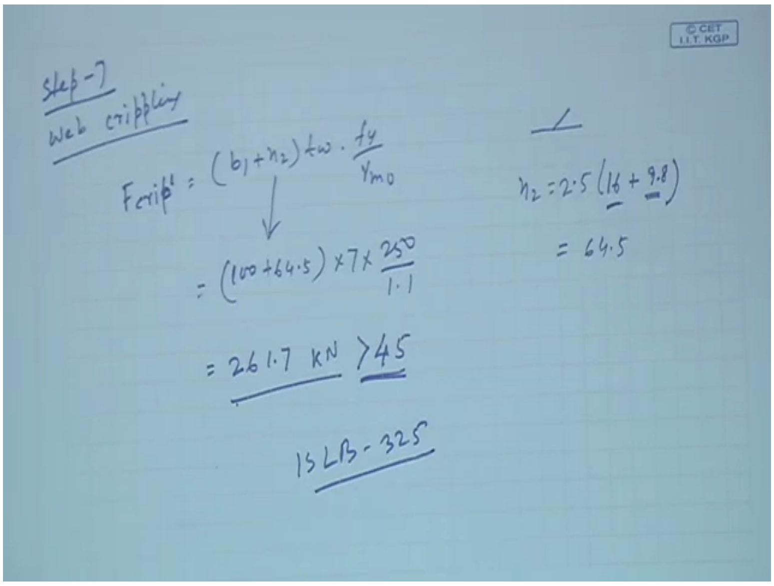

Now again we will see whether it is going to fail against web crippling or not. So in step 7 we check for web crippling, in case of web crippling we will find out crippling strength that will be b1 plus n2 into tw into fy by gamma m0. Now we can put those value so b1 is 100 n2 n2 we know that it will be (())(32:52) with 2.5 slope, right. So n2 value will become 2.5 into 16 plus 9.8 9.8 is the tf and means thickness of flange and 16 is the root radius R1. So the n2 value we can find out from this as 64.5.

So puting the value of n2 here as 64.5 now we can find out the crippling strength, right. So this is becoming 261.7 kilonewton and at the support the maximum force is coming which is shear force 45 kilonewton and crippling strength is much more higher than this, so the section is safe against web crippling. So this is how we can check one by one the section is whether section is safe against deflection, shear, web crippling, web buckling after getting the section size from the flexural point of view, so all these checks we have to we have to carry out to find out the final section size. So here the section size is ISLB 325, right.

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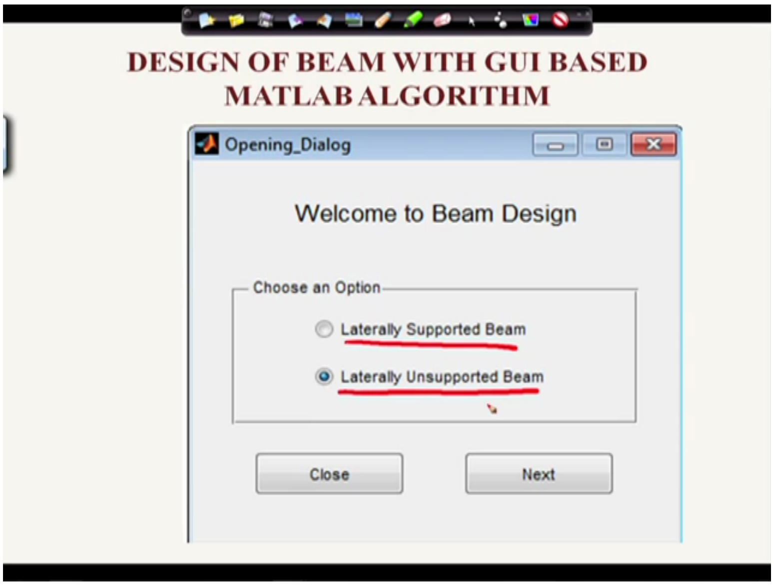

Now I will go few go through few slides that is the design of beam with GUI based MATLAB algorithm. So here what we have seen that especially when the design has to be done for unsupported beam we need to do lot of iteration, right. So manually to do all these things is very hectic therefore what we suggest that if we can develop a algorithm GUI based algorithm then once it is developed very easily we can make it useful. So through my students some software has been developed one of them I am demonstrating here where the beam design is done for 2 cases one is for laterally supported beam and laterally unsupported beam, right.

So by choosing a particular type we can go to the design of that case, right. So once we choose say for this case we have chosen unsupported beam.

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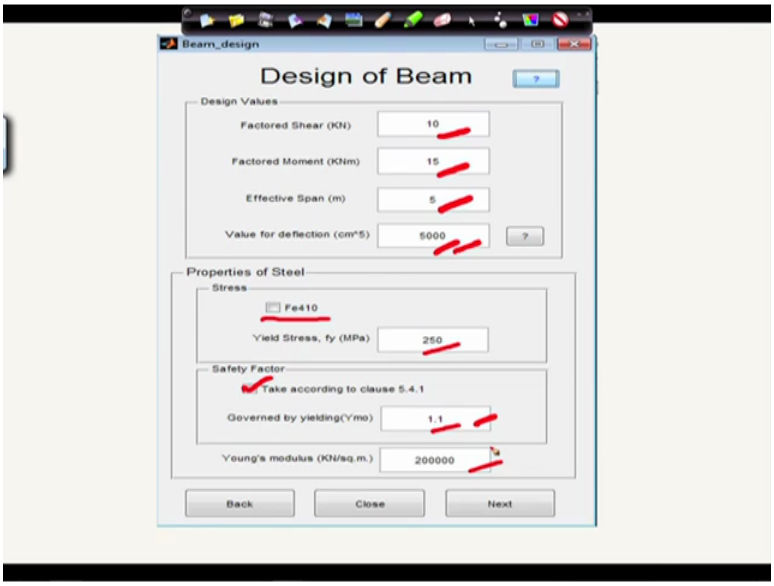

Then if we go to next then we can provide this requirement like what is the maximum factored shear, right maximum factored shear. Then what is the maximum factored bending moment, then what is the effective span these are the input which we need to take from the user and maximum deflection coming on the on the beam. So maximum deflection we can calculate from the formula and this also can be done through means through algorithm but that will be very complicated because we in that case we have to find out what is the support condition, what is the loading condition and because of loading and support condition deflection will be different and that we have to find out. Therefore means we can calculate manually for particular case and we can enter this value what is the maximum deflection.

Then what we can do other properties like we can put what is the yield stress whether we are going to consider Fe410 which are mostly used or if not then we can enter the value the yield stress of the steel. Then factor safety factor so gamma m0 value which is govern by yielding whether it is 1.1 which is given in clause 5.4.1 or something else we are going to take if something else we have to enter here otherwise if we give the check box here then automatically it will take 1.1.

Then also young modulus we have to enter, so all these value once enter then we can go for design, right. So though it shown very easy means it is okay.

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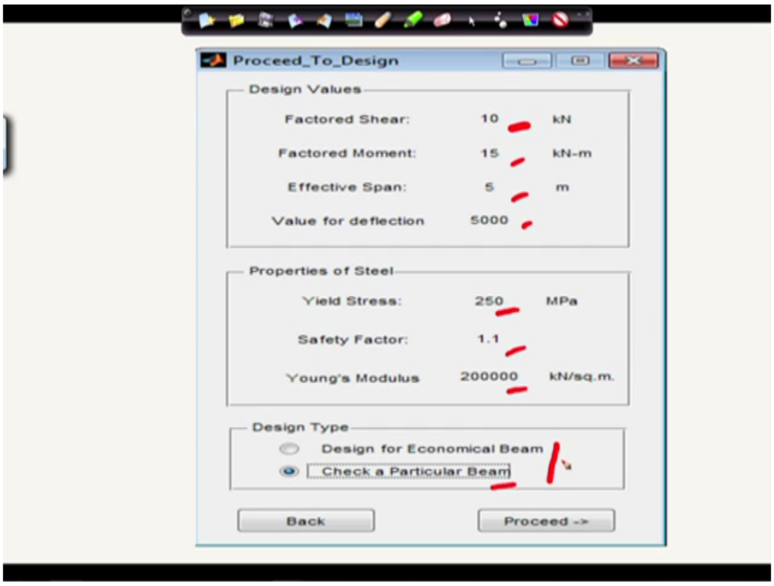

So once we go to next it will show whatever data we have entered are shown here. So whatever data we have taken finally it has been shown then you have two option here one is design for economic section and check for a particular section. So if user want to find out an economical section economical section means the lowest size of the section which will be safe under the given condition and check for a particular section means we can chose a particular section and we can check whether that section is safe or not. So these two both the options are kept here so according to the users choice he can he can find out means which one is required.

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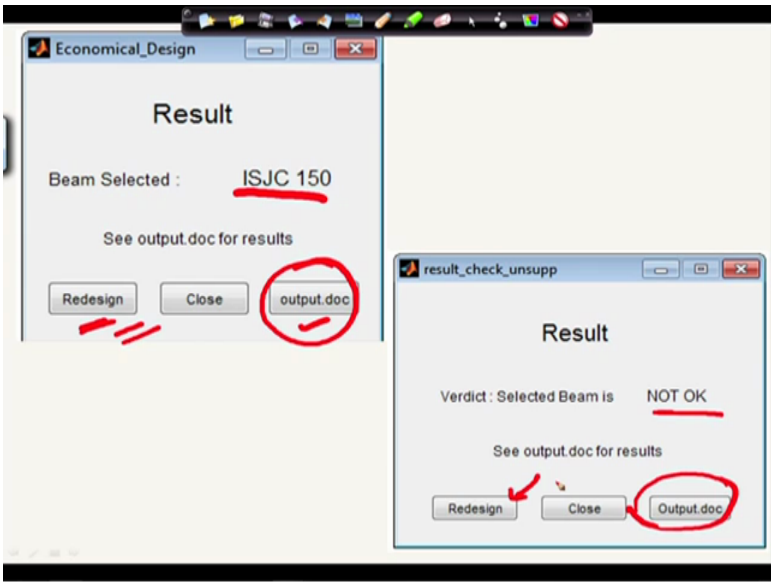

So after that if we click on proceed then it will show the results. So in the results we will see that here for economical section if we consider say the software is giving ISJC 150, right so for ISJC 150 the section is safe. So now if we click on output.doc then the intermediate calculations are given in the file which can be seen and if one user want to check in between means if he has a doubt on the results on the software then he can check the intermediate results from this output file and he can see whether it is okay or not means the results whatever has been calculated is correct or not, if it is not correct then he can change the means software means the algorithm he can change and he can modify it, right means for the for getting the confidence he need to check intermediate calculations so for that also it has been given.

And if the user want to redesign also that option is there he has to click on redesign then it will go back to the first slide and it will ask for data, right. So the option of redesign is there can be used. Another option is if we check for a particular section then we can check for a particular section also. So for that we have to click on particular section and then we will see whether it is okay or not, say for this case the selected beam was not okay so that is shown and there also you can find out the output and why it is not safe that can be found in details through that output and then again he can redesign and can find out some other section which may be safe.

So this is how one can develop the logic and one can make a flow chart and then can find out algorithm, okay. So I would suggest the viewers means those who are seeing this video I will suggest them to make their own algorithm according to their own logic, let them try an algorithm and write a program whatever language they are comfortable may be Python, may be C, may be MATLB, may be Fortran whichever language is comfortable he can make and according to his choice and his requirement he can develop the software and that will be customized software he can use forever, right.

And once it is developed he can again extent means he can make it (())(41:57) from different angle so that later he can include certain other aspects and and he can make it useful, so that he does not have to manually and he does not have to go for Tds calculations, right. So this is all about the design of beam. In next class we will discuss certain other things like the how to calculate the plastic section modulus that we will see because that I have not covered in this class, okay and also purlin and gantry girder also will be thought in next few classes, thank you.