Course on Design of Steel Structures
Prof. Damodar Maity
Department of Civil Engineering
Indian Institute of Technology Kharagpur
Mod 10 Lecture 48
Design of Laterally Supported Beams

Now, I am going to discuss the design procedure of a laterally supported beam. So in last lecture we have discussed how to calculate the design bending strength of a laterally supported beam. How to calculate the design shear of a laterally supported beam. So in today's lecture first, I will go through very quickly the design steps for laterally supported beam and then I will go through one workout example.

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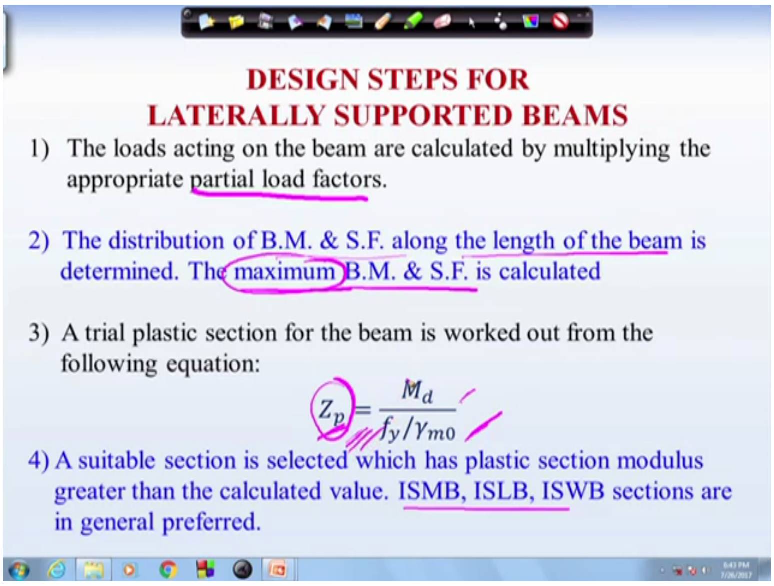

So in first step, what we can do we can find out what are the load acting on the beam and then we can calculate the appropriate load by multiplying the partial load factor. So whether it is due to dead load, live load or due to wind (())(1:07) load or seismic load depending on that we can find out what is the load coming and what will be the partial load factor. So from that we can find out the bending moment distribution and shear force along the beam length and then from that we can find out maximum bending moment at shear force, because I have to design the beam against the maximum bending moment and maximum shear force.

So on that basis then I can find out a trial plastic section Zp, Zp as Md by Fy by gamma m0, considering whether it is high shear or low shear irrespective of that, first I will find out a trial plastic section from this formula that is Zp is equal to Md by Fy by gamma m0, where

Md is the maximum bending moment, which we have calculated, Fy is the yield stress of the material and gamma m0 is a material safety factor, right. So from this we can find out the trial plastic section and then we can select a suitable section, you so from the plastic section modulus we can find out a corresponding section whether we are going for ISMB or ISLB depending on that we can find out section whose plastic section modulus is greater than this slightly greater than this.

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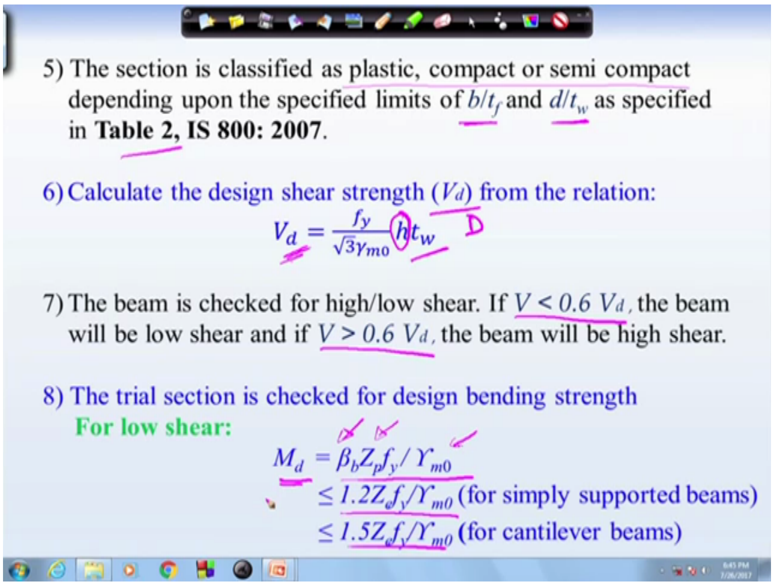

Then we can classify the section as plastic compact or semi-compact from table two, right compact, semi-compact or plastic. So depending on the b by tf ratio and d by tw ratio, I can find out from table 2 that whether the assumed section is plastic or compact or semi-compact. Once it is done then I can find out the design shear strength Vd , Vd will be calculated as Fy by root 3 gamma m0 into h into tw, h we can write or D (())(3:27) write D where h or is a overall depth, right. So design shear strength Vd can be calculated from this and then I will check whether, it is high shear or low shear. If the v is less than 0.6Vd then the beam is will be low shear and if it is more than 0.6Vd then beam will be consider as high shear.

So considering high shear or low shear, the formula will be different for calculating design bending strength. So if it is low shear then I can find out Md value as this that is beta b into Zp Fy by gamma m0, right. So now for a particular section we know Zp value and depending on the type of section whether it is plastic, semi-plastic sorry, plastic, compact or semi-compact, I can find out the beta b value and gamma m0 value I know. So from that I can find out the design bending strength Md and it has to be less than 1.2Ze Fy by gamma m0 and for simply supported beam and for cantilever, it has to be less than 1.5Ze Fy by gamma m0. So in this step, we could calculate the design bending strength for low shear.

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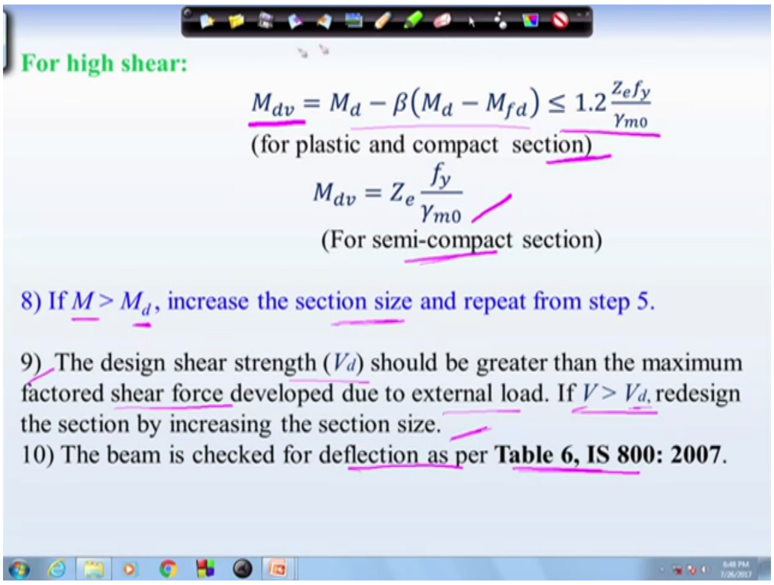

And for high shear, the design bending strength will be calculate from this formula where Mdv is equal to Md minus beta into Md minus Mfd and it has to be less than or equal to 1.2 Ze Fy by gamma m0 and this is for plastic and compact section and for semi-compact section Mdv can be calculated as Ze Fy by gamma m0. So Mdv value for high shear can be calculated depending on the type of section from this formula and now, if we see that M is greater than Md then we have to increase the section size and repeat from step 5, right. That means if the design bending strength is less than the actual moment then I have to increase the section size and then I have to repeat from step 5 otherwise if it is satisfying then we can go to step 9.

So from step 5 to 8 will be repeated till the design bending strength is more then the bending moment developed bending moment. So if it is more then fine otherwise I have to repeat and once it satisfy then I will calculate the means I will calculate design shear strength Vd and it should be greater than the maximum factor shear developed due to external load. So maximum factor shear V has been already calculated. So and that design shear strength should be greater than this, if this is **is** fine then we can go to next step otherwise if V is greater than then Vd then redesign the section by increasing the section size.

So if we see that the shear is more than the design shear strength then we have to redesign by increasing the section size and next step we have to check for deflection, which is also another important aspects that is the beam has to be checked for deflection as per table 6. In table 6, the limiting deflection criteria has been given and the maximum deflection can be calculated from the given boundary conditions and the loading conditions. So from that we can find out the maximum deflection and maximum deflection has to be less than the limiting deflection given in table 6, if it is okay then fine otherwise we have to again increase the section.

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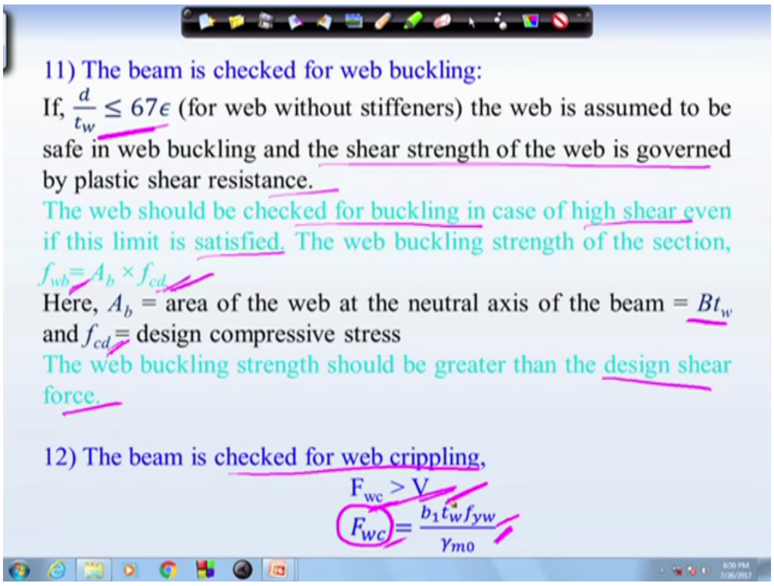

Now we have to check for web buckling. The beam needs to be checked for web buckling that is if we see the d by tw, this is less than 67 epsilon for without for web without stiffness then the web is assumed to be safe in web buckling and we do not need to check. So the shear strength of the web is governed by plastic share resistance and the web should be checked for buckling, in case of high shear even if this limit is satisfied and the web buckling strength can be calculated we know that is Fwd is equal to Av into Fcd, where Av is the area of the web at the neutral axis that is B into tw and Fcd is the design compressive stress, which can be found from table 9C, because it is buckling class C.

So from this I can find out the web buckling strength and this web buckling strength should be greater than the design shear force at that point, right. So if web buckling strength is greater than the design shear strength then fine otherwise we have to increase the bearing plate (())(9:05) length, either we have to increase the bearing plate length or we have to increase the section size to increase the web buckling strength. So once it is okay then we will go for checking web crippling. Web crippling that Fwc web crippling strength, this has to be also less than the shear force at that point and Fwc is a web crippling strength we can calculate from tis formula that is b1 tw Fyw by gamma m0, where b1 is the dispersion width and tw is the thickness of the web and Fyw is the yield strength of the web, right.

So web crippling strength Fwc can be found from this formula and it has to be more than the shear force coming on that section. So if it is satisfying this criteria then fine otherwise again we have to increase the section size or we have to increase the bearing length to make the section safe from the web crippling. So these are the steps which we need to follow to design a beam with laterally supported.

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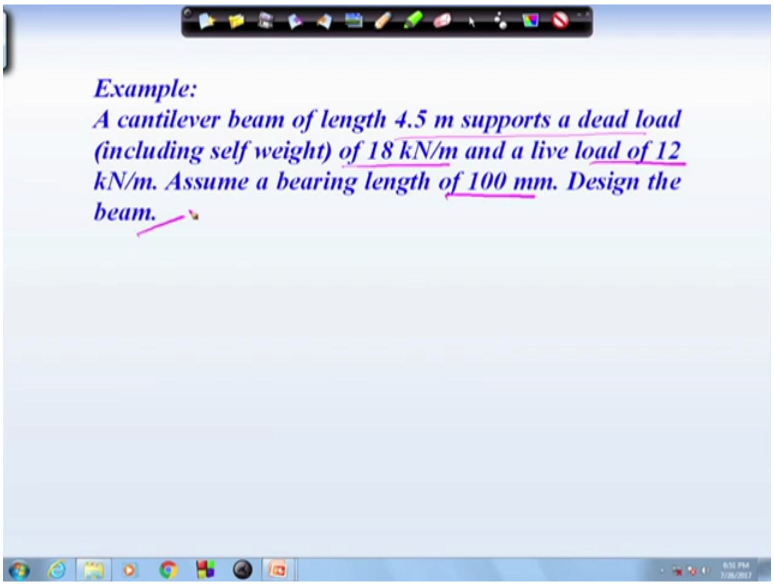

So now we can go through this example where a cantilever beam of length 4.5 meter supports a dead load which include self-weight that is 18 kilo newton per meter and a live load of 12 kilo newton per meter. Assuming a bearing length of 100 millimeter. Design the beam. So a cantilever beam you have to design where the length of the member is 4 5 and load is given 18 kilo newton and 12 kilo newton as dead load and live load and we have to assume the bearing length has 100 mm and applying we have to design the beam.

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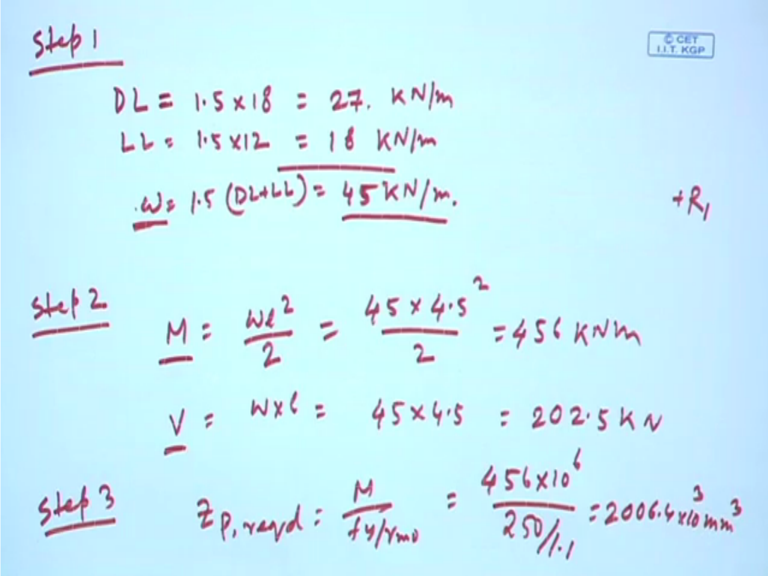

So let us come to step one in which we have told we have to find out the dead load with load factor, so dead load 1.5 into 18 and live load also 1.5 into 12 which was given. So this will be 27 kilo newton per meter and this will be 18 kilo newton per meter. So total load dead load plus live load into 1.5 times w is equal to this is equal to say 45 kilo newton per meter. So in step one, we have calculated the factor load w which is coming 45 kilo newton per meter.

Now we will go to step two. In step two, we can find out the maximum bending moment as wl square by 2 for cantilever beam. Maximum bending moment will be at the support, so w is 45 l is 4.5 by 2. So that is becoming 456 kilo newton. Similarly the maximum shear force will be at the support that will be w into l, so 45 into 4.5 that will be 202.5 kilo newton. So in step two the maximum bending moment and maximum shear force we have calculated. Now we have to choose a trial section. So in step three, we can choose a trial section for that we can find out Zp require that will be M by Fy by gamma m0, M is 456 kilo newton meter, so 456 into 10 to the 6 newton millimeter by 250 by 1.1. So this is becoming 2006.4 into 10 cube millimeter cube, okay.

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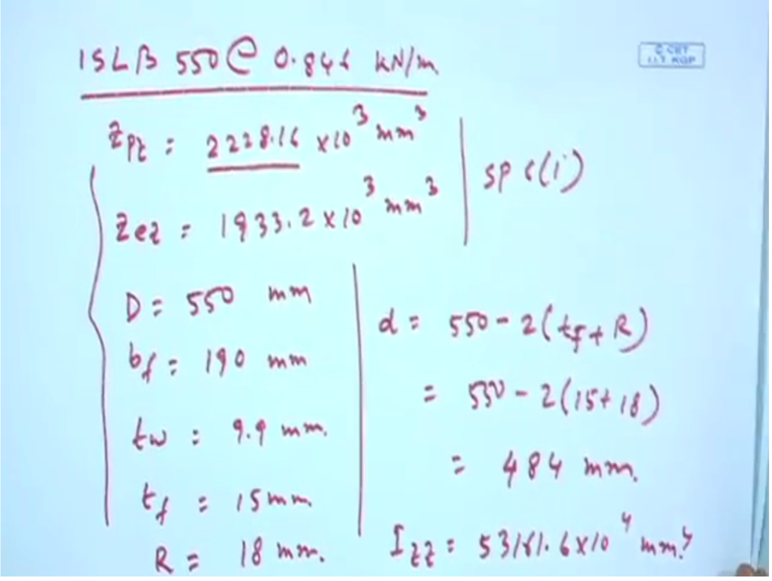

So in step three we could find out the Zp require and now we can find out a suitable section from sp6 and if we look into sp6 (())(14:09) we can say that ISLB 550 at 0.846 kilo newton per meter, we can choose this section with Zpz is equal to 2228.16 into 10 to the 3 millimeter cube. We need 2006 and we are providing 2228, right and Zez here will be 1933.2 into 10 to the 3. So these values are obtained from sp6 (())(14:52), right and also we could find out D value as 550 the overall depth, width of flange 190 mm, thickness of the web 9.9 mm, thickness of flange 15 mm and root radius R will occupy an 18 mm, right.

So from this also I can find out the d value small d that will be 550 minus 2 into tf plus R is equal to 550 minus 2 into tf is 15 plus R 18, so this is becoming 484 millimeter and also, Izz value we can find from the sp6 (())(14:52) that is 53161.6 into 10 to the 4 millimeter to the 4. So these are the data which will be require to calculate the design bending strength and other details, right.

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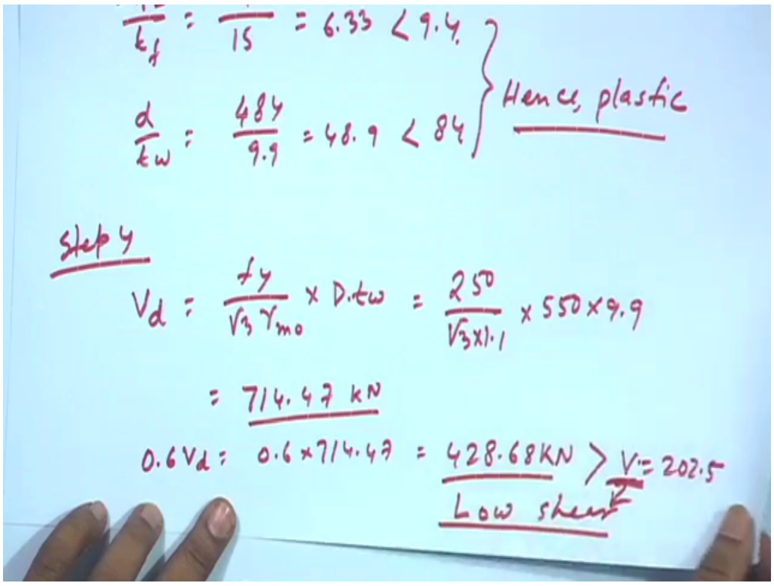

Also, I have to find out what is the section here, whether it is plastic, compact or semi-compact. So now here we know bf by here bf by 2 by tf is equal to it will be bf we found as 190by 2 by 15 is the thickness of flange. So this is becoming 6.33 and this is less than 9.4. Similarly, d by tw we are getting 484 by 9.9 will be 48.9 less than 84 okay. So from this I can say this is a plastic section. So if it is plastic section then I can find out the value accordingly right.

So now in step 4 also we have to find out that what is the shear capacity Vd, because before calculating the bending moment bending strength of the section, we need to know whether it is high shear or low shear, so for that we have to find out what is the design shear strength of the section and also we have to know whether it is plastic, compact or semi-compact according to that the beta b value will be calculated, right.

So here Vd will be Fy by root 3 gamma m0 into D into tw, so I can put value that is D is 550 into tw is 9.9, so these values are 714.47 kilo newton, right and 0.6Vd is coming as 0.6 into 714.47 this is 428.68 kilo newton, which is more than the V and V value is coming 202.5 kilo newton, right. So what will be see that here the design shear strength is becoming 714 kilo newton and 0.6Vd is coming 428 which is more than V, so it is low shear. So we can see this is as low shear, because shear force is coming less compared to the design shear capacity, okay.

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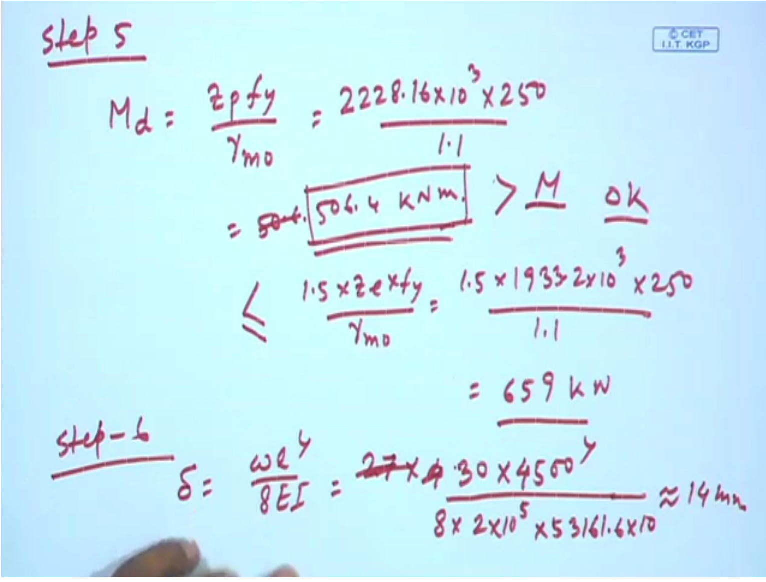

So if it is low shear then I can find out the design bending moment according, design bending strength accordingly design bending strength accordingly? So in step 5, I can find out design capacity of the section design moment capacity of the section, it is Md. So Md will be simply Zp Fy by gamma m0, so Zp value we find earlier which is this Fy is 250 and gamma m0 is 1.1. So this is 506.4 kilo newton and it has to be less than as it is a cantilever beam. So it has to be less than and equal to 1.5 Ze into Fy by gamma m0 that is 1.5 Ze is 1933.2, 10 cube into 250 by 1.1, right that is 659 kilo newton. So Md is this, Md is less than this, so we can consider the design bending strength of the section as 506.4 kilo newton, right.

So next we will find out and this is more than the moment coming maximum moment coming, right so okay. Now in step 6, we can check for deflection. So check for deflection delta we know that will be wl to the 4 by 8EI. This will be the maximum deflection for cantilever beam. So if I calculate w will be 27, because this will be under service load. So it will be 27 into 45 sorry, w will be 18 plus 12, this will be 30, 30 into 4500 whole to the 4 by 8, E is 2 into 10 to the 5 into I we found earlier that is 53161.6 into 10 to the 4, right. So this is coming around 14 mm right.

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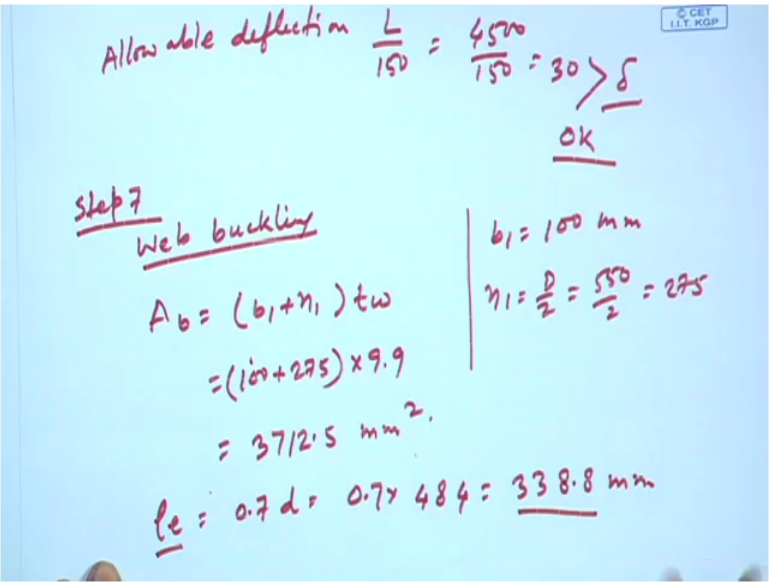

An allowable deflection, we can find out allowable deflection, allowable deflection will be L by 150 that is 4500 by 150 that is 30 mm, so which is more than the actual deflection, so it is okay. So from deflection point of view also the section which is assumed is find.

Now we will go to next step that is step 7, which will be dealt with web buckling. So we have to see whether it is buckling means, its web is buckling or not. So the cross sectional area of the web for buckling that is Ab we can find out that is b1 plus n1into tw, because of the support only, it will be and b1 is, actually b1 is 100 okay, b1 is given as bearing length that is 100 mm and n1 will be D by 2 that will be 550 by 2, 275 so Ab we can find out that is 100 plus 275 into tw as 9.9. So cross sectional area of web for buckling will become 3712.5 millimeter square and effective length of web le is equal to 0.7d that will be 0.7 into d we calculate earlier 484. So this is becoming 338.8 millimeter. Now I can find out moment of inertia I.

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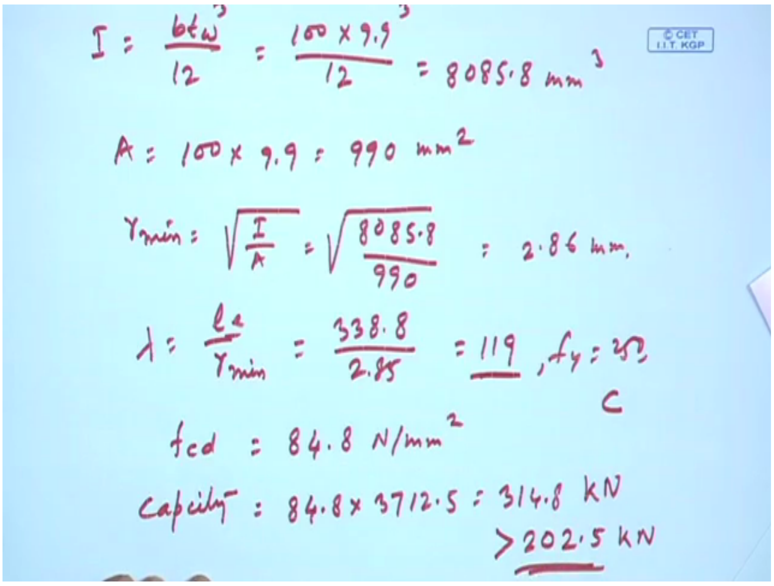

So I will be, bt cube by 12, so b has been considered as 100, t is 9.9 by 12. So this is becoming 8086.8 millimeter to the cube and area we can find out this is as 100 into 9.9, so 990, right. So r minimum I can find out, r minimum will be I by A, so I is 8085.8 cross section area is 990, this is becoming 2.86 and lambda I can find out, l by r we locate it by r minimum, l effective we found 338.8 r minimum is 2.85, so this is becoming 119.

So allowable stress Fcd for lambda 119, Fy as 250 and buckling class as C. so from table 9C, I can find out the value of Fcd. So Fcd value is coming as 84.8 newton per millimeter square. So this is obtained from table 9C. So capacity of the section, I can find out, capacity buckling strength I can find out as Fcd value 84.8 into area 3712.5. So this is becoming 314.8 kilo newton and that is greater than the maximum shear which was coming to 202.5 kilo newton, right. So it is okay.

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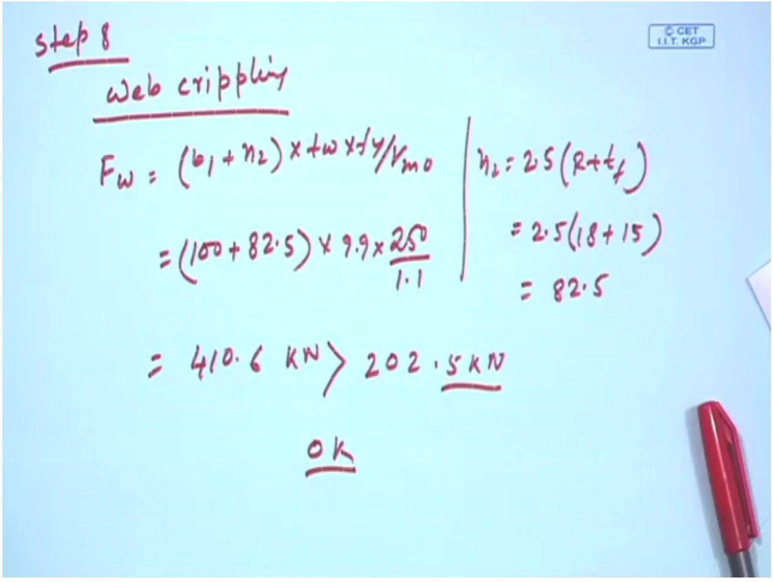

So the section is safe against web buckling. Now next step I will go that is step 8 web crippling. We have to check for web crippling. So for web crippling I have to find out the web crippling strength Fw is equal to b1 plus n2 into tw into Fy by gamma m0, right. Here, n2 will be 2.5 into R plus tf, because it will disperse with 2.5 slop 2.5 is to 1 slop. So 2.5 into R was 18, thickness of flange was 15. So this is becoming 82.5. So b1 we have consider 100 mm length of bearing, so 100 mm plus 82.5 as n2 and thickness of web is 9.9 then 250 by gamma m0, for this is becoming 410.6 kilo newton and this is greater than 202.5 kilo newton. So the section is safe against web crippling right. So this is how we can find out the web crippling strength and we can see that the section is safe against web crippling.

So from this what we can see that we have to design the beam stage by stage. So the steps are discussed earlier, so according to these steps, we have gone through and we have checked every step that we are the assumed section is safe against moment, against shear, against deflection, against buckling and against crippling. So all the checks are satisfied, so the sections which are assumed is okay. So whatever I have done, I am quickly going through this the power point presentation so that you can keep note.

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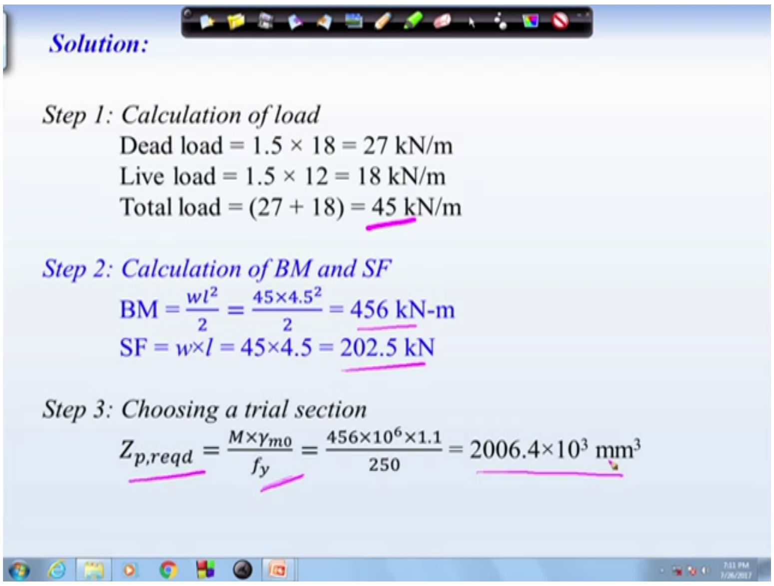

So for example here, in first step we have calculated the load factor load which is coming 45 kilo newton per meter, 1.5 times dead load plus live load and then we have found the maximum bending moment, which will be wl square by 2 and maximum shear force which will be wl at the support. So maximum bending moment and maximum shear force are calculated in step 2. Then we have to choose a trial section so for that we can find out the plastic section modulus require, which is M by Fy by gamma m0 and from that we can find that the Zp require as 2006 into 10 cube millimeter cube. So this is the require of Zp.

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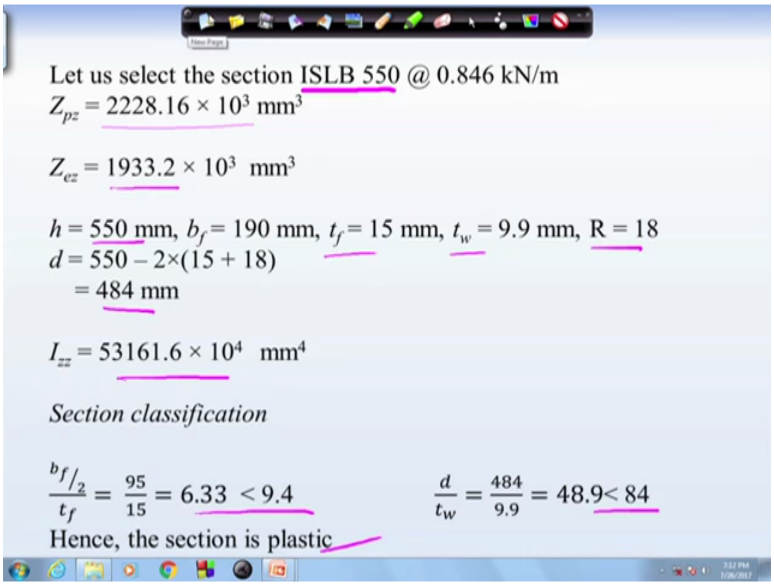

And we will try to choose a section further its Zp value becomes little higher than the requirement. So through sp6 we could find a section whose size is ISLB 550 and its Zpz is becoming slightly more than the requirement that is 2228.16 into 10 to the 3 millimeter cube and also we found the value of Zez then the overall depth, small d we can find and also we can find the tf, tw, root radius and Izz, right also we can find the section classification. So from section classification we can see, it is less than 9.4 and less than 84 as a result this section is a plastic. So the ISLB 550 when we are going to use, it will be a plastic section and its properties are given here.

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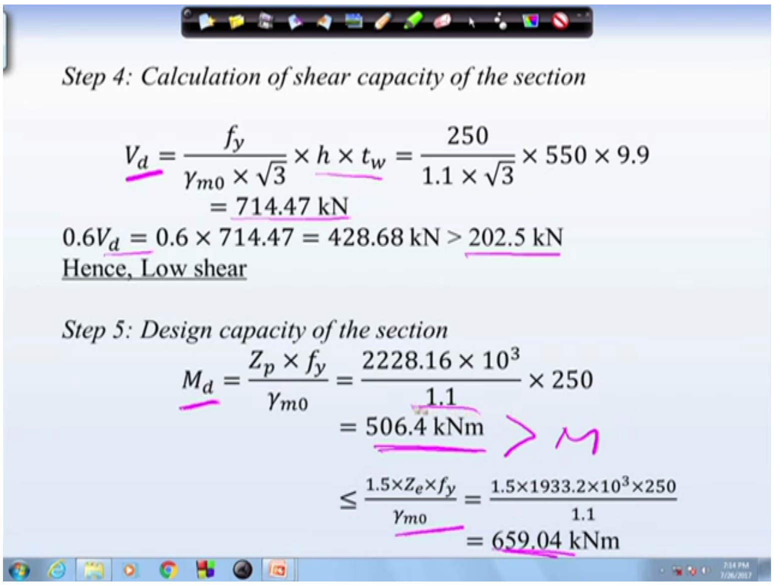

So considering this property we can now find out the shear capacity of the section in step 4 that is Vd is equal to Fy by root 3 gamma m0 into (area) shear area which is h into tw. So this value is coming 714 kilo newton and 0.6 times of that is greater than the developed shear. Therefore, it is low shear. So for low shear the design capacity of the sections can be calculate from this formula, where Md is equal to Zp into Fy by gamma m0.

So we can find out the Md value as 506.4 kilo newton meter, which is greater than the develop moment wl square by 2. So it is okay and then also we have to check whether it is less than this or not, 1.5 Ze Fy by gamma m0. There we can see that Ze Fy by gamma m0 is 659. So Md value can be considered as this.

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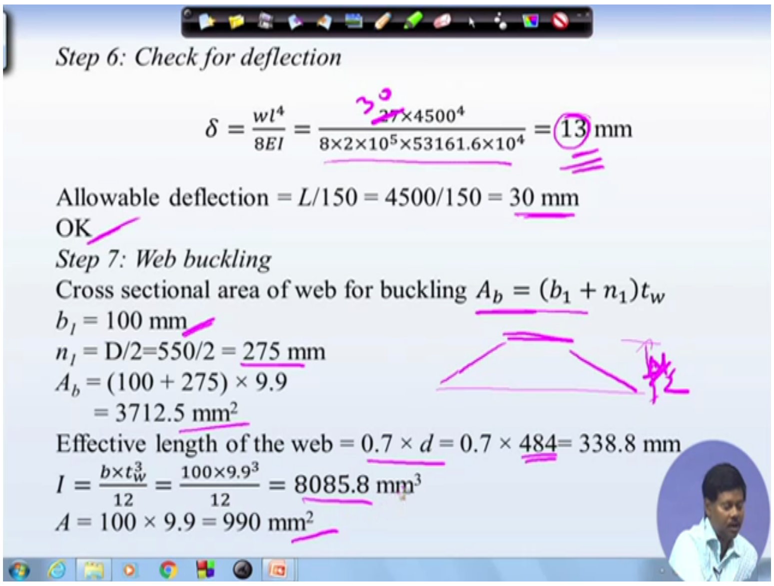

Now we will go for deflection. So for deflection we will find out delta is equal to wl to the 4 by 8EI, w will be 30 into 4500 to the whole 4 by 8EI then is value we have to check may be around 14 mm it will be and allowable deflection is coming 30 mm, which is much higher than this, right. So from deflection point of view, the (())(34:20) section is safe.

Then we will go for web buckling and add the bearing length was given 100 mm, so I can find out the cross section area of the web for buckling. So for that b1 we know and n1 because if this is bearing then it will be dispersed 45 degree up to neutral axis and this is d by 2, right which is n1. So n1 is d by 2, is 275, so area of the web we can calculate and effective length of the web is 0.7d, where d was calculated earlier, so we can find out I value, A value.

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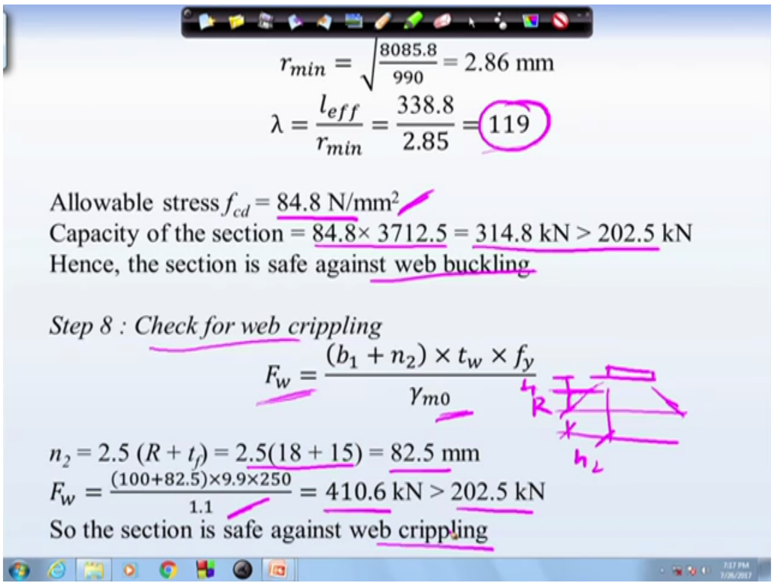

And then I can find out the r minimum as 2.86 and then lambda, right. Once lambda is found we can find out the value of allowable stress Fcd, because corresponding to this lambda and with buckling class C for Fy is equal to 250, the allowable stress is becoming 84.8 from table 9C and then capacity of the section can be found from the Fcd into Av and it is becoming more than the shear force coming on the support. So the section is safe against web buckling and then we will go for web crippling.

So crippling strength also we can find out Fw is equal to b1 plus n2 into tw into Fy by gamma m0 and n2 will be calculated with a dispersion of 25 is to 1. So and it will be calculated if this is the flange thickness tf and if this is the root radius then up to this, right. So this will be n2. So n2 value is becoming 82.5 and then I can find out the crippling strength which is becoming 410 and is more than 202 kilo newton. So the section is safe against web crippling is. So this is how all the checks are performed and the size of the section which has been assumed is safe, right. So this is how we can design a section under low shear with its means which is means laterally supported beam means is it is laterally supported and low shear then how to design that has been demonstrated through this example, okay.