Advanced Design of Steel Structures
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Lecture - 49
Crane hook

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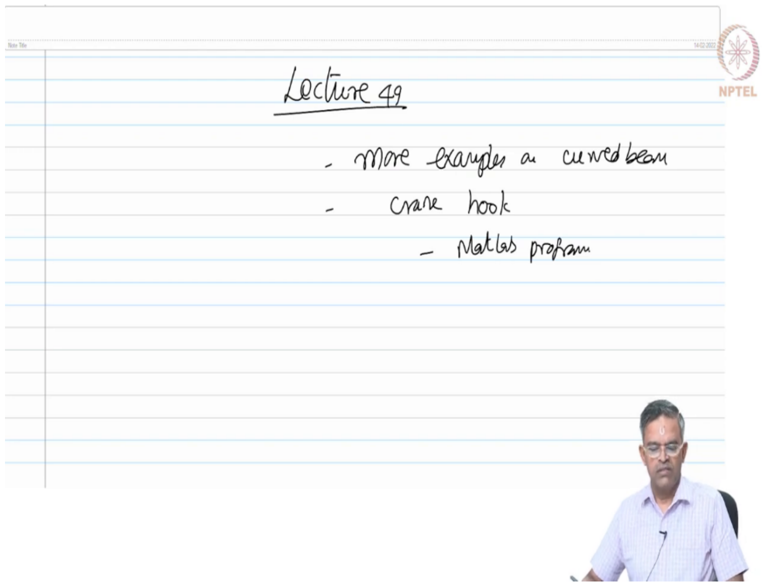

Welcome friends to the lecture-49 of Advanced Steel Design course. In this lecture, we are going to do more examples on curved beams, we will also do an example on Crane hook, we will also use MATLAB program for solving the problem. Friends, the MATLAB coding for these numerical are available in my standard textbook Advanced Steel Design published by CRC is given in the list of references of this course.

I request you to please go through that download the program and use it freely for your MATLAB and MATLAB extensively supports NPTEL courses thoroughly. You can also get a free training for using MATLAB programs with the MATLAB incorporation. Please download the software, use it freely so that academic purpose. We encourage very strongly that you should use MATLAB program, write your own code.

But, in this course we are able to share the code with you can make some small modifications in the code so that you can make it more I mean compact and look faster to execute. So, we will continue with the discussion on working on problems for the curved beams we said Winkler Bach equation is a very good compact set of solution for solving a curved beam.

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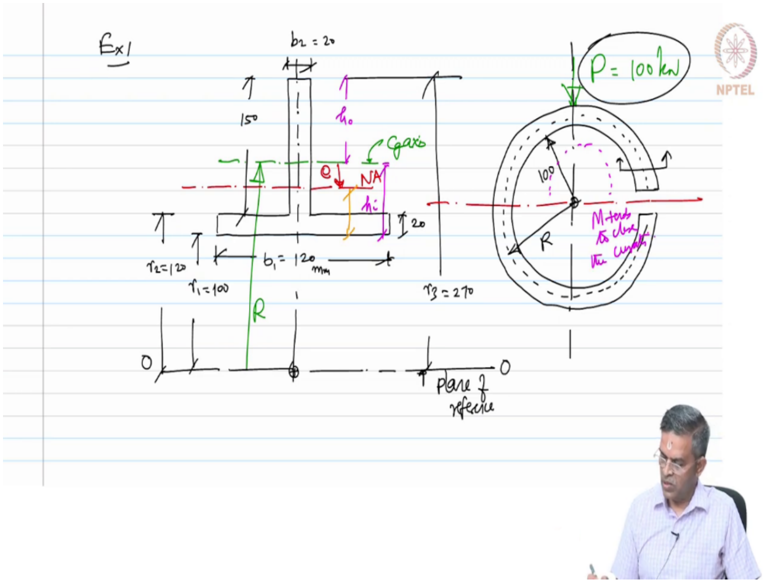

Let us take an example and try to solve a problem for a curved beam. So, let us say we have a circular proving ring which is used for loading purpose. Proving ring is a very common thing used in experimental studies which you must be aware. So, I have a proving ring which is circular in shape. So, this is my centroidal axis of this and let us say this is subjected to a downward force of 100 kN acting on the proving ring which is circular in shape.

So, let us also mark the centroidal axis of this curved beam which has a radius R from the centre and we call this radius as 100 mm. If you cut a cross section of this curved beam the cross section looks like a T section, if this becomes my plane of reference which is O, O and let us say the neutral axis is located here and the centroidal axis is somewhere here as marked on the figure.

So, our job is to even find out this axis, but let us mark the eccentricity of the neutral axis from the centroidal axis as e which is measured towards the center of curvature. Let us mark the dimensions of this particular T section. We call this as b_1 which is 120 mm all dimensions are mm. This has a thickness of 20. Let us call this as r_1 from the plane of reference and let this be 100.

And, we know this is r_2 which is 120 and we call this as r_3 which is 270 which means this dimension is 150, and this thickness is said as b_2 which is 20. So, we have all the dimensions and we will say this is my radius which is R. R is to be computed, let us say this is 100. This is 100. R need to be computed. The intrados is 100. R need to be computed.

So, these are the data we have and we want to find the stresses that intrados and extrados of this curved beam.

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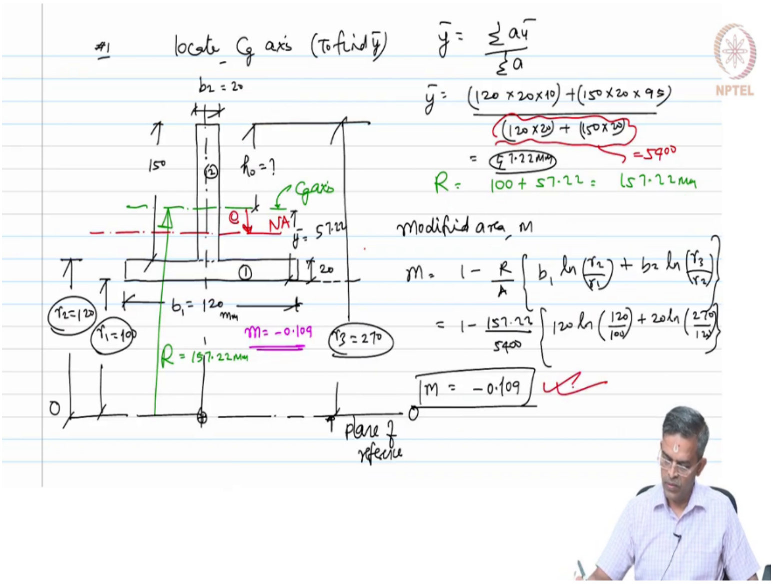

So, our first step is to find out the centroidal axis locate the centroidal axis. Let us copy this figure take it to the next screen and we will do the calculation. So, let me call this distance as y bar. Now, I want to find y bar. So, y bar is given by sigma a y bar by sigma a we will divide this into two parts, let us do that. So, this is piece number 1 and this is piece number 2.

So, y bar is now equal to 120 into 20 into 10. I take this as my reference plus 150 into 20 into 95 divided by 120 into 20 plus 150 into 20. This gives y bar as 57.22 mm. Therefore, I can now write R value as 157.22 mm. Therefore, R is 100 plus 57.22, 157.22 mm.

Now, we have an equation to find the modified area factor m. m is given by 1 minus R by A; refer to the equation for rectangle series of rectangles we already have a generic form I am writing the general equation $b_1 ln\left(\frac{r_2}{r_1}\right) + b_2 ln\left(\frac{r_3}{r_2}\right)$. So, let us say this is my r_3, this is my r_1, this is my r_2. Let us substitute for this. 1 minus 157.22 by 5400, possibly if you add up this if you add up this should be equal to 5400, as a total area. multiplied by b_1 is 120 you can see from the figure.

$$\bar{y} = \frac{\Sigma a\bar{y}}{\Sigma a}$$

$$\bar{y} = \frac{(120\times20\times10)+(150\times20\times95)}{(120\times20)+(150\times20)}$$

$$\bar{y} = 57.22mm$$

$$R = 100 + 57.22 = 157.22mm$$

$$m = 1 - \frac{R}{A}\left\{b_1 ln\left(\frac{r_2}{r_1}\right) + b_2 ln\left(\frac{r_3}{r_2}\right)\right\}$$

$$m = 1 - \frac{157.22}{5400}\left\{120ln\left(\frac{120}{100}\right) + 20ln\left(\frac{270}{120}\right)\right\}$$

$$m = - 0.109$$

which gives me m value as minus 0.109. Let me write down this value here for our reference m is minus 0.109. Having said this, let us try to find out the shift of neutral axis from the centroidal axis.

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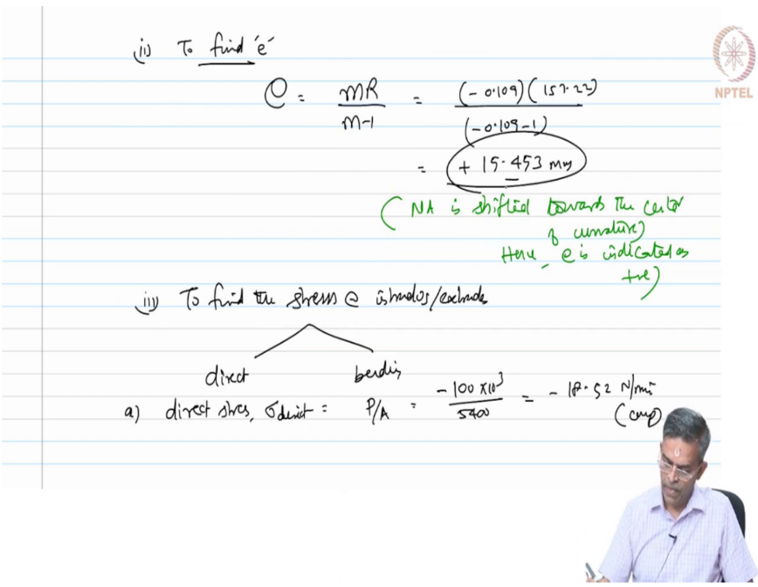

$$e = \frac{mR}{m-1} = \frac{(-0.109)(157.22)}{(-0.109-1)} = 19.453mm$$

$$\frac{P}{A} = \frac{-100\times10^3}{5400} = - 18.52\frac{N}{mm^2}$$

So, step number 2 will be to find e. e is given as $\frac{mR}{m-1}$. So, let us do minus 0.109 into 157.22 by minus 0.109 minus 1 which gives me as plus 15.453 mm that is neutral axis is shifted towards the center of curvature. So, that is the positive sign. So, step number 3, I want to find the stresses at intrados and extrados. First let us find the stress of two parts.

One is the direct stress, other is the bending stress. So, let us find the direct stress first. Sigma direct will be equal to simply P by A which will be now let us see the problem is subject to a compressive axial force of 100 kilo newton. So, minus 100 10 power 3 by 5400 which is minus 18.52 minus indicates compressive.

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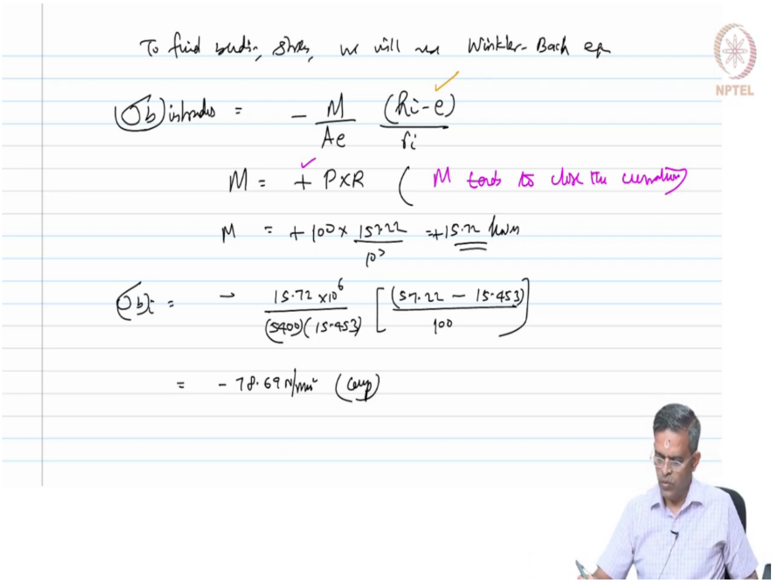

Now, let us go for bending stress. We will use Winkler Bach equation. To find bending, stress we will use Winkler Bach equation. The bending stress in intrados is given by minus m by A e h_i minus e by r_i. It is very easy to remember this equation. Look at this figure. From the CG you know from the CG, this is h intrados and this is h outtrados extrados.

$$\left(\sigma_b\right)_{intrados} = -\frac{M}{Ae}\frac{\left(h_i - e\right)}{r_i}$$

$$M = +P\times R = +100\times\frac{157.22}{10^3} = +15.72kNm$$

$$\left(\sigma_b\right)_{intrados} = -\frac{15.72\times10^6}{5400\times15.453}\frac{(57.22-15.453)}{100} = -78.69\frac{N}{mm^2}$$

We always measure from the CG, but I want the distance from the neutral axis. So, that will be h_i minus e that is what I am writing here. So, now, let us see what is my m value? m value is P into R, I put a positive sign here because m is m tends to close the curvature. See here m is applying this form. So, it will try to close the curvature. If it closes the curvature then we say it is positive.

So, it is positive. Let us see what is the value which will be equal to 100 into 157.22 by 1000 that is 100 kN. So, it becomes 15.72 positive. So, now I want to find $(\sigma_b)_{intrados}$ which will be minus 15.72 into 10 power 6 newton mm divided by A e 5400 and e is 15.453 that is what e we have of h i is 57.22 see here h_i is 57.22 because you know this distance was 57.22.

Minus e; e was 15.453 divided by r_i; r_i is 100. So, this gives me the value as minus 78.69 compressive. Let us try to find out sigma b o that is extrados.

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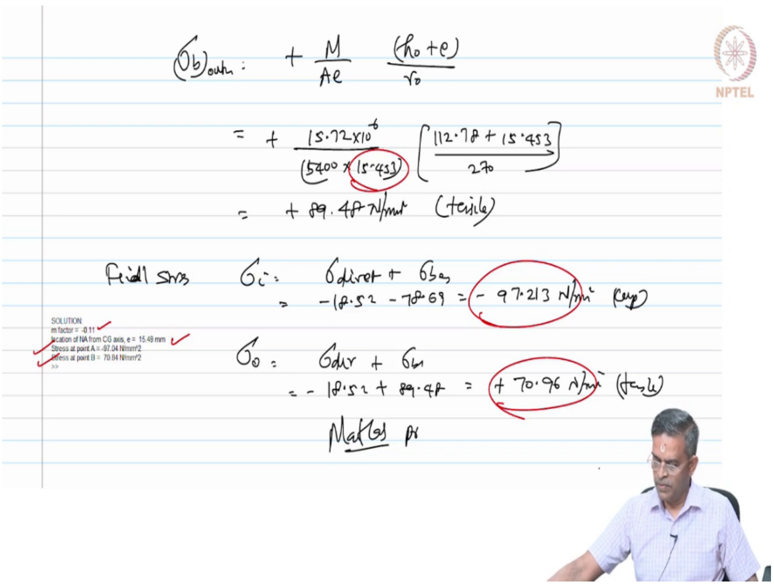

$$(\sigma_b)_{outrados} = + \frac{M}{Ae}\frac{(h_o + e)}{r_o}$$

$$(\sigma_b)_{outrados} = + \frac{15.72\times10^6}{5400\times15.453}\frac{(112.78+15.453)}{270} = + \ 89.48\frac{N}{mm^2}$$

$$\sigma_i = \sigma_{direct} + \sigma_{bending} = - 18.52 - 78.69 = - 97.213 \frac{N}{mm^2}$$

$$\sigma_0 = \sigma_{direct} + \sigma_{bending} = - 18.52 + 89.48 = + 70.96 \frac{N}{mm^2}$$

Let us see what is my value in the extrados. So, sigma b o is given by positive M by A e h_o plus e by r_o. So, which will become plus we know the m value which is 15.72 by 5400 into 15.453 of h_o. You can find out this value geometrically. You can find out this value. This is h o which will be 112.78 plus 15.453 divided by 270 which will give me this value as plus 89.48 tensile.

So, the final stresses sigma I will be sigma direct plus sigma bending direct was compressive. So, minus 18.52 bending was also compressive 78.69. This is minus 97.213 compressive. Sigma extrados will be sigma direct plus sigma bending which is minus 18.52 plus 89.48 which gives me this value as plus 70.96 tensile. Friends let us run a MATLAB program with this input and see how do we do it.

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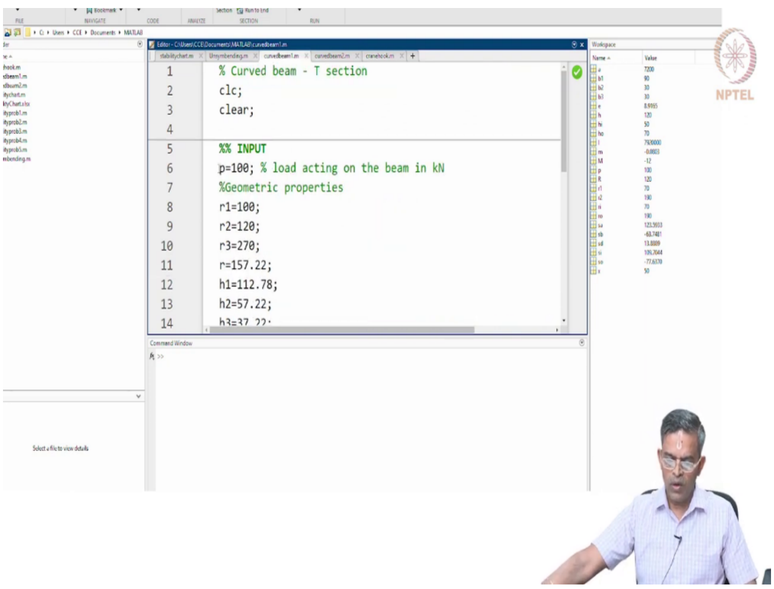

So, now I am going to use a MATLAB program. So, the MATLAB program is shown on the screen for you. It is a T section. We know we are going to apply a load of 100. Please look at these values. You can very well see from the figure r_1 is 100, I will just mark it here. r_1 is 100, r_2 is 120 and r_3 is 270; radius is 157.22 we already computed that.

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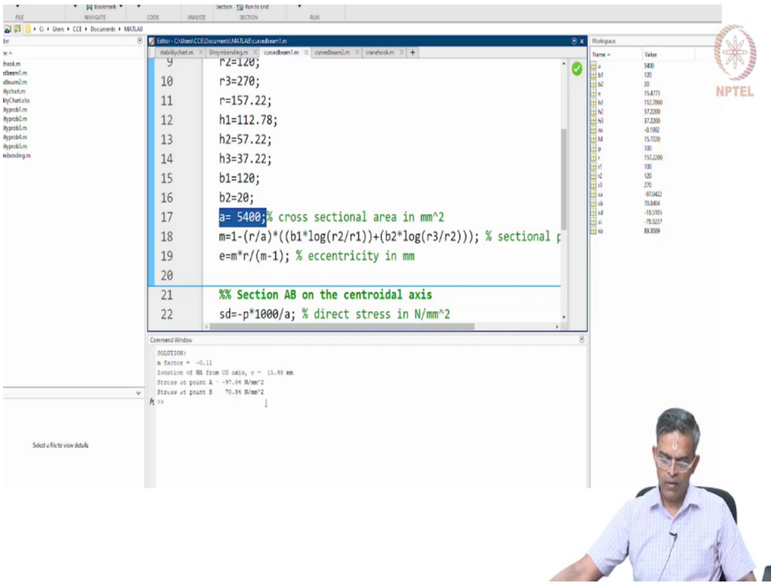

And, h intrados and h extrados has been also plotted and b_1 and b_2 are given, and area is now input. So, we wrote the equation. Now, we run this program and copy these values and take it back to our screen. I will plot these values and take it back to our screen these are the values I have let me mark it here. Let me bring it down here.

You know friends we have m value as minus 0.11, let us see what m value we have minus 0.11. So, we had e values 15.48 we have 15.453 it is and stress at point intrados is 97 compressive 97 and extrados 70, you have 70. So, the program is easy to run the Winkler Bach equation and get to the stresses in the intrados and extrados of this curved beam.

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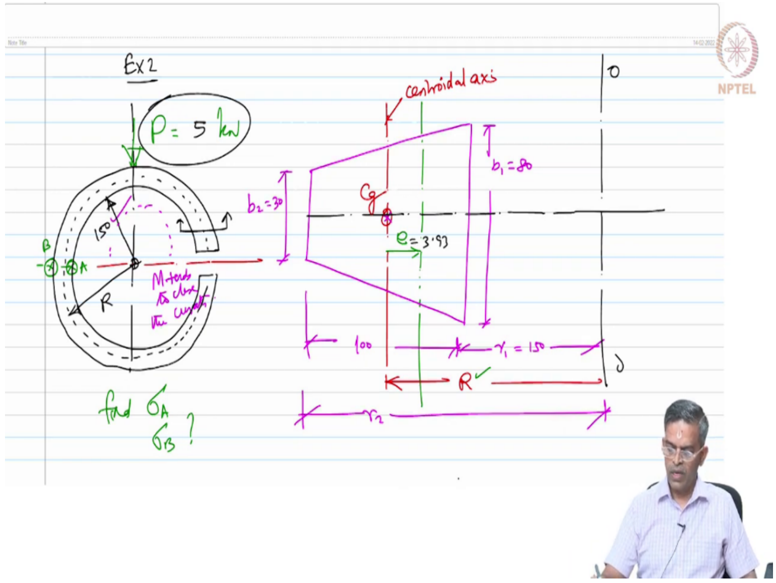

Let us do one more problem on a curved beam. We will say example 2. Let us say we have again a curved beam, but the cross section is different in this case. I will copy this curved beam. Take a selection tool copy this curved beam, but the load is 5 kN and this value is 150. The cross-section I am drawing here which is going to be this is my plane of reference which is O, O. This value is b_1 which is 80 mm and this value is b_2 which is 30.

Now, let us say the depth of the section is 100 mm. The section has a centroidal axis which is at a distance R from the plane of reference which we do not know. We have to compute that this the section also has the neutral axis. We assume that shifted towards the center and we know this shift is e, if it is positive.

Let us also mark these values. So, this is r_1 which is 150 as given in the figure see here and this is r_2 from here with r_1 plus the depth of the section b_1, b_2 all data are available to us. Now, this is my Cg. So, we want to find the stresses at the intrados and extrados, let us mark the points. So, I want to get the stresses at two positions intrados is A, extrados is B. I say we want stresses at. So, find stress at A and stress at B.

So, since it is a curved beam I cannot use a standard theory for bending, I have to use a Winkler Bach equation. I will use that use a MATLAB program and try to solve this. Let us do that. So, with this data I will directly take you to the MATLAB program, let us see what are the inputs we want. So, one can find the x bar value I think that I leave it as an exercise. You should be able to get the R value.

Simply using the first principles you should be able to get or locate the centroidal axis and you should be able to get the R value.

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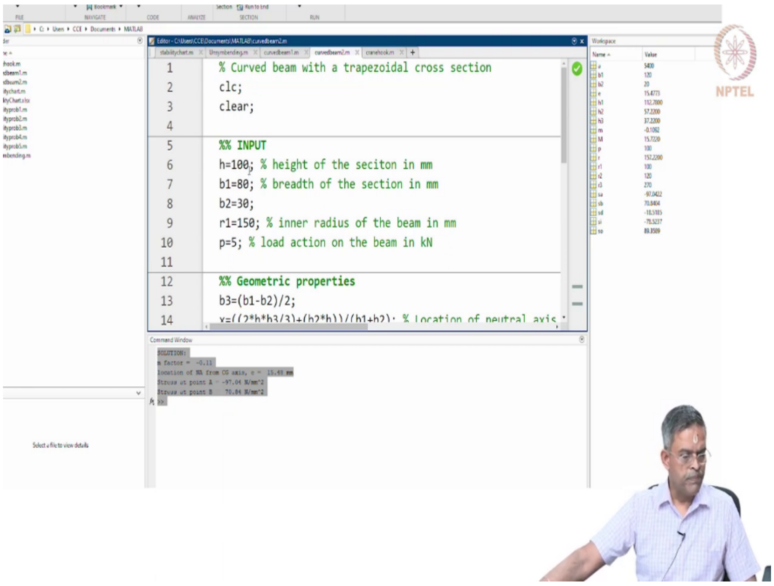

Let us take you directly to the MATLAB program. So, as you see from the figure height of the section is 100 mm. b_1 is 80 and b_2 is 30, r_1 is 150 and p is 5 kN.

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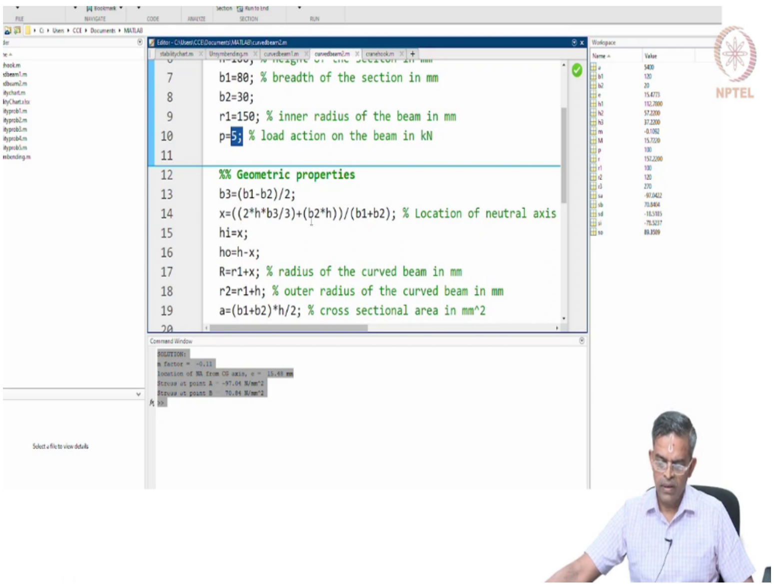

So, for the geometric property you can calculate the neutral axis and the centroidal axis, I will run the program. So, I get m as 0.02 and 3.93. I will copy this value directly put it here.

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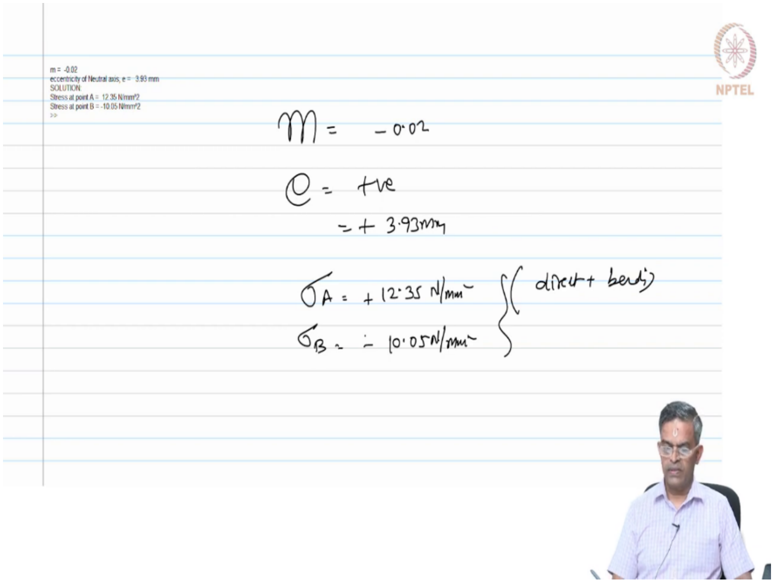

$$m = -0.02$$

$$e = +ve$$

$$e = +3.93 mm$$

$$\sigma_A = +12.35 \frac{N}{mm^2}$$

$$\sigma_B = -10.05 \frac{N}{mm^2}$$

So, friends m is obtained directly from the program as 0.02 negative, e is taken as positive which is plus 3.93 mm. It means this is shifted towards the center of curvature. After we got this, we apply the equation and get stress at intrados is 12.35 and stress at extrados is 10.05. Let us see.

Now, when I apply, I get these values the net stress compressive. this will be sum of this will be sum of direct stress plus bending stress. So, I get here as plus and minus as a final result. So, easily one can use the MATLAB program directly with the input available and try to find the stresses in these sections.

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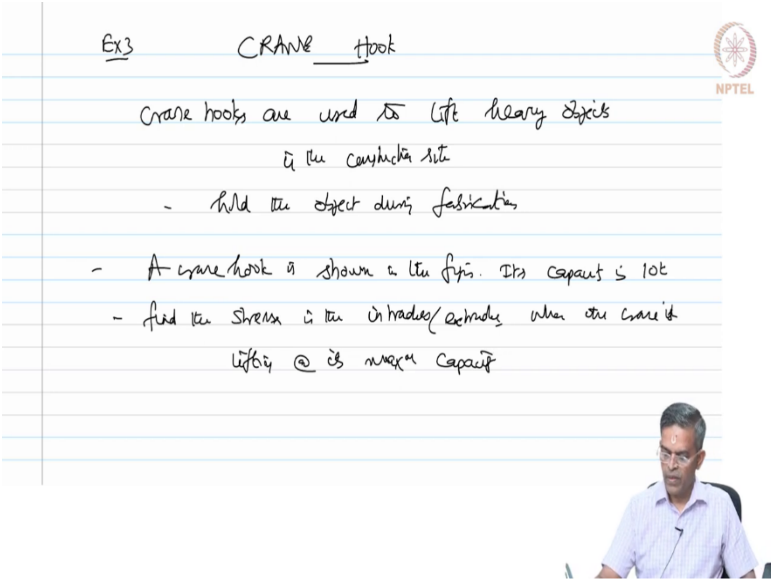

We will take one more problem which is now on the crane hook. Crane hook is also considered as a standard curved beam which can be used for various purposes crane hooks are actually used to lift heavy objects, in the construction site. They are also useful to hold the object during fabrication. Friends, in many circumstances choosing an appropriate crane capacity itself is a big challenge.

If you use a wrong crane capacity and try to lift a job or an object what they call as a job there can be fracture initiated in the crane hook which can cause a permanent damage to the crane hook. So, it is very important for us to know how to compute the stresses in a crane hook for a given lift of a job load. So, let us say a crane hook is shown in the figure its capacity is 10 tons. Find the stresses in the intrados and extrados when the crane is lifting at its maximum capacity.

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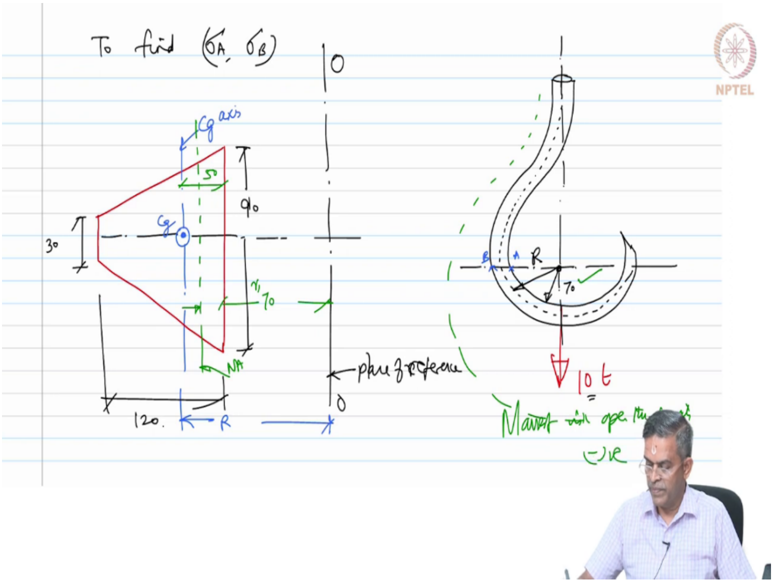

Let us see what is the cross-section of the hook. The crane hook is like this I am just drawing the figure we will do this later. from here this radius is 70 let us also mark the center line of this that is where R will be marked. It is now subjected to a load of 10 tons that is what is going to lift. The points are these two A and B. We want to find the stresses at A and B which happens to be the intrados and extrados of this crane hook.

Let us see the cross-section of the crane hook. Let us draw the plane of reference. So, this dimension is 90. This dimension is 30 and depth of the section is 120. Let us say it has got a centroidal axis and the neutral axis. the centroidal axis is at a distance R from the plane of reference and the shift of the neutral axis from the centroidal axis is taken as e towards the center of curvature. Now, we want to locate the C g. We call this as we copy this figure, we will copy this figure.

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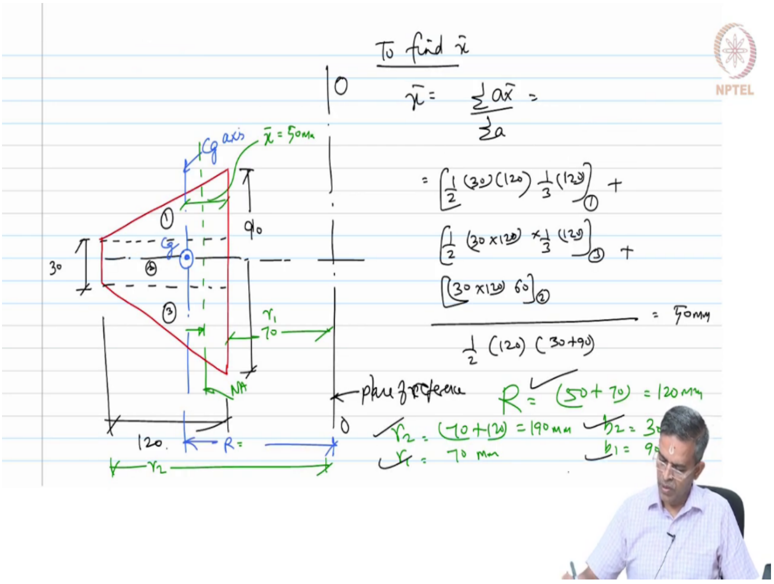

Let us say we want to locate this distance. We call this distance as $\overline{x}$. So, I want to find $\overline{x}$. I can say x bar is sigma a x bar by sigma a which will be I will divide this into triangle and this way. So, I will call piece number 1, piece number 2 and piece number 3. We will say which will be half into base into height into one third of height or piece number 1; half into base into height into one third of height this is for piece number 3; plus, the rectangle which is 30 into 120 into 60, this is for piece number 2 divided by the whole area half h a plus b I get x bar as 50.

So, I have this value as 50 mm. So, R is now you know this value from the figure is 70, this is r 1 is given. So, if I say this is 50, then I can say R as because this is 70; 50 plus 70 which is 120 mm. Now, this becomes my r_1, this becomes my r_2 and r_2 will be now equal to 70 plus 120 which is 190. So, r_1 is 70 and of course, b_2 is 30 and b_1 is 90.

$$\overline{x} = \frac{\Sigma a\overline{x}}{\Sigma a}$$

$$\overline{x} = \frac{\left(\frac{1}{2}\times(30\times120)\times\frac{1}{3}\times(120)\right)_1+\left(\frac{1}{2}\times(30\times120)\times\frac{1}{3}\times(120)\right)_3+((30\times120)\times60)_2}{\frac{1}{2}(120)(30+90)}$$

$$\overline{x} = 50mm$$

$$R = 50 + 70 = 120mm$$

$$r_2 = (70 + 120) = 190mm$$

$$r_1 = 70mm$$

$$b_1 = 90mm$$

$$b_2 = 30mm$$

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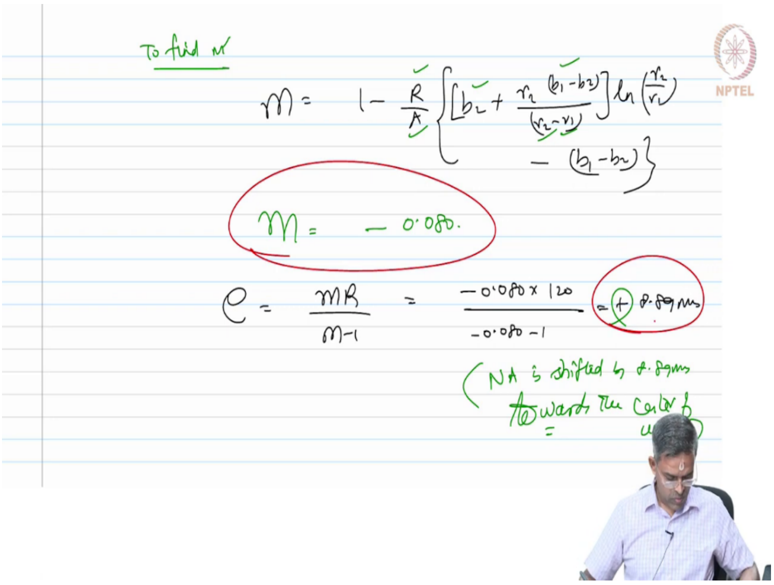

Now, let us write the equation to find the modified factor m; m is given by

$$m = 1 - \frac{R}{A}\left[b_2 + \left(\frac{r_2(b_1-b_2)}{r_2-r_1}\right)ln\left(\frac{r_2}{r_1}\right) - \left(b_1 - b_2\right)\right]$$

$$m =- 0.08$$

$$e = \frac{mR}{m-1} = \frac{-0.080\times120}{-0.080-1} =+ 8.89mm$$

We have this equation derived; you can check that minus $b_1 - b_2$. Let us substitute for all the values we already have the values here R we have, r_1, r_2, b_1, b_2 we have. So, we have R, we have b_2, we have b_1, we have r_2, r_1 and we have area also.

We substitute m will become minus 0.080 and we know e is given by mR by m minus 1. So, minus 0.080 into 120 divided by 0.080 minus 1 which I get plus 8.89 mm which says that the neutral axis is shifted by 8.89 mm towards the center of curvature. How can I say towards? Because it is positive.

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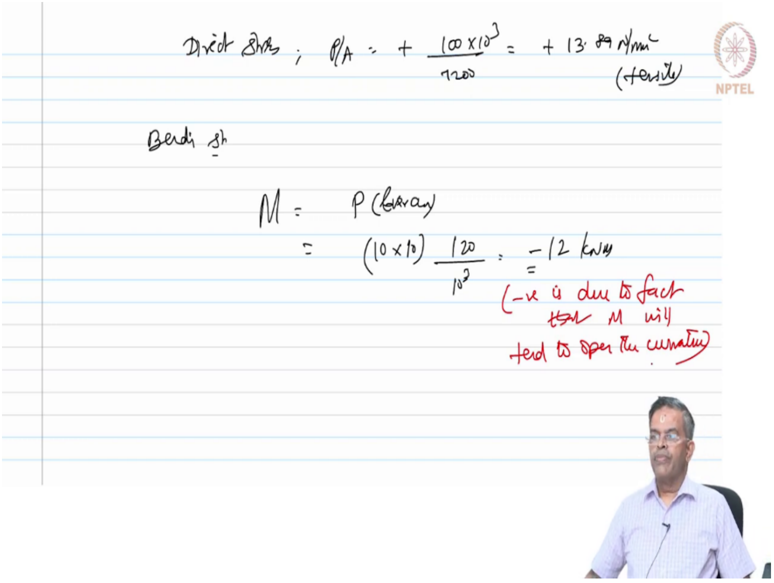

Having said this, let us find the direct stress which is P by A which is. You can see very carefully here friends this will try to create a tensile stress. So, the direct stress will be tensile plus 100 into 10 power 3 by 7200 that is the area we get plus 13.89 which is tensile. Now, I want to find the bending stress. So, let me find the moment which will be P into lever arm.

$$\frac{P}{A} = \frac{+100\times10^{3}}{7200} =+ \ 13.89\frac{N}{mm^{2}}$$

$$M \ = \ PR \ = (10\times10)\frac{120}{10^{3}} =- \ 12kNm$$

Now, look at this figure P will have a tendency to open. Moment will open the curvature. When you apply this, I will try to open the curvature node. So, it is negative. So, M will be now equal to 10 into 10 power 3 is 110 tons. So, 10 into 10; so, I get so many kN into 120 that is my R value divided by 1000 which will be minus 12 kNm. This negative is due to fact that M will tend to open the curvature.

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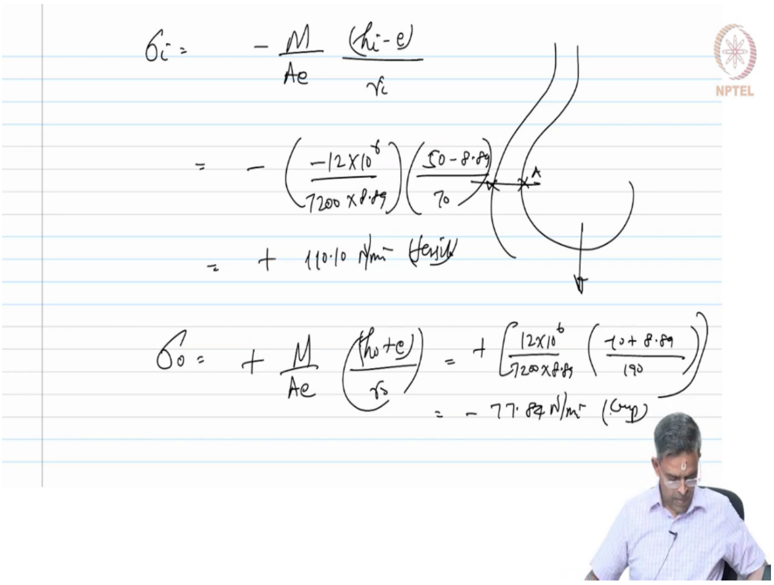

So, now we can run the MATLAB program and find the stresses sigma i will be minus M by A. How can we say that let us say I have a hook pulling I have this intrados A. So, intrados will be subjected to tensile and extrados should be compressive is it not because it is going to pull.

$$\left(\sigma_b\right)_{intrados} = -\frac{M}{Ae}\frac{\left(h_i - e\right)}{r_i}$$

$$\left(\sigma_b\right)_{intrados} = -\frac{\left(-12\times10^6\right)}{7200\times8.89}\frac{(50-8.89)}{70} = +\ 110.10\frac{N}{mm^2}$$

$$\left(\sigma_b\right)_{outrados} = +\frac{M}{Ae}\frac{\left(h_0 - e\right)}{r_0}$$

$$\left(\sigma_b\right)_{outrados} = +\frac{\left(12\times10^6\right)}{7200\times8.89}\frac{(70+8.89)}{190} = -\ 77.84\frac{N}{mm^2}$$

So, my M by A e h_i minus e by r_i which will be minus of minus 12 10 power 6 by 7200 into 8.89 into 50 minus 8.89 by r_i which is 70 which will give plus 110.10 tensile sigma extrados will be plus m by A e h_o plus e by r_o in my case going to be plus times of 12 10 power 6 by 7200 0 8.89 into 70 plus 8.89 divided by 190. I get this value as minus 77.84 compressive.

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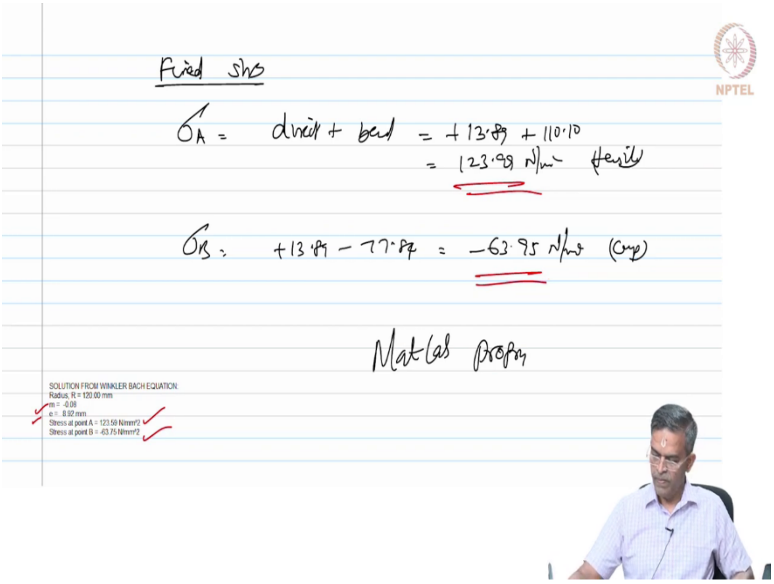

$$\sigma_A = \sigma_{direct} + \sigma_{bending} = + 13.89 + 110.10 = 123.99 \frac{N}{mm^2}$$

$$\sigma_b = \sigma_{direct} + \sigma_{bending} = + 13.89 - 77.84 = - 63.95 \frac{N}{mm^2}$$

Now, the final stresses sigma A will be direct plus bending; direct was plus 13.89 and bending was 110.1 which gets 123.99 which is tensile in the intrados. In the extrados this is plus 13.89 minus 77.84 which will be 63.95 which is compressive.

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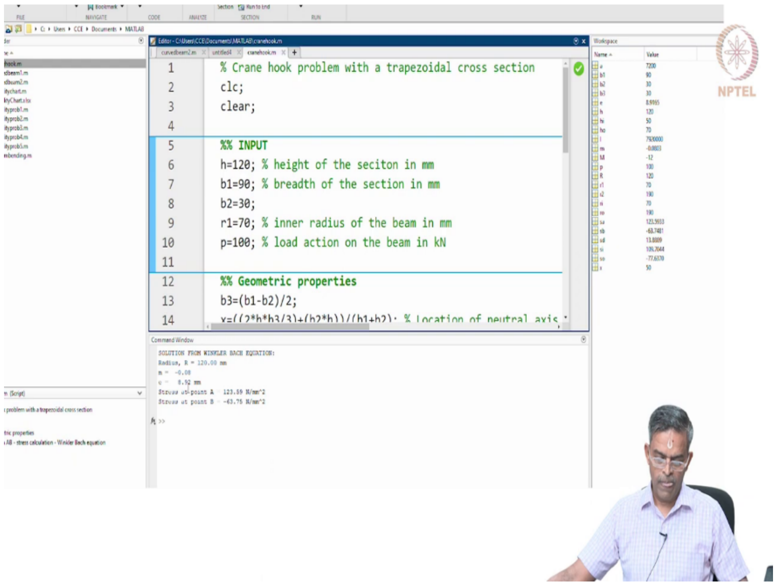

We can also run a quickly a MATLAB program for this. I will show it on the screen. Look at the MATLAB program. The load is in kilo newton. So, it is 10 ton. So, it is 100 kilo newton and we have given the values h 1, h 2 I mean h 1 is the depth of section b_1, b_2, r_1 and this let us run the program. So, I get I will just copy these values take it back to my screen you will see my m value is minus 0.08.

Let us see how do we how much did we get minus 0.08 and this e value is plus 8.92, e got plus 8.92 then we have the final stresses at A is 123 and at B is minus 63.

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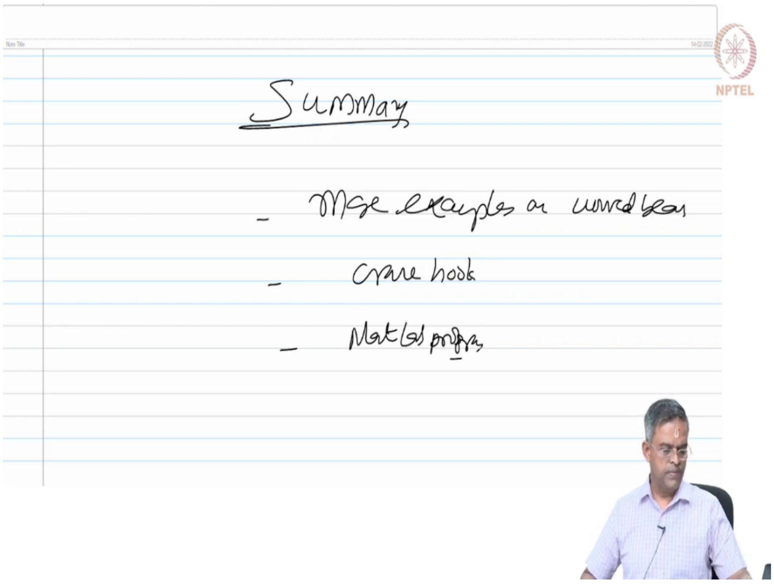

So, friends we understood in this lecture more examples on curved beams. We also solved a problem on a crane hook. We have used MATLAB program to solve these problems and understood the stress nature generated intrados and extrados of a given crane hook for a given kind of load.

So, this would be very interesting friends in curved beam examples where we have got proving rings, we have got crane hooks where a mechanical engineer or a structural engineer is supposed to check the stress across the cross-section of the crane hook or the proving ring before is subjected in a specific kind of lift job. So, this lectures will be helpful for you to do a preliminary study and try to get the stresses on the sections at (Refer Time: 45:10) points for a given load before it is put to the job work.

Thank you very much and have a good day.