Design of Connections in Steel Structures
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Module - 3
Lecture - 15
Design Example of a Weld Group

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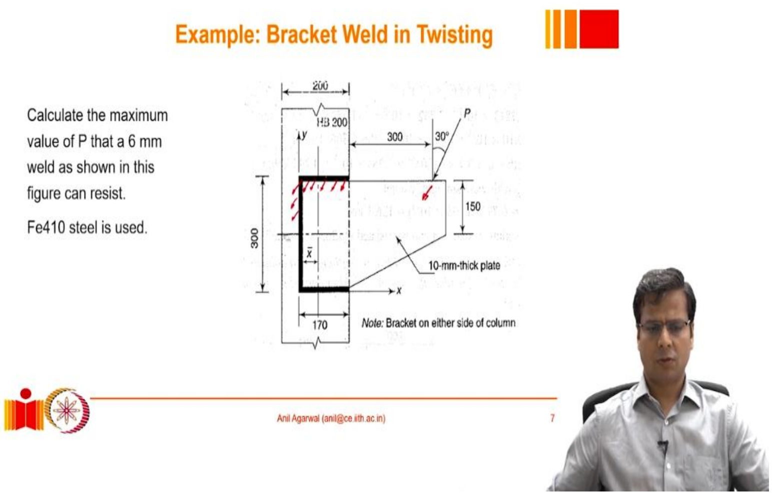

So, we just did an example where we had to solve the problem of a bolt group where a number of bolts were subjected to a force which was introducing a torsional effect on the bolts. Since the bolts individually cannot resist any torsion, the lever arm between the bolts was able to resist that torsion, the twisting moment. And we solved that problem and we found out how to calculate the forces in the individual bolts for a given twisting moment.

Now, a similar kind of a problem can be also addressed by using welds. So, similar kind of structure is shown here. Here, you have a column and a bracket. The bracket is supported by the column. And the bracket is resisting a load which is acting at this location P at an angle 60 degree again from the horizontal. And this time, the bracket is welded to the column rather than bolted. And this weld this time is not a symmetric weld.

Even if it was symmetric, still there are issues associated with the situation of, with the configuration of this bolt. That we will take a look at. So, just a few more details that I would want to emphasise. The problem statement is that we need to calculate the maximum value of

P that is 6 millimetre weld as shown in this figure can resist. So, we need to find out what is the maximum P value that this weld can resist safely.

The steel that is used is Fe 410. So, its ultimate stress is 410 MPa. The weld dimensions are mentioned. The horizontal portion of this weld is 170 millimetre. This is a fillet weld and the vertical component of this weld is 300 millimetres to 1 vertical leg and 2 horizontal legs. And the plate thickness is given as 10 millimetres. We need not check all that because 6 millimetre weld is provided; that is already given to us.

The load, the point where the load is acting is 300 millimetres away from this edge of the weld. And also the weld length is 300 millimetres and that is exactly the same height where the load is acting. So, in this thing, let me just mention that we will call 300 as d, small d, and 170 as small p. So, this is a rather interesting configuration if you see, but this is a very common one.

What would happen is that, because of the load, the way it is acting, it will introduce a direct stress like it did for the bolt group. So, because of this force that is acting here, every portion of the weld will be subjected to this kind of a force demand. So, there will be a force that will be acting because of this. And assuming that this bracket plate is very stiff, we can make a deduction that, if the plate is stiff, the different portions of this weld will be deforming by the same amount.

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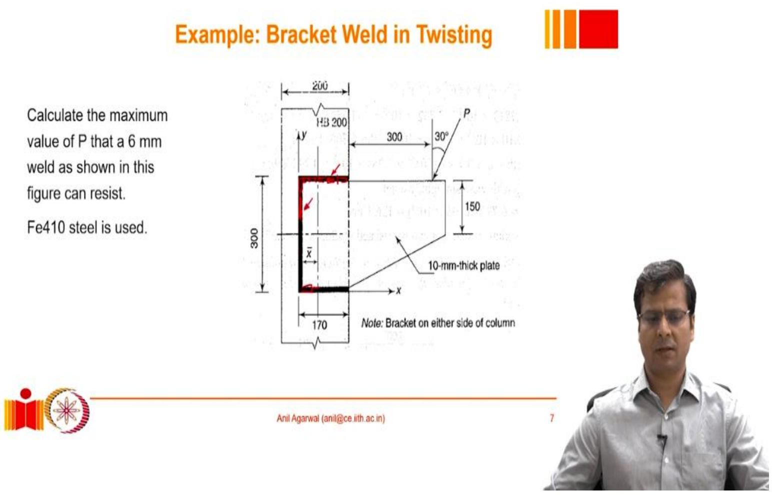

And also, another assumption that we can make is that all these small portions of these welds, if you can imagine in small segments, all those portions are having equal stiffness when they are subjected to this force. So, if every weld portion has equal stiffness irrespective of its orientation; so, this weld is in this orientation; this weld is in this orientation; but when subjected to this load, we are making an assumption that they all have the same stiffness. We will get into that point where this assumption is not really true. But for the time being, we are making that assumption.

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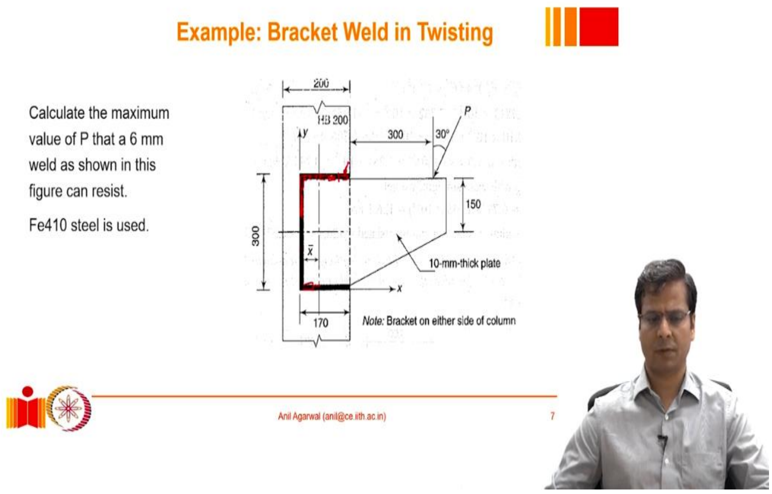

And with that assumption, we can calculate what is the actual, what is the direct effect of this force.

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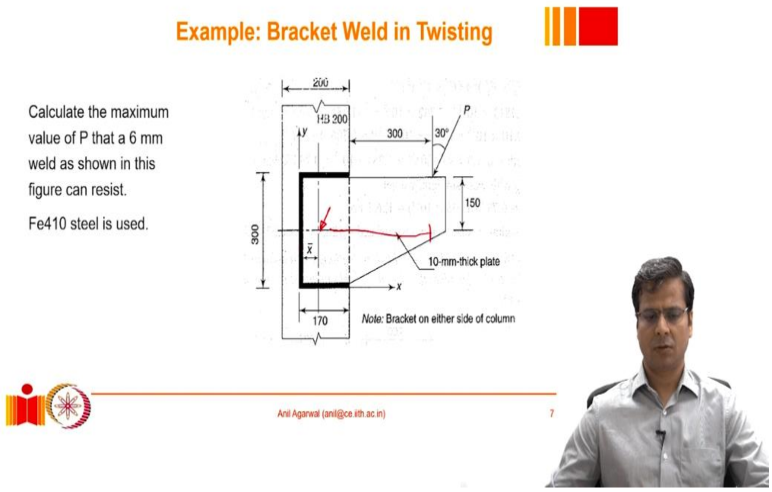

However, that would have been the resistance or that would have been the stress had this force been acting actually at the centroid of this weld group. But this force is not actually acting here, but it is acting at an eccentricity which is this much here. So, this eccentricity we need to calculate. How much is this eccentricity?

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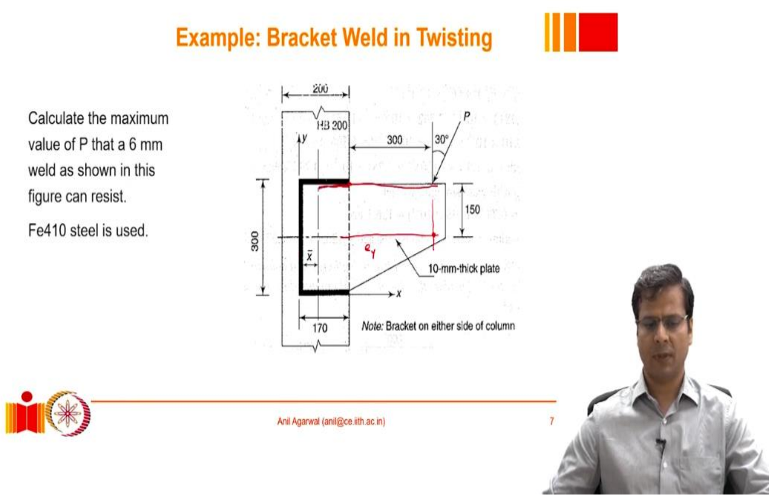

The eccentricity in this direction, in the x direction which is relevant for the vertical component of the force, we will call it e_y. This is equal to 300 millimetres here; and the distance of the centroid from this edge, that is added together. So, that is your eccentricity. That is relevant for the y component of the force.

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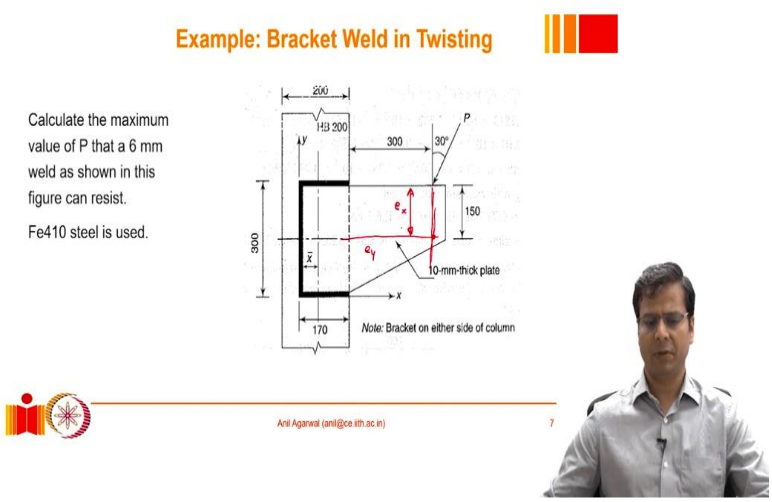

We will call it e_y even though it is in the x direction. Likewise, the eccentricity which is to be multiplied with the horizontal force will be this distance, and we will call it e_x. So, we will be using these two quantities later on. Now, what happens is that, because of this force, the way it is acting, it introduces this moment.

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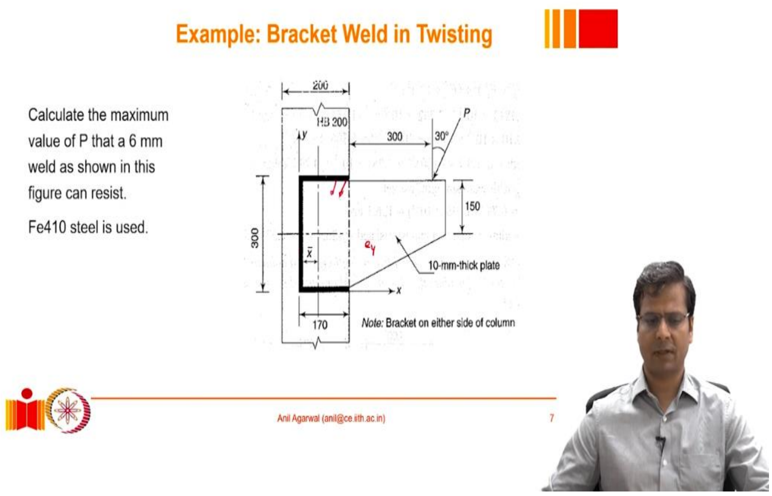

So, other than this direct force effect, it also has a moment effect.

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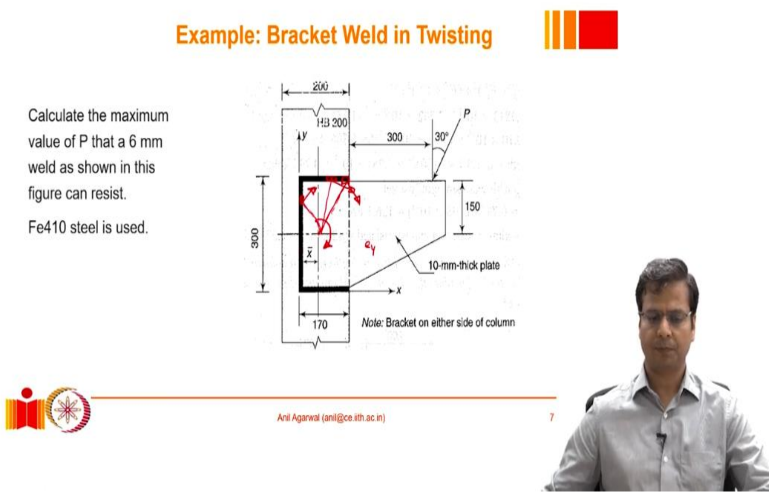

This moment is basically making this weld twist this way. So, this is kind of a twisting action. And again, like in the previous case, individual portion of the weld; let us say there is a small portion of the weld here, and its radial distance is marked here in this line. So, there is a force demand on this weld which is perpendicular to this radial line. And this force direction keeps changing for every weld segment.

So, let me take a segment here. Its radial line is in this direction. So, the force because of the twisting moment will be in this direction and so on. So, they will be all resisting the force, the twisting in these respective directions by applying a force in these directions, and we need to account for all of that. Now, this is obviously twisting situation.

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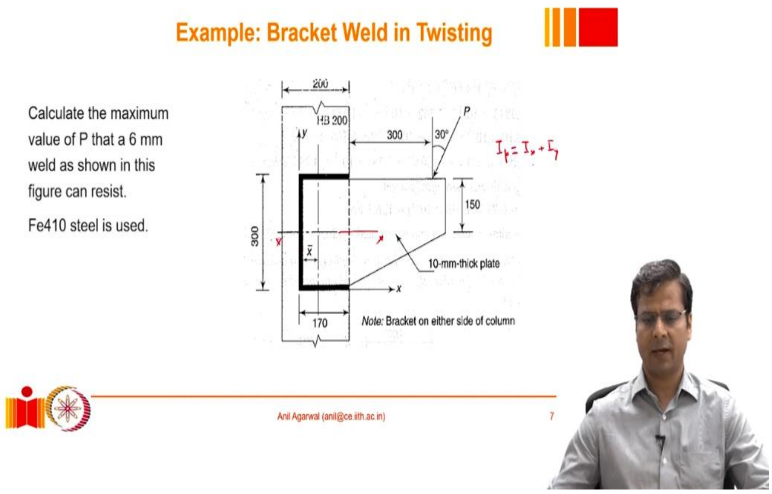

So, we know that the inertia against twisting is basically known as polar moment of inertia, I_p, which is equal to $I_x + I_y$. Wherein, I_x and I_y would be; if we calculate the moment of inertia about this horizontal axis, we can call it I_x; and if we calculate the moment of inertia about the vertical axis; so, we need to calculate the neutral axis in x direction and y direction. And when we calculate the moment of inertia about these 2 axes, we add them together and we get I_p, polar moment of inertia. So, that is one quantity that we will have to utilise.

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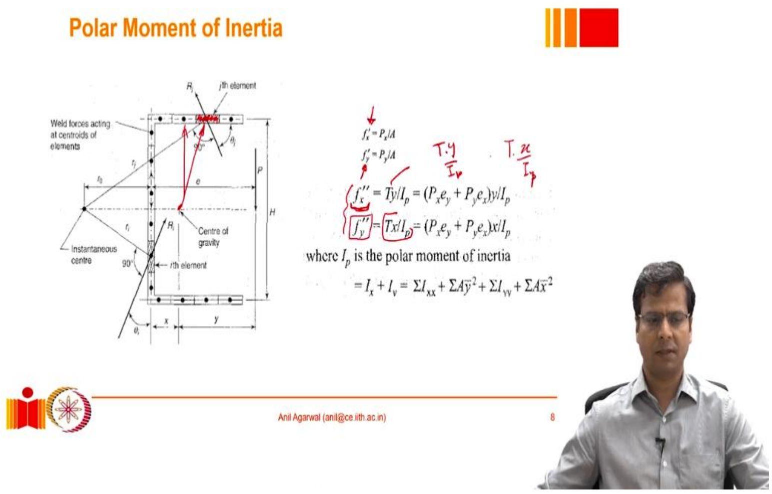

So, basically, the idea is that first we would calculate the direct stress. f'_x and f'_y basically represent the direct stresses, which are all parallel to each other because they are parallel to the direction of the force. In addition to that, there is another component of f_x and f_y which arises out of the effect of the twisting. So, the stress in any component; if we take a small component, the stress because of twisting in this component will be equal to the twisting moment T multiplied by the distance, the radial distance.

So, here when I say y, I mean the vertical component of the radial distance T multiplied by y divided by the I_p value. Similarly, this is the x component of that force; the y component of the force will be T multiplied by x divided by I_p, which is written here. So, this is the vertical component of the force which is resisting the twisting moment. And if we can calculate the total twisting action, we can calculate these values as well.

So, that is the basic philosophy that we will follow. And again, like in the previous case, the entire weld will not be subjected to same amount of force. So, different portions of the weld will be at different level of stress, and we need to identify the area which is under the highest stress and then design for that. The rest of it can be automatically considered to be safe. The calculation of I_p may not be always very straightforward. Sometimes, depending on the geometry, it can be slightly complex; we have to calculate I_x and I_y. We can calculate it ourselves, but also there are some guides available to us.

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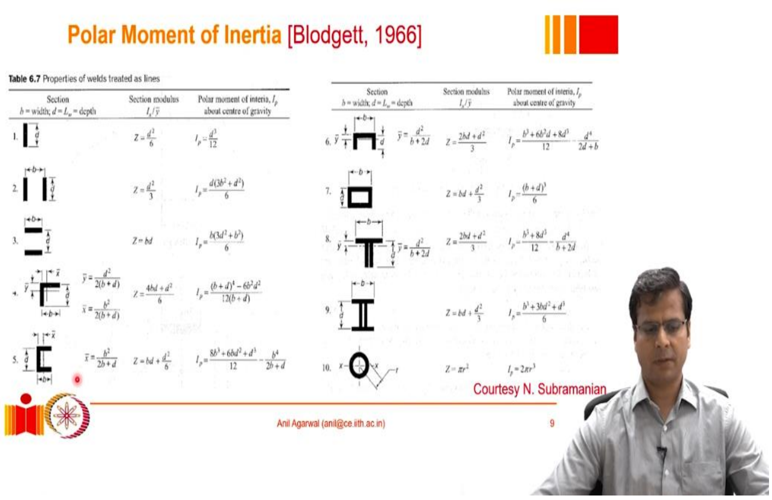

So, there is this table which was developed by this author in 1966. I have taken this table from the textbook, that is Doctor N. Subramanian's book. For different commonly used weld shapes, weld geometries, it provides you the location of the neutral axis if it is not obvious, if it is not symmetric, and also the polar moment of inertia at section modulus as well. So, we can utilise these to calculate some of these critical properties.

So, the section, the shape that we are talking about resembles this one, number 5 here. So, this is how our weld shape was. So, b was the width of the base, the bottom weld which was 170 millimetre and d was the depth of the weld. The neutral axis distance $\bar{x}$ for the vertical neutral axis is given as $b^2/(2b + d)$. And the polar moment of inertia I_p for this entire weld is given by this expression, which is basically again a function of b and d values, which we understand what it is. So, we will use this expression.

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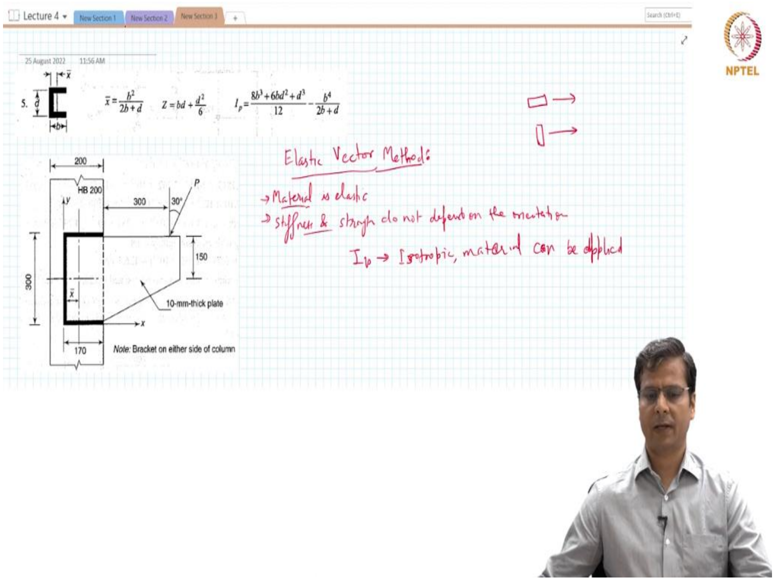

So, we will go step by step to calculate the strength of this weld and calculate how much is the maximum force this weld can resist. By the way, the method that we have just discussed is known as elastic vector method. And we will get to the assumptions here and what are the drawbacks of this approach. So, one assumption here is that we are assuming that material is elastic throughout.

Other assumption is that the stiffness and strength; when I say material, I mean weld material; and strength do not depend on the orientation. So, therefore, the idea of I_p which was developed for isotropic material can be applied. The moment of inertia's concept can be applied directly only with these assumptions, if we assume that stiffness and strength do not depend on that orientation. What do I mean?

As we had seen in the beginning for fillet welds, if the force is applied in this direction, we call it an edge fillet; but if the force is applied on a fillet in this direction, then it is called an end fillet. And the strength and stiffness values are very different between the two. However, in this particular case, we are assuming that all of these welds perform exactly the same. And with that assumption, we can do this kind of an analysis.

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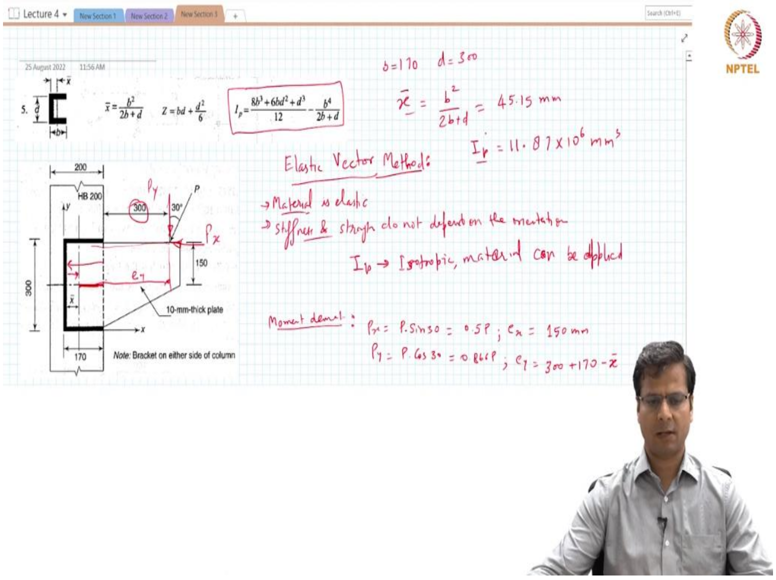

So, first thing that we will do is that we will calculate the value of $\bar{x}$ which is given by b square divided by 2b + d. We know that b = 170 and d = 300. Now, we substitute these values. And what we get is, this value turns out to be 45.15 millimetres. And also we can calculate the I_p value. For us to be able to calculate the I_p value, we will substitute the respective values in this expression.

So, when we substitute these values, we get I_p as 11.87 x 10^6 millimetre cube. So, this is the polar moment of inertia and this is the location of the neutral axis. Now, like before, first we need to calculate the moment demand. So, moment demand, earlier what we had done was, we had taken the force and we had tried to calculate the distance of the eccentricity with respect to that total force.

This time, we will do it slightly differently. Either approach is fine, but this time let us try it slightly differently, just to showcase that there are 2 ways to do it. We will take a P_x component, and then we will take a P_y component. And then we will calculate the eccentricity for P_x separately and we will calculate the eccentricity for P_y separately. That might make some calculations relatively cleaner even though it may take slightly more time.

So, the P_x component can be calculated as P multiplied by sin(30) and P_y component can be calculated as P multiplied by cos(30). Both of them will be equal to; the first one will be 0.5P and this one will be equal to 0.866P. So, we have calculated the 2 components. Now, we can calculate the eccentricity in each direction. So, eccentricity e_x; now e_x is the eccentricity which needs to be multiplied with P_x.

So, this is the eccentricity e_x, even though it is in y direction. So, e_x is equal to 150 millimetres from the centroid of the weld to the load. And e_y will be the eccentricity from here to the point of loading; this is e_y. How much is that? This is basically equal to this distance 300 millimetres plus this distance. And how much is it? This distance is basically equal to 170 - $\bar{x}$. So, we will call it 300 + 170 - $\bar{x}$.

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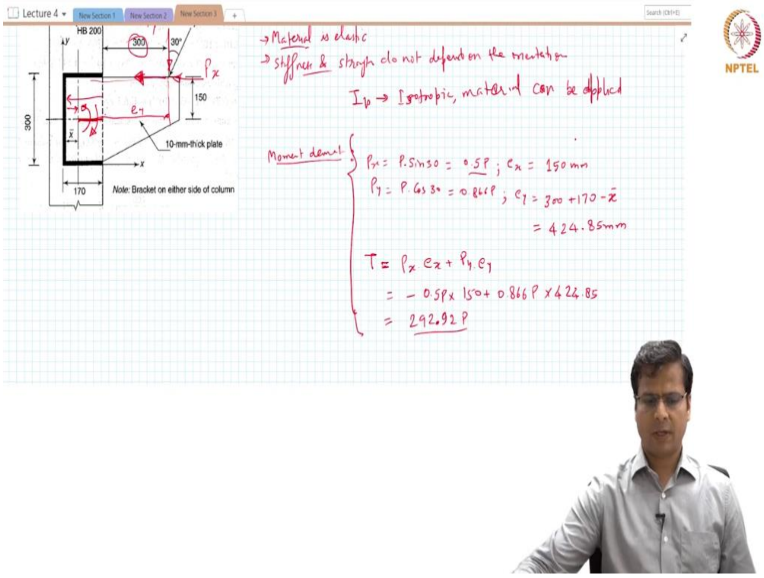

Which turns out to be; and we had calculated the $\bar{x}$ value. $\bar{x}$ was calculated as 45.15. So, we substitute that here. And what we get is 424.85 millimetres as the e_y value. Now, all this calculation is being done to calculate the moment demand. The twisting moment now can be calculated as P_x x e_x + P_y x e_y. So, P_x is known as 0.5P. And P we do not know yet, so, we will keep the P term as unknown. 0.5P multiplied by 150.

Also be mindful that this will have a moment in this direction which will have an anti-clockwise effect, and P_y will have a clockwise effect. So, anti-clockwise and clockwise, let us calculate T in clockwise direction. Therefore, we will put -0.5P multiplied by 150 plus 0.866P multiplied by 424.85, which will be equal to 292.92P. This many, if P is in newtons, this many newton millimetres. So, that is that twisting moment demand. Now, we can take the next step and calculate the actual stresses or actual forces in each segment.

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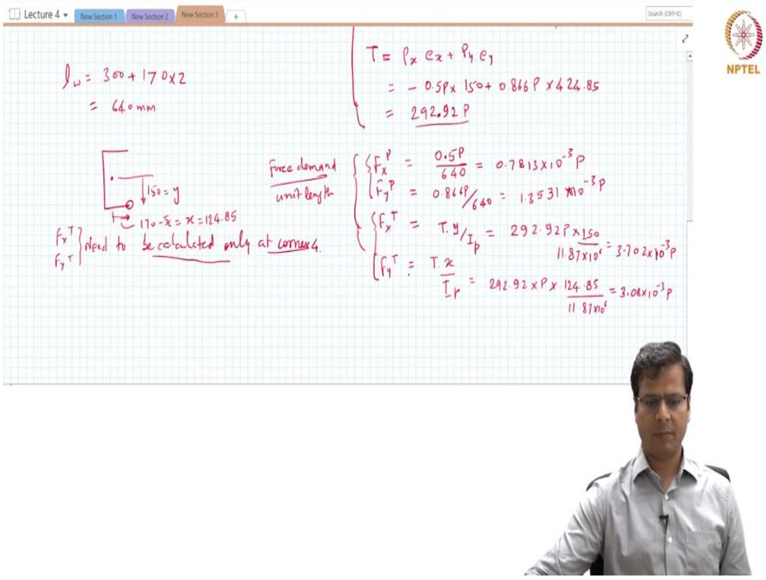

So, force demand over unit length. So, first we can calculate the F_x because of the applied force directly and F_y because of the applied force directly. Then we can calculate F_x because of the twisting moment and F_y because of the twisting moment. So, F_x because of the applied force directly will be very simple. We will have F_x which is, total force is 0.5P. That is, 0.5P is marked here.

So, that is the total force in x direction divided by the length of the weld. What is the length of the weld? l_w = 300, that is the vertical leg, plus 170 multiplied by 2, which turns out to be 640 millimetres. So, we will divide by 640 here. And which turns out to be 0.7813 multiplied by 10^{-3} P. Likewise, F_y P will be equal to 0.866P which was the total force divided by 640, and that is 1.3531x10^{-3} P.

If you want to calculate the force per unit length because of the twisting moment; the approach we would have to use is first twisting moment multiplied by, if we are calculating F_x, then we have to take the distance y divided by I_p. Now, these 2 forces, F_x because of P and F_y because of P, they were uniform throughout the length of the weld because we had made this assumption wherein we have said that the stiffness and orientation do not matter.

So, stiffness remains uniform throughout, irrespective of the orientation of the weld. So, distance and orientation did not matter because the P force was acting at the centroid. But actually, the P force is not acting at the centroid and there is a moment effect of that. Now, that moment, of course, the force will change, the force because of that moment will change because each weld is or each segment of the weld is at a different distance from the centroid.

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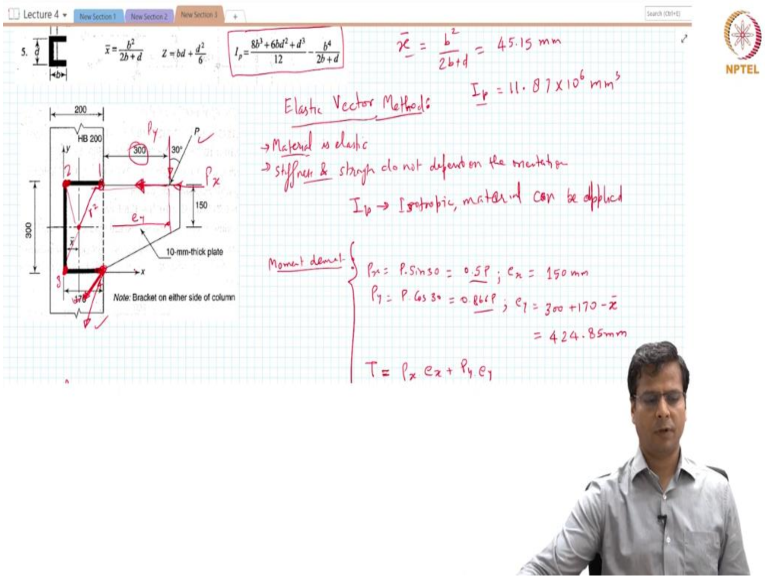

Just to emphasise, as we had mentioned, if this portion of the weld is at this distance from the centroid, it will contribute more towards resisting the moment. And its contribution towards resisting the twisting moment will be proportional to this distance squared. But the reason for that is, first, the force for a given rotation, the force in that segment will be proportional to the distance.

And in addition to that, the moment because of that force will again be proportional to the distance. So, because of that, this distance comes twice in the equation. So, now, we do not know, for each segment, the force value will be different. That is, the force that it applies to resist the moment, that will be different. So, for which segments should we look at? So, again, we know that corners will be the ones that are going to be critical from this point of view, because corners are the farthest apart locations.

So, we should actually be looking at the 4 corners, and one of those corners will be giving us the highest value. Now, between the 4 corners; let me call it corner 1, 2, 3 and 4; among these 4 corners, corner 4 and corner 1 are the farthest. So, they should be giving the highest force demand because of the moment. Corner 2 and 3 will give you slightly smaller force demand because of the moment.

In addition to that, also the resistance or the force because of the moment, because of the twisting at corner 4 is almost aligned with the force that is acting at corner 4 because of force P directly. So, again the same principle will apply, that we applied in the previous example. These 2 forces are almost parallel to each other. And therefore, the net contribution of these forces at corner 4 will be the highest. So, let us look at only corner 4.

Again, F_x^T and F_y^T need to be calculated only at corner 4. This would change if the orientation of the force changes. If the force is acting in some other direction, this location would change. But for this orientation, the way this force was applied, it should be corner 4 that should be the critical one. So, why we have to use y? Because we are talking about force in x direction. So, the moment will be F multiplied with y.

We substitute the values; the torque value or the twisting moment value was 292.92P multiplied by y; y is 150 for that corner 4. So, this corner is at a distance of 150 millimetre in y direction and at a distance of 170 minus $\bar{x}$ is equal to 124.85. That is the distance from the centroid. So, we substitute 150 for y, divided by I_p. I_p we had already calculated, which was equal to 11.87×10^6.

And this turns out to be 3.702×10^{-3}. Similarly, F_y^T can also be calculated. This is again equal to T multiplied by x divided by I_p. And that will be equal to 292.92 multiplied by P multiplied by 124.85 divided by 11.87×10^6. And this, in y direction, the force is 3.08×10^{-3}P. So, now, we have calculated F_x and F_y values because of the force P directly and because of the twisting moment. Now, total F_x can be calculated, total force can be calculated.

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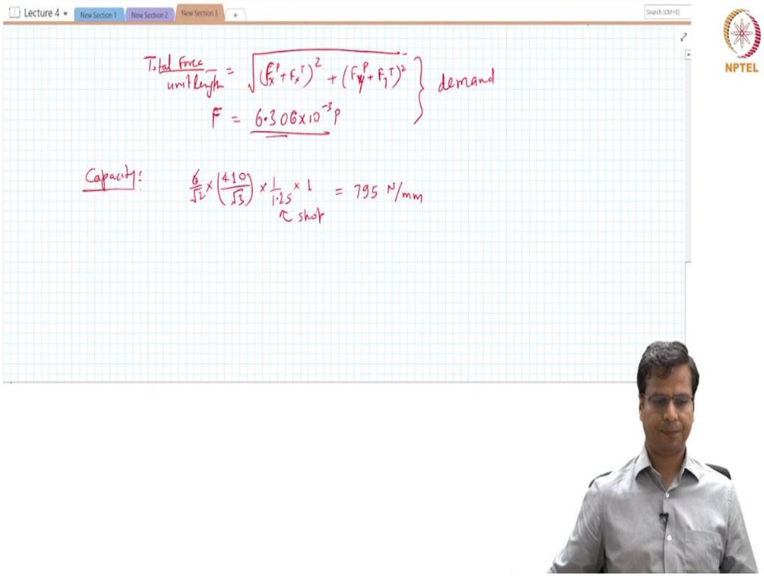

Force per unit length is equal to square root[($F_x^P + F_x^T$)^2 + ($F_y^P + F_y^T$)^2]. When we substitute the values, what we get is 6.306 x 10^{-3}. We have basically substituted these F_x and F_y values here. This is what we get. This is total F. And now what we need to do is; this is the demand for a given P; we need to calculate the capacity of the weld. So, it is given that it is a 6 millimetre fillet weld.

So, the capacity for this weld would be, if the weld size is 6 millimetre, its throat thickness would be 6 multiplied by or 6 divided by √2. Then, as per the Indian code, the strength is governed by f_u divided by √3. This is the material property that we would use, material strength. That is, f_u divided by √3; f_u is the ultimate stress of the parent material, and √3 is the factor for von Mises stress Divided by 1.25; this is the γ value to represent the shop welding of this thing. And multiplied by the l_w; l_w we are assuming unit for the time being. And this can be calculated as 795 newton per millimetre. So, this is the capacity of this weld per millimetre length, and the demand was this much.

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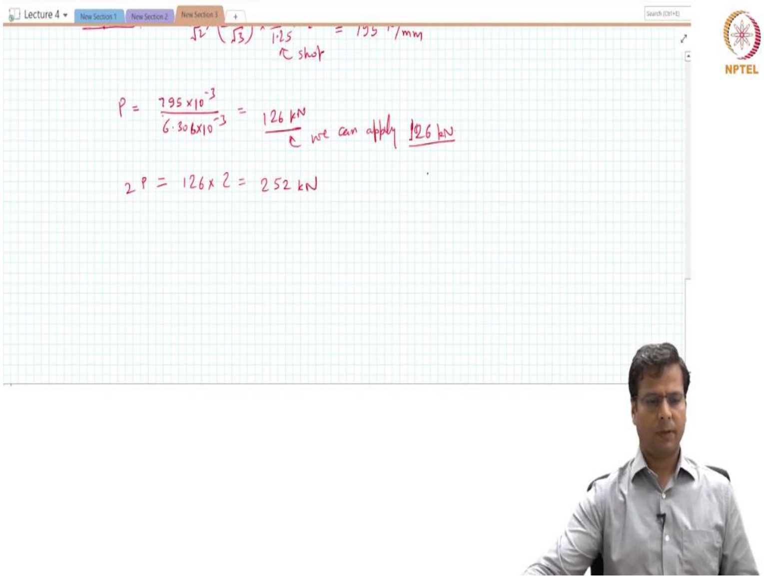

So, from this, when we equate the two, we can get P is equal to 795 x 10^{-3}. If we write this in kilonewtons, divided by 6.306 x10^{-3}. And this turns out to be 126 kilonewtons. So, basically what it means is that we can apply 126 kilonewton external load at that orientation to resist this load safely. Now, that is the capacity for a single plate.

It is also mentioned in this one, bracket on either side of the column. That means there are 2 such plates. So, if there are 2 plates, so, we will use 2P. So, therefore, 2P will be equal to 126 multiplied by 2, which is basically equal to 252 kilonewton.