Design of Connections in Steel Structures
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Module - 2
Lecture - 13
Design of Fillet Welds - 2

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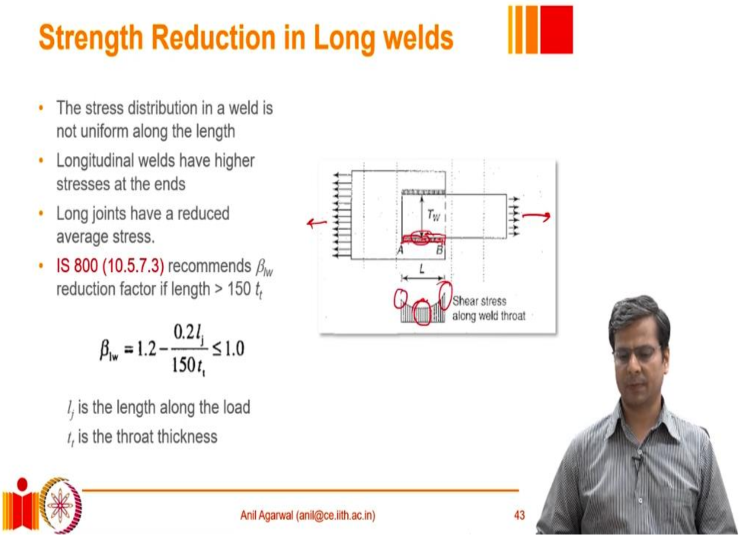

Also there are some challenges when we design welds. There are some other considerations that we have to keep in mind. If we provide a weld which is very long in comparison to its size, then we have to be mindful of the situation, which is shown here through this schematic also. So, here is the lap joint. You are pulling this plate in this direction and restraining the other plate in this direction.

And if we plot the stresses, the shear stresses in this weld, in the fillet weld, because of these forces, we could soon find out that at the edges, the edges of this weld resist much greater forces, but the middle portion does not resist as much of force. And because of that, the stress distribution in the entire weld is not uniform.

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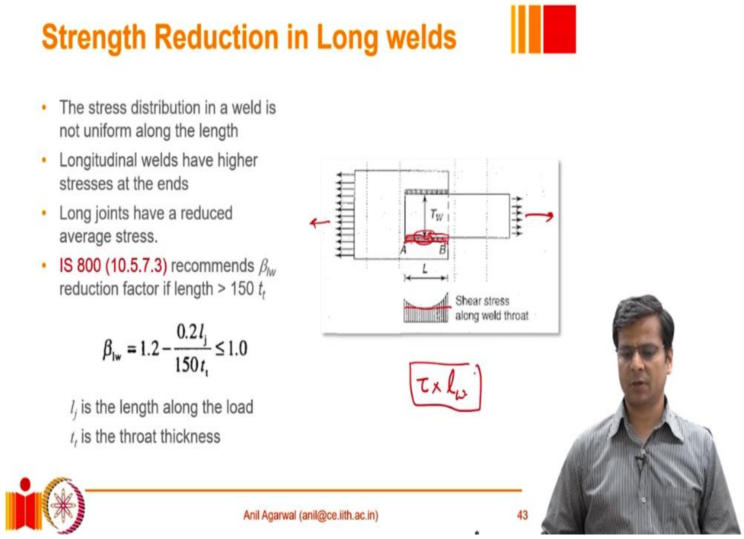

So, if we know that this weld has a particular strength, we cannot simply multiply it with the length of the weld and say that this is the strength of the entire weld, because the stresses will not be uniform, and we have to be careful.

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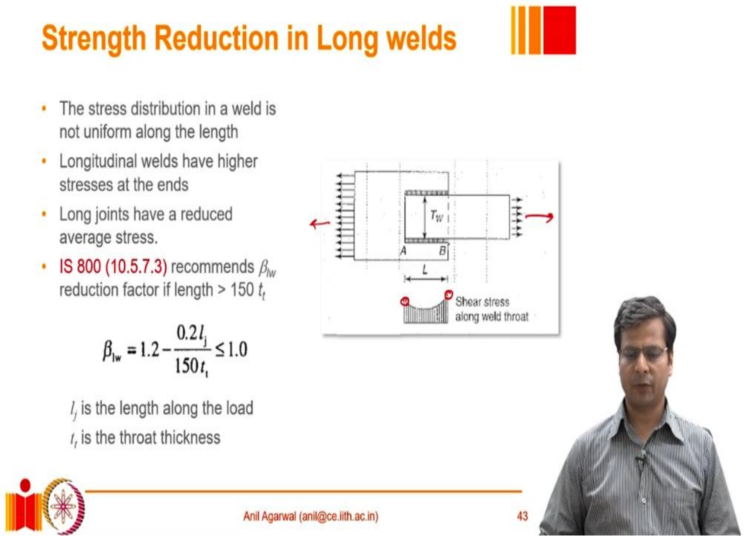

As soon as 1 portion of the weld starts to fail, we have to consider the weld to have failed.

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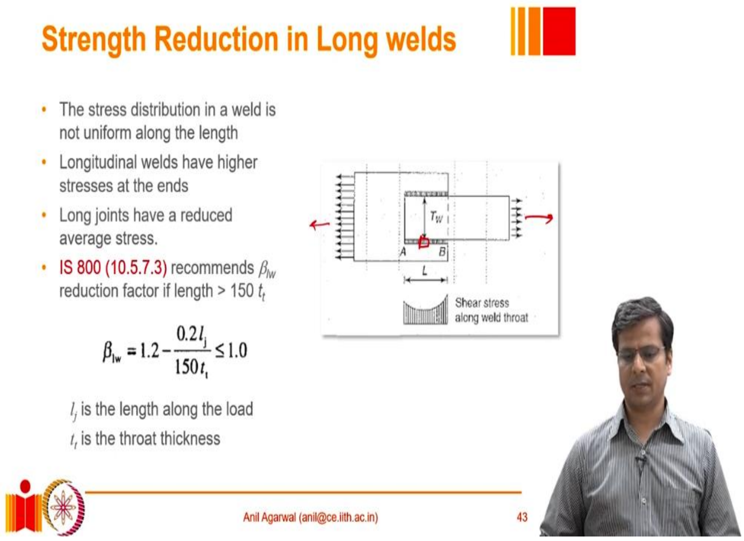

And because of that requirement, we cannot simply take the ultimate strength at any place as the actual strength of the entire weld.

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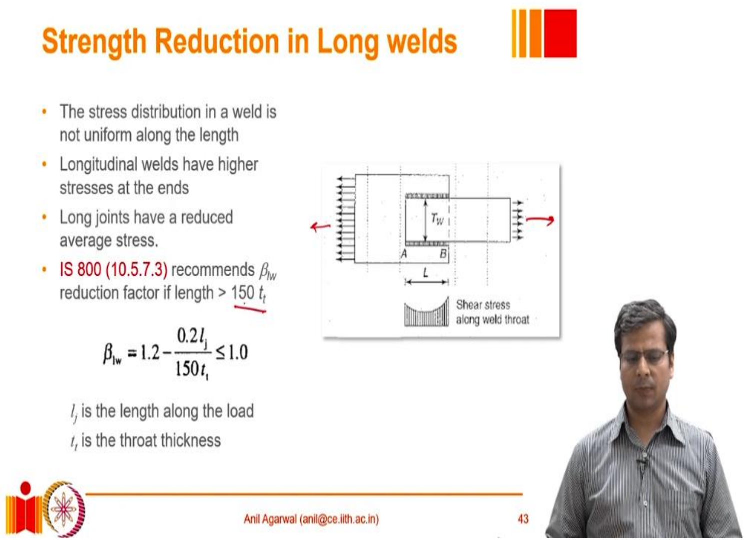

This kind of a situation arises especially when the weld is very long.

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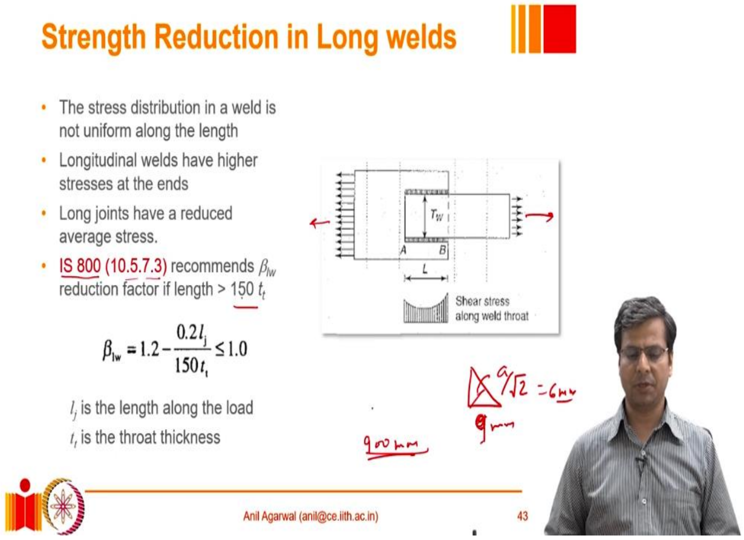

So, the recommendation in our Indian standard IS 800 in clause number 10.5.7.3 is that, if the weld is longer than 150 times the throat thickness of the weld. So, if it is a fillet weld, the throat thickness would be a divided by √2; this is a. So, the throat thickness will be a divided by √2. So, t t will be a divided by √2. And 150 times that; let us say a by √2 is equal to 6 millimetres, then 150 multiplied by 6, 900 millimetres we are talking about. So, for a weld of about 8 or 9 millimetre size, we are talking about almost 900 millimetres as the weld length.

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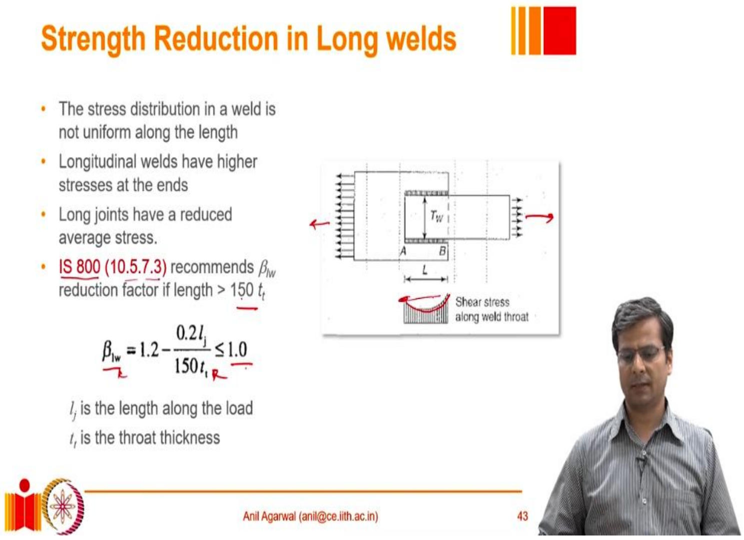

If the weld is that long, then the code recommends that we use a beta value which is basically a reduction factor based on the length of the weld and the throat thickness. So, which gives us a value of less than 1. If this expression has a value of more than 1, we reduce it further. So, basically, that is a way to account for this non-uniformity in stresses and say that because of this non-uniformity, we will not be able to have a uniform stress. And we cannot simply multiply this stress value with the entire length and say that, that is the strength. And because of that, this effect is there.

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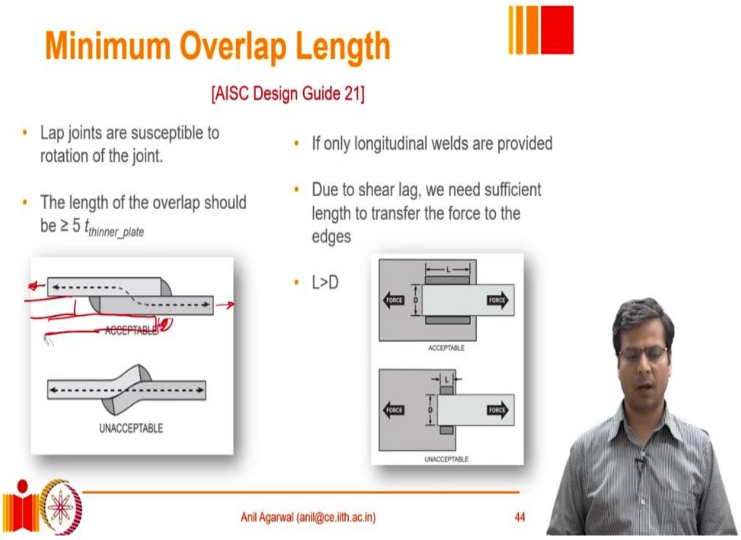

Also we have to be mindful about the geometry of a lap joint when we use fillet welds. If let us say we are using fillet welds to join these 2 plates together using a lap joint. Now, as you might realise that in a lap joint, typical lap joint, the forces are not really concentrate, the forces are not aligned; 1 plate has to be at a misalignment from the other plate. So, one option to overcome this obvious option is to actually use a double lap, wherein, one more plate is used and a lap can be provided with this.

And then, again this joint can be repeated. However, that may not always be advisable or so critical. In any case, still we have to make sure that because there is an eccentricity, there is a moment acting at this joint.

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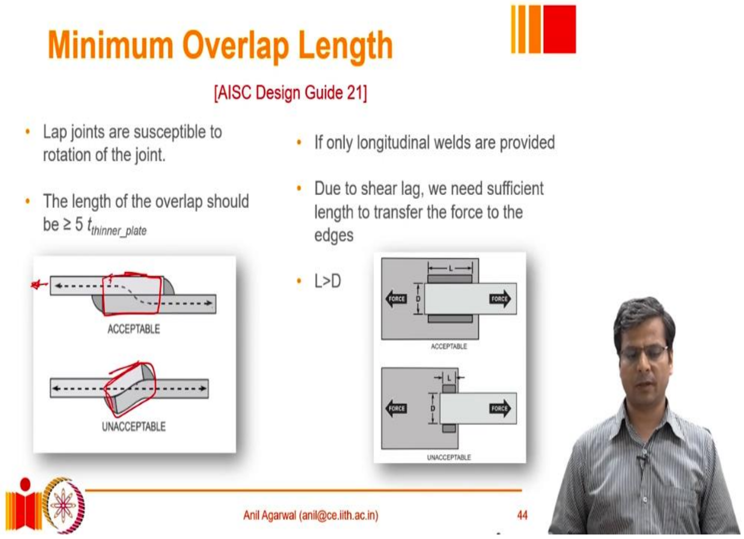

This joint is subjected to a bending moment demand. And there is a possibility that the joint will become more flexible, or it will bend in such a way so that these forces align. And therefore, once these forces would align, the moment demand will disappear. However, we have to prevent such a possibility. We have to make sure that the weld does not have such a large moment demand which can make it bend this way.

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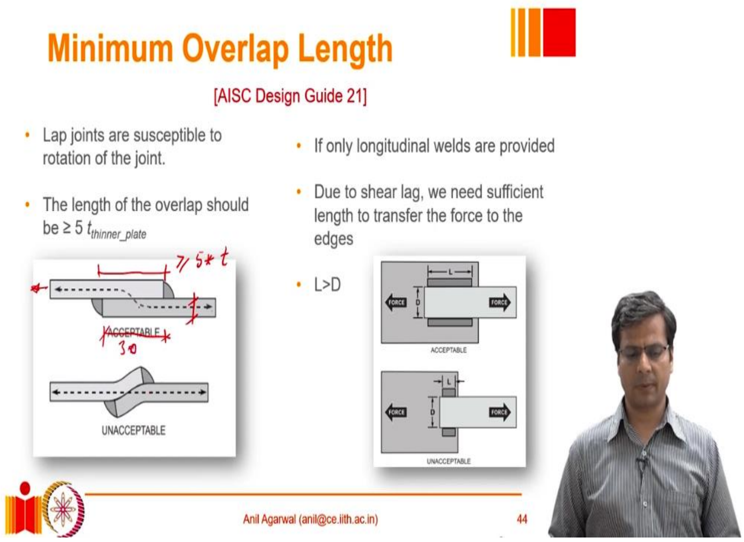

One way to achieve that is to make sure that this length of the overlap that is provided here should be at least greater than or equal to 5 times the thickness of the plate. So, we know the plate thickness. If plate thickness is let us say 6 millimetre, we have to at least apply, make sure that 30 millimetre overlap is available; and larger the overlap, smaller the moment would be.

Other dimensional consideration that we have to keep in mind when we provide fillet welds like this, especially in lap joints is the spacing between the fillets. So, in this particular situation, this plate is being resisted or is welded to the base plate using these 2 side fillets.

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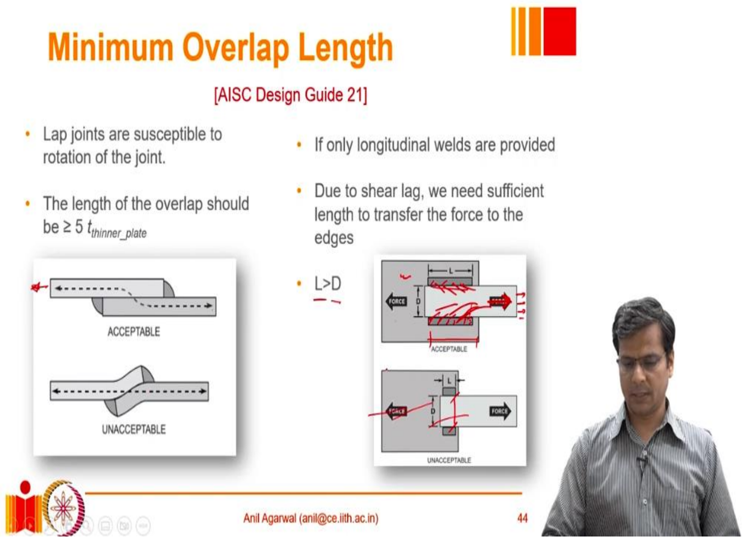

Especially, when we are using only the side fillets, the force distribution has to take place through the edges. So, here, the stresses are all uniform, which means the centroid of the force is at the centre. However, at the welded joint, all that force has to come through the edges. And when the force has to come through the edges, we need to provide sufficient length of these joints.

We have to provide sufficient length for these joints so that the force can get transmitted from centre to the edges. So, for that, there is a condition that the length of the joint should be greater than or equal to the width of the plate, because, wider the plate is, longer it will take for the forces to get transferred to the edges.

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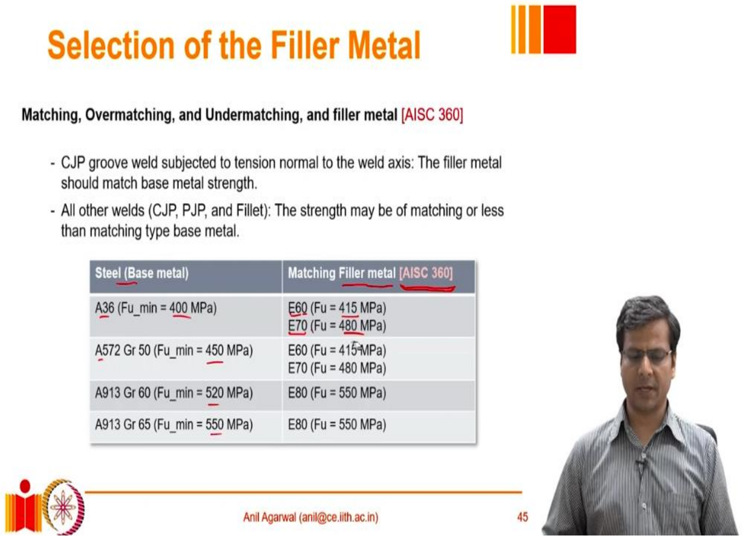

Also, there is an important question to understand. What type of electrode or what kind of filler material can be utilised for what type of a base material? So, if my plate that I want to weld is made of let us say an ultimate strength or 410 MPa, the question is, what kind of filler material we could utilise. So, there is a catalogue, AISC 360 gives this kind of a table. There are many other documents where some welding association documents also provide us this similar tables, which specify which filler metals match with what type of steel.

So, this is from American Standard. So, this A stands for ASTM codes. And there are different strength materials, 400 MPa ultimate strength, 450, 520 and so on. And for them, certain types of electrodes; these are the designations of electrodes which are prevalent in the US. So, E60 basically is an electrode, a filler material electrode which has an ultimate stress of 415. Likewise, E70 has an ultimate stress of 480 MPa.

So, the code says that; generally, the requirement is that we should go for a matching type of filler material. So, basically, if we have a 40 MPa steel, we should use an electrode which is somewhere in the similar range.

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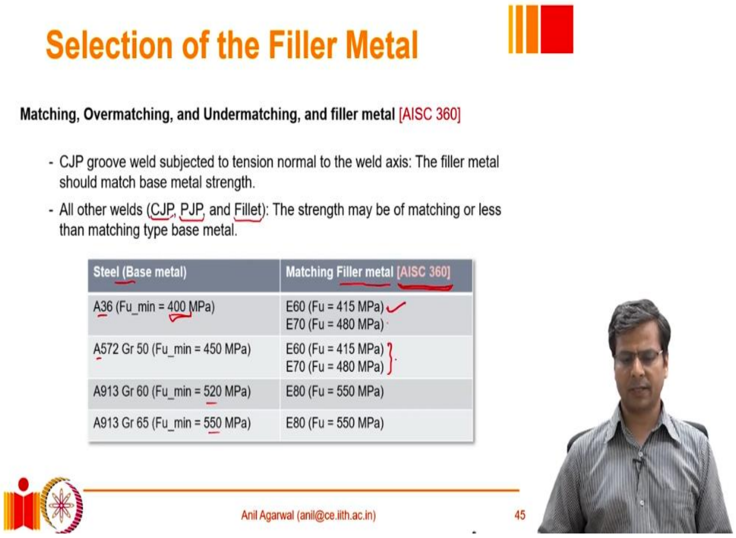

Likewise, a 420, 450 MPa steel, we could utilise electrodes which are slightly lower or slightly higher than that strength. Likewise, all these specifications are mentioned. In addition to these, generally, it is okay for most of the complete joint penetration groove welds, partial joint penetration welds and fillet welds. Generally, it is okay to either use the matching strength or you use a lower strength.

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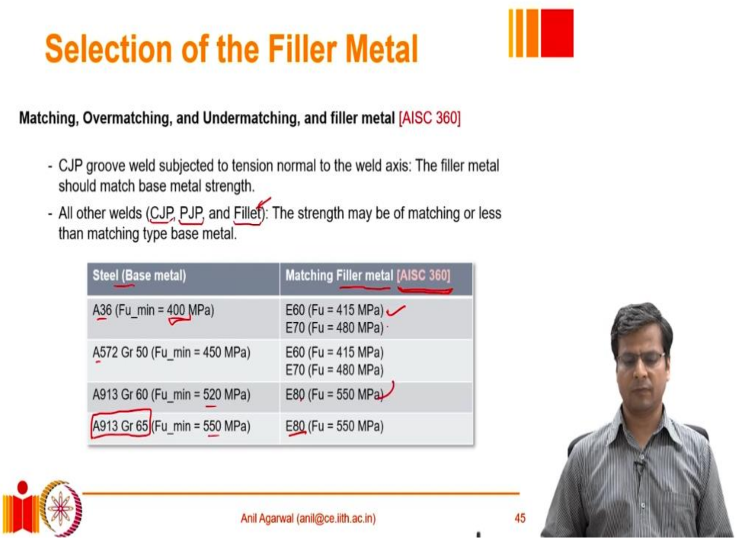

So, for example, if I am dealing with an A913 grade 65 steel plate and I want to weld it to another plate of similar strength, I can either use a E80 if I am using a fillet weld let us say. I can use E80 or I can use any of these which have lower strength than E80. In certain conditions, we are not allowed to go for lower strengths, such as, when it is a complete joint penetration weld subjected to tension demand.

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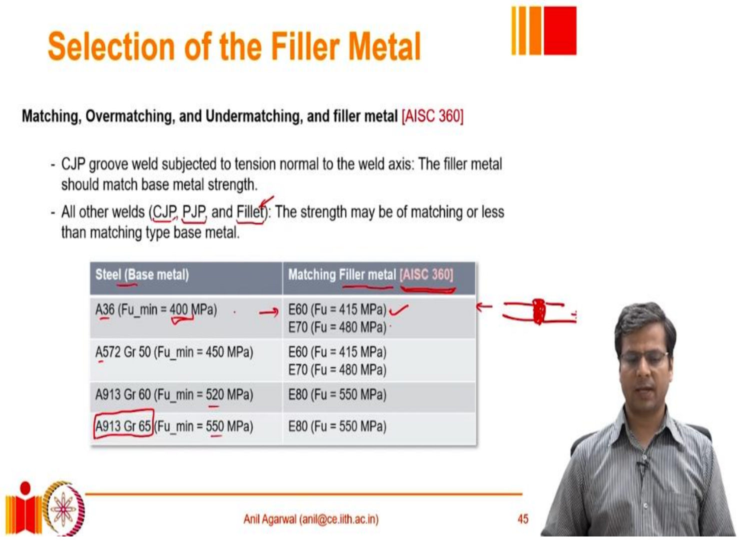

So, which may happen, say for example, we have 1 plate. The first example that we did in this chapter, which was on the welded connections. We had this complete joint penetration weld subjected to tension. Such kind of a weld, we need to use only the electrode which is matching with that base metal; we cannot use a lower strength electrode.

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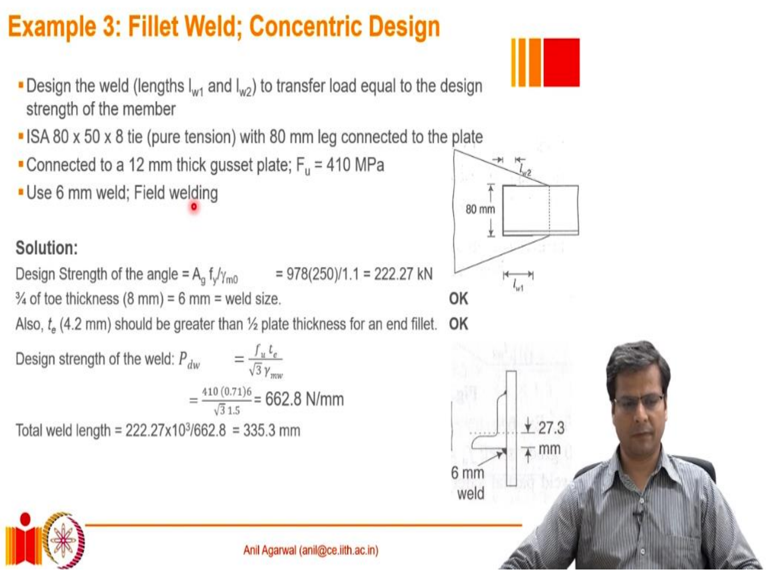

So, let us do one example now on the designing of a fillet weld. So, here is the question. We have got a gusset plate. This is a gusset plate that is connected to an angle by using a number of fillet welds as shown here. So, the total fillet weld is connecting the angle to the gusset plate on 3 sides. The angle dimensions are; it is an IS standard angle of size 80 millimetre by 50 millimetre by 8. So, that is this angle. And this is the gusset plate.

The angle is subjected to pure tension and the angles 80 millimetre leg. So, there are 2 legs. 1 leg is 80 millimetre wide; the other leg is 50 millimetre wide. So, the wider leg of the angle is connected to the gusset plate by using fillet welds on both faces. And the gusset plate itself is 12 millimetre thick. And both materials, the gusset plate as well as the angle are made of Fe 410 steel, which is basically having an ultimate stress of 410 MPa, the yield stress of 250 MPa. And we are required to use 6 millimetre weld, a fillet weld of 6 millimetre size, equal sided fillet, and the welding is done in the field.

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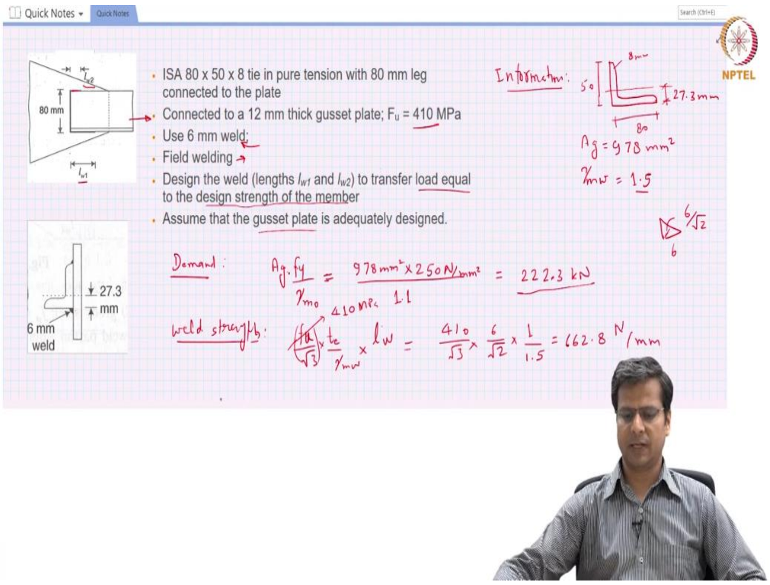

The question is now that the weld, this weld has to be designed in such a way so that it is able to transfer the entire load that is equal to the design strength of the member. So, whatever is the design strength of the member, that much of load we should be able to transfer. So, first we need to calculate the demand, and then we will calculate the requirement. Also, the gusset plate can be assumed to be adequately designed.

So, we do not have to worry about the design of the dessert plate itself, we will just design the weld. So, starting with the beginning, let us collect some information. So, this angle that is 80 by 50 by 8 in dimensions; this side is 80, this side is 50, and the thickness is 8 millimetres. We will calculate the cross-section area of this angle. And it turns out to be 978 millimetre square.

We only need the cross-section area, we do not need the net section area, because there is no reduction in the cross-section in this angle. Additional information that might be required is, since this is a fillet weld done on the field, the γ_{mw} value for this weld will be 1.5. We have discussed this. And additionally, we may need to know the centroid of this weld. So, its location, the location of the neutral axis, elastic neutral axis in this plane, it can be obtained from the respective tables; and it is found to be 27.3 millimetre from the extreme edge.

So, now, let us start with calculating the demand, demand on the weld. So, demand on the weld, it is given, we need to design the weld to match the design strength of the member. So, first we need to calculate the design strength of the member. Design strength of the member would be given by A_g x f_y divided by γ_{m0}. This part is not part of this particular course, but it is expected that when you are coming to learn the design of connections, you should have basic understanding of design of members themselves in pure tension, etcetera.

So, this is quite straightforward. We will use the cross cross-section area multiplied by yield stress divided by factor of safety. So, gross cross-section area for the angle, we had calculated already, 978 millimetre square; multiplied by yield strength; yield strength for this metal, f_u, is 410, so, this is E250 steel and it will be taken as 250 newton per millimetre squared divided by a factor of safety of 1.1.

And this can be calculated as 222.3 kilonewton. So, that is the tensile strength, the design tensile strength of the angle. And it is required that the weld should be designed to match this strength. And it is also mentioned that the weld has to be 6 millimetre in size. So, what is the information given about the weld? The weld is 6 millimetre in size. It has 3 components or 3 legs you may say, or 3 lengths, and one of those lengths is actually equal to the size of the weld.

So, 280 millimetres is the bare minimum we will provide, and let us say we have to provide certain length here and certain length here. Now, what should be the considerations when we put this weld? We can decide to provide any length. But the idea here is that, let us try to provide the weld in such a way so that there is no eccentricity between the weld and the load. And where is the load acting in this angle?

If you look carefully, there is a cross-section area under this neutral axis is much greater than the cross-section area on this one, and that is why the neutral axis has shifted downward. It is not exactly at the mid depth. So, this is where the neutral axis is, which is that 27.3 millimetre distance from the bottom edge. So, if this is where the neutral axis is, if the force was acting over here, it would not introduce any bending in the member.

So, we should design this fillet in such a way so that it also has its neutral axis located at the same location. So, in order to achieve that, let us say we require an l_2 length on the top edge and l_1 length at the bottom edge. So, first, we will start calculating how much is the total length required. So, the weld strength is equal to, it is a fillet weld, and no matter whether it is a fillet weld longitudinal or fillet weld transverse, according to the Indian code, we use only this much of strength, f_u divided by $\sqrt{3}$ multiplied by t_e, that is the throat thickness, divided by γ_{mw} multiplied by l_w.

That is the length of the weld. The throat thickness f_u divided by 3 is nothing but the ultimate stress and shear. That is what we use for all types of fillet welds as per the Indian code. And if we start substituting the values here, f_u is equal to, f_u is minimum of the two minimum of the ultimate stress of the metal and the filler material. So, which can be taken as 410 MPa, because that is the material that is given to us.

$\sqrt{3}$ is corresponding to shear strength. t_e would be the throat thickness. So, if the weld has a size of 6 millimetre, the throat will be equal to 6 divided by $\sqrt{2}$. So, we will substitute that value, 410 divided by $\sqrt{3}$ divided by 6 divided by $\sqrt{2}$ multiplied by l_w. So, for the time being, because we do not know the length, let us assume the length to be 1 millimetre.

And we are just calculating the strength of the weld of 1 millimetre length, just a notional value; and gamma mw which is 1.5 for a field weld joint. And this value turns out to be 662.8 newton per millimetre length of the weld, because we had assumed the length of the weld to be 1 millimetre in the beginning.

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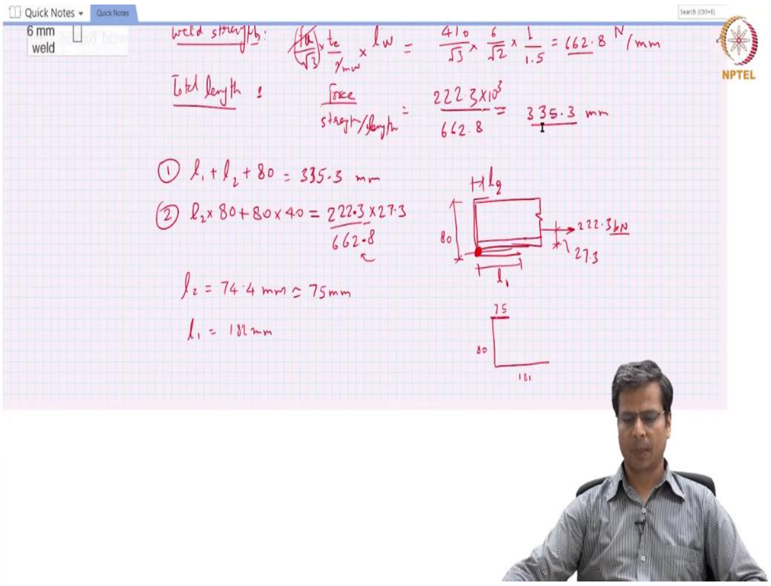

So, this is the weld strength per unit length. Total length required will be force divided by strength per unit length, which is basically 222.3 divided by 662.8. And that can be calculated, multiplied by 10^3 because it is kilonewton in the beginning and now it is changed to newtons. This gives me a total length required length of 335.3 millimetres. So, this is the total weld length which has 3 parts l 2, 80 and l 1.

So, what we know is that force balance will require that l_1 + l_2 + 80, this is the total length that will be equal to 335.3 millimetre. The second condition that I had mentioned before was that we have to do a moment balance, meaning that the moment that is introduced because of this actual force or the pure tensile force, that has to be balanced by the weld, which implies that; let me draw that portion again.

So, these are the locations where the loads are acting 27.3, l 1, l 2 and 80 millimetres. And what we would do is, if we take the moment about this point, the point that is shown here for all the forces, so, the contribution from the length l_1 will be 0. And we will take contributions only from the other 2 welds. So, l_2 which is at a distance of 80 millimetres from this axis plus 80 millimetre length, which is at a distance of 14 millimetres, half of the total length; that has to balance the total force of, how much is the external force? 222.3 multiplied by 27.3.

So, this is the total force, 222.3 kilonewton, that is acting at 27.3 millimetre distance from that point. And divided by the weld strength per unit length. This was the strength per unit length. You divide by that. And then, from here, from the second equation, if we solve for it, we get l_2 = 74.4 millimetres, which we can approximate as 75 millimetres. And we substitute this value into the first equation and we can get l_1 = 181 millimetres.

So, basically, now we have calculated the total weld length. Total weld length will be 335 approximately, out of which 75 will be l_2, 80 will be on the side, and then 181 will be provided at the bottom. So, this will be the total weld length to be provided to be able to resist the applied load concentrically.

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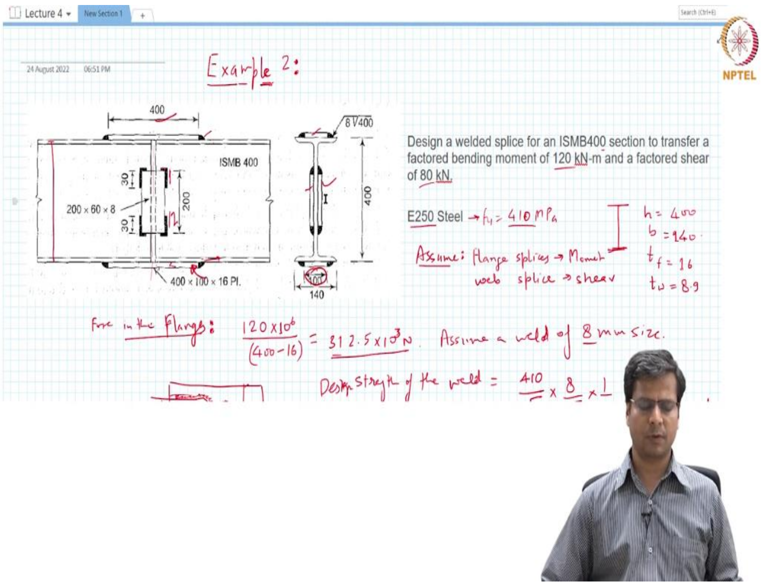

So, now we should do another example again using a fillet weld system. This example, we will see how to design a beam splice. These are all simple connections. So, that is why we are discussing them here. In later chapters, later lectures, we will talk about more complex weld designs where the weld groups act different, resist different types of loads simultaneously. So, here is the problem actually, statement is that we need to design a welded splice for an ISMB 400 section.

And the requirement is that it should be able to transfer the factor bending moment of 120 kilonewton metre and a factored shear force of 80 kilonewton. When we say factored, we mean that already the load factors have been incorporated in these values. So, these values do not have to be additionally increased for the corresponding load factors. So, basically, these are the final demands 120 newton metre in the moment and 80 kilonewton as the shear force demand.

And the cross-section is ISMB 400, and we need to design the splices. So, as we know that this section is going to resist both the bending moment as well as the shear force, we need to design the splices for those. As you again know that bending moment is primarily transferred through axial forces in the flanges, therefore, it is an obvious choice to provide the splices for resisting bending moment next to the flanges.

And for resisting the shear force, we should provide the splices near the web. So, this is the cross-sectional view of the proposed solution, we would have 2 plates, one on each side of the web, that will be fillet welded to the web right here. So, splicing is basically, that is where the beam is discontinuing. This is the line of discontinuity and a splice is provided. So, 4 such plates are provided, one on each flange and 2 on either side of the web.

Additional information is that the section ISMB 400 is made out of E250 steel which has an ultimate stress of 410 MPa. So, let us start with the designing process. So, let me also write the basic geometric properties of this ISMB 400 section. It has the total height, total depth of the section is 400 mm. The width of the section is 140 mm. Thickness of the flange is 16 millimetres and thickness of the web is 8.9 millimetres.

These informations you can get from the respective codes. So, when we start with the design, we will first make an assumption that these splice plates will be resisting only the moment, flange splices resist moment, that is bending moment. And the web splice resists the shear force. So, they do not interact. And that is okay because we are not making them continuous; they are discontinuous.

So, near the web, near the centroid of the web, it will be anyway shear force; it will be very effective to transfer. So, that is a perfectly good assumption. Now, we know how much is the moment demand, but we want to know what is the actual force that needs to be transferred to the splice. So, we can simply calculate the actual force that is acting on these flanges and that will be the force that needs to be transferred to the splice flange splice.

So, we will calculate the force in the flanges. So, since we are assuming that it is just the flange splice which is resisting the entire moment, we will take the lever arm which is from the flange to flange, and we will assume that the entire force is going to be transferred by that flange only. So, 120 kilonewton metre is the moment; converting that to newton millimetres, we will multiply with 10^6; this is the moment, divided by the lever arm.

And for the lever arm, we will take the distance from the centre of the flange to the centre of the flange. So, as we know, total depth of the section is 400 millimetres, but one flange thickness is 16 millimetres. So, the distance from centre of the flange to centre of flange will be 400 - 16. And this value turns out to be 312.5 multiplied by 10^3 newtons. So, this much of force is acting on the flange, and this force needs to get transferred to the flange splice using a fillet weld. So, if I can see this section from the top.

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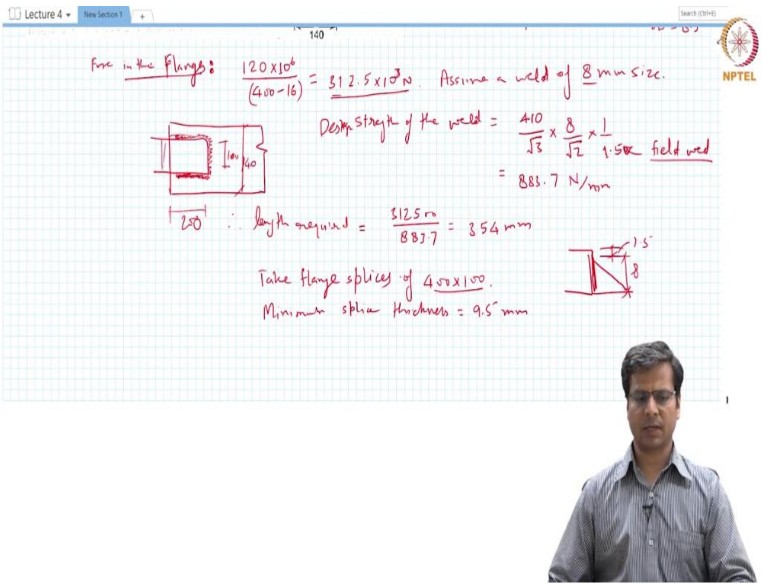

This is the top flange. There is a web under it, I am not drawing that. And there is a splice plate which will be coming here. And a weld needs to be provided all around this flange splice. Now, we know that this much of force 312.5 into 10 to the power 3 newton has to be transferred. Let us try to assume a weld size. So, assume a weld of; this is an iterative process, I have already done these iterations, so, I know that this type of weld would work; weld of 8 millimetre size.

So, if the weld size is 8 millimetres, the strength of this weld for per unit length will be, design strength I would say, will be equal to f_u, we know that, divided by √3. So, which represents the shear strength of the material multiplied by the throat thickness which is weld size divided by √2. Then, since it is a field weld, we will divide by a factor of safety of 1.5. And that gives us the weld strength of 883.7 newton per millimetre.

1.5 stands for the field weld. So, this weld per unit length has this much of strength. Total strength requirement is 312.5 kilonewton. So, we will say length required will be 312500 divided by 883.7, and which turns out to be 354 millimetres. So, this is the total weld required on one side of this plate. Now, we have not yet decided the size of the plate, but we have decided the weld size.

We need 354 total length. That means, we need which has to go from on 3 sides. On this side, since the total flange width is 140 millimetres, we can take a splice of 100 millimetres which will be far away from the edges. So, there is no issue there. So, 100 millimetres is covered here. Total we need 354. To be on the conservative side. Let us take the flange plate of, flange splices, in such a way so that it has 200 millimetres on each side available.

So, 200 metres, if we want to do a welding, we have got 4 + 100. Total 500 millimetres almost we have available for a welding. So, of 400 by 100 millimetre size; but the thickness still needs to be decided. Minimum thickness should be, that should be governed by these considerations that we have discussed before. It is a square edge. So, we know that if the weld is of 8 millimetre size, we should have at least 1.5 millimetre additional available to us. That means, it should be 9.5 millimetres at least.

From the load point of view, the plate also has to transfer the entire load which was getting transferred through the weld. So, the load demand on the flange was 312 kilonewton. And again, since the plate is, does not have any large effective length, it is not going to buckle in compression, and it is not going to rupture in tension. The limit state of tension or failure would be yielding.

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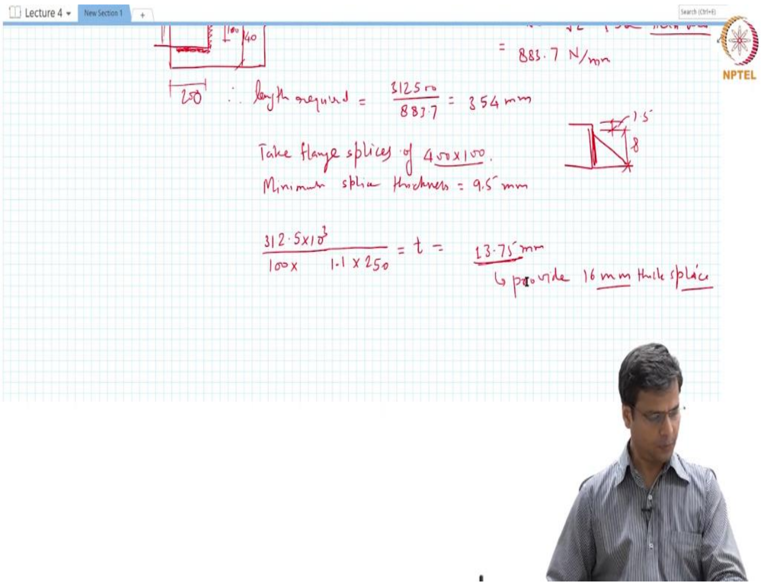

So, if we assume that, we know that the force demand is 312.5 kilonewton; so, I convert that to newtons; divided by the dimensions I have figured out; so, 100 millimetre width multiplied by whatever the thickness is, thickness we do not know yet; divided by 1.1, that is the factor of safety, and divided by 250, that is the yield stress of steel. And this basically gives me; this should be equal to; so, the thickness should be equal to this much which turns out to be 13.75 millimetre.

So, the thickness of this plate that is required to resist the load is 13.75. Let us provide 16 millimetre thick splice. This is the flange splice we are talking about. So, basically, what we are doing? We are providing, if 2 flange splices, one at the top, one at the bottom, each one has a size of 400 by 100 and a thickness of 16 millimetres. So, we have designed the splice for the flanges.

The dimensions are clear here. It is 400 by 100; this width is 100 and the thickness is 16 millimetres and the weld itself is 8 millimetres in size, which has a total length of 354 something millimetres, 354 millimetres as shown here. Now, let us plan the web splice.

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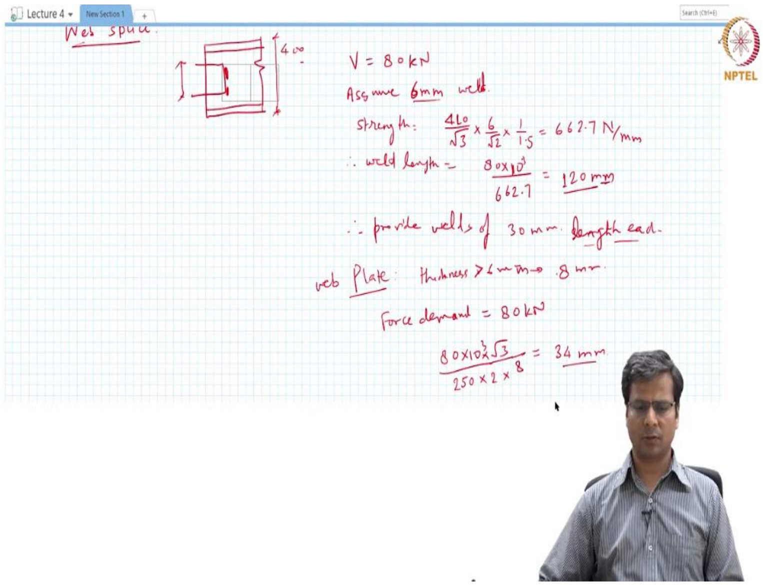

For the web splice, we will provide a plate. We know that the total depth of the cross-section is 400 millimetres, out of which 32 millimetres will go away. So, anything around 300, 200 millimetres should be sufficient for the web splicing. Let us also try to do a force check, the force demand check also. And we would provide welds at these 2 edges and we will see how much is the force demand. So, how do we go about doing this?

So, the force demand is 80 kilonewton; it is given to us already. And if we assume that we will provide a 6 millimetre size fillet weld, so, a 6 millimetre weld would have a design strength of; first 410 is the ultimate stress divided by √3 corresponds to the shear ultimate stress multiplied by the throat thickness which is 6 divided by √2, then divided by the factor of safety, and which gives me a strength of 662.7 newton per millimetre length of the weld.

Therefore, we can calculate the weld length which will be equal to 80,000 newtons divided by 662.7 newtons, which will give me a value of 120 millimetres. So, a total of 120 millimetre length weld is required. Now, if we look at this diagram again, you might notice that there is one splice provided on each side of this web. So, which basically means that there is a portion of the, there are basically 4 welds to resist that load, 1, 2, and then there are 2 on the other side of this web.

There are total 4 webs. Total length required is 120. So, we can provide welds of 30 millimetre size each, 30 millimetre length. And there are 4 such welds and that is 6 millimetre weld. So, that is how we can design the plate. Of course, the plate has to be the web splice plate. That also needs to be designed. So, that has to be thicker than 6 millimetres. So, we can go for something like 8 millimetre thick plate or something like that.

And the total force demand is 80 kilonewton. 2 plates will be resisting that load simultaneously, 80 into 10^3 in shear. Therefore, we will divide it with the 250 MPa multiplied by √3. That is the shear stress or shear strength. Since 2 plates are going to resist this load, this much, and divided by the thickness of the plates. So, if you are taking 8 mm as the thickness, then we can get the depth of the plate, what is the plate depth that is required.

When we calculate it, what we get is, we get the total depth of 34 millimetres, which is very small. Actually, we are planning to provide 2 welds of 30 millimetres each.

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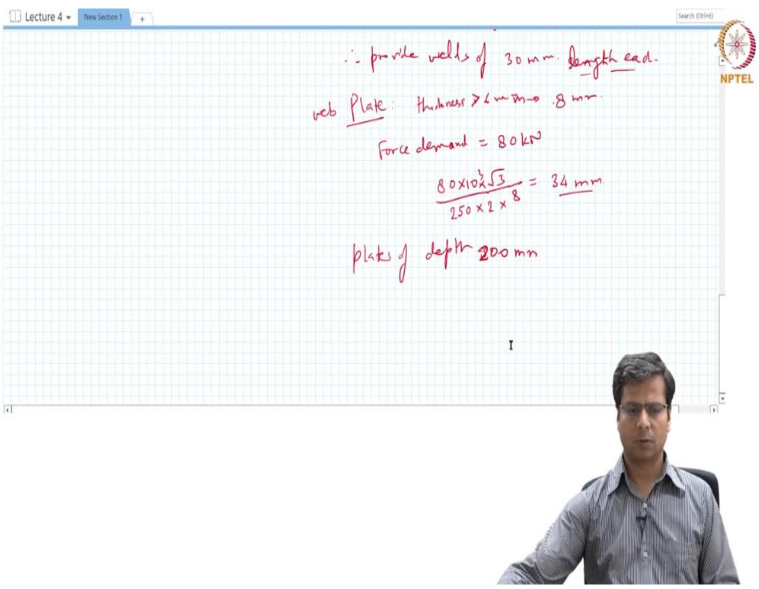

So, let us provide at least a plate of depth 200 millimetres at least. So, the web splices are 200 millimetre deep and 8 millimetre thick, one on each side, which are supported by these welds of 30 millimetre length and 6 millimetre size. So, that is how this example can be solved in web splices, and flange splices can be designed for the required force and moments.