Design of Connections in Steel Structures
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Module - 2
Lecture - 8
Fillet Welds - 1

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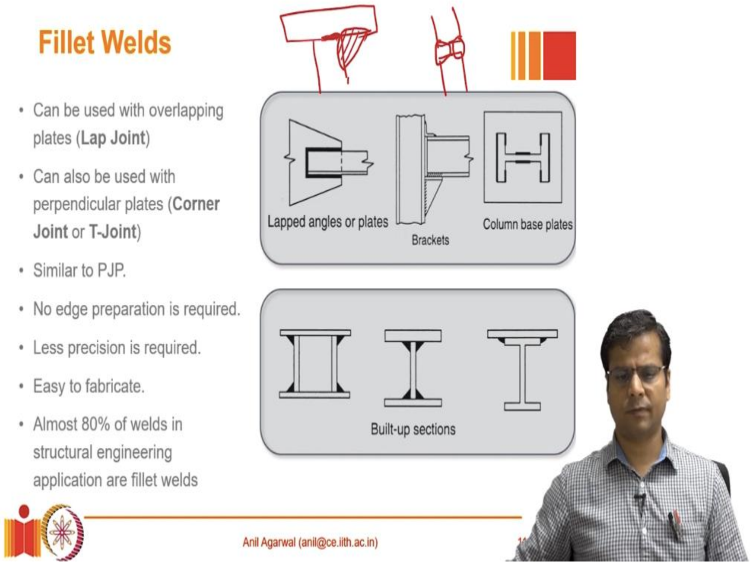

The next part is fillet welds. So, so far we have talked about complete joint penetration groove welds, partial joint penetration groove welds. And the most common type of structural welds are fillet welds. Fillet welds, as we have seen before, basically require 2 surfaces which are almost at 90 degree from each other. And the 2 surfaces can be fused by placing a triangular deposit of filler material.

It can be used in various geometrical configurations such as a lap joint, a corner joint or a T-joint. Here you can see some examples. Here there is a gusset plate and an angle is welded to the gusset plate. So, the welds around this angle are all lap joints or fillet. Corner fillet is shown here for example. Here you have these 2 plates that you wanted to join at 90 degrees. So, at a corner of course, we do not have a, we cannot get a smooth flush corner like the way we were able to get in a groove weld, but we can use a fillet by extending this flange slightly outside the web and then we can use a fillet here to join these plates together.

So, this would be called a corner or a T-joint. So, these are the examples of T-joints. So, in many ways fillet welds are somewhat similar to partial joint penetration groove welds. The reason for that is that in partial joint penetration groove welds also, some surfaces are fully fused but some surfaces are not fully fused. That is also the case with a fillet weld. I will show you here with an example.

So, if this is one plate and this is another plate and the 2 plates are being welded together and we provide a fillet here, that fillet typically fuses this part of the 2 metals. However, in that process, these 2 metals get fused in this area, but right around this area, the 2 metals are not fused together. There is an option of going for a deeper penetration fillet weld, depends on the amount of energy we are releasing; but let us not get into that.

Typically, you would always have a portion of the parent materials which are fused together and leaving behind a portion of the interface which is not fused together. So, such kind of an interface which is not fused together produces or creates a location where the stress concentration can occur. So, in that way, this joint is somewhat similar to a partial joint penetration weld.

There too, there was a possibility; let us say these 2 plates were to be joined together, but we fuse only this portion and maybe this portion and leave some portion of the interface which is not joined together, fused together. Unlike a groove weld, a fillet weld typically does not require any edge preparation, because we have these 2 plates and we can simply join them; we do not have to ensure that the fit is, does not have to be very accurate.

Even if we are a couple of millimetres off, it does not really change the welding protocol very significantly. And because of this flexibility that they provide in terms of less precision is required and no edge preparation is required, fillet welds are easy to fabricate and therefore they constitute a majority, a significant majority of the total welds that are usually practiced in engineering construction.

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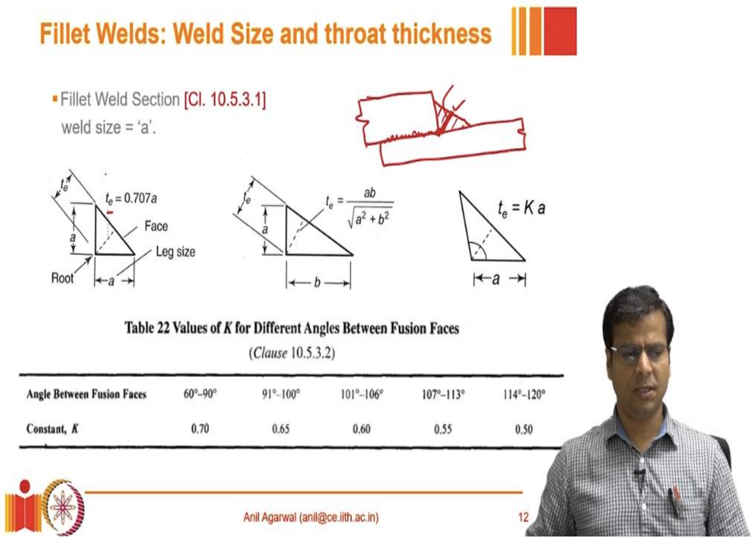

When it comes to the dimensions of fillet welds, there is one specific dimension of a weld that becomes very critical when it comes to the strength of a fillet weld. So, unlike a groove weld where it takes the geometry or the shape of the parent material itself, a fillet weld has a triangular shape. Again, let me show through an example. If we are joining these 2 plates together through a fillet weld, even though the fillet has a geometry of a slight convex shape, we can approximate it as a triangular shape.

And in this triangular shape of the fillet weld deposit, obviously, these 2 metals are not fused along this interface until to the very root of the weld. And here, obviously, the smallest distance between the interface free surface and this interface would be this perpendicular distance and that would be called the throat thickness. So, this t_e is actually known as the throat thickness, and that is a critical dimension when it comes to a fillet weld.

So, if the weld has to fail, it would most likely fail at this throat. So, therefore, the strength of the weld will be governed by how much throat thickness is available. The most common type of fillet weld is actually an equally sided fillet weld. So, both dimensions are a and a in this case; so, this is an equally sided fillet weld. And in such a case, the throat thickness can be calculated quite easily.

This is basically equal to a, where a is the weld size divided by square root 2. However, sometimes we may be required to provide fillet welds of unequal sides. So, for example, in this case, the horizontal dimension of the fillet is greater than the vertical dimension of the fillet.

And in such a case, the throat thickness can be calculated with this expression. It can be derived very easily using geometry.

There can also be another possibility where the 2 surfaces that are going to be joined together are not exactly at 90 degrees. Typically, they are at 90 degrees, but sometimes they can be at an acute or an obtuse angle. And if that is the situation, again effective throat thickness would be different from the one that is available if the angle is 90 degree. In such a situation, the Indian code IS 800 provides a table that can be used to calculate the effective throat thickness.

So, basically, what it says is that, if the angle here is between 60 degree and 90 degree, from 60 degree all the way up to 90 degree, we can take that constant as 0.70, multiplied by a will be the throat thickness. So, the throat thickness is basically same as what it would be if the angle was 90 degrees. So, if the angle is smaller than 90 degree, ideally the throat thickness, theoretically the throat thickness should have been greater than 0.7 times a.

But it does not give us any advantage for that because also there are challenges in getting a full penetration all the way to the root. However, when the angle between the 2 surfaces increasing beyond 90 degrees and as it goes to 120 degrees, we can see that this K factor which basically tells us what is the throat thickness if a weld size is a, it reduces further from 0.7 and goes all the way to 0.5. And an angle greater than 120 degree is not allowed for a fillet weld.

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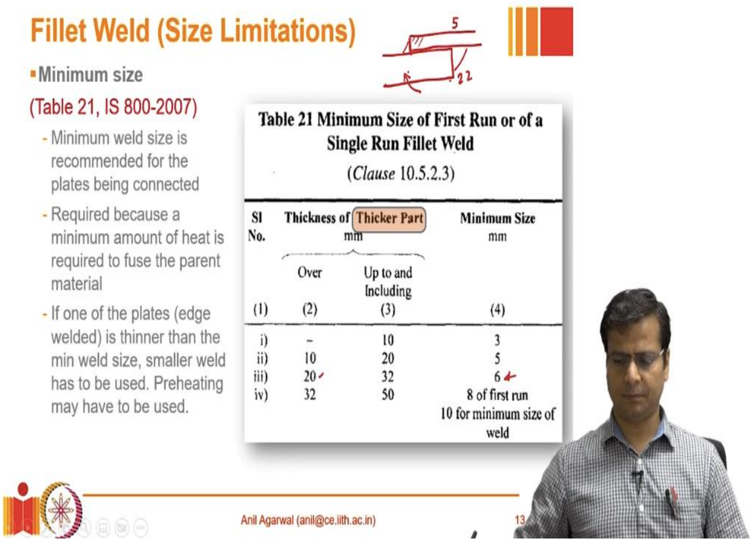

Now, as we had seen for partial joint penetration groove welds, there was a prescribed minimum weld size as per the American code and also as per the Indian codes. So, similar provisions also exist for the fillet welds. For the fillet welds, the Indian code IS 800 has this Table number 21 which specifies the minimum weld size for the first run basically. So, if the weld requires several runs, then the first run has to be of a particular size and the total weld size also has to be limited by a certain number; at least that size should be provided.

Again, the purpose for providing this minimum thickness requirement is to ensure that there is sufficient heat supplied to the weld materials so that the plates are able to fuse together sufficiently. The guideline here actually depends on or is controlled by the thickness of the thicker plate, which seems reasonable because it is the thicker plate that dissipates the heat fastest.

So, therefore, if the thicker plate is going to control the amount of heat dissipation, its thickness should control the size of the weld also. However, there may be some situations where we may not be able to provide such thick welds. I will show you an example. If let us say we are welding these 2 plates in a lap joint and one of the plates is let us say 22 millimetre thick, and the other plate is only 5 millimetre thick.

If we have to provide a fillet weld here, a 22 millimetre thick plate requires that we provide at least 6 millimetre fillet. However, since the plate, the other plate is only 5 millimetre thick, I cannot provide a 6 millimetre fillet weld here. Here I can; here I may be able to provide a 6 millimetre weld. And let us say from design consideration, from the load consideration, a 5 or a 4 millimetre size weld is sufficient, but this table still requires us to provide a 6 millimetre minimum weld.

Then what do we do? In such a scenario, the code allows us to use a smaller size weld than what is prescribed in this table. However, we have to do additional heating treatment of this plate. So, this plate needs to be heated before we put the weld. So, if the plate is already at a high temperature, then it does not dissipate the heat as quickly and in such a situation, we can first heat the plate and subsequently we can provide a smaller side weld.

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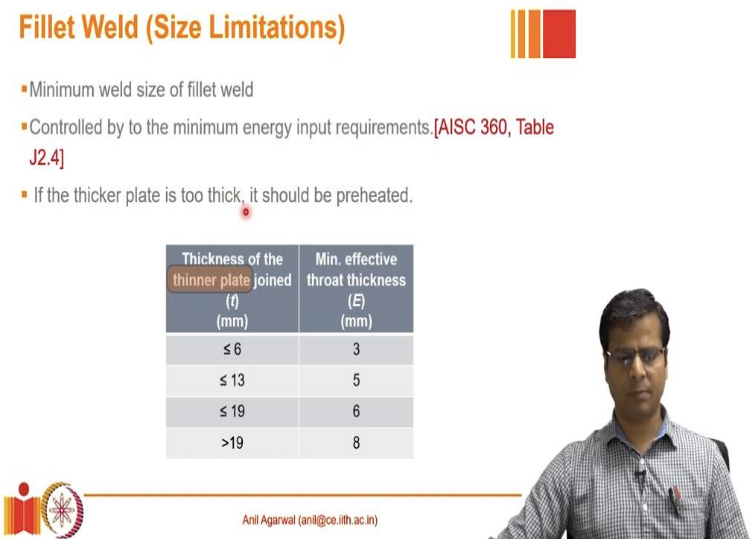

Similar to the Indian code, the American code AISC 360 also has a requirement of a minimum size for a fillet weld. Here you can see the table. If let us say the plate thickness is around 20 mm, 19 mm, we need a minimum welds of size 6 millimetre, which is very similar to the Indian code value, about one-third of the plate thickness. However, here you might notice that the provision is governed by the thickness of the thinner plate and which basically does away with the requirement of the additional clause that we had discussed.

Wherein, if one of the plates was too thin, then we had to do preheating. However, there is another challenge here. If one of the plates is too thick, so, one plate is thin and that is controlling the weld size, but there is another plate which is very thick. So, in such situation, that plate also has to be preheated. So, in any case, the 2 provisions are very similar in spirit and also the number wise.

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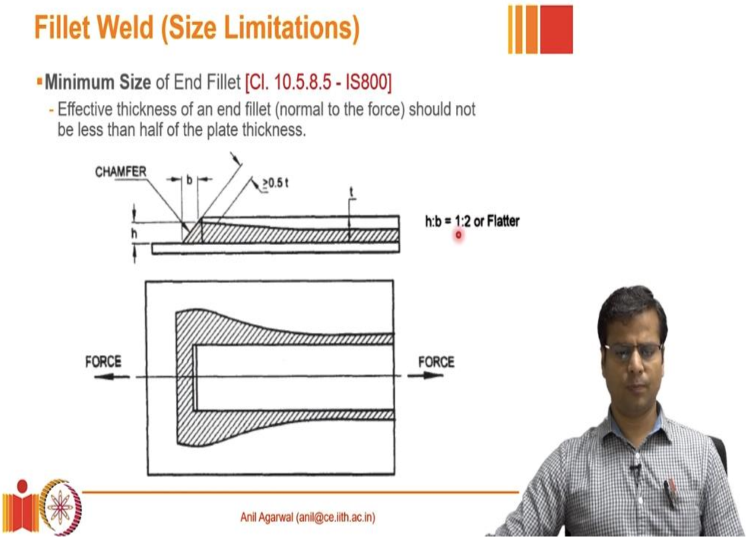

In addition to these requirements for the minimum weld size to ensure that there is sufficient heating or heat input into the weld material, also there is a special requirement for the minimum size of the end fillet. So, an end fillet here is shown through an example. These are the 2 plates. This is one plate; this is the other plate. These are lap joint using a fillet, an all-around fillet.

So, this is a side fillet. Why we are calling it a side fillet? Because this is the direction of the force. So, the surface that is perpendicular to the direction of the force would be called end fillet, and the surface that is parallel to the direction of the force will be called side fillet. So, the side fillet weld and end fillet weld are acting in combination together to resist this force. In such a situation, the Indian code requires us to have an end fillet in such a way so that it creates an angle of an inclined plane on this surface.

If you see, a chamfer of such a way so that this h x b ratio is 1 to 2 or flatter. So, this weld should not be an equal sided weld. It has to be in such a way so that the horizontal dimension in this diagram is greater than the vertical dimension by a ratio of at least 2. Also at the same time, it should be ensured that the effective thickness, that is the root thickness of this weld, of this fillet should be greater than or equal to the thickness of this plate.

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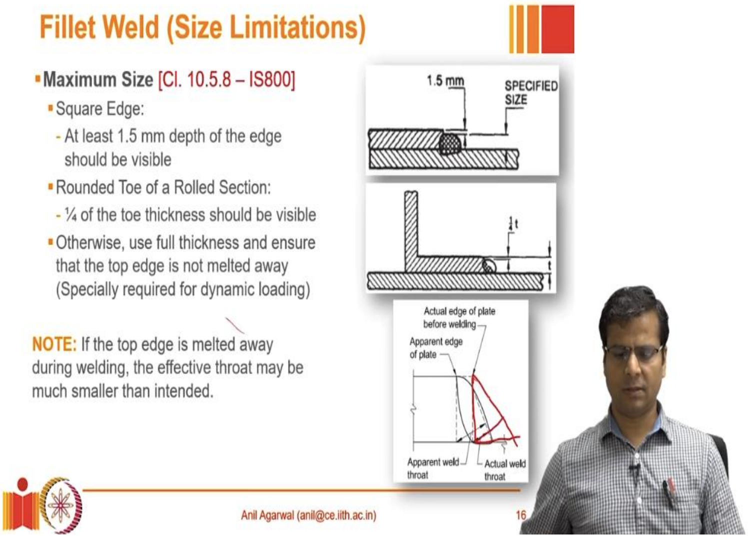

There are a couple of other requirements, but these requirements are on the maximum size of the weld, of a fillet weld. If we are joining these 2 plates together through a fillet that is provided in such a way, if this surface, this edge is a square edge, which is often achieved by machining the surface or by gas cutting it; in such a situation, the weld, the fillet should be provided.

The maximum size of the fillet should not be more than the plate thickness minus 1.5 millimetres. Or in other words, the top 1.5 millimetres of this plate should continue to be visible after the weld. If the edge here is not a square edge but a rounded toe, which is often achieved in a hot rolled section; in such a situation, we should ensure that at least one quarter of that thickness remains visible after the welding.

So, our weld should not be thicker than that three-fourths of the thickness of the plate. Here it should not be thicker than or should not be deeper than the plate thickness minus 1.5 millimetres. In certain conditions, we can use a full thickness weld or full thickness of the plate could be used for the fillet weld. In fact, under dynamic loading conditions, that is the one that is encouraged, that is the type of weld we should use.

But in regular static conditions, we should use a weld which is slightly smaller than the total plate thickness. The reason for that is actually not coming from the regular stress concentration or anything. It is just the possibility, the practical aspect of the possibility of the top edge getting melted away during, in the welding process, and we may not know exactly where the top edge existed.

So, this schematic if you can see, here, this edge represents the top edge of the bottom plate; this edge is the top edge of the top plate; originally, the plate was up to this point; and we were required to provide a weld of this size. Now, ideally, we should have deposited this material from here to here of that size, and we would have achieved sufficient throat thickness. So, ideally, the fillet should have been from here to here covering this length, and we would have had sufficient throat thickness.

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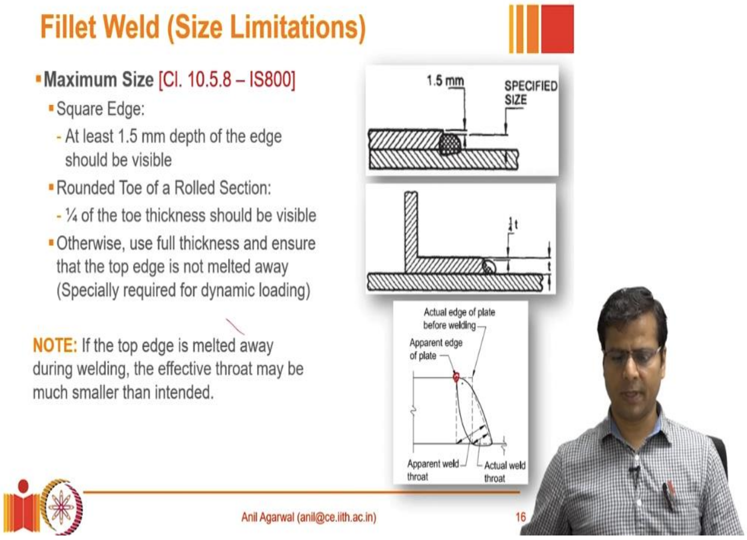

But what may happen is, if we do not protect the top edge of the top plate, it may so happen that the top edge of the top platen may get melted away.

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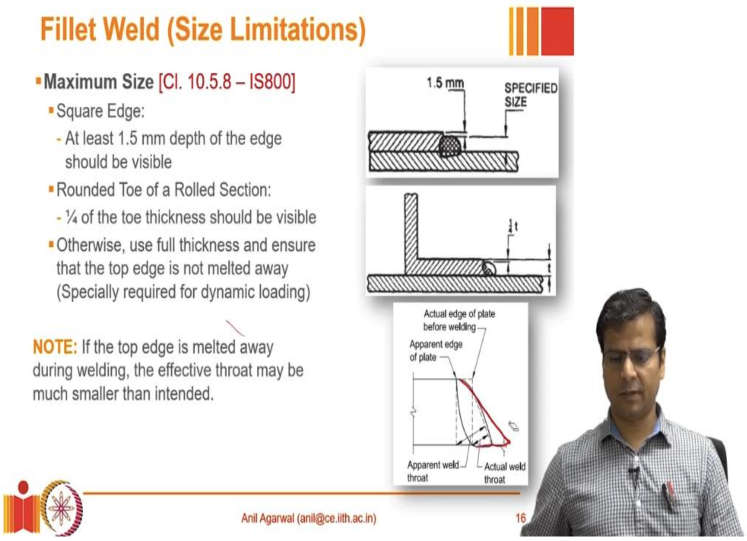

And if that happens, we may not deposit sufficient width of the weld.

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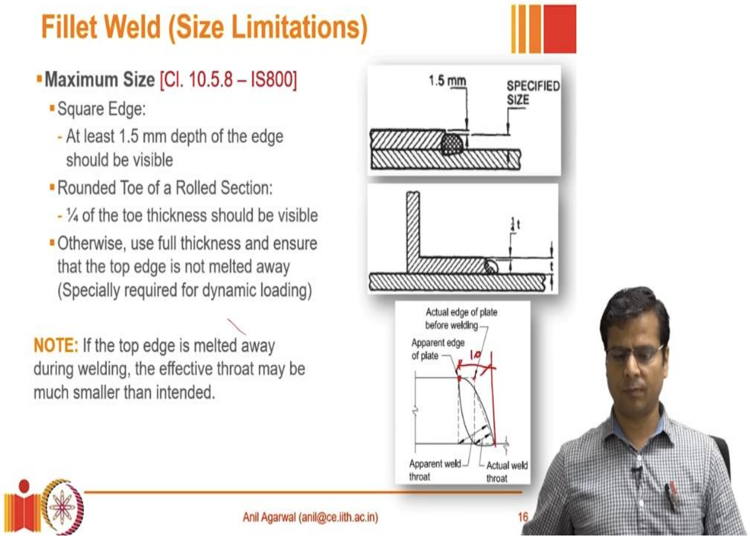

The welder may imagine that if the required width was let us say 10 mm, they may think that they have provided 10 mm thickness from where they can see the edge now, instead of where it was before, because of it getting melted away.

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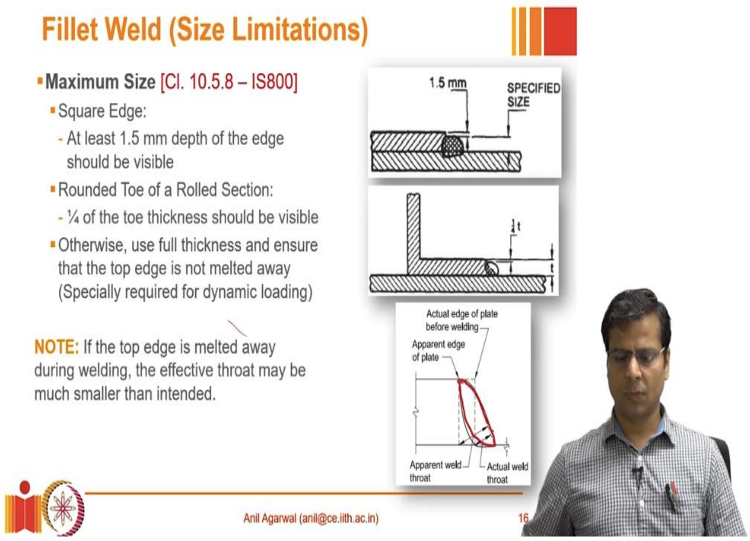

And if that is the situation, the actual weld that is deposited here is only this much.

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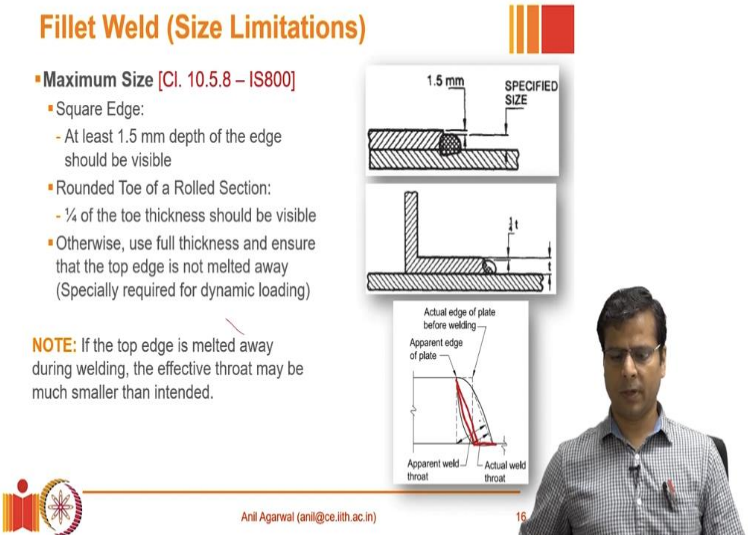

This situation can be approximated as a situation of an obtuse angle.

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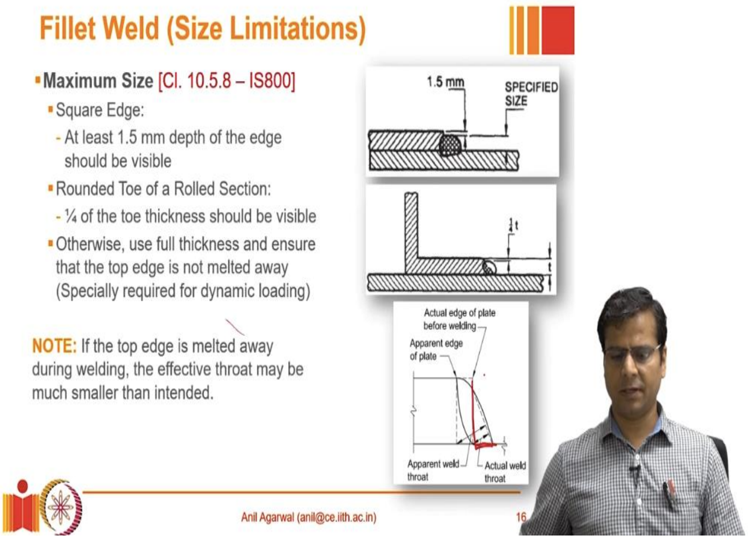

So, basically, the angle which was actually 90 degree angle has been now turned into an obtuse angle.

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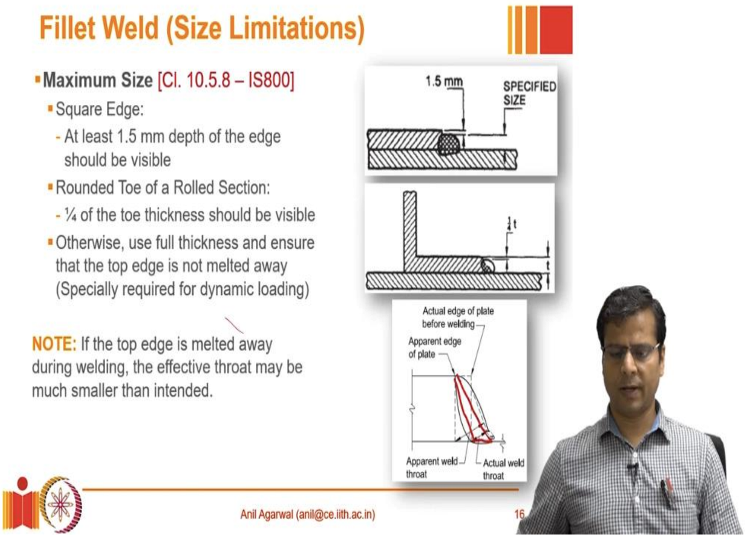

The geometry of the weld has been modified. And as a result, the net throat that is available to us is reduced than what was originally intended.

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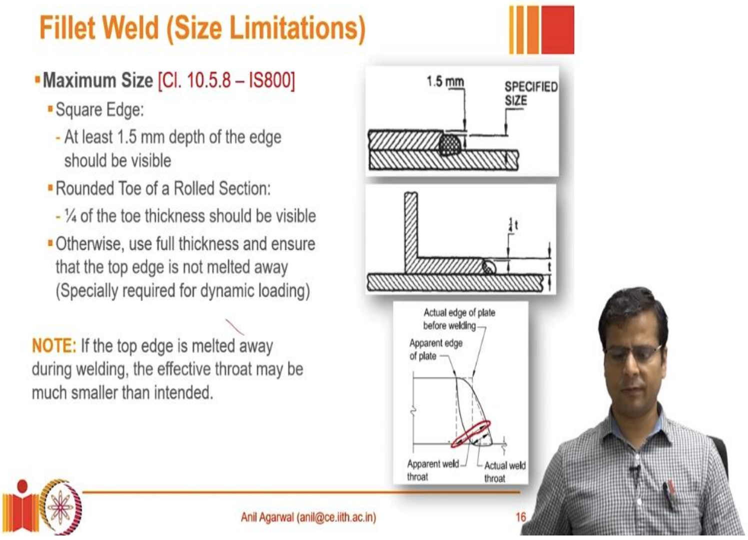

So, the welder may think that actually this much of throat thickness is available.

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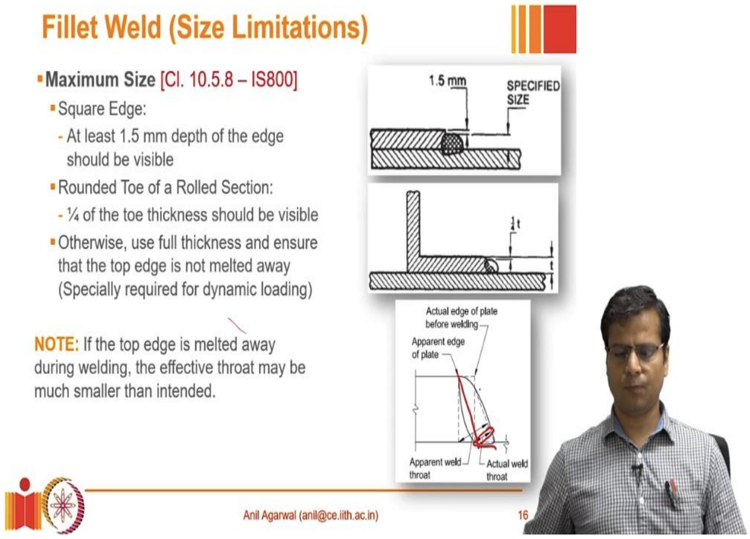

But actually the throat thickness is only this much of throat thickness is available because the angle has been modified from 90 degree to an obtuse angle. And in order to prevent this kind of a possibility, we can either make sure that the top edge remains visible, we do not melt it away. Otherwise, we can cover the whole thickness, but we have to double make sure that we have not melted away the top thickness, and there are proper inspections that are required for that.

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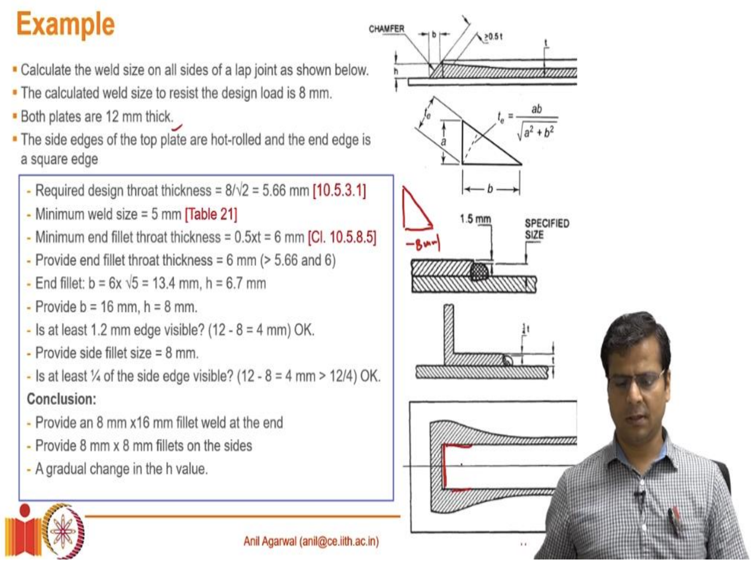

Now, let us do one example. So, we have seen various constraints that play a role in deciding the amount of, or the size of fillet weld that we can provide in various conditions. Let us try to solve one example based on these considerations. So, let us consider this possibility where these 2 plates are being lap joint. And we are using a combination of end fillet and side fillet. And we need to calculate the weld size on all sides of the lap joint.

Some additional conditions are given. The weld size required to resist the design load is 8 millimetres. That means, we require a weld of at least 8 millimetre size. If it is an equal sided weld, we require at least 8 millimetres size weld. Both plates that are being joined are 12 millimetre thick each. So, both plates themselves are 12 millimetre thick. The side edges of the top plate are hot rolled and the end edge is a square plate.

So, if you look from the top, this edge is a square edge and these edges are hot rolled curved edges. Now, let us try to calculate some of the basic requirements from what the information is given.

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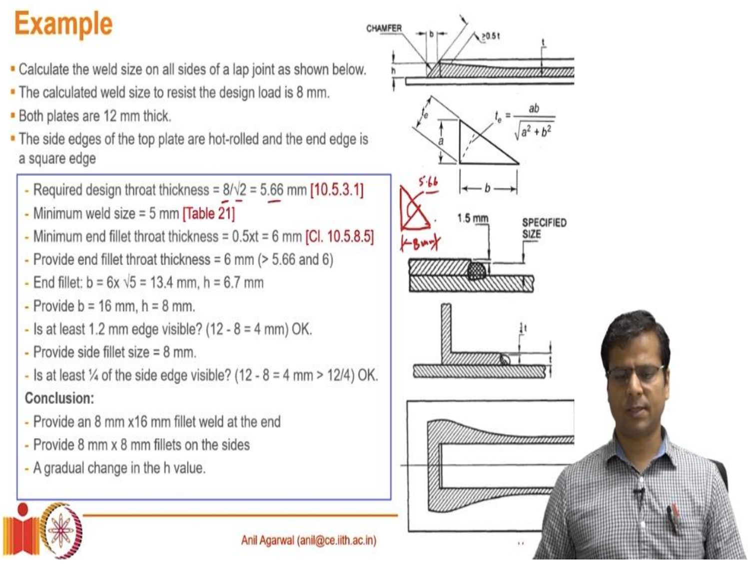

So, if the weld size is 8 millimetre, for an equal sided fillet, what would be the throat thickness? The throat thickness can be calculated as 8 divided by square root (2), which comes out to be 5.66 millimetres. So, wherever we provide a weld in order for it to be able to resist the required load, we need to have a throat of at least 5.66 millimetres everywhere.

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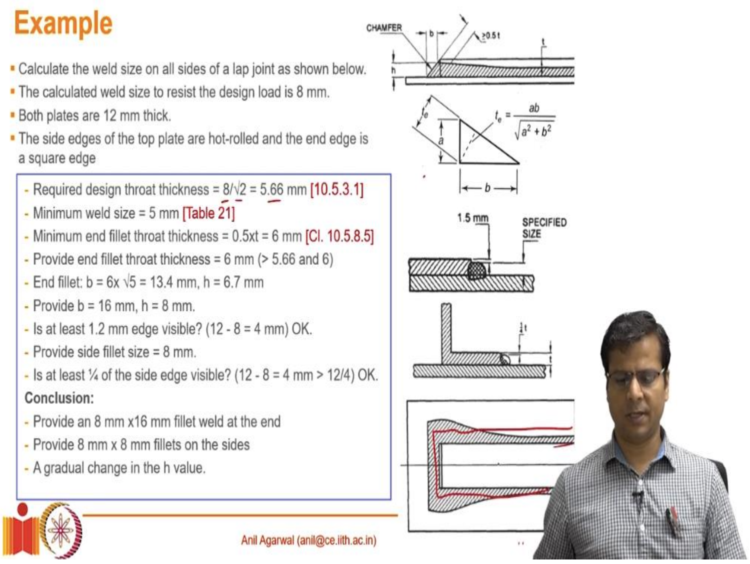

So, all around this, from here, all the way around this plate, the throat thickness should not be less than 5.66 millimetres.

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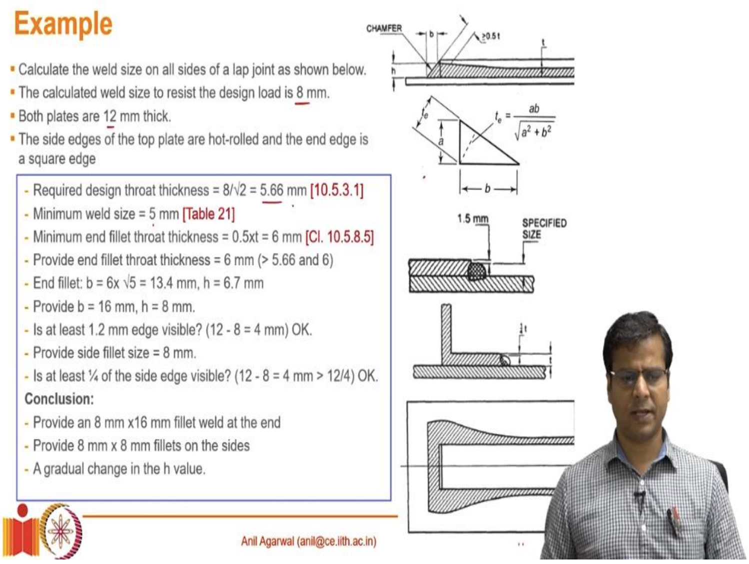

What is the minimum weld size that is allowed? So, we will look at the plate thicknesses. We will go to Table number 21. Table 21 of IS 800 says that for a plate thickness that varies between 10 millimetre and 20 millimetre, the minimum fillet should be of at least 5 millimetres. So, from there we know that for a plate of 12 millimetre which falls between 10 and 20, the weld should be at least 5 millimetres in size, which is okay because the throat itself was 5.66 and the weld size required for the design requirement itself was 8 millimetres.

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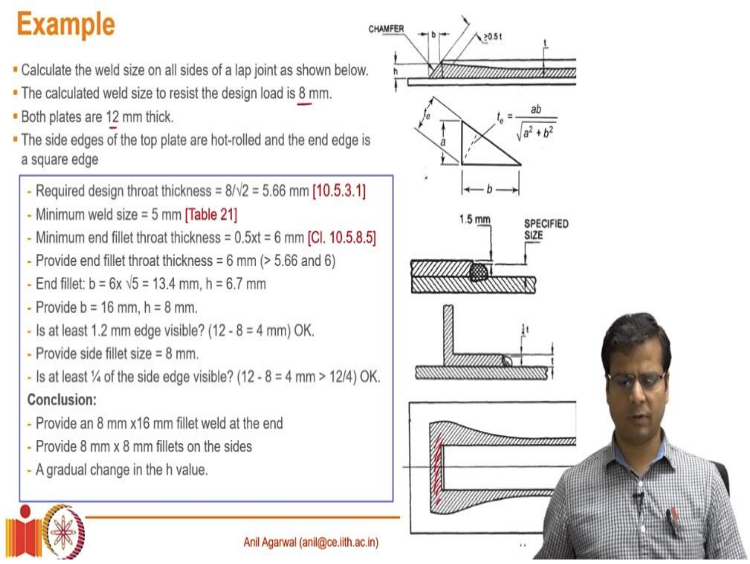

So, no issues. In addition to that, we have seen that in the portion that is in the end fillet, this portion of the weld, the throat thickness should be at least 50% of the plate thickness.

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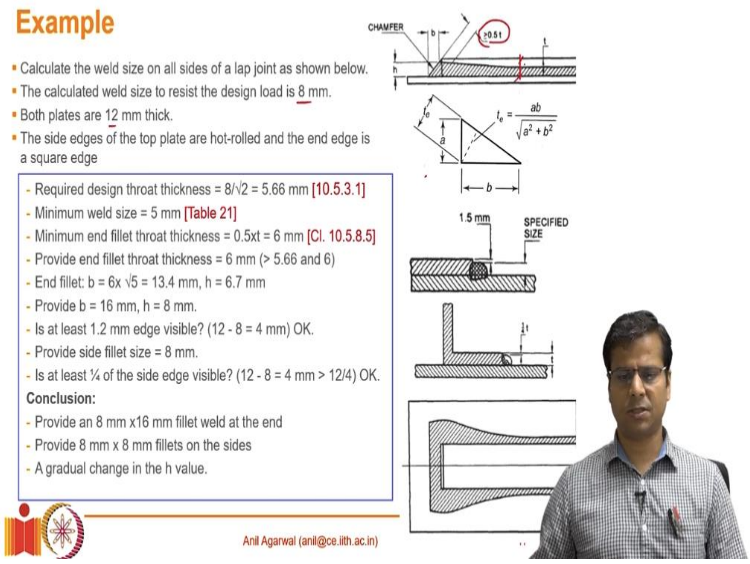

So, if this is the plate thickness t, the throat thickness should be at least 0.5 times t.

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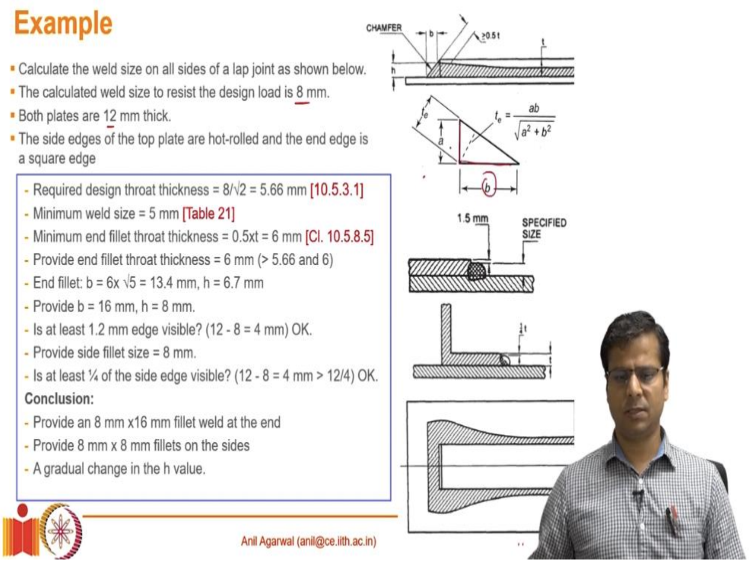

And also the shape of the weld should be such that b is 2 times the a value. So, what should be the thickness now in this portion?

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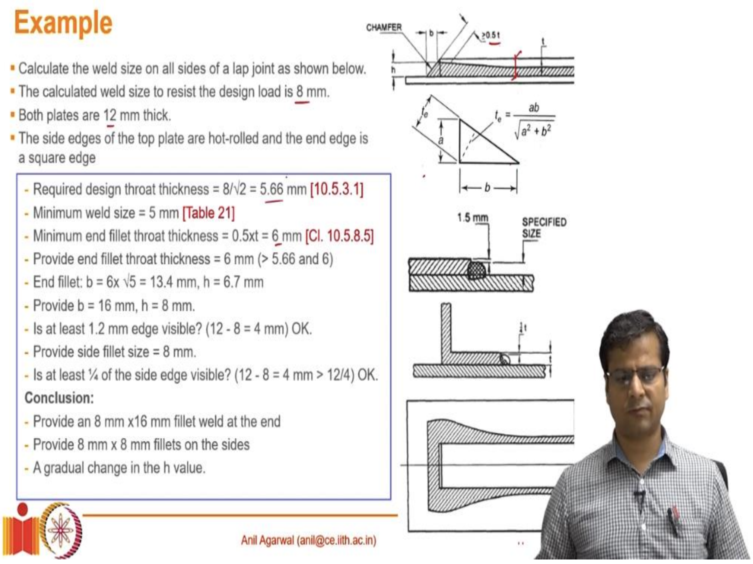

0.5 times t, the t value is 12 millimetres. So, 0.5 times 12 is 6 millimetres. So, the throat thickness in this part should be at least 6 millimetres. The original minimum throat thickness was 5.6. Therefore, now we know that the end fillet throat should be at least 6 millimetres in size.

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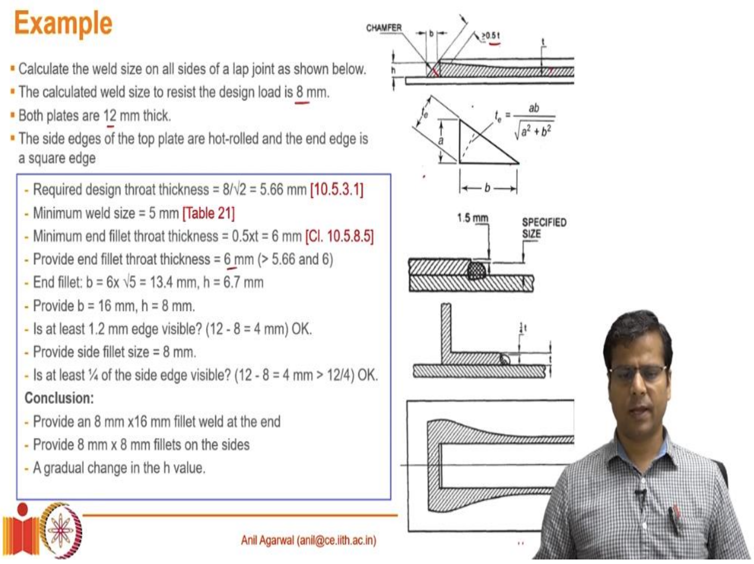

So, the throat here should be 6 millimetres, and the throat elsewhere can be 5.66 millimetres. In addition to that, now we look at this geometry of the end fillet.

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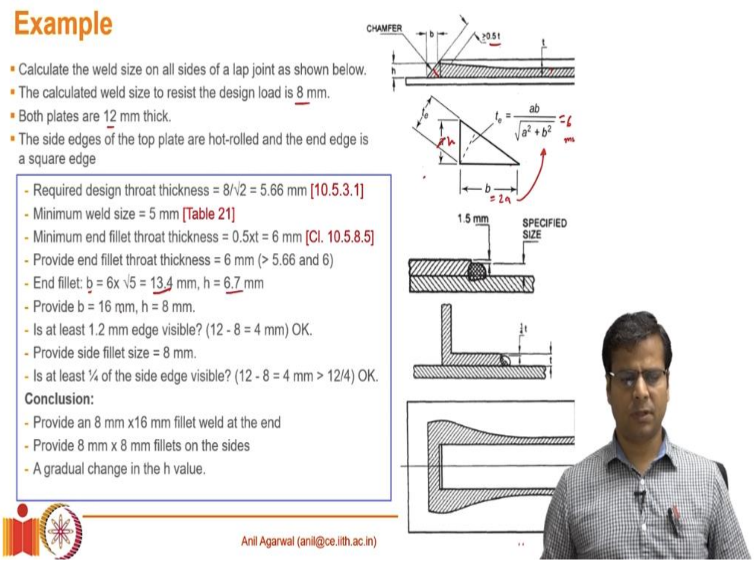

We know that b is 2 times a. And if we substitute that b value into this one, we can calculate the b for a throat thickness of 6 millimetres, that we just calculated. So, if the throat is 6 millimetre thick, we can calculate the value of b from this expression by substituting b = 2a. If we do that, we find out that b turns out to be, which is the horizontal dimension, turns out to be 13.4 millimetre, and h; can be called a or h here; and h turns out to be 6.7 millimetre.

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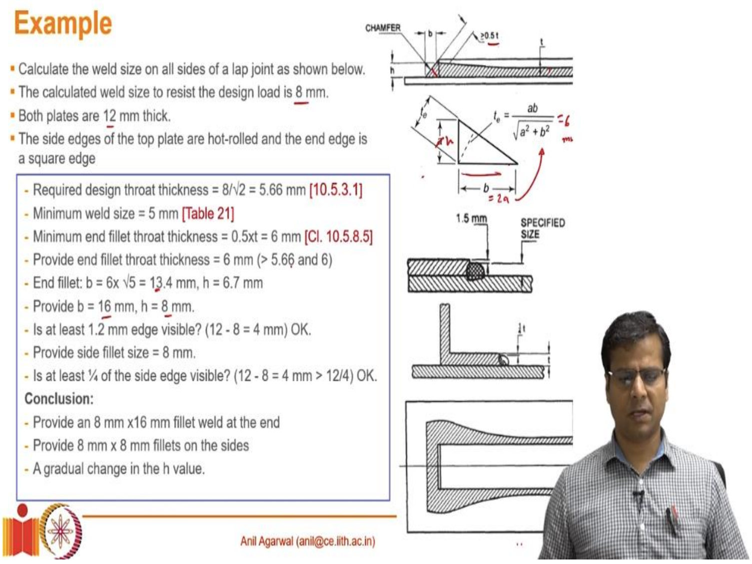

So, now, to be slightly conservative, what we can do is, we can take h as 8 millimetres and b can be taken as twice that size, that is 16 millimetres, which is significantly higher than the minimum requirement. So, 16 millimetres is the b value, and h value is 8 millimetres. And of course, that will satisfy the requirement of the minimum throat thickness. Now, we need to make sure that the other requirements of, the edge thicknesses being visible after the welding, whether that is satisfied or not.

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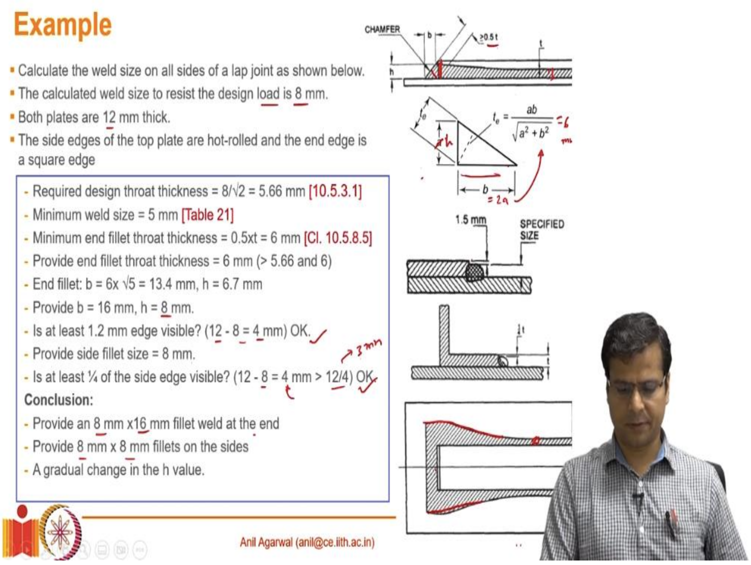

So, at the square edge, that is this edge, the weld size is, the vertical dimension of the weld is 8 millimetre, the plate is 12 millimetre thick. Therefore, we have 4 millimetre unwelded surface which is visible outside the weld, and that is greater than 1.5 millimetres. Therefore, that requirement is satisfied. On the side fillet, let us try to figure out, if we had provided 8 millimetre as the weld height here, h; let us also provide a weld of 8 millimetre on this side, because that is also the requirement as per the design calculations.

So, if that side fillet is also 8 millimetre in size, a quarter of the plate thickness would be 12 divided by 4, that is 3 millimetres. And the weld size is only 8 millimetres. That means 4 millimetres is visible, only 3 needs to be visible. That means, I have satisfied that requirement as well. So, essentially, the final design turns out to be, we provide the weld of size 8 millimetre height and 16 millimetre horizontal dimension at the end.

On the sides, we provide 8 by 8 fillet weld. That is, horizontal dimension is also 8, vertical dimension is also 8 millimetres. And of course, there will be a gradual change from here to here as the dimensions change from the end fillet to the side fillet.