Design of Connections in Steel Structures
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Module - 2
Lecture - 10
Weld Symbols, Defects, and Filler Material

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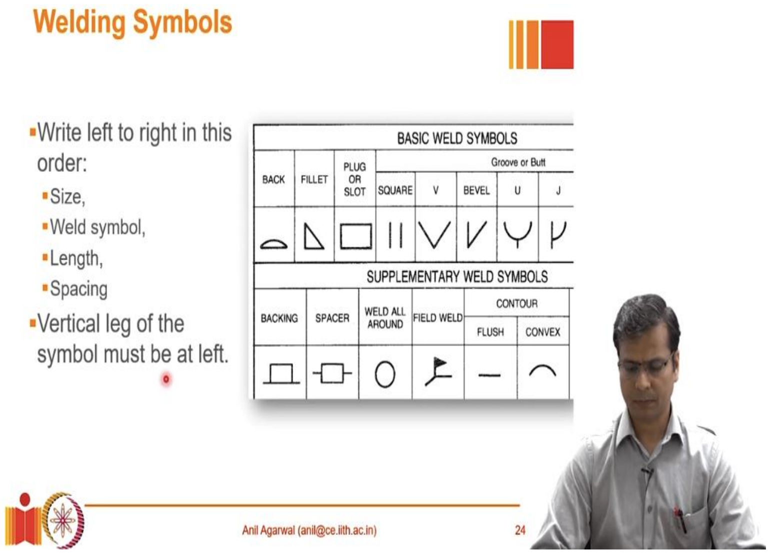

There are various symbols that are used to represent different types of welds in engineering drawings. We will see through some examples. So, basically, first we mark the weld location; from there we draw an arrow. And then, on that arrow, we put various symbols. Some of the important symbols that are marked here are of importance for us. So, for example, a fillet weld is typically shown with a triangle.

If it is a plug or a slot weld, it is typically shown with a box sitting on that line. If it is a groove weld, depending on what type of groove it is, whether it is a square groove or if it is a V groove or a bevel groove and so on, so, these symbols are shown. If it is a double square or double V or double bevel, that means both faces of the plates are machined to create the groove. Then, this symbol is repeated on both sides of that line.

If a backing plate is used, again there is a box, but this box is drawn above the line. If a spacer is used, then that box is drawn in the middle of the line. If the weld is to be done all around, then a symbol a circle is shown. If it is a distinction between a weld which is to be provided in the field or at a fabrication shop; so, if it is a shop weld, then we do not put this flag, but this flag, if it is provided in the drawing, it means that this is to be done at field.

In that symbol where we marked the weld dimensions, the details have to be present in this order when we read from left to right. So, first, the size of the weld should be mentioned. So, if it is a fillet weld, so, size is basically these 2 legs; if the 2 legs are of equal size, we will simply mention one number. If the 2 legs are of different sizes, we would mention a multiplied by b.

Weld symbol: So, first we will mention the number which will be the weld size, then, to the right of it, we will mention the symbol, so, whether we will put a fillet or we will put a square or we will put a V and so on. Then subsequent to that, we will mention the length. So, if the length is not what the obvious length is; so, if some of the welds could be throughout the length of the member, then we do not have to mention the length.

If that is not the case, we need to mention the length of the weld also. And then, if it is an intermittent weld, then we mentioned the spacing. Then all the other symbols are also provided on that same arrow. When we mention fillet weld, we have to make sure that the vertical leg should be at the left.

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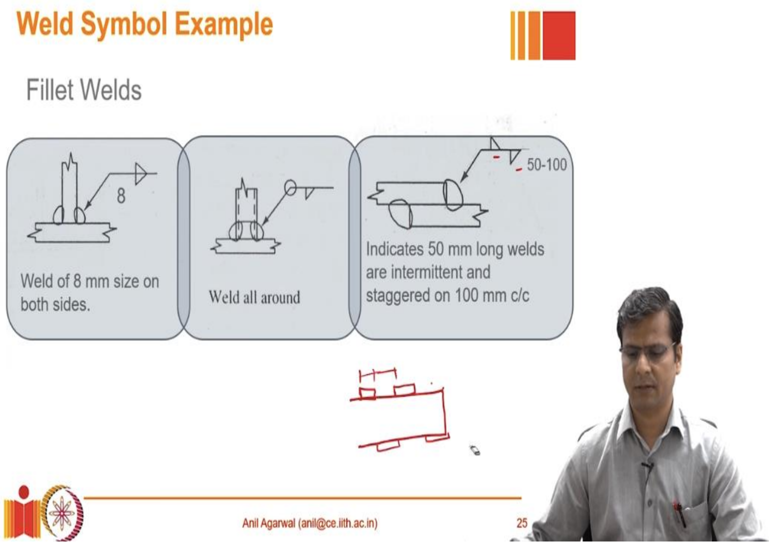

So, here are some examples of fillet weld symbols as provided in an engineering drawing. So, let us try to read this sign. This is one plate. This seems to be another plate. And then there is a fillet weld; there is a weld on this side and there is a weld on this side. How do we represent it? We represent it with an arrow like this. So, this arrow points to the weld here. The number before the first number that is written on that arrow, that number represents the size of the weld; so, which basically means that this weld, a triangular weld, fillet weld, has a leg size of 8 millimetres; followed by a triangle.

Now, if you may remember, this triangle represents a fillet. Here we can see one triangle above the line and one triangle below the line. What does that mean? It basically means that there is a fillet on this side and there is a fillet on this side. That means there are fillets on both sides of the same size, 8 millimetre. So, that is what this symbol means. If it is a weld all around a tube; so, basically, what you see here is basically a plate, and this tube, hollow tube is welded to this plate.

So, now, in this case, we cannot weld it from inside of course, because we do not have access to inside of the tube. So, the weld is only on the outside. And because the weld is only on the outside, only this weld is present. On this particular part, there is no weld present on this side. That means, this fillet symbol is provided only below the line. In addition to that, there is a small circle drawn right at this corner.

That circle represents that this weld is to be provided all around this tube; so, weld all around. In this particular case, what you may see here is that these 2 plates are being lap joined. So, in such a situation, you can see an arrow starts from here. Then it shows 2 fillets, but the 2 fillets are not overlapping. Unlike here, now they are staggered. What does that mean? That probably means that there are staggered welds.

Now, in addition to that, the size should be written here, but the size is not mentioned, just to not distract us. Ideally, a size of the weld should be mentioned. But after that, it is mentioned that it is a 50 -100. So, as we had seen, the first number on the right of the weld symbol is the length of the weld, and the second number after that is the spacing of the subsequent welds. So, what does that mean?

It means that these are intermittent welds of 50 millimetre length each. And then, subsequent to that, there is a spacing of 100 millimetres. It basically means that; there is a weld here; then there is a gap of 50 millimetres; then there is another weld here and so on. So, the weld length is 50 millimetres. Then there is a gap of 50 millimetres. So, essentially, the centre to centre spacing becomes 100 millimetres.

And then, on the other side of this plate, if I am looking at this thickness, other side of the plate, there, there is a staggering. So, that is why there is a gap between this and this. So, which basically means that these welds are staggered, they are not exactly opposite each other.

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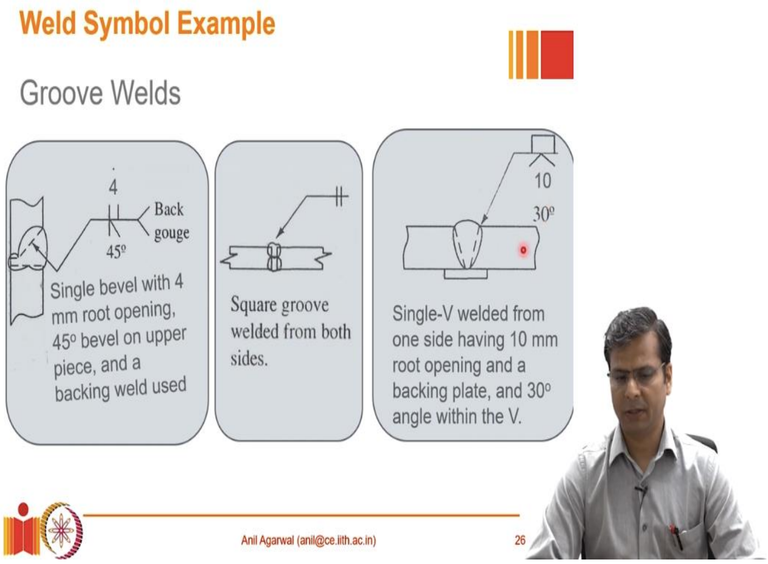

Also, let us do a few examples of groove welds. So, groove welds require many more details because there are many more details during the welding as well. So, as we had seen, a square symbol basically represents a square groove and this represents a bevel. So, basically, it means that on one side, on this side of the plate, we have a 45 degree bevel. A bevel, as we know, means that only one of the plates is to be grooved, the other plate remains a square; that is this symbol.

The 45 degree angle here represents the angle of this bevel. And then, on the other side, above the square sign, there is a number written 4. The 4 basically represents the root opening of the square groove. So, we need to prepare this groove in such a way so that there is a root opening of 4 millimetres in between on the backside. And on the front, we have a 45 degree bevel.

In addition to that, and then, that has to be welded together because this is a bevel weld and this is square weld. So, how do we do a square weld and a bevel weld? Of course, it automatically means that we cannot do both welds simultaneously. So, we have to do this weld from the backside, which is also clear by the sign back gouging. Back gouging basically means that first we will weld from this side, we will fill this gap; whatever small, not fully unfused, not fully fused metal is deposited on this side, that we will remove through machining, and then we will do another weld on the backside.

So, that will be called a backing weld. This is a simple symbol. Now, here what you can see is that 2 squares are marked opposite to each other, which basically means that there has to be one square weld on the top, and then another square weld. So, there is no groove, specialised groove to be cut; it is a square groove that is filled with filling material. In the third symbol, you can see a couple of details.

First of all, it says, this arrow has a V shape under it. So, V shape basically under it means that on this side of the plate, we have a V. On top of the arrow, we can see is a rectangle drawn. That rectangle represents a backing plate. That means we need a backing plate behind this weld. In this weld, there was no backing plate mentioned. That means, there was no need of backing plate, but back gouging was used still.

Then there is a number 10; basically, here again represents the root opening. So, the root was 10 millimetre wide; because the root was 10 millimetre wide, there was a possibility of the weld material to leak or to slip out from here. That is why they have provided a backing plate. In this particular case, the root opening was only 4 millimetres. And then, this 30 degree again; right below 10, they have written 30 degree; 30 degrees represent the angle of this V groove.

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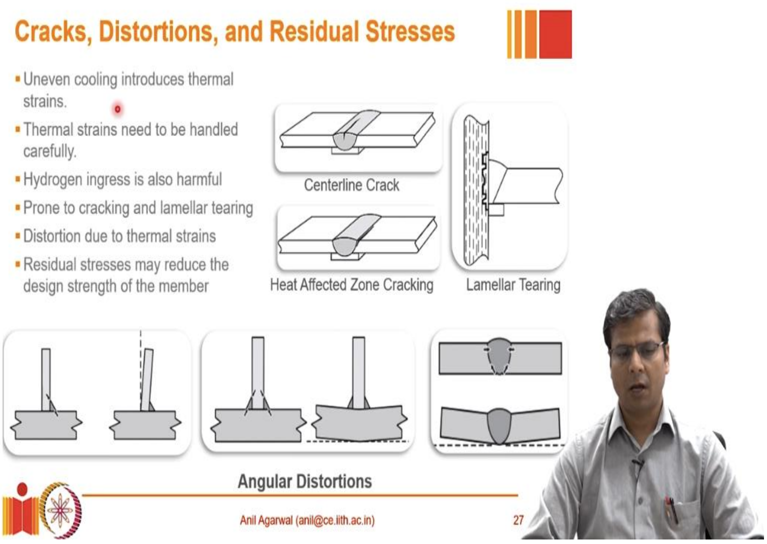

You might also be familiar with the phenomenon wherein the thermal strain, thermal stresses that are introduced during the welding process can bring in some defects and some kind of a distress in a welded joint. So, the issues that arise out of those thermal process can be categorised into 3 broad categories, the development of cracks, distortions and residual stresses in welded members.

So, after a weld is completed, the member can undergo some cracks or some kind of unwanted fissures can be created. Alternatively, the member can deform in such a way in which it was not intended, and that is also because of the thermal strains that are introduced as a welding process. If both of these are prevented, still there is a very high likelihood of developing residual stresses in the built up sections or in the joints which are prepared using welded joints.

So, as we might have guessed, the primary reason for development of these distresses is the uneven cooling of the system. So, when we use welding, we basically heat the system or heat the structure locally, around that portion where we are depositing the welding material. So, the metal, the parent material also melts and also the molten filler material is deposited in that area.

However, as soon as the structure starts to cool down, that neighbouring area start to cool down, the metal shrinks. And sometimes, that shrinking also involves; since the rest of the material is not flexible, it is still at cool temperature, it offers much higher level of rigidity. And if that cooling happens rather suddenly, that can lead to some kind of fissures or some kind of cracks appearing in the welded connection.

That is basically, that destroys the weld property, weld quality. So, we need to handle these situations very carefully. There is a possibility of cracks appearing; there can be 2, 3 different types of cracks which may appear. So, there is one which is typically known as centerline cracking which usually happens immediately after the welding is done. There is also something called heat affected zone cracking which often happens because of some kind of a hydrogen ingress, and it happens after a few hours after the welding is completed.

It does not happen immediately after the welding is completed. And if we can prevent the hydrogen from the atmosphere; and mostly the source of hydrogen is presence of moisture in the electrode or in the areas surrounding this weld. That moisture can ionise and turn into hydrogen. And that hydrogen can actually affect the quality of the welds, especially the areas near the weld.

So, we need to handle that carefully. Also, if we are welding some hot rolled sections, often it is observed that if any hot rolled section as a part of the process of hot rolling, some internal defects are introduced. And these defects are usually parallel, which basically create weak zones or weak interfaces between the layers of material. And if we weld another, provide a weld with connection and the welded connection is provided in such a way so that it introduces a tension on those interfaces, there is a high likelihood that there will be a failure which is typically classified as a lamellar tearing.

So, lamellar tearing basically corresponds to the tearing of these interfaces which are introduced as a part of hot rolling process. So, in order to prevent this kind of tearing, either we should opt for a material which does not have this kind of weak zones or has a minimal amount of those weak zones. Or we have to cut grooves in such a way so that the entire weld is not done to a single layer, but it is done to several layers.

So, in this particular case, the groove is only cut on this plate; but if there was a possibility to cut a groove into this plate also, that might have prevented this kind of a lamellar tearing. Not only cracking, there is another possibility of distortion. So, even if the cracking does not happen, which is basically, if this member is not fully restrained and this weld wants to shrink, there is also a possibility; as it is shown here, this big plate is welded with a thin plate here and through 2 fillet welds.

And when the welds start to cool down, this shrink. And as a part of shrinking process, they can pull the big plate up, introducing this kind of a distortion in the plate. This kind of a distortion, if it is a simple connection, it can be tolerated even though there are stresses because of this; but if it is a complicated structure, this kind of a distortion can affect the fit at other locations and will introduce more and more stresses subsequently.

So, here are several examples. In this case, only one sided weld is provided. And as a result, you can see some angular distortion appearing here. So, all of these examples are angular distortions. There are other types of distortions also, that you can read about from the textbook. If we are able to restrain these members in such a way so that they do not distort, and also we are able to make sure that these kind of a cracks do not appear in the welded area, still there is a possibility that the members will develop a significant of amount of residual stresses.

And those stresses will again anyway reduce or affect the design strength of the member. So, we need to be very mindful of these residual stresses also. So, residual stresses can be handled to some extent using design equations, by changing the capacity of the members somewhat. However, the other types of situations, especially, where we have very large distortions or with where there is a possibility of a crack appearing in the welded zone, those things have to be prevented and some precautions have to be taken.

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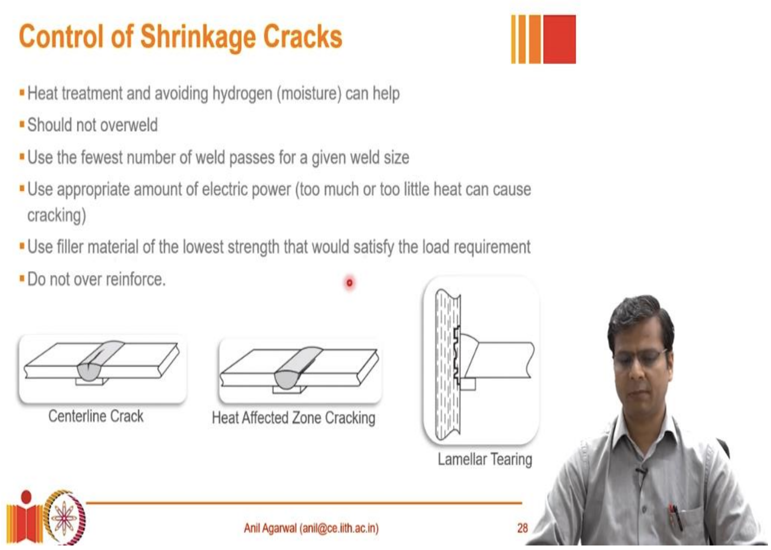

So, generally, the reason for developing a shrinkage crack or an excessive distortion is basically a poor heat management. So, we should take care of; first of all, if we do a heat treatment, meaning that we heat a larger portion of the structure and then we make it cool down slowly after the welding; if we can do that, that can more or less resolve the issue of development of cracks due to welding.

And also we need to make sure that there is no moisture present in the atmosphere near the weld, or the material that we are using for the welding, it does not have much of a moisture. That can also prevent the heat affected zone type of cracking which actually happens in the parent material, but because of the hydrogen ingress. We should also make sure that we do not overweld.

So, if the design weld requirement is let us say 6 millimetres, we do not have to provide a 15 millimetre or 12 millimetre weld there. So, we should provide only as much weld as required, because overwelding means more and more residual stresses or more and more shrinkage stresses being introduced, and they can lead to excessive deformations, distortions or excessive cracking.

We should also try to minimise the number of passes. So, what do I mean by passes, weld passes? So, for example, if this weld is let us say 12 mm thick, but I do not want to use an electrode which can do a 12 mm weld in a single pass. I may also have an option of going with a smaller electrode and do more than one pass. So, maybe I can go with a 6 millimetre weld at once and then the second pass can allow me to do another 6 millimetre thickness of this.

So, that is perfectly okay to do. However, we should try not to overdo it, meaning that we should not go for too many passes. So, we should try to optimise the weld size, the electrode size in such a way so that we can accomplish this task with the minimum possible number of passes. Because every time we do one weld pass, basically we heat the system again and we cool it down again, and we introduce new thermal stresses in the structure.

Also, if the filler material is of higher strength, it usually has lower ductility. That means that it can crack easily. So, typically, it is recommended to go for the material that is of the lowest strength that would give us the required design capacity. So, if we are able to use a lower strength material, but I am able to get the required design capacity, there is no use, it is rather avoidable to go for a higher strength material, because that would be more likely to crack.

And we should not over reinforce. As mentioned before, we should not try to use excessive amount of weld. And also this portion, that convex portion of this weld is called the reinforcement. So, without that, we could have also made it flat; but generally, to make it safer, we make it slightly reinforced slightly. We make it bulge outward, but we should not overdo it, because that can also lead to excessive thermal stresses.

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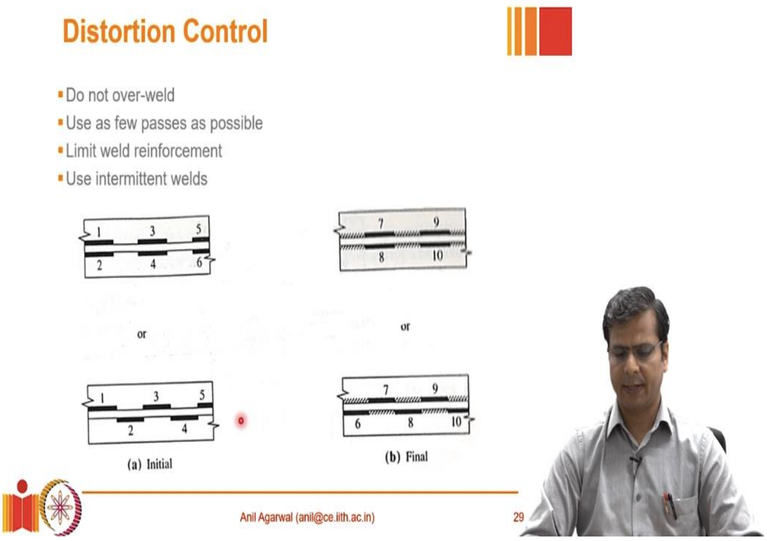

In order to prevent distortions, all the methods that were discussed before are all relevant. They should also help with the distortion. However, in addition to that, another technique that can be employed in such a situation is called using intermittent weld. So, for example, I have this plate and I want to weld this plate. This is basically a plate that is in the plane outside of the board. So, these 2 plates need to be welded.

One option would be to just weld one side of this plate in a straight line, and then come back again and weld the other side of the plate. However, what you may realise is that, as soon as you are done welding with the one side, the plate would bend completely and the entire structure would distort quite a bit. If you want to avoid that, the preferable option would be to first go in this way.

So, instead of doing the full weld, we split into smaller groups and let us say this each part is 100 millimetres. So, we do a 100 millimetre, 1, 2, 3, 4 and so on. So, with each group, we are always balancing the thermal stresses in such a way so the distortion is not very high. And subsequently, we come back again and we fill up these spaces. So, once we fill up these spaces, then the whole weld is one and we do not have to consider this as an intermittent weld anymore.

Alternatively, instead of going 1, 2 right back to back, we can also go in a staggered fashion. That is also acceptable and that is also very effective in controlling the distortions.

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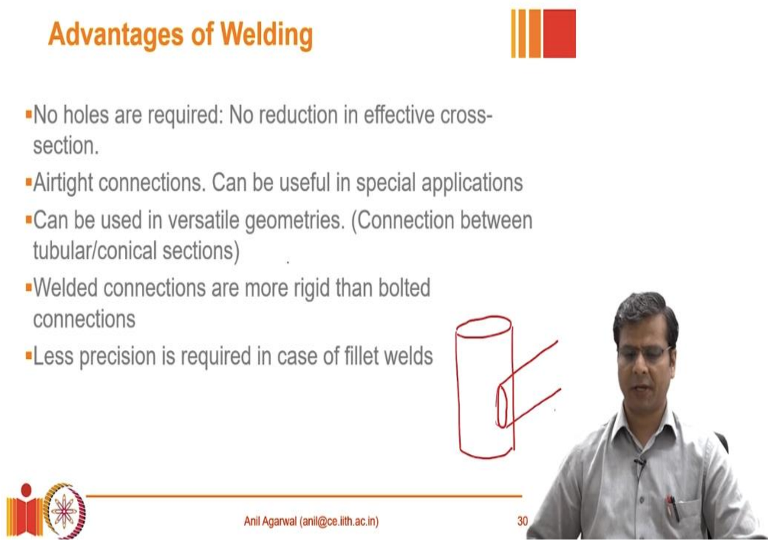

So, to summarise, we have discussed about various things of welded connections of groove welds, fillet welds and so on. What are the major advantages of welding in comparison to other techniques of joining members. So, first of all, holes are not required. When we provide welds, unless we go for a plug weld type of a connection, holes are not required. So, when we provide a hole; for example, if you want to go for a riveted or bolted connection, we need to provide holes.

And those holes cause a reduction in the cross-section. But that is not the case here, and that adds to an automatic economy of structural sections. Also welding can provide us airtight connections, which is usually not possible in a bolted connection. Sometimes, in a bolted connection, if we want to develop an airtight connection, we have to use some kind of a gasket etcetera, and their maintenance and repair becomes a problem.

However, in case of a welded joint, more or less most of the times, we are able to get airtight or watertight connections. And there are certain applications where this ability becomes very critical. Also welded connections can be used in versatile geometry. So, to give you an example, if I wish to weld 2 tubular sections coming at a particular angle and meeting here. So, doing this through welding is very easy.

We just need to find out that shape of that geometry and then we can simply weld it around this member. It is relatively easy. However, if we were to bolt it, it could have been a huge challenge actually. Creating the exact profile of that surface and then bolting them together, making sure that there is sufficient strength available, that becomes a huge challenge. So, in such kind of a complicated geometries, welding is the obvious option, obvious choice.

Also welded connections by default are more rigid than bolted connections. Bolted connections usually allow some level of slip. And even if we go for a high strength friction grip bolts, those bolts also, first of all, they reduce the cross-section area. So, automatically that member itself becomes more flexible. But in spite of that, also when we do compare that with welded connections, we see that they have almost no slip and there is higher level of rigidity available in welded connections.

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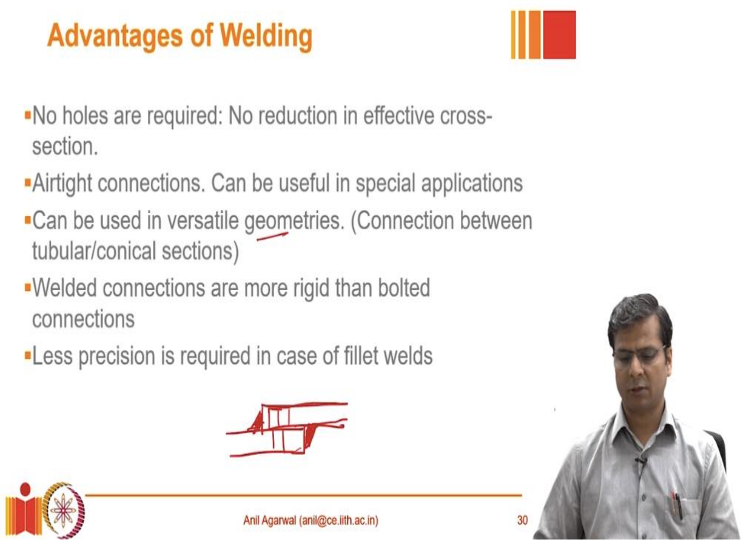

Also, if we opt for a fillet weld, then the level of precision required in fabrication is relatively low. So, for example, if you want to do a lap joint like this and we are planning to do a fillet weld between these 2 plates; and because of some lack of precision, our plates are, they were supposed to meet here, but exactly they do not meet here. This plate actually ends up only being here.

If that is the case, if it was a bolted connection, this would have completely disturbed the construction process because our holes would have misaligned. However, in case of welding, that is not a concern.

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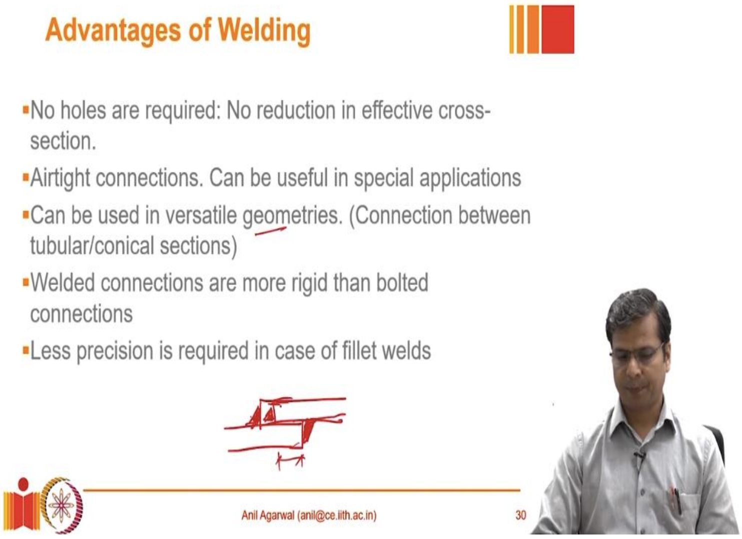

Even if we were not able to come all the way to this point, even if we were able to come only to this point, as long as it is not disturbed the other considerations such as the lap length etcetera, we can provide the weld here. And that will be as effective as the weld here.

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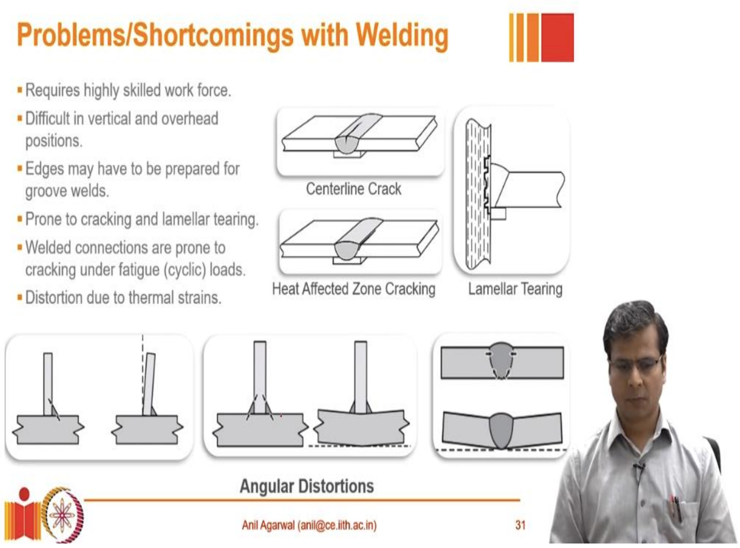

What are some of the major shortcomings of welding? Again, in comparison to other types of connections, welding usually requires higher skill level in comparison to bolting. So, bolting, if it is not a high strength friction grip bolt, it is a very simple process, almost semi-skilled person can do it. But welding is a very specialised skill, especially, if you are talking about structural welding where the weld sizes are very large.

Tack welding, you can see, lot of people can do. Outside, on the streets also you can see, several people can do it, but they may not be certified to do a structural welding. Structural welding is a highly specialised skill and there are special certifications required for those. Also a very regular, a very detailed inspections are required after welding process, because there is a very high likelihood of introducing any kind of an impurity or any kind of a distress point in a weld, and that has to be investigated, inspected rigorously after every weld.

Welding also becomes relatively difficult in certain orientations. So, for example, doing an overhead weld or doing a weld on a vertical flat surface or doing a weld on top of a very inaccessible area. In comparison to bolting, welding in such a situation becomes more difficult, because you have to carry all the cables, etcetera. Whereas bolting, all we need is a couple of bolts and a spud wrench.

Welding also requires edges to be prepared, especially if you are going for a groove weld. So, often groove welds are quite common, especially in case of splicing, etcetera. And in such a situation, we need to spend lot of time and cost on developing the edges, which is basically removal of the material. And then, again we have to fill that with the welding material. Again, as we just discussed, welded connections are susceptible to cracking, lamellar tearing and other types of defects, and that can affect the life of the structure.

Also under fatigue conditions, the welds typically are considered to be, are found to be performing more poorly in comparison to bolted connections. So, weld, since they can internally have lot of sharp corners and those are the portions which introduce shear stress concentrations, and that is where cracks can start under cyclic loading conditions. So, therefore, under fatigue and under cyclic condition, welds are typically found to be less reliable. And also they can introduce distortions in structures, which have to be prevented if they go beyond a certain limit.

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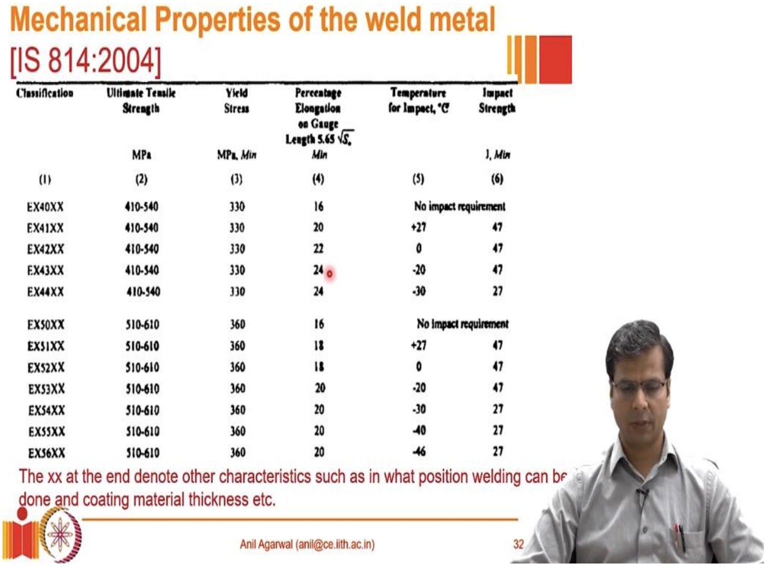

Mechanical Properties of the weld metal
[IS 814:2004]

Classification	Ultimate Tensile Strength MPa	Yield Stress MPa, *Min*	Percentage Elongation on Gauge Length $5.65\sqrt{S_o}$ *Min*	Temperature for Impact, °C	Impact Strength J, *Min*
(1)	(2)	(3)	(4)	(5)	(6)
EX40XX	410-540	330	16	No impact requirement	
EX41XX	410-540	330	20	+27	47
EX42XX	410-540	330	22	0	47
EX43XX	410-540	330	24	-20	47
EX44XX	410-540	330	24	-30	27
EX50XX	510-610	360	16	No impact requirement	
EX51XX	510-610	360	18	+27	47
EX52XX	510-610	360	18	0	47
EX53XX	510-610	360	20	-20	47
EX54XX	510-610	360	20	-30	27
EX55XX	510-610	360	20	-40	27
EX56XX	510-610	360	20	-46	27

The xx at the end denote other characteristics such as in what position welding can be done and coating material thickness etc.

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So, now we have gone through a brief summary of different advantages and disadvantages of welded joints. Now, we will move into some designing considerations for welded connections. So, for understanding the designing, we should also look at the material characteristics of the filler material that is typically used in welded connections. So, in case of regular manual spark welding, we use the electrode which is also the filler material and the electrodes are classified with these symbols.

What you can see here is that EX40XX. Here, basically, 40 represents the strength and the ductility properties of this electrode material. And the last 2 symbols, this XX actually, this will be replaced with some other symbols which could denote the other relevant characteristics which are not really so important from a structural engineering point of view, such as in what position the welding can be done and what is the coating material thickness, etcetera.

The electrodes are available in various strengths. IS 814 provides us some details of different strengths that are available. So, they are typically denoted by the ultimate strength of the material and the corresponding yield stress values are also specified in the same code. The difference between 41 and say 43 is the level of ductility that is available between the 2, between the 2 electrodes.

So, this electrode is less ductile or otherwise it is not suitable to be used in impact conditions where the loading could be of a very high strain rate. And however, when we opt for an electrode, lower in this order, such electrodes are capable of resisting impact loads up to -20 degree centigrade temperatures. That is, they have had a quite high impact and strength even at a very low temperature, and they exhibit greater level of ductility also.

So, this is a measure of ductility which is percentage elongation before the rupture. And likewise, we have higher strength electrodes also. So, the electrodes have to be picked appropriately.

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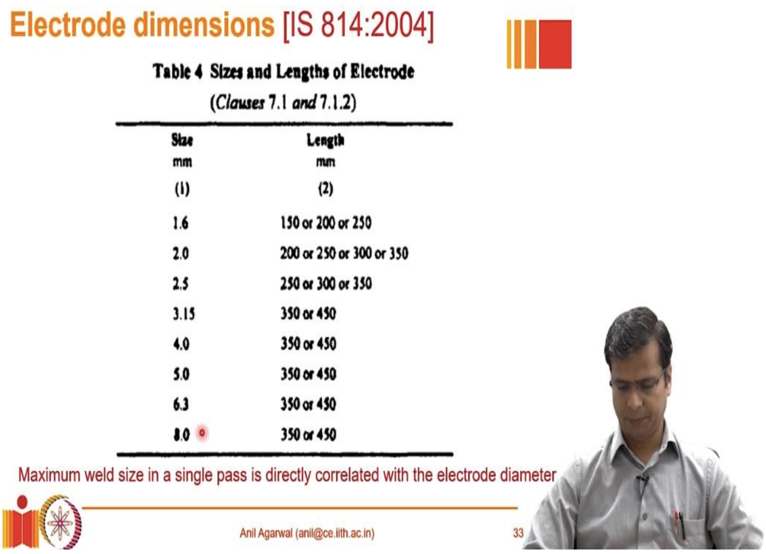

Table 4 Sizes and Lengths of Electrode
(*Clauses* 7.1 *and* 7.1.2)

Size mm	Length mm
(1)	(2)
1.6	150 or 200 or 250
2.0	200 or 250 or 300 or 350
2.5	250 or 300 or 350
3.15	350 or 450
4.0	350 or 450
5.0	350 or 450
6.3	350 or 450
8.0	350 or 450

It is not only the electrode strength that is relevant, it is also important to pick the electrode dimensions, because, the length of the electrode of course has some role to play, but most significantly, it is the diameter of the electrode. This is not really a responsibility of structural engineers. Usually, the welders, they themselves are qualified enough and they are supposed to pick the appropriate electrode size for a given weld size.

So, if the structural engineer would mention a weld size of 8 millimetre, then the welders have their own manuals, they need to refer to those manuals. And then, accordingly they pick for that given weld size what is the electrode diameter that they should go for, because there is a direct correlation. If the electrode diameter is larger, you can do a larger weld size. And also they need to pick the amount of current, because that also has a strong role to play in deciding what size weld can be used, can be provided with which diameter electrode.

So, they pick the electrode diameter and the power output, and then they are able to do the required weld. Here this table specifically lists the different lengths which are available for a given diameter.