Design of Connections in Steel Structures
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Module - 2
Lecture - 7
Groove/Butt Welds

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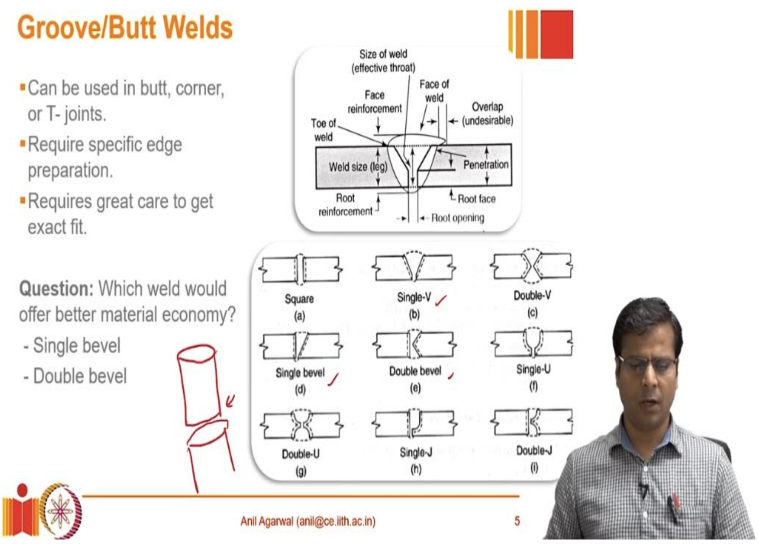

Let us discuss groove welds first in some more detail. So, as we had seen, groove weld is also known as butt weld in common language. So, basically, if we have these 2 plates that we want to join together, the easy option is just to have a groove in between and fill it with filler material. Now, the groove can be just the gap between the 2 plates and we do not have to create this kind of an inclined groove.

However, because we want to also make sure that we are able to fuse sufficient amount of depth of this cross-section, it may be advisable to create an inclined groove so that the electrode wire that can reach sufficient depth so that the material at depth can be fused sufficiently. If the plates are very thick, the grooving or the creating of these inclined surfaces becomes almost essential, we cannot avoid it.

If the plates are relatively thin, we can manage with a square kind of a groove where we do not have to do any chamfering at the surfaces. If we need to prepare surfaces for the weld material to get deposited, there is one option where we do not use any special treatment, which is just a square surface, but often we may go for a V or a double V, single bevel or double bevel or U or J type of grooves.

The difference between a bevel and a V is that in a V groove, both plates have to be grooved. So, let us say, if we figure that we require an angle of about 60 degrees in between for the electrode to be able to access the deepest positions, then that 60 degree angle can be achieved either by cutting 30 degree from each plate or just simply cutting 60 degree from a single plate. So, that is a designer's choice.

Depending on which option is more convenient, the designer may choose to go with a bevel or a V groove. Now, the difference between single versus double is whether the welding will be done from both sides or from a single side. If the welding needs to be done from both sides, that requires, for that, you need to have access from both sides. There might often be situations where we may not have access from both sides.

So, if that is the situation; let us say we want to weld 2 tubes together. So, there is a tube and this tube needs to be groove welded with another tube here. Now, we only have access from outside; we do not have access from inside for welding. So, therefore, we have to go for a single V or a single bevel. We will not have the option to go for a double V or double bevel. However, if we have straight plates where we have option to weld from both sides, we may opt to go for double V or double bevel.

Groove welds are not as common as the fillet welds. There are couple of reasons for them. One major reason for that is that first we have to prepare the edges and which is time consuming and cost also is involved; creating those edges takes money and time. Secondly, a great care has to be taken to make sure that these 2 parts meet exactly at the distance that is intended.

So, maybe, if we wanted this gap to be let us say 10 mm and because of some fabrication errors or something, if this distance turns out to be 20 mm, which is quite common; 10 mm on and off is very easy in any decent sized project. If that happens, then the entire weld becomes very complicated and we have to do take care of so many different things to make sure that the weld develops good fuse surfaces.

Because of these challenges, usually groove welds are less common in comparison to fillet welds. Now, I have a question. We discussed about a single V and a double V or a single bevel and a double bevel. So, let us say if we want to go for a bevel kind of a groove, between single bevel and double bevel, which option would provide us more material economy? Let me explain the question again.

So, between these 2 options, if let us say the 2 plate thicknesses are the same; let us say it is 18 millimetre, 18 millimetre in both cases. Now, we want to use bevel grooves to join the two. One option is; and I have both options, I have option to either use single bevel or double bevel. Which one would use less material in your opinion? Please let me know what you think.

So, the answer to this question is, double bevel would provide better material economy and the simple way to do that is; let us say we calculate that we need a certain angle here to be able to get a good fuse. That depends on what is the size of the electrode and etcetera. So, if that angle has to be maintained and with the depth is 18 millimetre, here we can calculate how much material has to be first removed in form of a groove and then filled back again with the filler material.

And then we can calculate the area in a double bevel also for the same angle that has to be maintained. And you can very easily calculate that the amount of material that is required to be filled in case of a double bevel is much smaller than the amount of material that is required to be filled, first removed and then filled in case of a single bevel. So, double bevel is a more economical option from material point of view. So, now, let us start looking at the 2 distinct ways of providing groove welds. One method is known as a complete penetration joint and the other one is a partial penetration joint.

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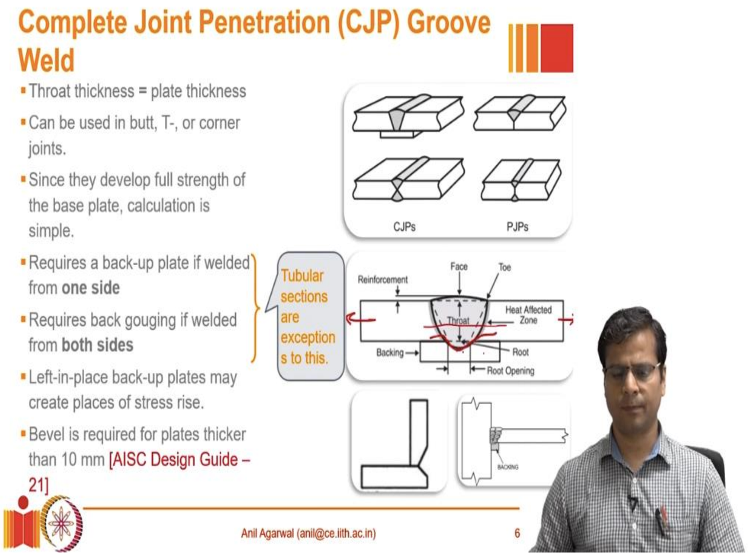

So, the Complete Joint Penetration, CJP type of groove weld is the one that is usually preferred in most of the situations. However, it is more challenging to provide, and therefore, it may not be as commonly used. So, we call a groove weld a complete joint penetration weld when the thickness of the groove weld is same as the thickness of the plates that it is joining. So, for example, in 4 images that are shown here, the first 2, these 2 images show a complete joint penetration.

So, in this particular case, the welding is done only from one side. However, the thickness of the weld is same as the thickness of the plate. In addition to that, there is some reinforcement provided which is this convex shape at the top. Also in this case, the welding is done from both sides, but it is done in such a way so that the entire thickness of the 2 plates are fused together using the welding material.

And in addition to that, there is an additional reinforcement provided. So, both these welds qualify as complete joint penetration groove welds. These are the examples of partial joint penetrations where only a fraction of the total depth of the plate or total thickness of the plate is welded through groove welds. So, this is a single sided one; this is double sided one; but in both cases you can see that some portion of the plate remains unfused, some thickness of the plate remains unfused.

So, this will be called a partial joint penetration. A typical groove weld consists of these parts. A complete joint penetration weld consists of these parts. These are the 2 plates that are going to be joined together. There is a groove created which may be square groove, which basically means no additional material to be removed. Or if it has to be bevelled, then these bevel surfaces have to be created, either V shape or a bevel, where in case of bevel, only one plate is bevelled.

Subsequently, if it is to be a single sided weld, that means we are going to weld it on only from one side, then there is a possibility that the material that we deposit will not completely fuse the 2 plates together, because at this side, there is a chance that it will leak out. In order to prevent that leakage, we have to provide a backup plate which is known as backing plate, marked here.

So, even in a single sided complete joint penetration weld, we provide a backing plate. And the idea here is, with the help of backing plate; and the backing plate itself is tack welded to the 2 parent materials. Then this backing weld basically keeps, provides kind of a cavity for the molten material to stay here. And in this process, the 3 plates, the backing plate and the 2 parent plates get fused together by the deposit of this filler material.

In addition to this deposit, we also need to provide a reinforcement which can be seen in the form of a convex surface at the top. Also we have to be very careful about the geometry of the toe. The toe should not be over protruding; it should be smoothly merging into the parent surface. Since this total thickness is essentially same as the thickness of the parent material, plus some additional thickness is available, which is known as reinforcement; calculation for these welds is very easy because geometrically it is basically same as the parent materials.

And the stress flow from one metal to other metal or one plate, one part to other part is also straightforward, without any discontinuity in geometry. As I mentioned, if we weld only from one side, we have to provide a backing plate. If otherwise, if we have an option of welding from both sides, we need not provide a backing plate even if there is some poor quality weld on the other side.

What we are supposed to do is, for example, in this case which is a double sided weld, first we weld from one side. Even if there is some area, some portions which are not properly fused, we need to back gouge. So, back gouging basically requires some machining of some of the area from the backside so that we get smooth surfaces and completely fused surfaces together.

We keep machining it until we get that kind of a smooth surface; and then, again we fill it from the other side. So, such kind of a filling is called double sided one. In tubular sections however, it may not always be possible to provide a back plate or to do a double gorging, but still sometimes we do a complete joint penetration weld in tubular sections. But, all other sections, we are usually required to either provide a backing plate or do a double sided weld.

This backing plate, if it is left at place; generally, it is left at place, however, when the members are going to be subjected to cyclic loading or large tension forces, in such situations, there are locations here and here which can rise to high levels of stress when it is subjected to stress. For example, if it is subjected to a tensile force demand, if these 2 plates are pulled apart like so, the stress ideally should flow directly through this filler material. However, since the backing plate is also fused together, some of this stress would want to flow from this part of the weld.

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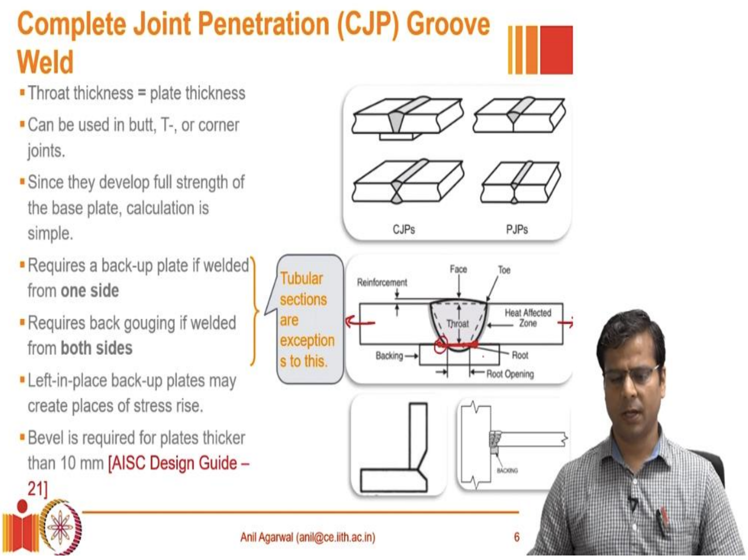

In that process, you might notice here, we are having a very sharp reentrant corners of unfused surfaces. So, some portion of these 2 plates are fused together, but some portions, maybe up to here it is fused together, but at this location, it is not fused nicely. And right there, you have very high sharp reentrant corner, and that is where we expect high stresses to develop.

And in certain earthquake conditions, it has been observed that backing plates were the reason for the development of cracks in welded connections. So, in such a situation, it is recommended that backing plates should be removed, and then it should be machined to get a smooth surface. AISC design guide 21 recommends that whenever we go for a plate, whenever we are providing a butt or a complete joint penetration groove weld, if the plate thickness is more than 10 millimetres, we need to bevel one of the surfaces at least.

So, bevelling will allow the electrode to go to the full depth. If the plate thickness is less than 10 millimetre, we can manage with a square groove. Such kind of welds can be provided in various geometries. So, the one most option, most common one that is there in its name itself, the butt weld, which examples are shown here. But also it can be done in a T-joint or a corner joint. So, here are some examples.

Here is one plate and another plate is being welded to it at 90 degree angle, but this plate is continuous and this plate, at the joint, and a groove is created right here at this gap and it is filled with a groove weld. An alternate requirement could be where this plate terminates at this location, and then a groove is created by bevelling both of these plates. It need not be both plates, only one can be bevelled and then this groove can be filled. So, it is a versatile joint but not as versatile as some of the other joints we are going to talk about.

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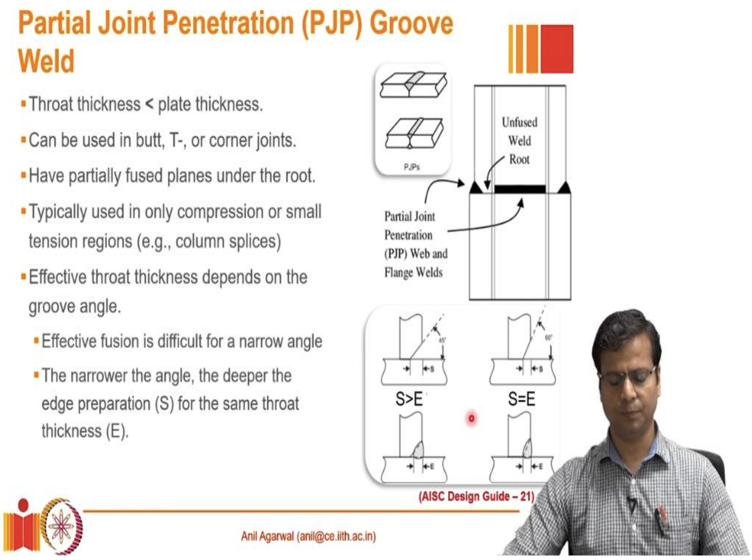

The other variety of groove weld is known as partial joint penetration weld. In case of a partial joint penetration weld, only a fraction of the total thickness of the plate is fused and the rest of the thickness remains unfused. It again can be used in various configurations including a butt joint, a T-joint or a corner joint as we saw before.

This is most commonly used in situations where the tension demand is not very significant and it is mostly dominated by compression force demand, because compression can be resisted directly through bearing between the members, and the weld does not have to resist very large amount of tension force demand. An example for that would be splicing of I-sections or columns.

So, here you can see one column. This is the flange; this is the web; this is another flange. And another wide flange section is sitting on top of this column. The 2 sections in this case are not exactly the same but almost similar. And you can see that in such a situation, we do not even have to provide a cover plate between the 2 sections. We can simply groove weld the 2 sections together, the web to the web, the flanges to the flanges.

And we do not have to even provide a complete joint penetration if this column is not subjected to large tension or flexural demands. If it is primarily compression, these welds should do the job. Now, in such welds where the complete thickness is not welded together, there are couple of challenges. One such challenge which one has to be careful about is that even though we provide a groove of let us say S thickness, so, the objective is that we will; let us say the plate has a thickness T and we know that we need a thickness s weld, and we provide a groove of s depth.

Now, when we start depositing the material, it may so happen that the material does not get deposited to the final depth; some portion of that groove may remain unfused. And that again is a function of how wide this angle is, because, if the angle is wider, the electrode can reach the deeper depths and the molten material can fuse the 2 plates together more effectively. But sometimes it may so happen that this angle is not very wide.

And if this angle is not wide, the electrode may not be able to push the molten material to the very end of the groove. And therefore, the E which is actually the effective throat thickness in this partial joint penetration weld is less than the intended value which was s. And in such a case, we have to account for it. There are guidelines; the American design guideline provides you some kind of a design guideline through which; if let us say I wanted to provide a throat thickness E, I have to account for this possibility that it may not fuse the entire groove completely. And I have to provide slightly larger groove if the angle is less than certain value.
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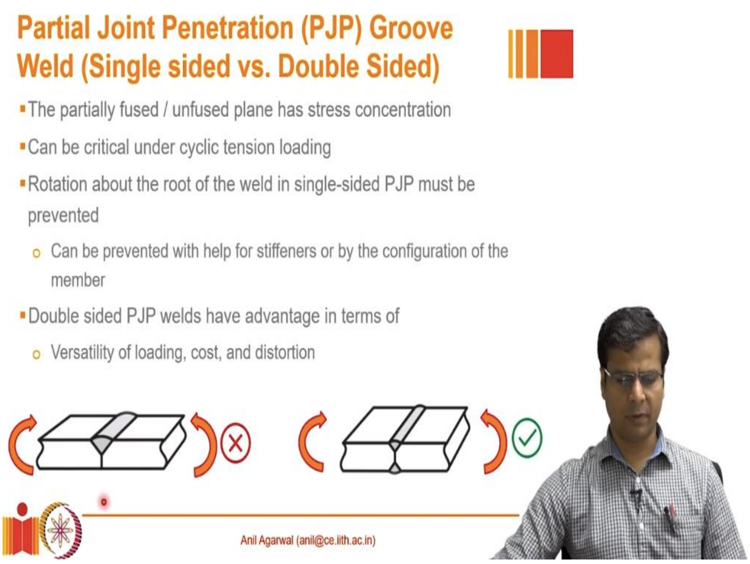

So, as we have discussed, partially joint penetration groove welds, they have; if part of the thickness of the plate that they are joining are fused and a part is unfused; so, in this case you can see, these 2 plates are being joined, this portion of the thickness is fused together, but this portion remains unfused. So, whenever we have such a situation where some portion of the thickness is unfused, that interface right there becomes the location where the stress concentration can occur under a stress condition.

So, when these plates are being pulled apart, at that location, we can expect some stress concentration. And that is where the crack can start. Especially under cyclic loading conditions, fatigue cracks are quite common and they are often observed to have started from such locations. Also one must be careful that when we provide a single sided partially joint penetration groove weld, the one that is shown.

For example, here, and if it is subjected to a loading in such a way so that this root at this location is subjected to large tension force demands, or if it is subject to a situation where it leads to some kind of stresses which produce opening of this weld at this location; for example, the type of loading that is shown here will produce a moment demand at the root of the weld.

Such type of loading has to be prevented in single sided partial joint penetration welds. However, in a double sided partial joint penetration weld, you may see, if weld is present on both sides, a moment which is applied like this does not produce a very large stress demand here, because there is a lever arm available. And therefore, such kinds of welds are more versatile they are able to carry different types of loads.

Even single sided partial joint penetration welds can be used in this kind of loading situations as long as we can prevent the stress development in this area. And such an objective can be achieved by providing additional arrangements such as a stiffener, or if this is not just a plate but an angle or something like that, where there is a lever arm available, and if that is available, this kind of a weld can be provided still.

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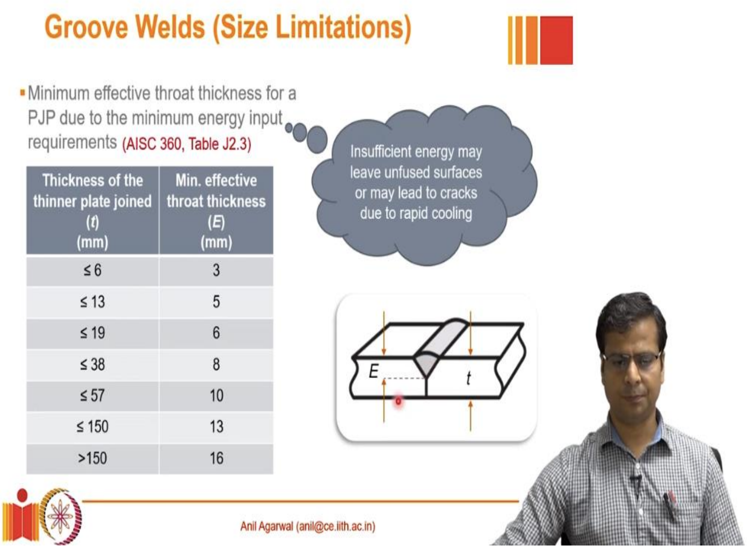

When it comes to the size of a PJP, that is Partially Joint Penetration groove weld, sometimes we of course have to provide the joint, the weld of sufficient size, so that it has the ability to resist the design loads, whatever the loads are coming; but sometimes, the load requirement may be very small and we may require very small amount of joint. But there are other considerations which force us to put a minimum weld size as per this clause here.

So, depending on the thickness of the thinner plate, the American steel design guide, that is AISC 360 recommends a minimum effective throat thickness of a partial groove weld. So, for example, if a plate thickness is say around 19 mm, just short of 20 mm, then a PJP throat thickness has to be at least 6 mm, to which you can see is approximately one-thirds of the plate thickness. So, up to about one-thirds is a minimum required groove thickness.

And the consideration why we have to provide at least this much of thickness is because at least a certain amount of material or certain amount of energy is required to be able to fuse the 3 materials together. So, if the weld size is very small, that means a very small size electrode and very small amount of current is required to weld that material. And if that is the case, but the plate thicknesses are very large, that amount of heat that is imparted may not be sufficient to properly fuse the 3 materials together.

And therefore, a minimum size is required which ensures that the 3; there is enough heat deposited to the base material, so that it reaches the required temperatures, so that the 3 materials can fuse together. If sufficient heat is not provided, one problem could be that 3 materials do not fuse together. Also the another problem could be that the thicker plates, they cool down very fast.

So, if the heat is not sufficient, that heat will, even after fusion, complete fusion, the heat will dissipate very quickly away from here, which will lead to large thermal stresses getting developed in the welded region. So, it is better that the weld cools down slowly. And for that to happen, there has to be sufficient heat imparted at the time of welding for a given plate thickness.

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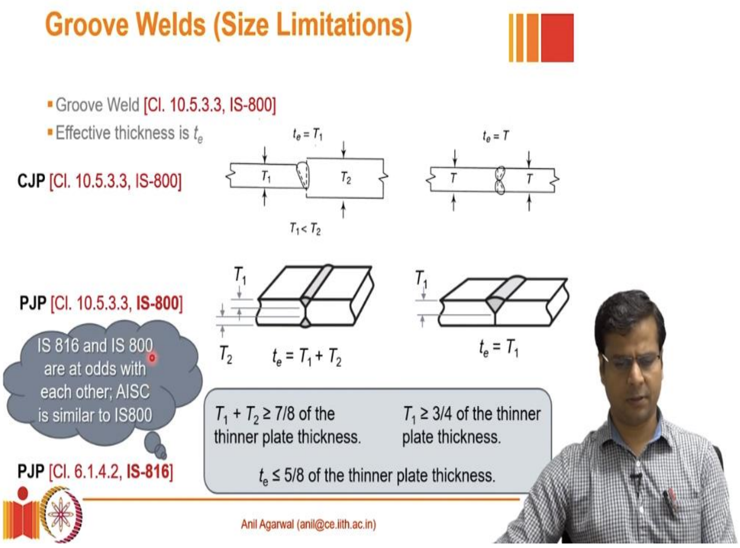

The American code recommendations you have seen; also the Indian code IS 800 has some recommendations. For full penetration joint, full joint penetration groove weld, it says that, it suggests that the weld thickness should be or the throat thickness of the weld should be at least equal to the thickness of the thinner plate. So, for example, if these 2 plates are being butt jointed, the throat thickness will be taken as t_1, wherein t_1 is smaller of t_1 and t_2.

If the 2 plates are of equal thickness, the throat thickness will be same as the thickness of the plate in case of a complete joint penetration weld. In case of a partial joint penetration however, the throat thickness is basically the summation of the 2 parts or a single part, whatever the total weld thickness is, that is taken as the throat thickness. That is as per IS 800.

In addition to IS 800, there is another Indian code which governs the welding considerations for construction applications, IS 816. And what IS 816 suggests for PJP, Partial Joint Penetration welds is that the throat thickness should not be taken to be more than five-eighth of the thinner plate thickness. So, if the 2 plates are being joined, even if we are welding a major portion of the weld plates together, the throat thickness in our calculations, we should not consider it to be more than five-eighths.

That is, three-eighths of the plate thickness should be assumed that it is not welded. In addition to that, it also requires that if welding is double sided, then at least seven-eighth of the total thickness of the thinner plate should be actually fused. So, $t_1 + t_2$ should be at least seven-eighth. And if it is single sided, then too at least three-fourths of the thinner plate thickness should be actually weld. This is in my opinion a very conservative guideline.

If we compare that with the American guideline where one is required to provide at least one-third approximately. I give you an example. When the plate thickness was 19 mm, at least 6 mm weld was required. So, that was approximately one-third of the thinner plate thickness was required. Whereas the IS 816 requires the PJP weld to be at least seven-eighth or three-fourths of the total plate thickness.

So, what we can see is that, here even IS 800 and IS 816 are kind of in disagreement. IS 816 has this requirement which is not present in IS 800. IS 800 simply says that you take these 2 thicknesses and that is your throat thickness. And you do not have to take it to be five-eighths maximum, which is very similar to the American standard. So, we can typically, being structural engineers, we can consider IS 800.