Design of Connections in Steel Structures
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Module - 3
Lecture - 16
Design of Frame Simple Connection

So, in the previous classes, we have discussed how to design a simple bolted connection, a simple welded connection. And in the previous class, we discussed how to design a group of bolts or a group of welds when they are subjected to a twisting kind of a moment demand. So, the forces that we had studied created a direct shear force and also a twisting force, which produced shear forces in various directions and we studied how to design bolted and welded connections for such kind of loading conditions.

Today, we are actually going to go into the details of frame structures. And actually, we will focus on the different types of simple connections that can be used in frames and how to design them. So, this is a very vast field and it is very difficult to cover the entire area in a small course, like a 1 credit course that we are doing here. But we will do a few examples and try to bring home the basic concepts.

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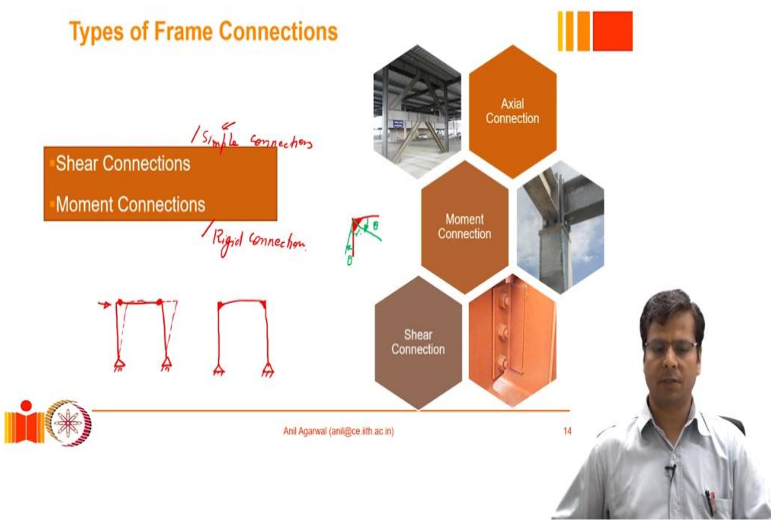

So, first of all, what type of connections are typically possible in a frame? So, if you have seen, when I say frame, I mean a portal type of a frame which could be used in a building type of a structure. So, what you see here are 3 examples of such frame systems. This is a frame which has a set of braces attached to it. This is also called a frame, but this is a braced frame.

And also there are alternative types of frames to resist lateral loads, which are known as Moment Resisting Frames, MRFs. In any typically steel building which has some such frames which resist lateral load, such as braced frames and moment resisting frames, in addition to these 2 types of frames, the majority of the other frames are typically only the frames which are designed to resist only the gravity loads.

So, such frames typically do not have a very high lateral load resistance. And the reason for that is, because the design and construction of such frames which can resist lateral loads is specialised, takes lot of effort and time and cost, therefore, the idea is usually to design only designate a few of the frames to resist the lateral load, while a majority of the frames just remain there and they lean or they deflect as the moment resisting frames or lateral load resisting frames allow them to deviate.

So, if the lateral load resisting frames were not there, the gravity frames would simply collapse, because they do not have much lateral stiffness. So, they are tied to the lateral load resisting frames, and that is how they remain erect. Most of the such frames which do not have significant amount of lateral load resistance, they consist of beams columns like they are supposed to, and in addition to that, there will be shear connections which will be joining the beams to the columns or beams to the girders.

So, if there is a grid system in the floor, then you would have primary beams which we may call girders and secondary beams which we may also refer to as simply beams. So, the connection between them or the connection of the girders or the beams to the columns; many a times, all those connections are not moment connections, they are simply shear connections. And shear connections are also referred to as simple connection.

And moment connections are also referred to as rigid connections. So, why is a frame with a moment connection able to resist lateral loads but a frame with shear connections is not able to resist the lateral loads? We can see it very easily through this visualisation. I will draw a small schematic here for your assistance. Imagine that we have a quarter frame and let us say the base is pin-pin.

Now, in this frame, if we have hinges here, that means there is no resistance against relative rotation. When I say relative rotation, I mean the rotation of the beam with respect to the column. So, if the beam and column can rotate with respect to each other, that type of a connection would be a shear connection or simple connection. Why is it called a shear connection?

It would still be a shear connection because when we apply vertical loads on the beam, this connection would be able to effectively transfer that force to the column. So, it is able to transfer the shear forces to the column effectively, but it is not able to transfer the moment. And therefore, the bending moment at that point will be 0, at the location of the hinge. And if that is the case, we can very easily visualise.

If you apply lateral load, this frame can simply topple over like this. It does not offer any resistance. Therefore, such frame systems, the frame systems which consists of only shear connections between beam and columns cannot resist lateral loads. However, the other type of frame could be the moment resisting frame which is one example of lateral load resisting system.

Again, I am keeping the boundary conditions the same, but this time, instead of having a hinge there, we have a rigid joint. So, a rigid joint theoretically does not allow any relative rotation between the beam and the column. So, if the column wants to rotate at this location to wherever there is a rigid connection, if the column say wanted to rotate by a certain angle theta, the beam also has to rotate by that same angle theta so that the angle between the beam and the column does not change. And that is the definition of a rigid connection.

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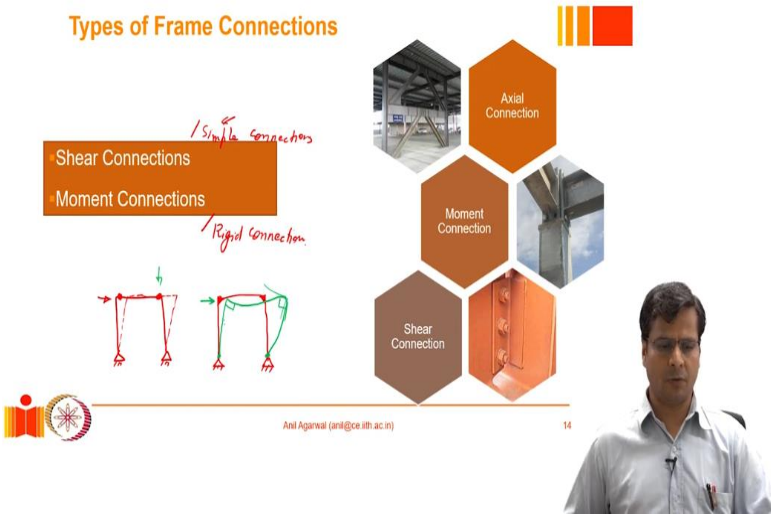

And in such a situation, if we wish to draw the deformed shape of this system, if we apply a lateral load, most likely we will end up with a deformed shape which would look somewhat like this. Excuse me for this inaccurate drawing, but I hope you get the idea. So, in this kind of a deformed shape, you can see that the members are going to be subjected to flexure; the members will not remain as rigid bodies like that was the case in the previous example.

Here, the members are subjected to flexure. That means, this frame is offering resistance to the lateral load. So, these 2 types of connections are very commonly used in steel structures and we will learn about them. So, in this section, we are going to talk about the simple connections which do not offer moment resistance so that they could be used in frames which are not going to be there to offer the resistance against lateral loads.

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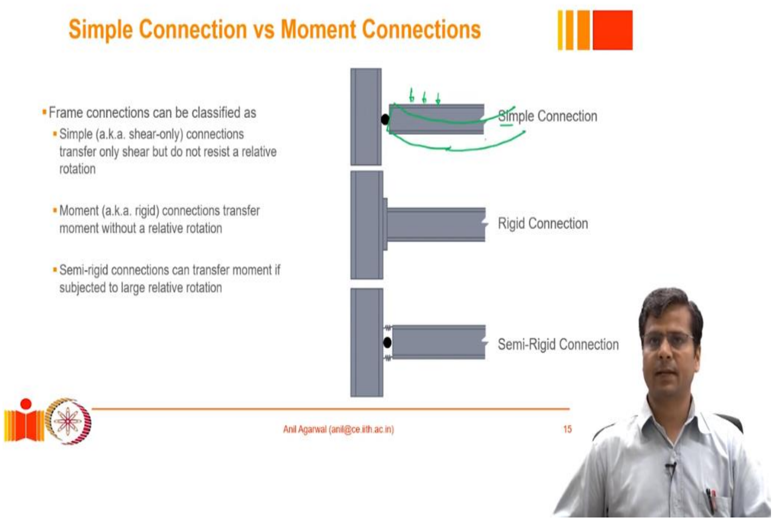

So, a simple connection can be schematically represented with this diagram. So, we can see that there is a column. It need not be column, it could also be a girder; but I have shown a column here; and this is a beam. The beam is supported by the column, meaning that the loads that are acting on the beam, if there are any loads acting on the beam, they will be transferred to the column, and that is how it will go to the foundation.

So, there are 3 examples. Now, a simple connection is meant to transfer all this load to the column without restricting the rotation of the beam here. So, basically, the expectation is that, when these loads are applied and the beam wants to deflect, the beam would be allowed to deflect as it would deflect as if it was simply supported beam. So, it would deflect and it would even rotate at the ends without having its rotation restrained by the support here. Now, of course, I have shown it in a systematic fashion by putting a dot here, a big dot here.

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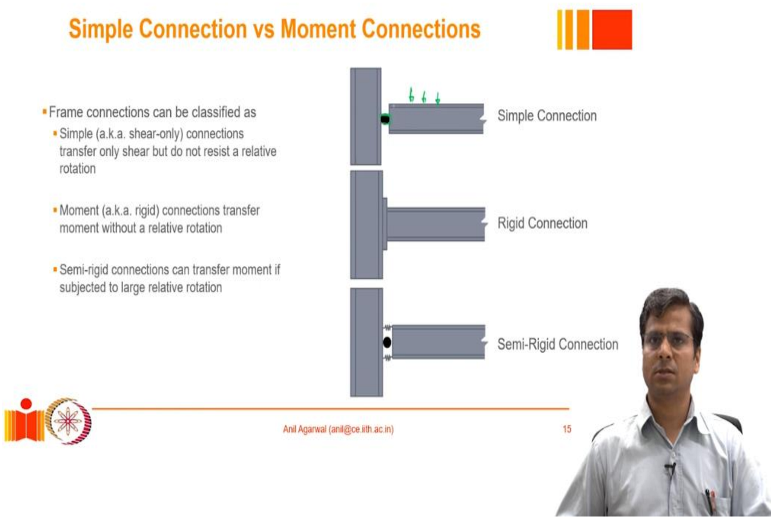

But actually what it means is that we are connecting the beam to the column closer to the neutral axis or not distributed over a large depth. So, that connection whatever we are providing, it should not be stiff or it should not be distributed over a very large depth.

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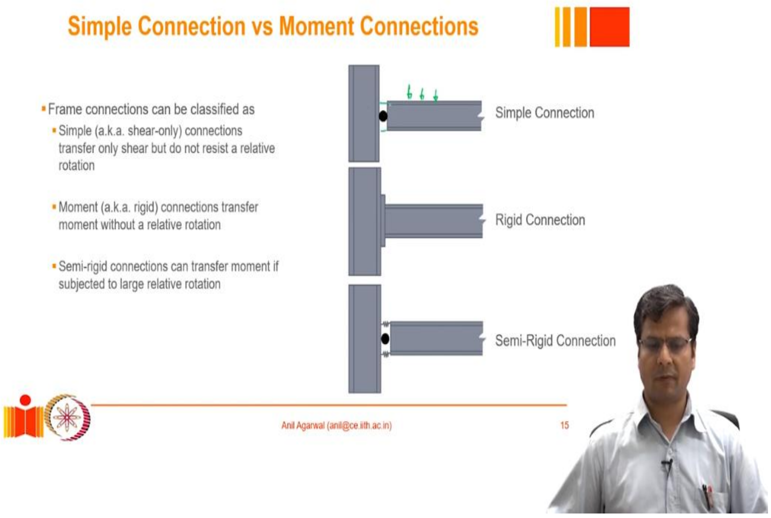

If it is connecting the top and the bottom flange also effectively with the column, that would introduce a resistance against relative rotation; and then it will not be simple connection.

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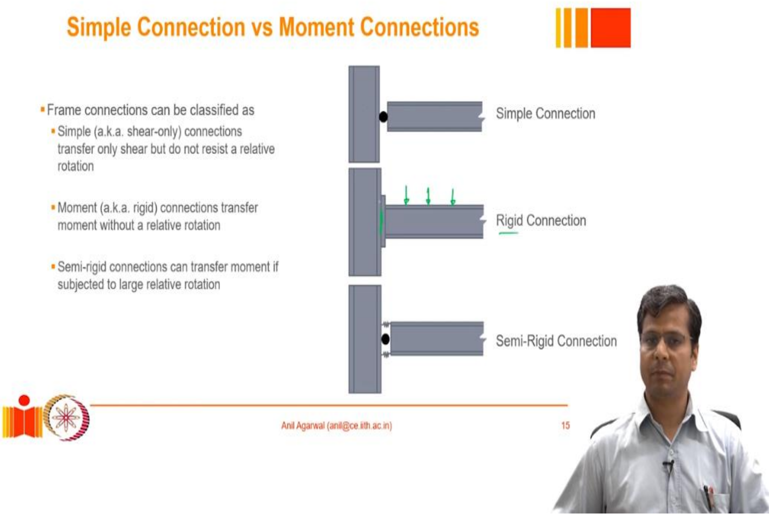

The exact opposite of this type of a connection would be a rigid connection. In case of a rigid connection, of course the shear has to be transferred. So, any vertical loads that are applied to this beam, they have to be transferred to the column through this interface, which is the interface between the beam and the column. And in addition to that, it also should not allow a free rotation of the beam.

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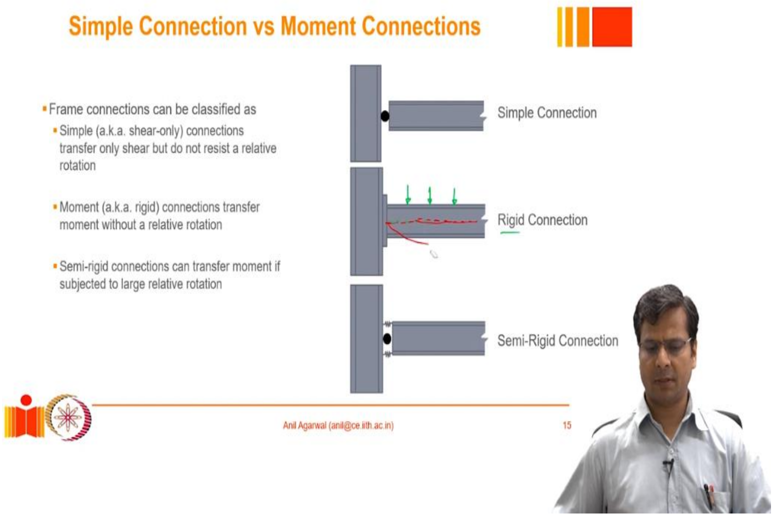

Meaning that; let me use a red pen; if this is the centre line of the beam in the beginning, before the deformation, after the deformation, it cannot simply rotate like this.

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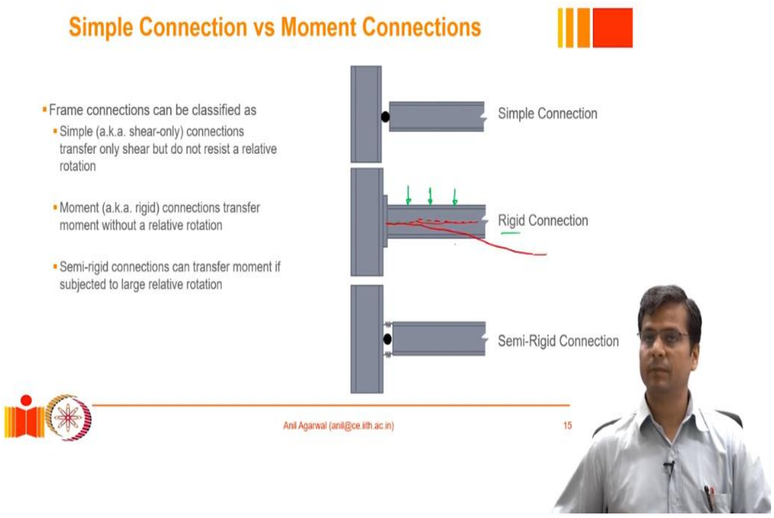

It has to maintain the 0 angle if the column is rigid; assume that the column is rigid for the time being. If the column was rigid, this has to maintain this line and slowly develop a double curvature kind of a deformation. And that would be possible if we have a rigid connection. And there is always an in between the two.

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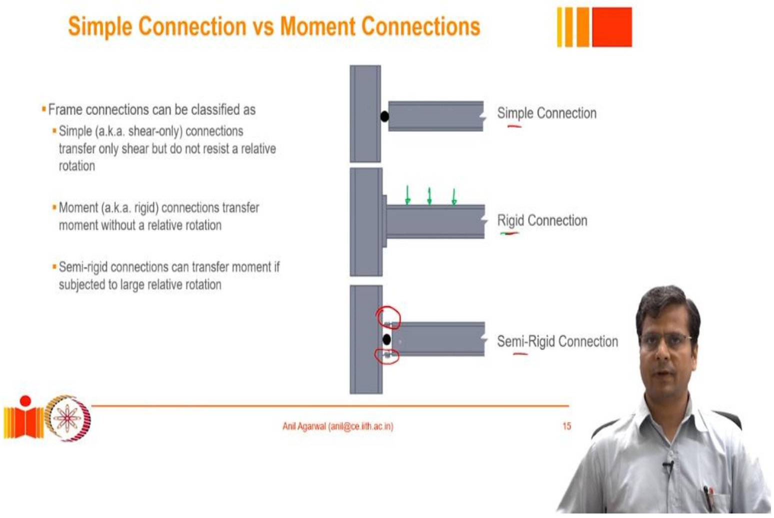

So, these are the 2 extremes, simple and rigid connection, then there is a possibility of semi-rigid connections, because sometimes we may design the connection as if it is a rigid connection, but these elements that we might be using to connect the flanges of the beam to the column may not actually be as stiff as they could be. And as a result, there will be some flexibility available, and that could lead to a semi-rigid type of a connection. These are also utilised, but generally when it comes to designing, we typically design a connection either as a simple connection or as a rigid connection.

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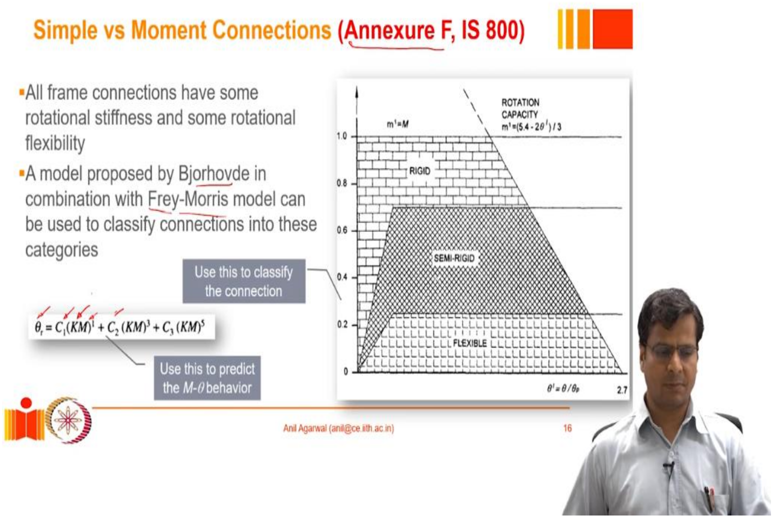

So, we saw that there are 2 primary types of frame connections, simple connections and rigid connections. Now, that is in theory, but in reality there is no real simple connection and there is no real rigid connection. And the obvious reason for that is because even a connection that we might believe to be simple connection does offer some level of restraint against relative rotation. That is, it has some moment capacity.

When we make it rotate relative to the column, it will offer some resistance and it has some strength. Similarly, a connection that we might have designed as a rigid connection, still consists, it is made of some kind of an elastic material. All those materials can deform. And therefore, any components that are used to make a rigid connection have some level of flexibility. Therefore, there is no true rigid connection.

And as a result, we cannot classify connections as rigid or flexible, or rigid or simple, and in black and white fashion. We have to use a grayscale to basically quantify the level of rigidity. And there is lot of research that has been done in this area and it is a very established field already. The special provisions that are incorporated in the Indian Standard, IS 800 Annexure F lists a set of formulae that can be utilised to ascertain whether a particular type of connection is a rigid connection or a flexible or simple connection.

So, this formulation was developed by Professor Bjorhovde. And then, in addition to the equations for connection stiffness that were proposed by Frey and Morris, this could be utilised to predict whether a given connection is a simple connection or it is a rigid connection. So, basically, what happens is that; there are large number of equations given in Annexure F; I am not going through all of that, beyond the scope of this course.

But what would happen is that, depending on the geometry of the connection and type of connection, so, whether it is a double angle type connection or shear type connection or double angle shear connection or a T stub connection, whatever type of connection it has; it has a list of pretty large number of connections; for those, you can calculate various parameters depending on the dimensions and type of connections.

Those parameters are C_1, C_2, C_3 and K. These are the different coefficients that depend on the type of connection. And M is the moment that we apply to the connection. And θ_r is the relative rotation between the 2 ends of the connection, that is between the beam and the column.

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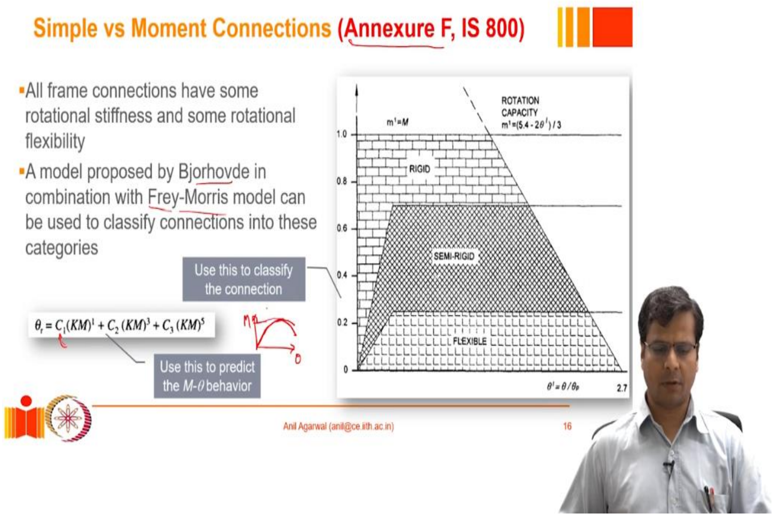

So, depending on what type of connection we have and what are the different material properties and geometric properties of the connection, we can develop an M – θ curve. So, M – θ curve would typically look somewhat like this. So, like any other force displacement curve, M – θ curve is also a type of force displacement curve it would have where M would be the vertical axis and θ would represent the horizontal axis.

And initially, there will be some linear part and there will be some distance parameter. There will be upper limit of this curve, which will give us the moment capacity. Then, subsequent to that, we can try to fit that curve or we can try to map that curve onto this chart. So, this chart basically gives broad guidelines of the stiffness ranges. So, this is again theta.

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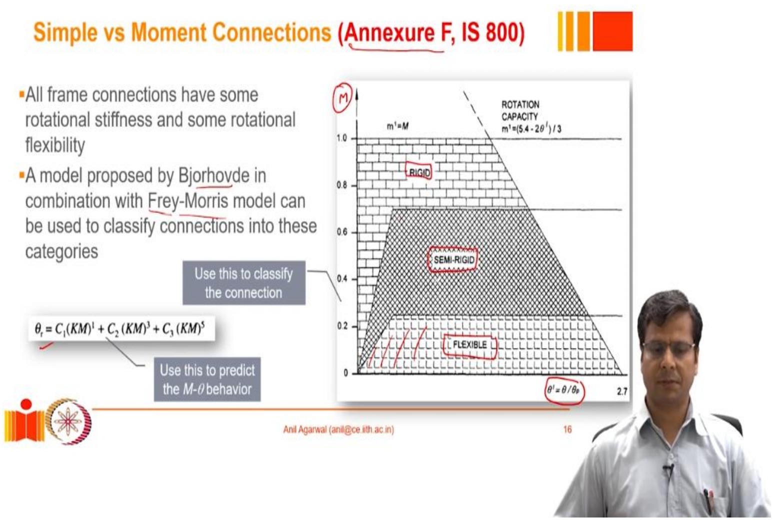

This is a normalised θ value. And this is M, again, normalised moment value; so, normalised against the moment capacity of the beam. So, we put that plot here, whatever plot we developed from this equation, we map it on this curve. And wherever it lies, if it lies in this zone which is marked here, then we classify it as a flexible connection or a simple connection. If it lies in this zone, then we classify it as semi-rigid connection.

If it lies in this zone, then we will classify it as a rigid connection. Now, these are some of the involved methods to classify a connection as a flexible, semi-rigid or rigid. However, in reality, it is not possible in a design office to do all that calculation. It is okay to develop one type of connection by using this method, but in a design office for day to day practices, it is not possible.

Therefore, every design office has a few set of predefined connections that they prefer to use, which they have already verified or somebody has verified, and they know that, that connection falls in this category. So, now we will talk about some of those commonly used connections. Even Annexure F in addition to this guideline which can help you identify a connection's type, it also gives you preselected types of connections which are pretty established, which are well established to fall into one or the other category.

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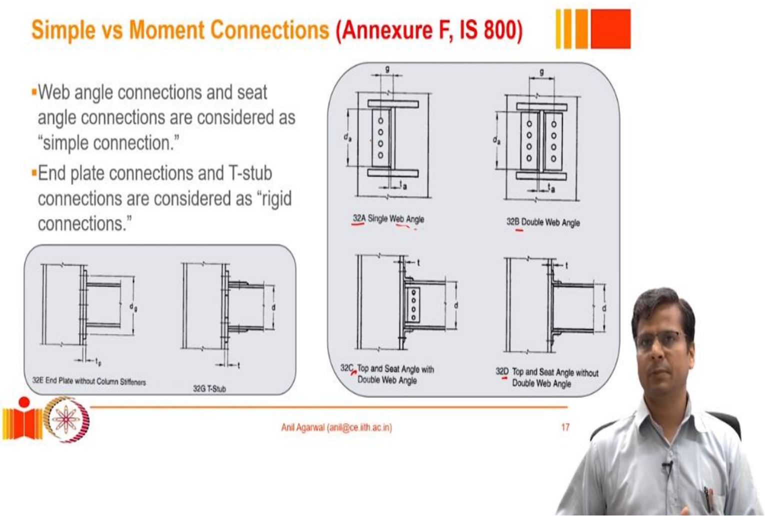

So, here are some of those connections I am listing. The 4 connections that you see here, let me name; they are named in the Indian code as A, B, C and D. So, these are all simple connections or flexible connections; they do not resist moment. This is a single web angle connection. And here, most of the times, the connections have bolts in these diagrams; but they need not have only bolts, they could also have some parts welded.

So, that is depending on the constructability and the prevailing practices. But a designer should be familiar with what parts can be welded together, what parts can be bolted, what is practical in the field, because a designer may think that I would have everything welded. But depending on the project's scope and ability of the manufacturer and ability of the construction company, they have to realise what can be done at the site, what can be done at the field, what is possible to be erected, what is not feasible to be erected and so on.

So, all those considerations go into deciding where we can put a bolt, where we cannot put a bolt and where we should put a weld. So, a single web angle basically is shown here, just to emphasise.

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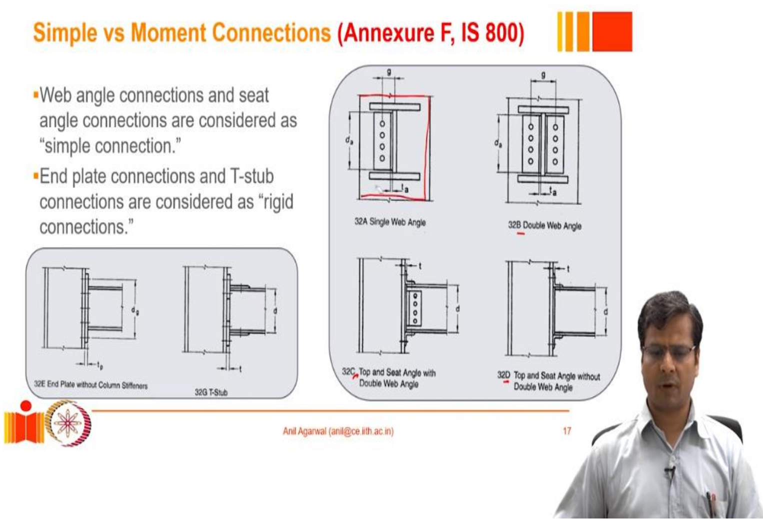

You can imagine that this square what you see here is the flange of a column. And in front of the flange of a column, a beam is going and meeting that flange, and we want to connect this beam to the flange.

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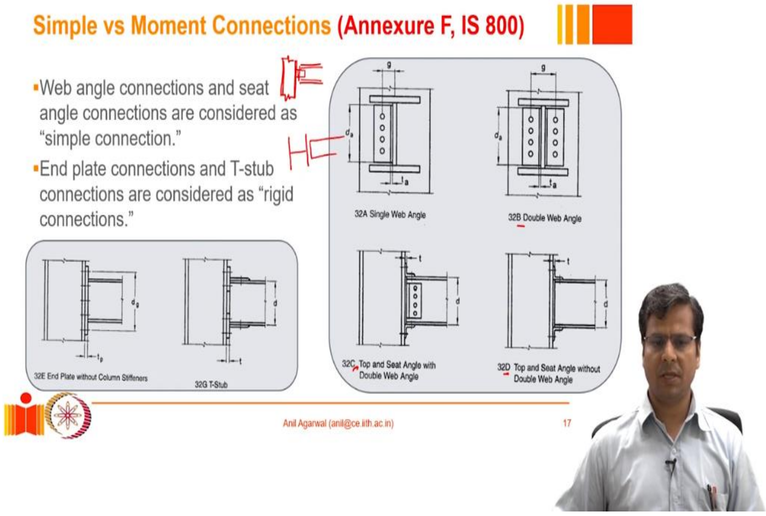

So, in the other view, if I take the side view, then this is the column and the column is extending this way. And at both sides, we have the flanges. And the beam is coming here and meeting the column. And what we do is, right between the beam and the column, we will put an angle. This angle, again let me show it from the top also. This is the flange cross-section. This is the beam flange.

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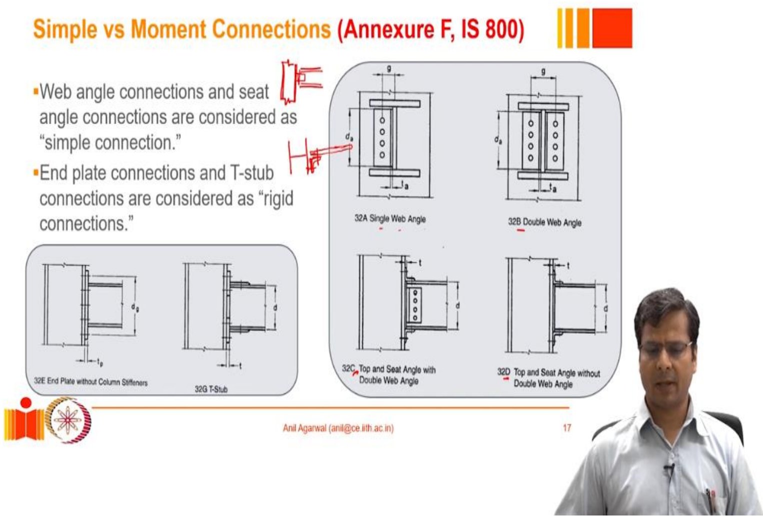

Let me go slightly below the beam flange and let me just show the web of the beam. So, this is the web of the beam which is coming and meeting the column here. And then, we would have a single web angle. So, single web angle will be an angle like this. This is not geometrically accurate. It will not be as wide the angle. So, this angle will be here and it will be bolted or welded to the web of the beam, and bolted or welded to the flange of the column.

So, such kind of connections are quite common. So, these are known as single web angle connection. Another variation of this connection would be double web angle connection. So, it is basically the same type of connection.

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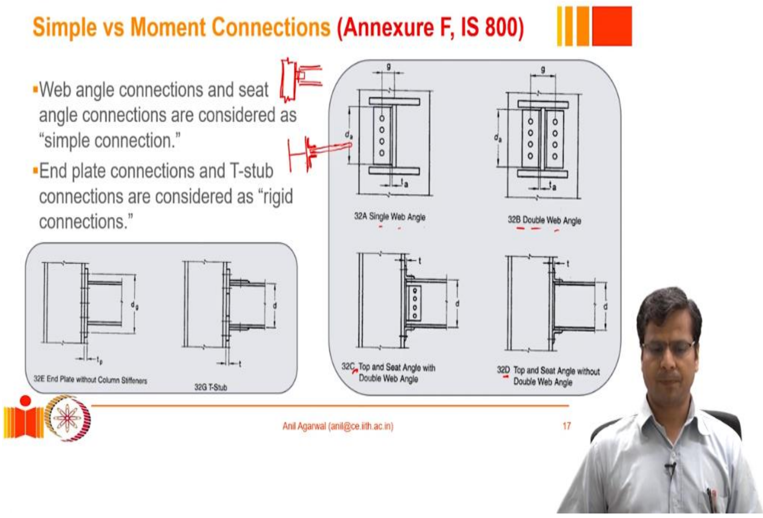

But since a single web angle connection allows some kind of an eccentricity of the load, because in this case, I am tying the web only from one side, not from both, and it may lead to some type of a twisting often and permit maybe the demand capacity, the force demand is too high and we want to use these bolts in double action, double shear. So, in such a case, we may even consider putting a double angle.

So, double angle connections are more stable and they are often utilised. So, in a double angle, we would have 2 angles back to back on that beam web. And then again, they will be welded or bolted to the column flange.

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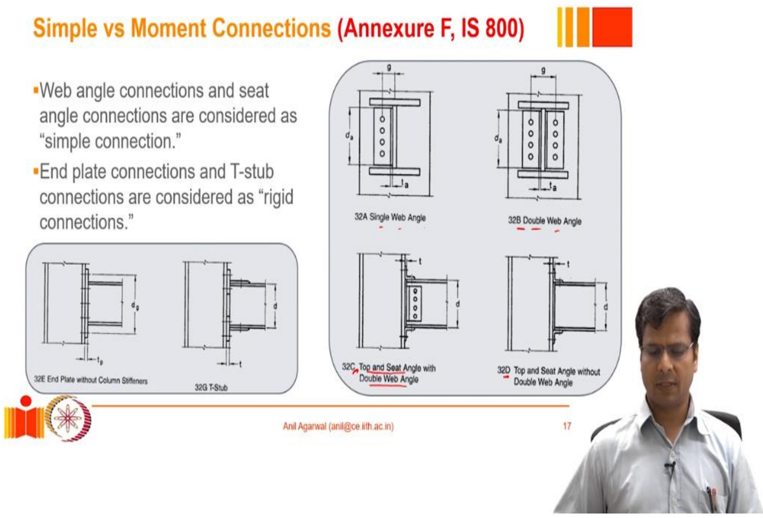

In addition to these, another commonly utilised type which is also specified in IS 800 is the type where we use double web angle in addition to top and bottom seat. So, there is a top angle and there is a bottom seat. So, please pay attention to this connection. This is the beam.

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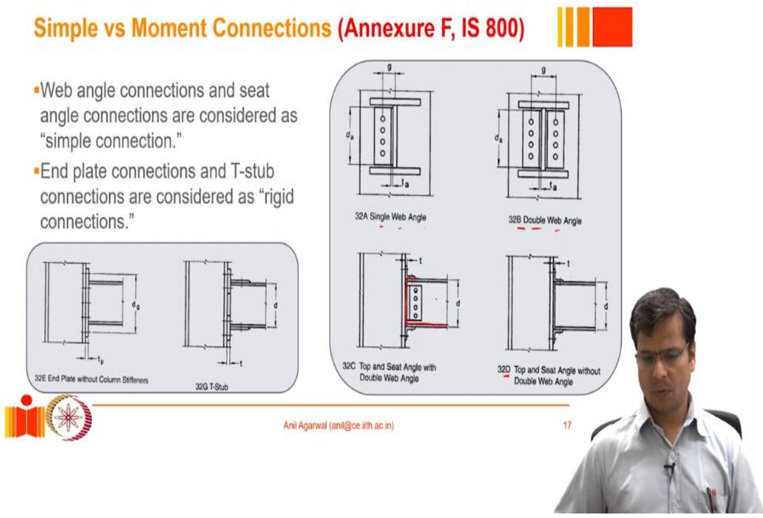

This part is the beam, and there is an angle or a set of angles which are welded or bolted to the web of the beam and again connected with the column. They could transfer some part of the shear force.

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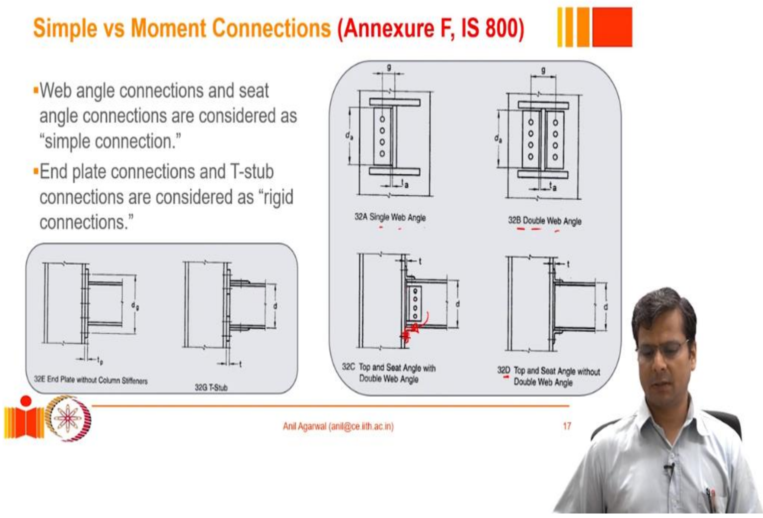

In addition to that, a seat angle has been provided below the bottom flange of the beam. And this seat angle does most of the heavy lifting. It carries most of the load that is applied to the beam, transfers to the column. And we typically have a couple of bolts here or a deep weld here to connect this angle to the column.

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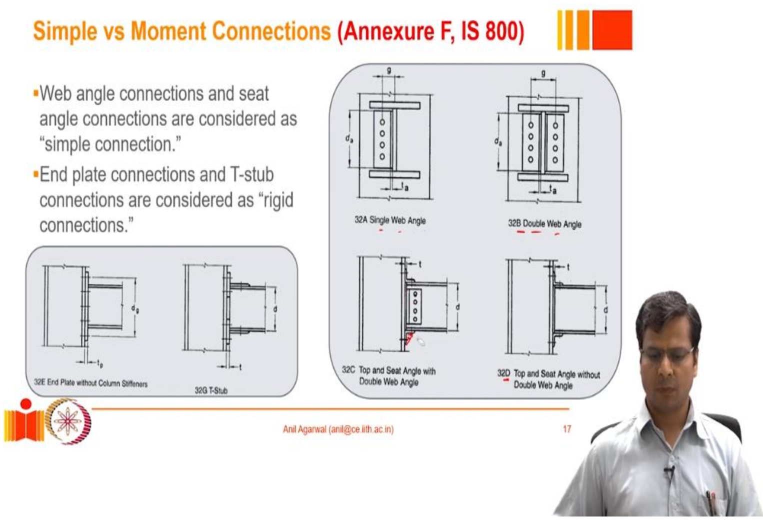

Sometimes this angle can even be stiffened. We may put a stiffener inside in this angle to help it resist the load more effectively. As you might realise, let me zoom into it a little bit.

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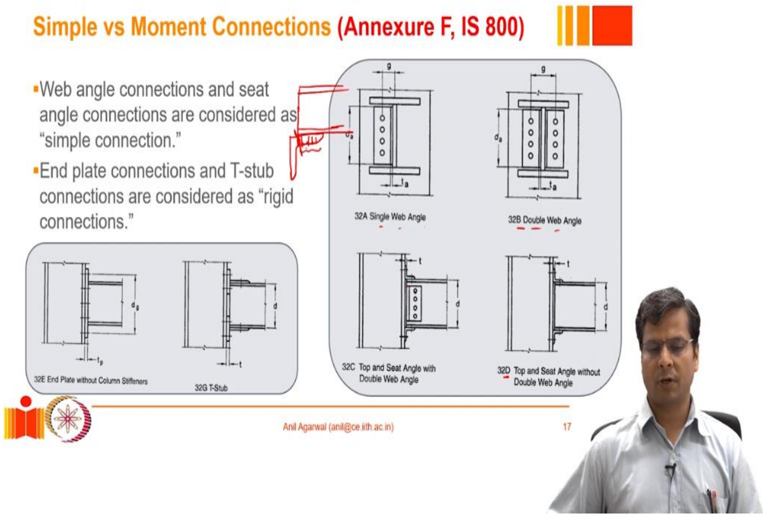

This is the angle geometry and the beam's bottom flange is sitting somewhere here like this. And because of that, this portion of the angle has to resist this load. And that will produce a very large bending moment demand or the shear force demand at this cross-section of the angle that I have just drawn.

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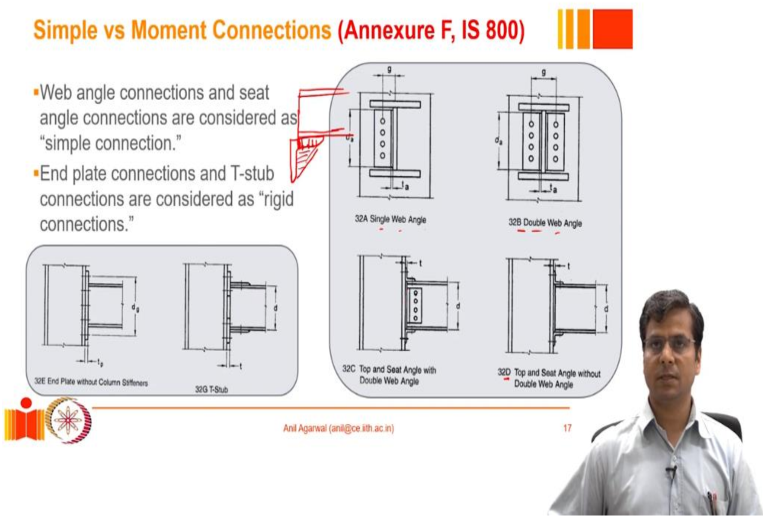

So, in order for it to be able to resist that load better, sometimes we may put a stiffener here. That stiffener will basically strengthen the angle.

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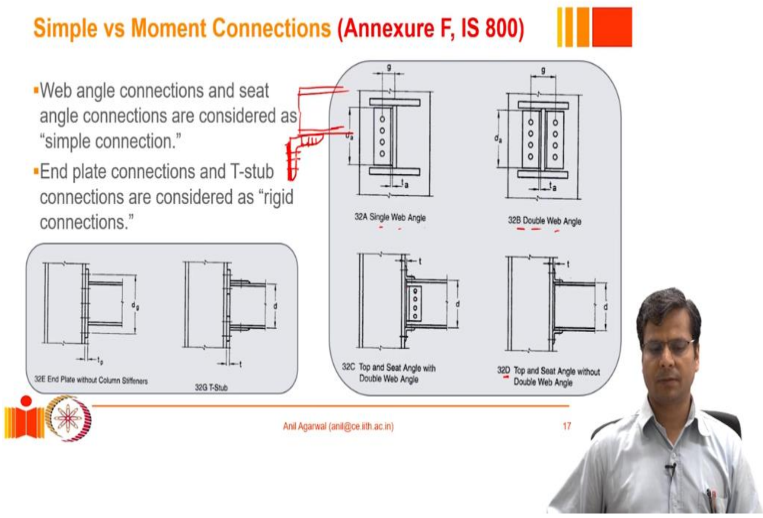

Also in order for it to be able to resist that moment, we may use more than one row, at least 2 rows or more than 2 rows of bolts if you are going to use bolts, or in deep connection, a long weld so that it can effectively resist that moment, moment because of the eccentricity of the load.

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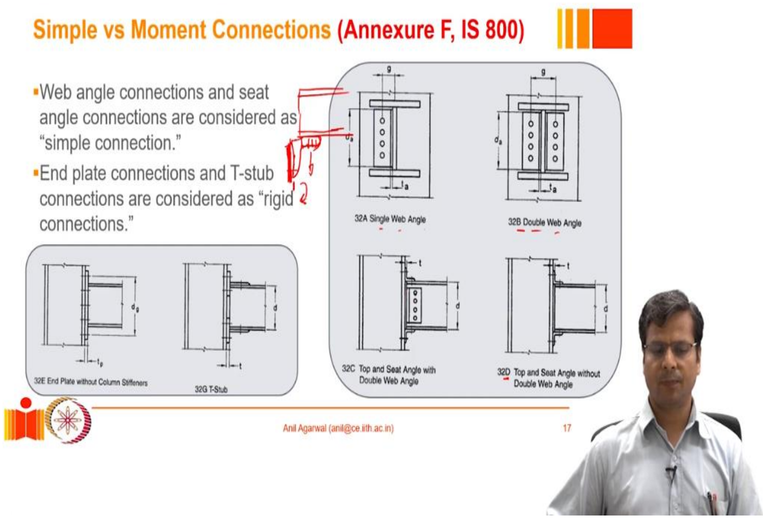

Effective load is acting here, whereas the connection is actually here. So, there is an eccentricity that needs to be resisted effectively.

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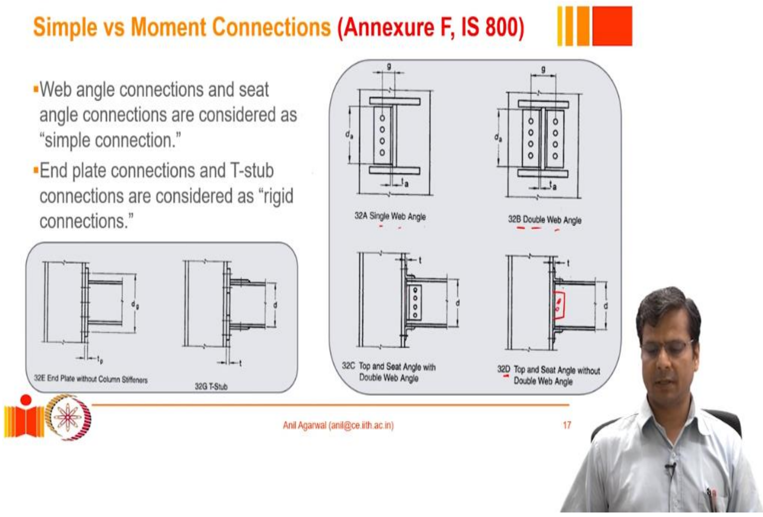

Another variation of this same connection is where we do not use any web connectors. We do not connect the web of the beam at all. We only use the seat and the top angle and then design the connection in such a way.

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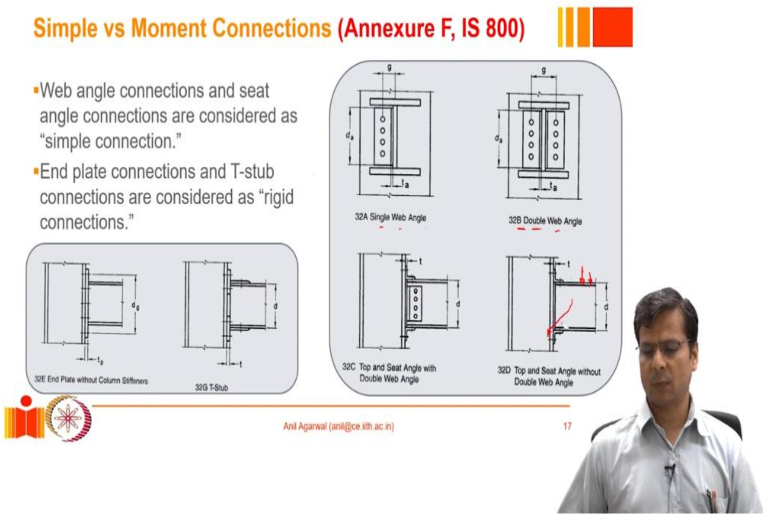

So, again, most of the gravity loads that are coming to the beam get transferred to the column. In this case as well, you might realise that it is contradicting what I had said earlier. I had said that the connectors should not be towards or very close to the flanges, because, if the connectors are placed close to the flanges, they may resist moment as well. But we are classifying these connections as simple connections even though we are putting the connectors close to the beam flange;

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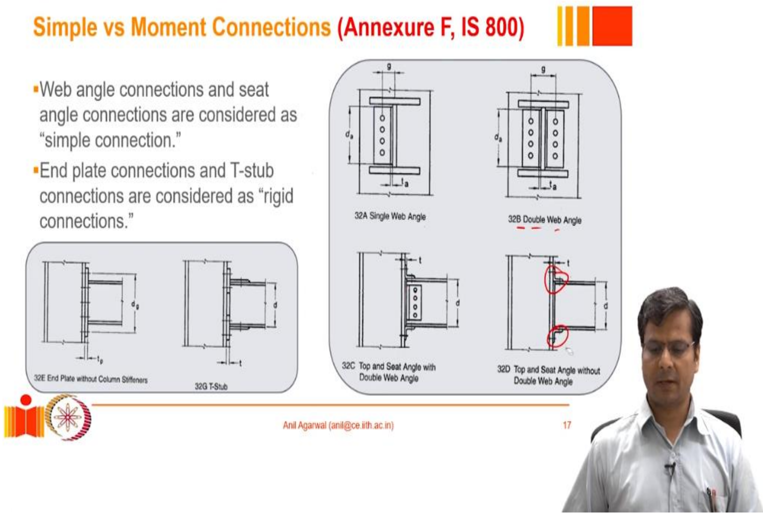

Like here and here. So, I will give you a moment to think about it. So, actually, there is no contradiction.

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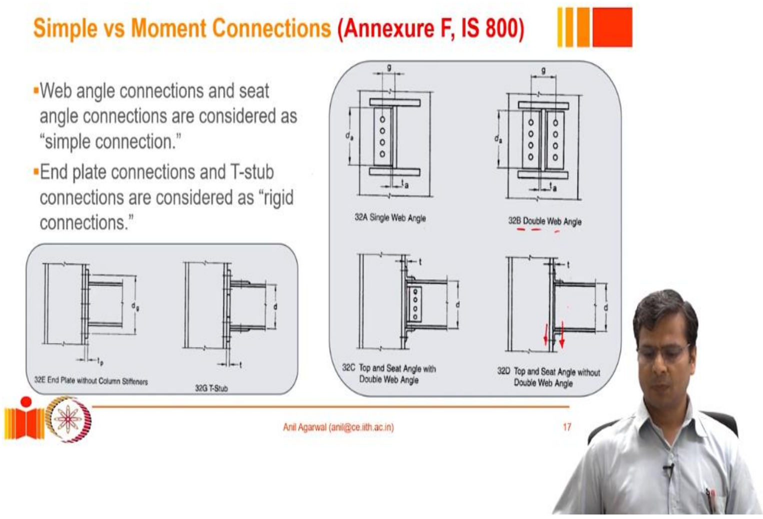

These connectors that we are providing, they have very high stiffness against shear.

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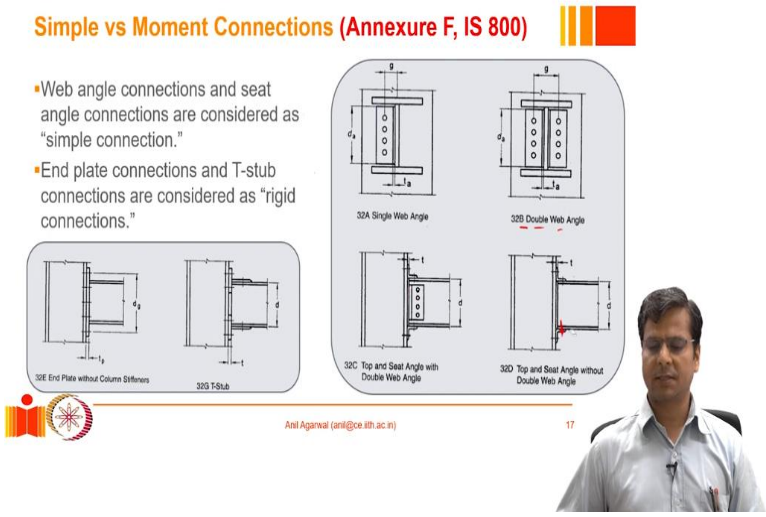

So, for example, the seat does not deform much before it starts resisting shear.

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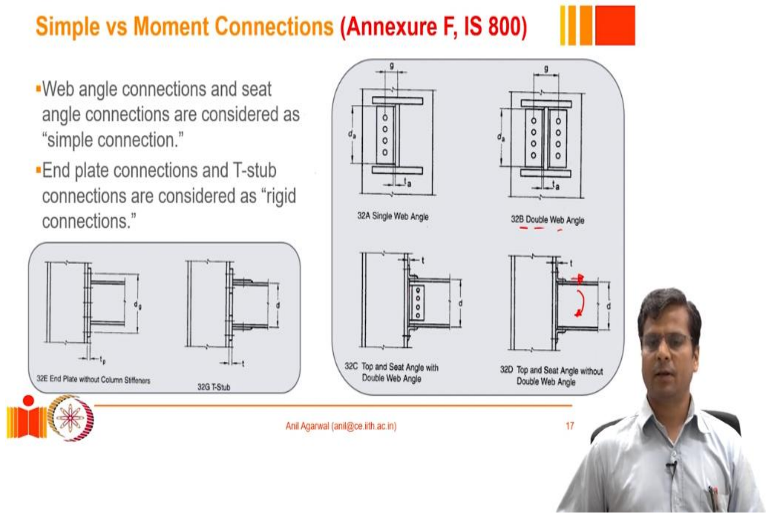

However, when this system is subjected to moment, that is a rotation demand in the beam, you would observe that this angle can deform quite a bit in this direction. When it is pulled inside, it can resist the load very effectively, but when it is pulled outward, it cannot resist much load and it will deform very easily. Therefore, these connections are relatively very flexible when they are subjected to moment demand, and that is why these can be considered as simple connections.

IS 800 also mentions a couple of types of rigid connections, the connections that can resist moment. So, again we have to go to Annexure F. There are these 2 types of connections are mentioned. One connection has end plate without column stiffeners, and there can be another variety of it where we put some column stiffeners to resist the load effectively. Let us not go into that; we will talk about that in the next lecture in more detail.

So, in this particular connection, if you see closely, you have a beam. That beam is typically welded; the end of the beam is welded to an end plate. So, end plate, as the name suggests, is a plate that is welded all around to the beam.

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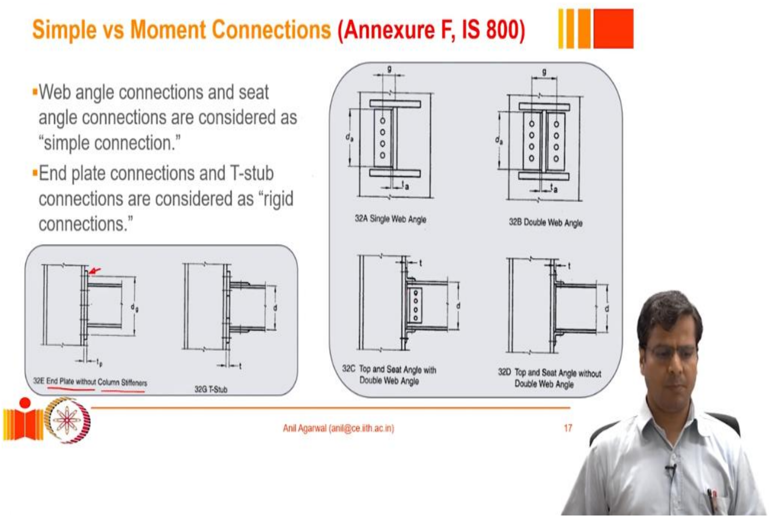

So, this plate is effectively or rigidly connected to the beam. And then, the end plate itself is typically bolted to the column flange.

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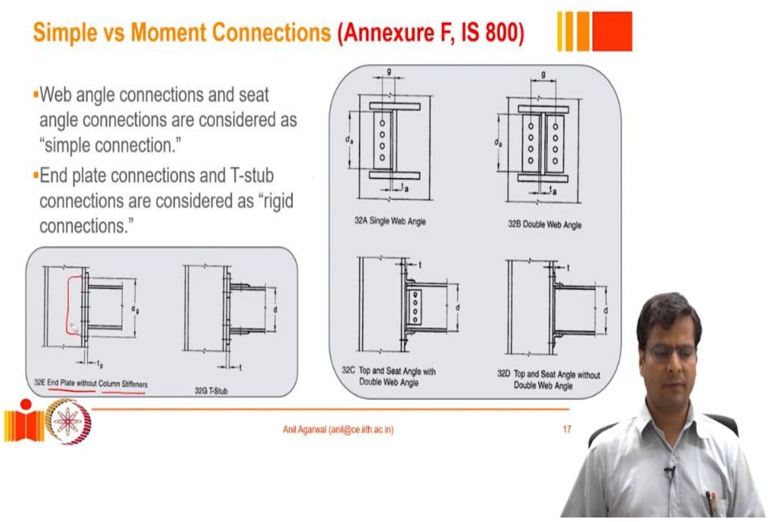

And sometimes, in spite of this, you might realise that the flange itself, or this local area of the column itself is not rigid enough;

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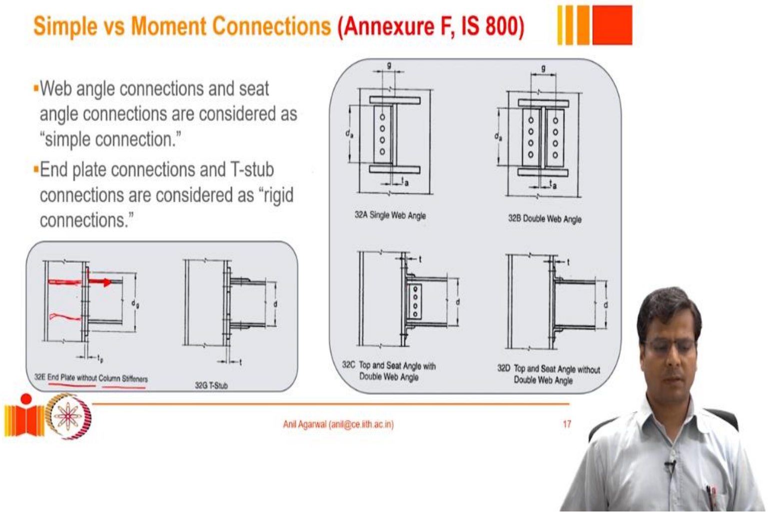

And so that it can carry or it can resist the force demand that is coming from the flange. So, one way to address that issue or handle that problem is to increase the thickness of the end plate. And sometimes, still that may not be enough and we may have to provide stiffeners in the column. Both of them are acceptable approaches. Another variation of the same method would be, instead of welding an end plate to the beam end, we can use 2 T stubs.

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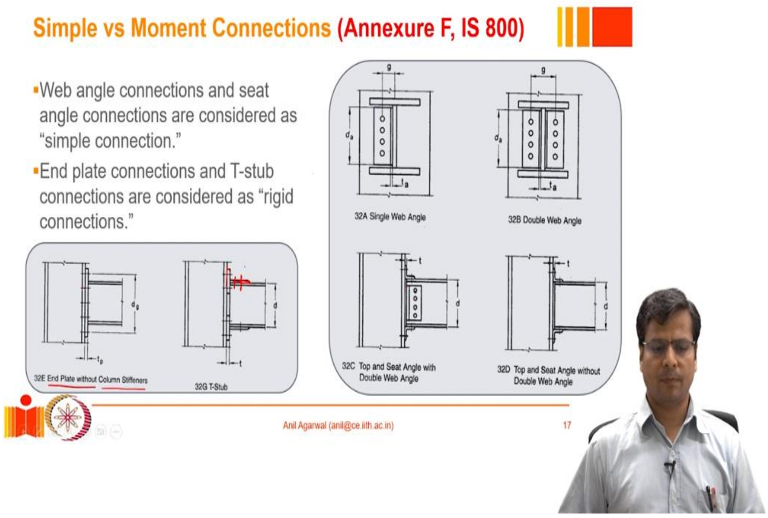

So, these are basically 2 T sections, and the web of the T section is bolted or welded to the beam flanges. And then, the flange of the T section is again bolted to the column.

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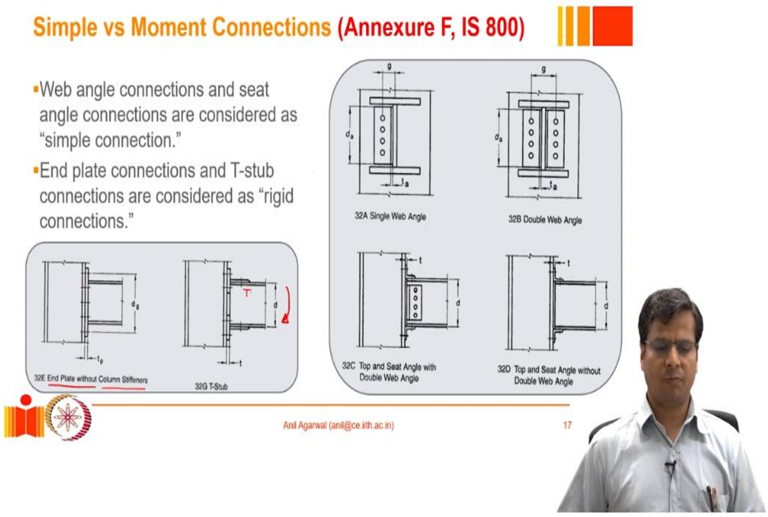

So, when this kind of a connection is subjected to a moment demand; let us say in this direction it is subjected to a moment. This is subjected to tension. and this flange would want to pull away from the column.

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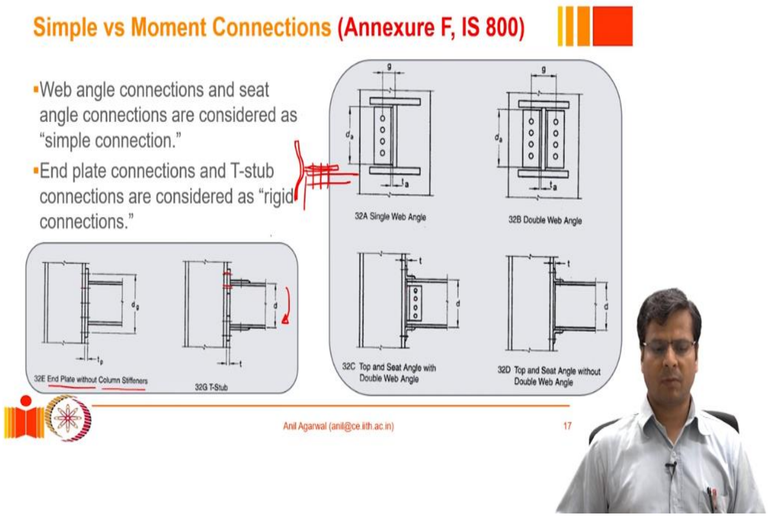

Then this T can resist this load by slightly deforming in this way. The flange would deform this way followed by the web remaining straight and then the top flange of the beam would be tied to this one. So, it may not be as stiff as maybe the end plate connection, but it all depends on how many bolts we provide here. So, if we provide enough number of bolts and if the plate is thick enough, the flange of the T section is thick enough, then it may offer just as much bending moment resistance.

And in these cases, there is no requirement of an additional shear force resistance, because these bolts themselves, they have very large tension capacity, and they also have sufficient shear capacity to resist the shear load.

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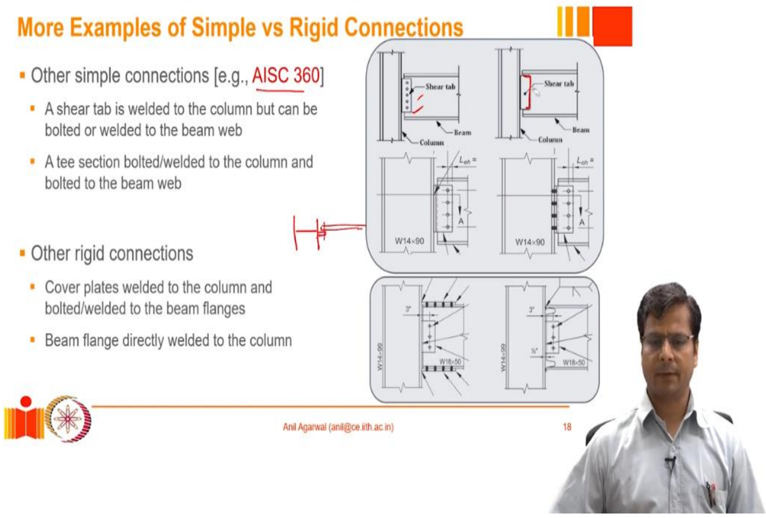

Now, the list that is available in Annexure F of IS 800 is not really an exhaustive list. There are many more types of connections which are practised in everyday life in India, abroad, everywhere; and you can actually, if you see any engineering drawing of any large structure, you would see at least dozens of different types of connections that are utilised. And it is very difficult to prepare an exhaustive list; it is all about the ingenuity of the designer.

So, designer can come up with a more engineer's type of connection method. If the components, individual components or individual elements of that connection have been studied well in the past, typically it is okay to go with it slightly with slight combination or variations of connections, and that is utilised or that is tried all the time. Here are some other variations of simple and rigid connections that I am listing here, which I have taken these drawings from AISC 360 Design Guide for Connections.

So, this is another variation of what we had seen before, which we called a single angle connection. So, earlier, what we had seen was that this is a column, looking from the top. Then this is the web of the beam. And then, there was a possibility of putting an angle on one side of the beam and have the angle bolted to the column and welded or bolted to the beam as well. So, this was a single angle connection.

One variation of this could be just using, instead of using an angle, just use a small plate. Actually, the angle's other leg does not do much of a work anyway, so, we can use a single plate. Let me draw it again. One plate, and then, this is the web of the beam. And this part, typically, now how do we connect this plate to the column? The only way to do that is to weld it because there is not enough width available for us to bolt it.

So, then, we have only one option to weld the shear plate. It is usually known as shear tab or shear plate. We weld it to the column flange. And then, the beam web can be either welded to this plate like shown here or it could be bolted to this plate like shown here. So, both options could be utilised. Typically, what they would do is, they would weld this shear tab to the column at the shop, in the fabrication shop.

Then it will be brought to the site, the beam will be lowered at the position. And then, simply we can decide to do a site bolting or site welding; so, the either one is okay. But generally, the practice is that we want to avoid site welding. Site welding invites too much of inspection and too many checks and balances are required, which can be very time consuming, and still there are chances of high level of defects. Therefore, we typically prefer to do shop welding and site bolting. So, at the site, we prefer to do bolding most of the time.

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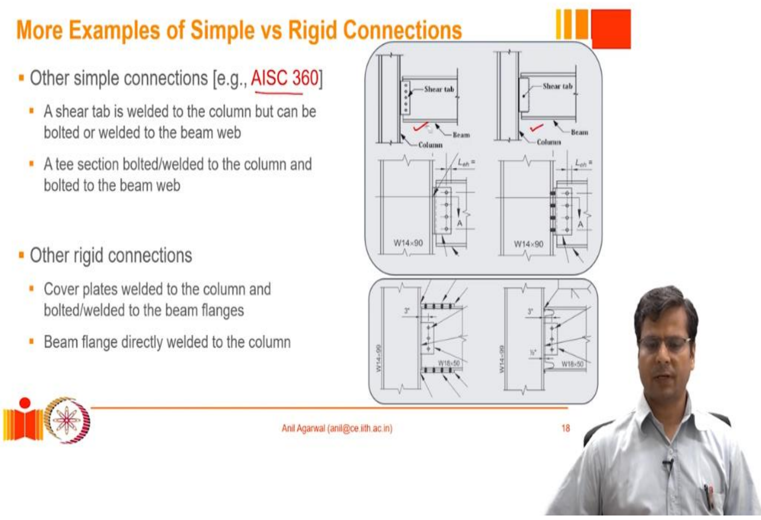

Therefore, you would see, these type of connections are more common than this type of connection. Both of them are very similar in behaviour, just that the sequence or the way they are constructed are different.

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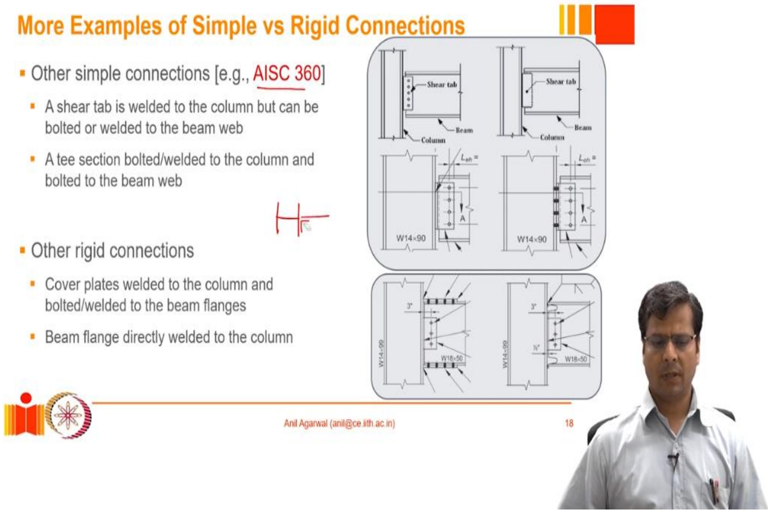

An alternative to this could be, we have just seen the variation where we had put an angle.

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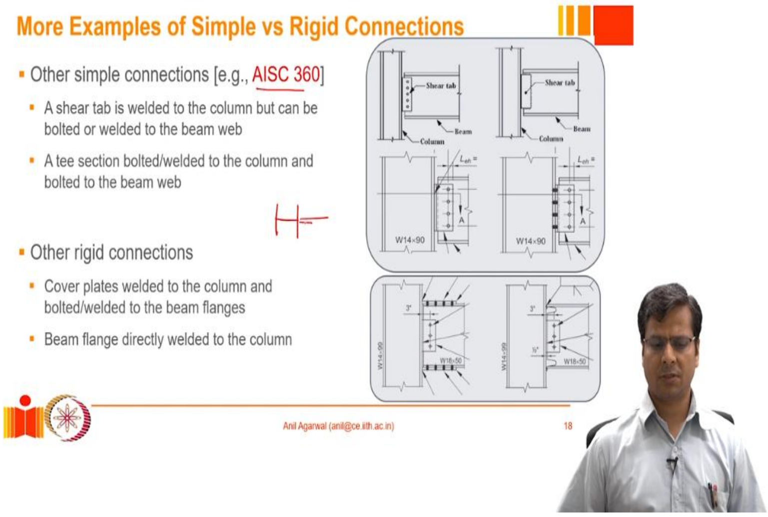

Then we saw another variation there we put a plate straight away.

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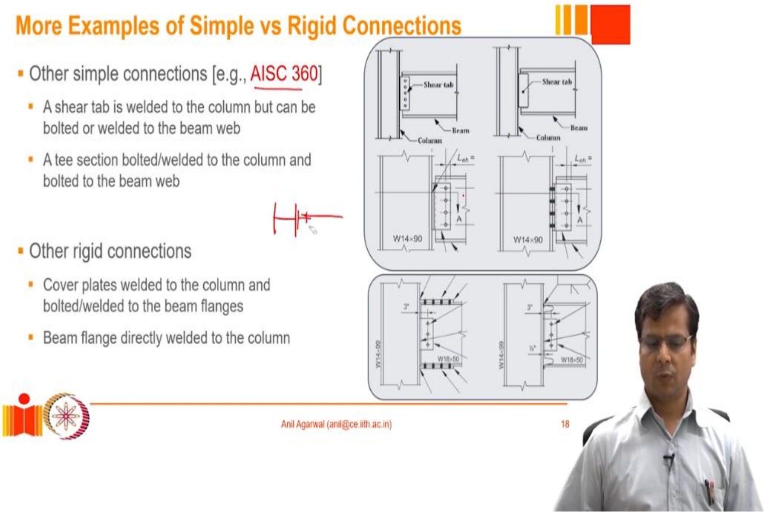

Also what we can do is, we can put a T joint or T section, and then the web of the beam. So, in this case, since this T is only tied or only connected to the web of the beam, and typically it is done through bolting, it is in flexible connection, and the flange of the beam is not connected.

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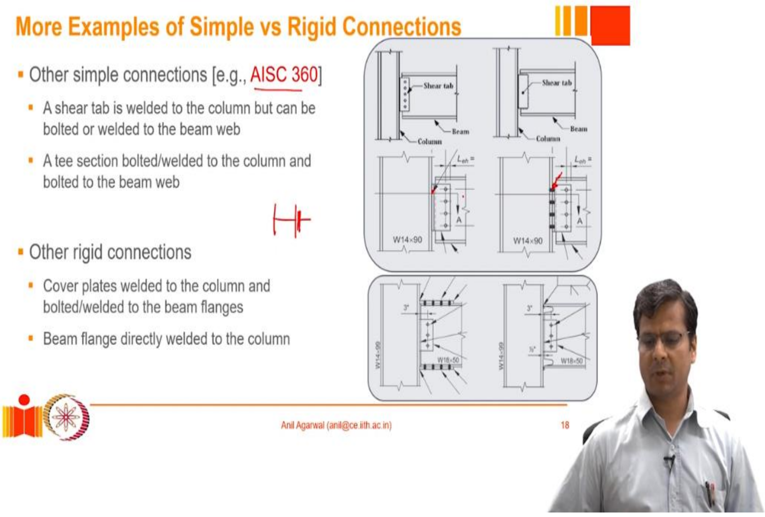

So, and the flange of this T section, this flange, either it could be bolted with the column or it could be welded with the column. So, this is one example where it is welded to the column; this is another example where it is bolted to the column; but they again behave in a very similar fashion.

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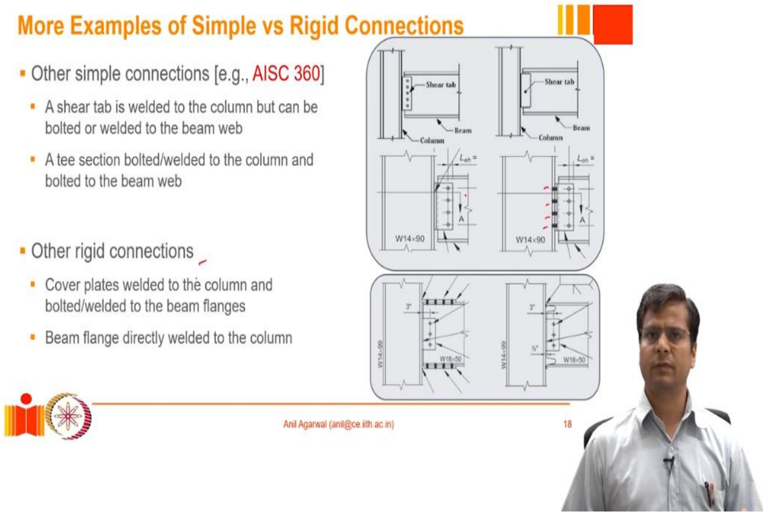

We have to be careful a little bit about their strength and the eccentricity that is coming on to these bolts. Some other internationally practised variations of rigid connections. So, the 2 types of rigid connections we saw before; one was end plate connection which is established, which has been studied by so many people, where the end plate is able to resist the load or transfer the moment effectively to the column.

There could be some variations of that where we can use stiffeners. We can use stiffeners within the column; we can use stiffeners between the beam and the end plate; and there are various such variations also. And the other one that we saw was where we had used 2 T stubs next to each flange to transfer the force.

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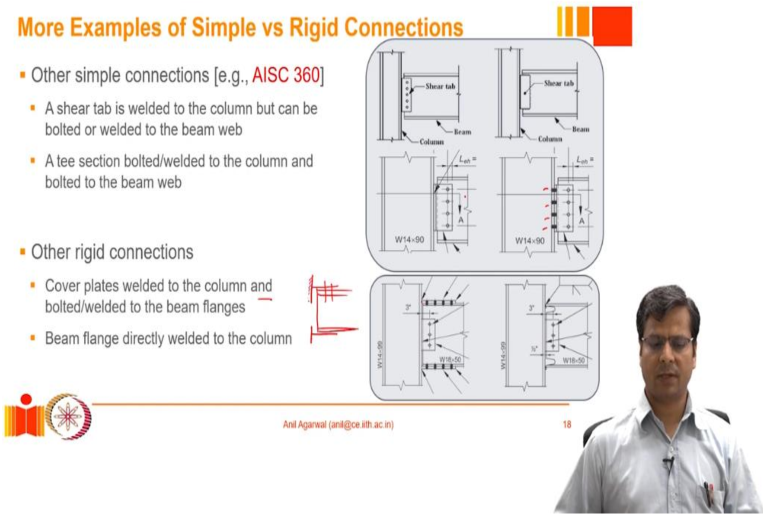

Another variation of the T stub type of a connection is, instead of that web wherein we do not use a T stub but we simply use a plate like a cover plate, and that cover plate is directly welded to the column. So, instead of having a T flange above and below; so, this is what we had done before. We have seen before where the beam's top flange was tied to a T stub and the T stub itself was welded to the column.

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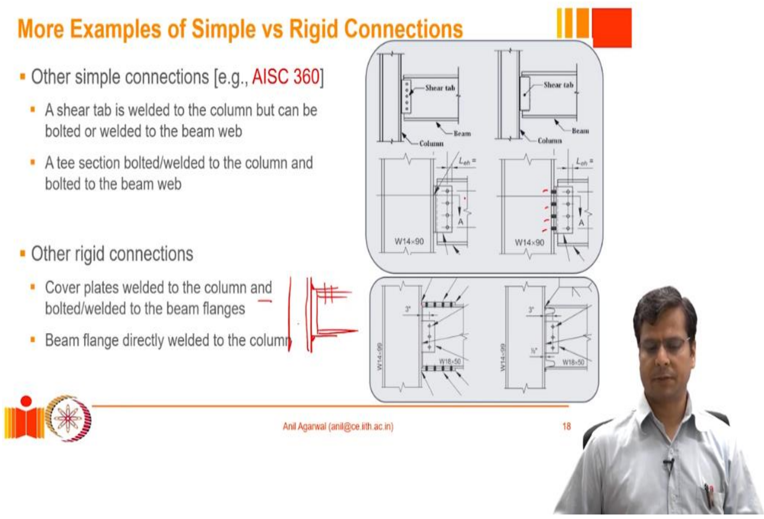

Instead of that, we can simply put these cover plates, and the cover plates could be welded typically, welding only, welded to the column plate, whichever plate is there in contact. And another type of connection which is in fact much more prevalent in the U.S. is the one where we do not use any other elements.

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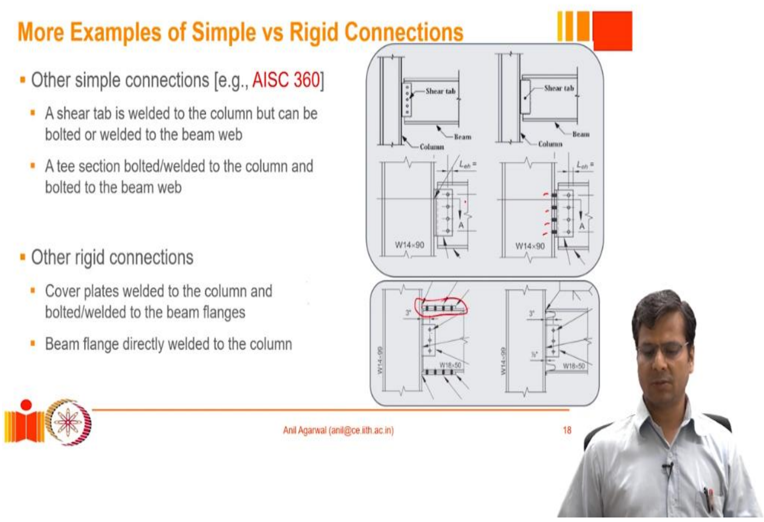

So, we do not have to use this bolting, these plates, etcetera.

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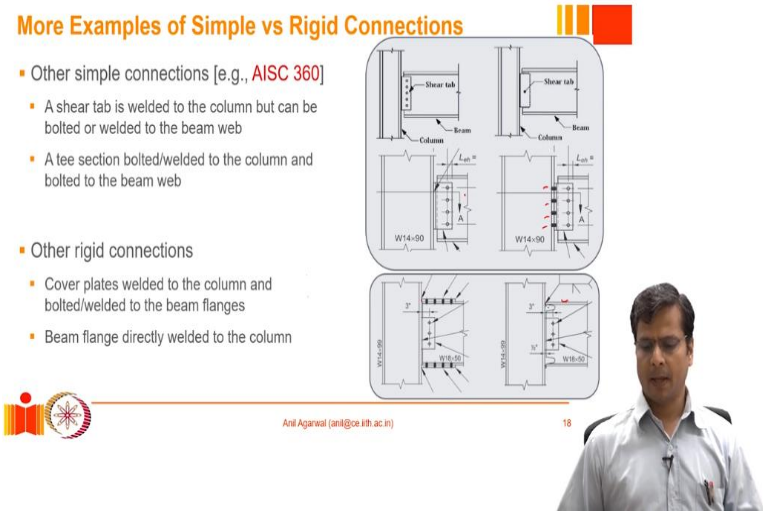

We can simply weld both flanges of the beam to the column. And here there are few details that I would like to discuss briefly. So, this is also a rigid connection and in fact it offers a very high level of rigidity. There are some drawbacks too.

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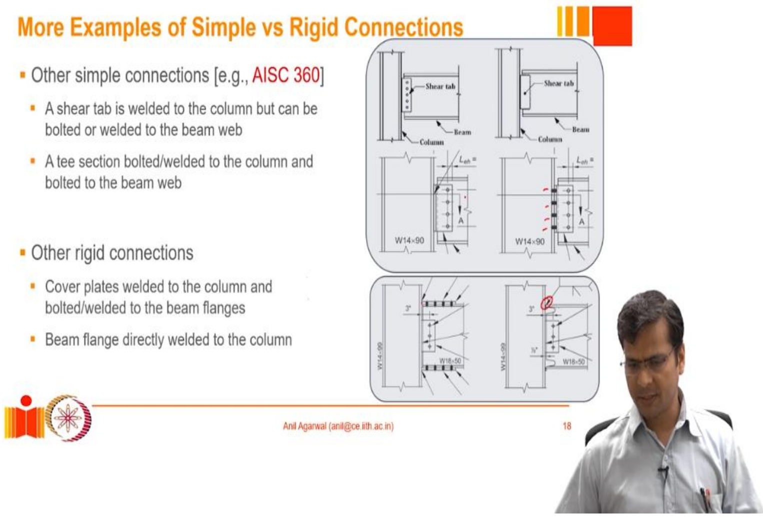

So, what you see here is, basically this arrow represents that there is a fillet weld between the beam and the column. And it need not be fillet weld; sometimes it is also a groove weld.

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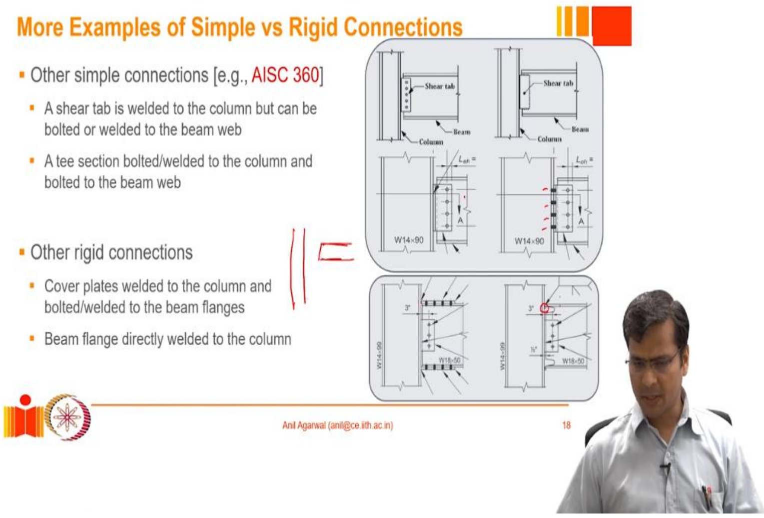

So, the end of the beam is machined or in a groove is created. This is the flange surface. What you see as a small square here; probably you can see it; is basically a backing plate.

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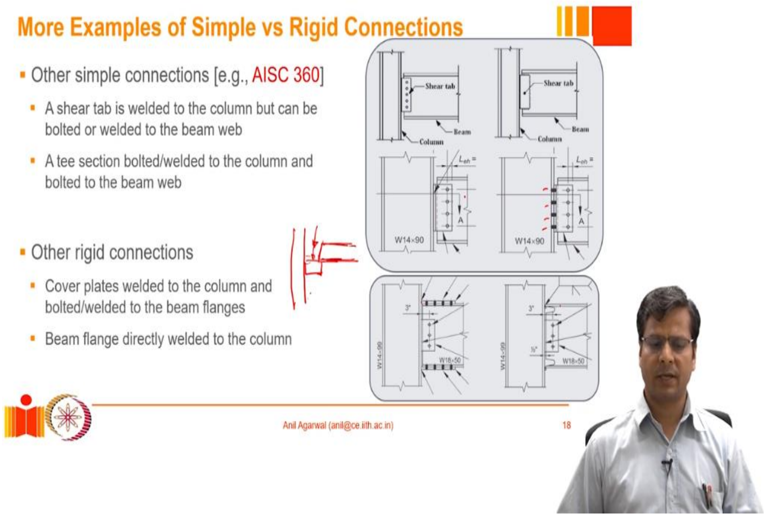

So, if we put a backing plate; backing plate may be required because, if the beam flange is thick enough or too thick, then it is very difficult to deposit the material, then we have to increase the groove distance. If we increase the groove distance so that we can reach the depth, then there is a chance of the molten filler material to flow away. So, in order to stop that, we put this backing plate.

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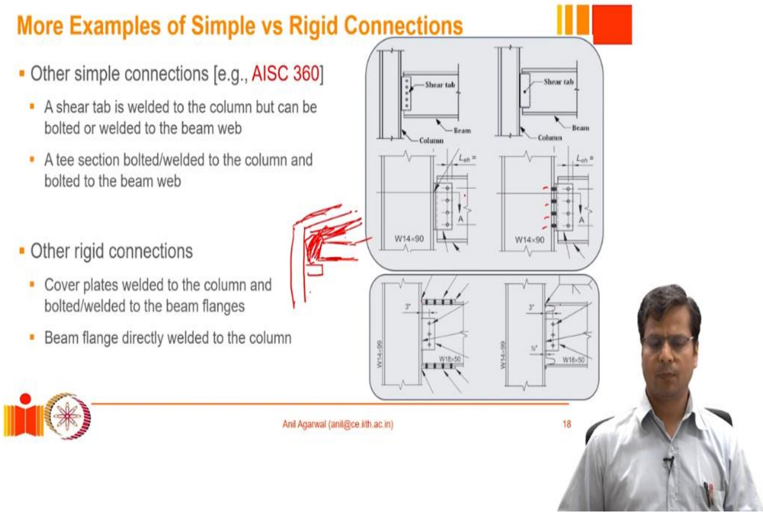

So, with the help of the backing plate, we fill this groove in the third direction; it is this way. So, this is the column flange, and this is the flange of the beam. And then, we put the deposited material here, which fuses the flange with the beam and provides large enough flexural resistance.

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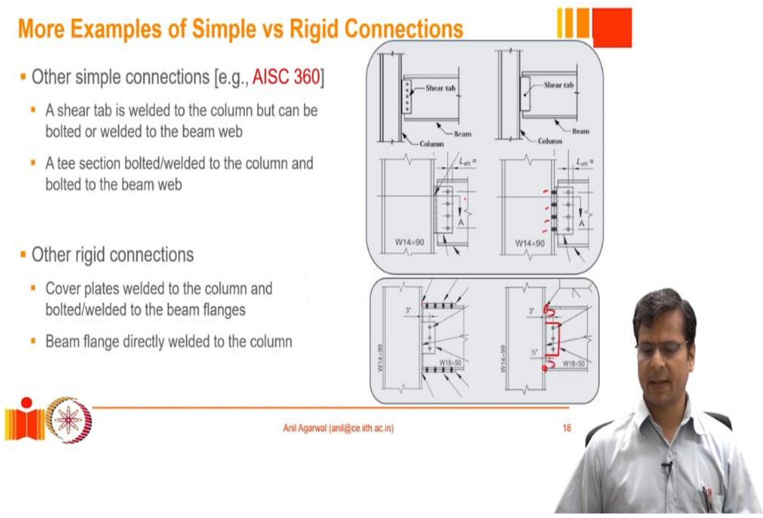

Here, also in addition to that, you might notice that we require separate provision for resisting shear, which we did not require typically in an end plate connection. The reason for that is because that these connections are very localised near the flanges and the shear force demand at the flanges is very small. And plus we sometimes have to create these kinds of cuts.

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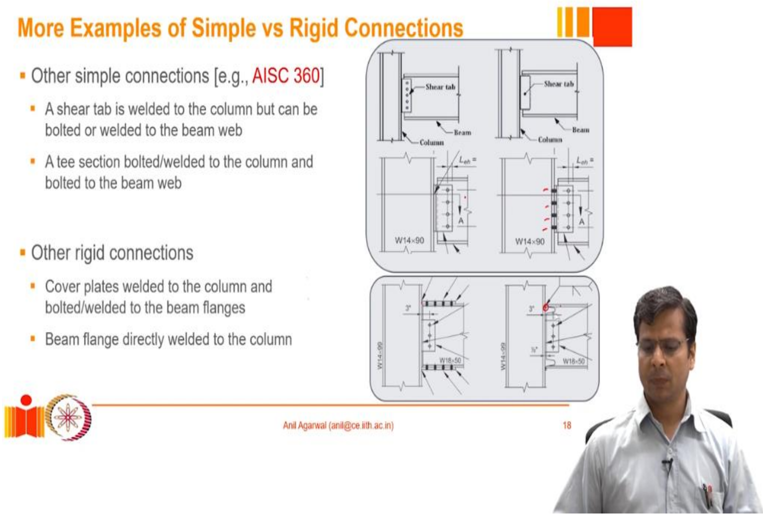

These cuts are excess cuts so that we can weld around this area comfortably.

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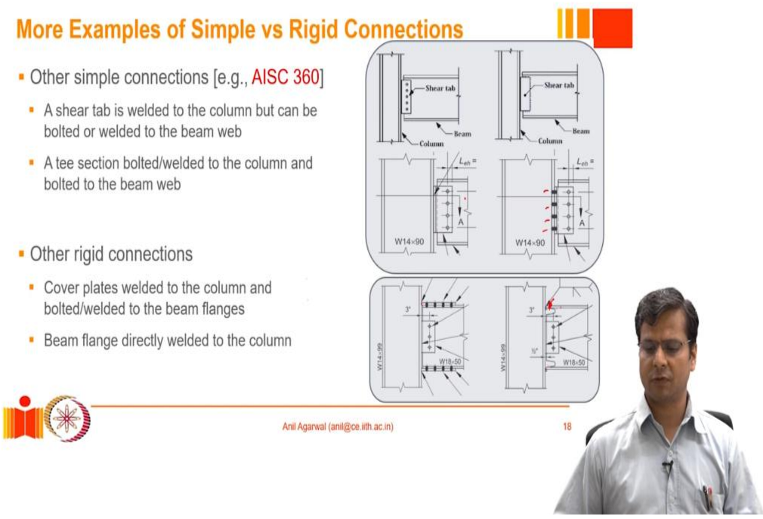

So, considering all of these, these parts cannot effectively transfer the shear force demand. So, these welds are not really meant to transfer the shear force.

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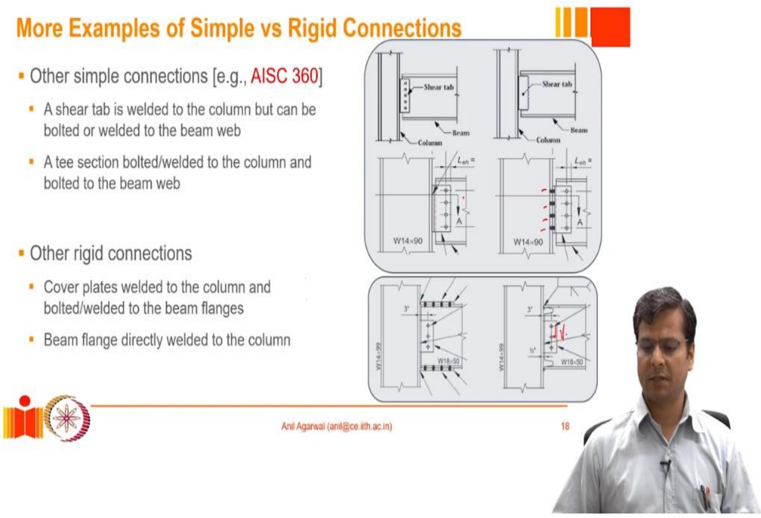

And the shear force which is anyway highest near the web or the centroid, that is the neutral axis;

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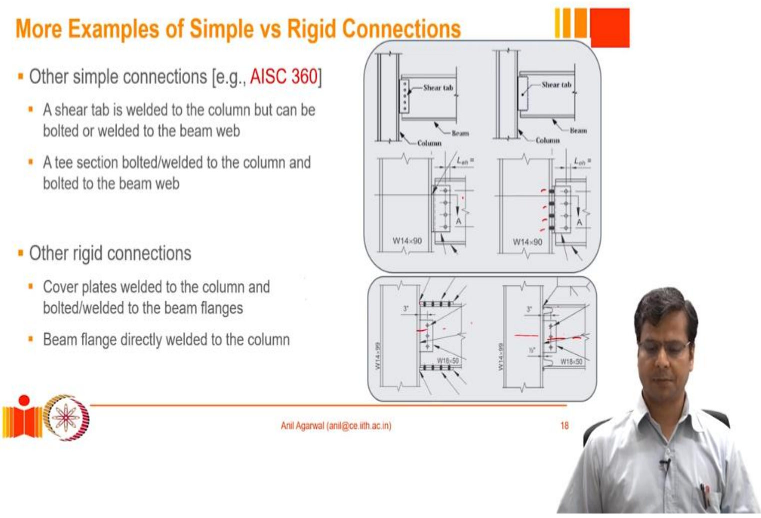

It is much more prudent to provide shear connection near the neutral axis of the beam in both cases.