Design of Connections in Steel Structures
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Module - 1
Lecture - 4
Correction Factors for Bolts for Long Joints, Long Grip Lengths, and Thick Packing Plate

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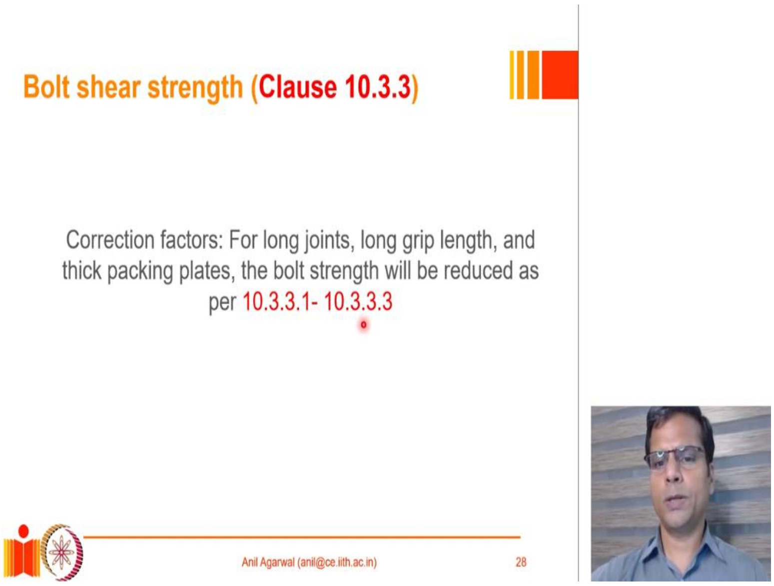

So, now, we will talk about some correction factors. So, as we have already discussed, the shear strength of a bolt and bearing strength of a bolt. However, there are certain conditions under which the full bearing strength or the shear strength of a bolt cannot be utilised. Some of those conditions are listed here. So, for example, if the joint is relatively long, what does that mean?

That means, the distance between the first bolt and the last bolt in a row of bolts in the direction of the force, if that is longer than a certain limit, then all those bolts do not participate equally. And as a result, we have to reduce the design strength which is available for any given bolt. Also, if there is a long grip length in a bolt, so, a long grip length leads to a reduction in the strength of the bolt, because the bolt also undergoes a flexure.

While the bolt is expected to undergo pure shear but it does undergo some flexure, and those flexural stresses reduce the shear strength of the bolt. Also, if there is a thick packing plate used in the bolted connection, that also reduces the strength for the same reason, there is a flexural component in the bolt, which reduces the shear strength. All these provisions are discussed in clauses 10.3.3.1 to 10.3.3.3 of IS 800. We will go through them one by one.

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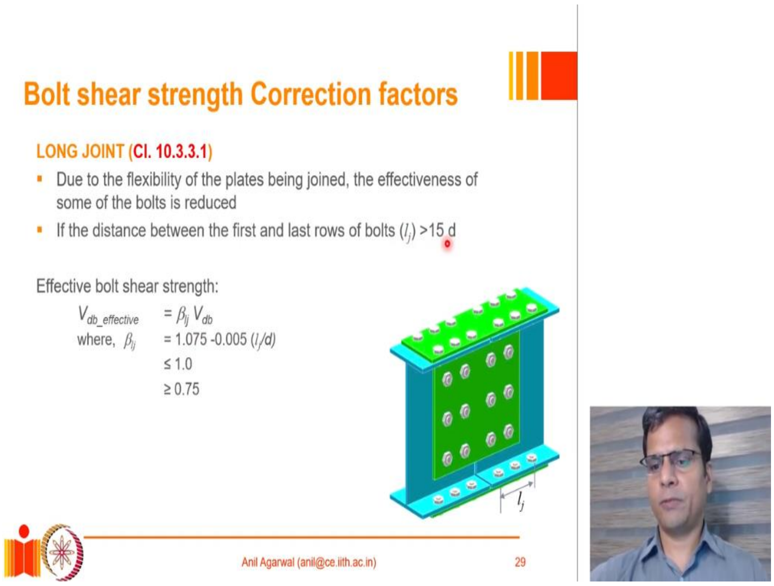

So, let us take a look of a possibility when the joint is longer than a certain limit. So, here I am showing you an example where 2 beams or 2 I sections, they are spliced together using this bolted joint. And I am looking at these 3 bolts which are forming a joint together. Now, if you want to calculate the strength of each of these bolts depending on the length of this joint, the force distribution to each of these bolts may not be uniform.

If the joint is small, we can assume that the plate in between the bolts is relatively stiff. And therefore, if we approximate it to a rigid plate, then we can say with certainty that each of these bolts will be having equal deformation or in other words, each of these bolts will be having equal force demands. And therefore, when one bolt fails, all the 3 bolts would fail at the same time meaning that we will be utilising their full strength.

And therefore, the design strength of the bolt can be calculated as strength of 1 bolt multiplied by 3. However, if this joint is bit too long, then the flexibility or the plate in between starts to deform elastically. And because of those deformations, the 3 bolts do not shear equally; that means they do not deform equally. Some of the bolts which are at the edge would deform more, whereas, some other bolts will deform less.

As a result, the total strength of the joint will not be equal to the strength of 1 bolt multiplied by 3. In such a case, what we do is, what the code recommends is that we reduce the effective strength of a bolt, so that we can still consider this as a bolted joint. So, the guideline is that if the distance between the first and last row of bolts; in this particular case, this is the first row of bolts; in this case, there is only a single row or a single line of bolts.

So, this is the first row, this is the second and the last row. So, the distance between the first and the last row, if it is more than 15 times the diameter of the bolt, then it will be considered as a long joint. And in such a case, the length of this l_j will be the length of the joint. And in such a case, a reduction factor of β_{lj} has to be used. And that beta sub l_j is given by this expression and its value has to be more than 0.75 and it has to be less than 1.0.

So, that beta l_j value which is calculated based on this expression, that is used to reduce the effective strength of the bolt. So, first we will calculate the bolt strength based on the shear strength and bearing strength calculation that we have discussed before. Then we will use this factor to reduce the strength if the length of the joint is more than 15 times the diameter of the bolt.

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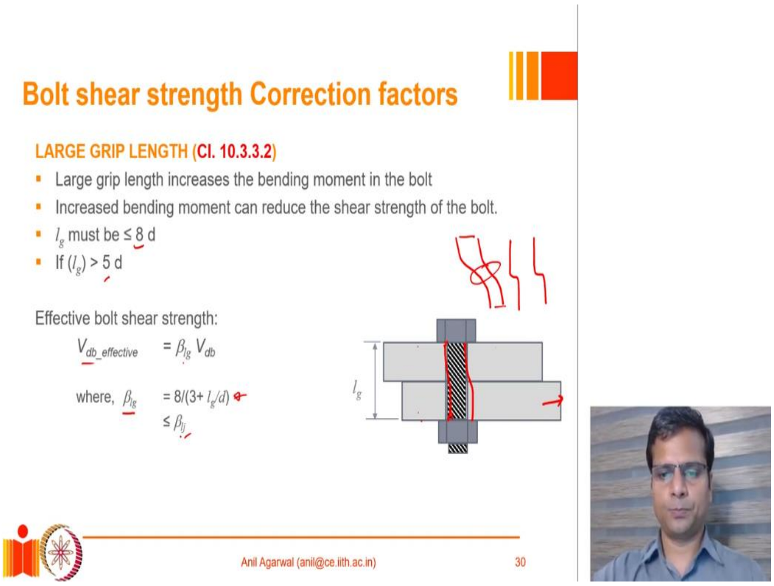

Other aspect or other correction factor that is relevant here is the bolt length. So, if the grip length or bolt length is more than a certain limit, then also the effectiveness of the bolt is reduced. So, here I am showing you an example, in this particular case, this bolt is holding these 2 plates together. Now, when this plate is pulled, this bolt will be undergoing a deformation like this.

And under this kind of a deformed shape, you might see that if this length is a bit extra, is too much, in such a case, this bolt will not be undergoing pure shear kind of a deformation, which ideally should look like this, but it will be going more of a flexural type of a deformation. It will be a combination of shear and flexure, and that depends on the length of the bolt versus the diameter of the bolt.

If the length is beyond a certain limit, in that case, it will be undergoing flexural deformation. And as a result, there will be flexural stresses introduced at this interface, which will subsequently reduce the shear strength of that interface or of that shear plane. So, again here, the l_g value is the grip length, which is basically the length of the bolt which can undergo flexure, and that divided by the diameter is a factor which if this factor becomes more than 5, length or grip length divided by the diameter, which is relatively unusual, but sometimes it may happen.

So, if this factor becomes greater than 5, then we have to account for this flexural effect. In any case, this flexure cannot be more than 8, which is not permitted as per the Indian code. So, length, grip length divided by the diameter of the bolt cannot be greater than 8 if you are going to design a structure as per the Indian code. If the factor l_g divided by d is between 5 and 8, in that case, we have to calculate this factor β_{lg}.

That is used to reduce the effective strength of the bolt. And the β_{lg} value is given by this expression, wherein l_g divided by d is a factor, and this value has to be less than or equal to β_{lj} which we calculated for the joint length. So, it cannot be greater than the β_{lj} factor that we have just calculated; that we have learnt how to calculate just now.

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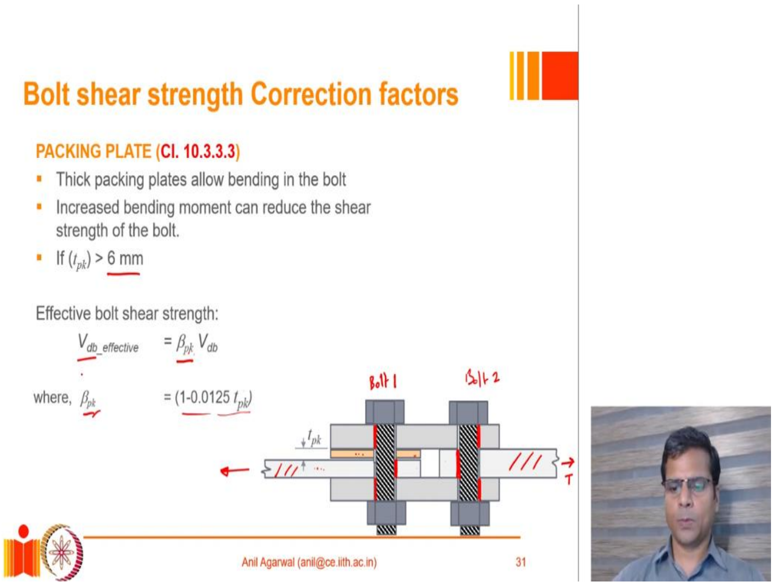

The third important factor here or correction factor here is the factor which accounts for packing plate. So, what is a packing plate, first we need to understand. So, you look at this example here, in this diagram, what you can see here is that there is 1 plate here and there is another plate here. These 2 plates are actually supposed to be spliced by using this joint. So, this plate, let us imagine a situation where this plate is in tension in this direction.

This plate is being pulled in the other direction. Now, when we want to splice these plates in such a way, we can use a lap splice, the kind that is shown here. However, since these 2 plates are of different thicknesses and we want to use a lap splice, in such a case, we have to use a packing plate. So, the one that is shown in this colour here, this plate is the packing plate.

That is required to achieve the same thickness so that a lap plate can be placed or a set of lap plates can be placed. So, now, again what happens is that, when we are loading these plates by these forces or these bolts by these forces, if I notice the bearing surfaces, you would see that this; say for example for this bolt, bolt 2; and let me call this bolt 1. In case of bolt 2, this surface will be bearing, this surface of the bolt hole will be bearing against the bolt, and also these surfaces will be bearing against the bolt.

So, the entire length of the bolt is kind of restraint, it is kind of bearing against one surface or other, the entire length. And as a result, it has less likelihood of undergoing flexural deformations. Let us look at bolt 1 now. In this case, the bolt is being pulled in this direction by this plate. Therefore, we would have a bearing surface on this side in this bolt. Also these plates which are basically tied to the other plate will be pulling in the other direction; so, there will be bearing surfaces here.

Now, in this situation, you might see that there is a portion of the total length of the bolt which is not restrained, which is not bearing against any surface and which is free to deform. That is the portion which is next to the packing plate. And when a length of the bolt is not restrained effectively, that length is susceptible to flexural deformations. So, if the packing plate becomes thicker than a certain limit, the limit is set as 6 millimetres as per the Indian code.

If this packing plate is thicker than 6 millimetres, in that case, there is a possibility of excess flexural stresses developing in the bolt, which will reduce the shear strength of the bolt. And the corresponding factor is known as β_{pk}, standing for packing plate. β_{pk} is calculated as per this expression, where t_{pk} is the thickness of the packing plate. And the effective strength of the bolt is reduced by $\boldsymbol{\beta_{pk}}$.

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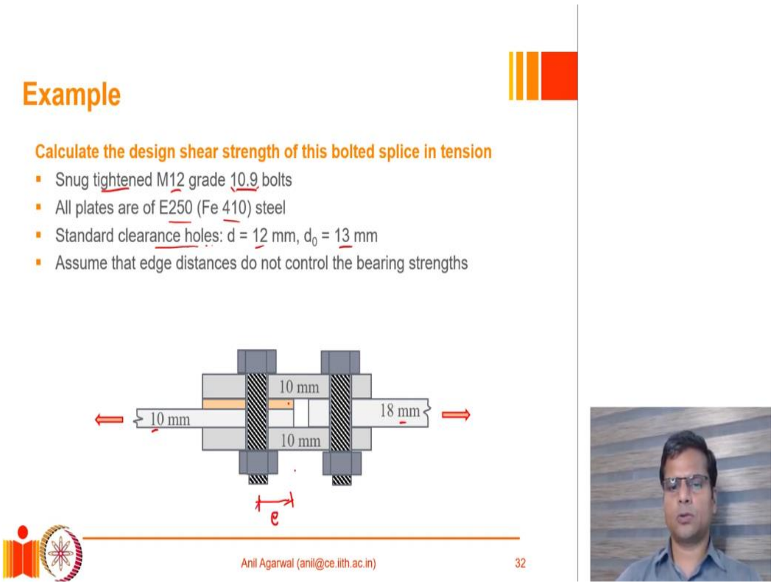

So, now, we have seen these 3 correction factors and we have also seen how to calculate the shear strength and bearing strength of a bolted joint. So, let us do 1 example. We will take the same example that we were working with before with some minor changes. So, let us calculate the design shear strength of this bolted splice in tension. This is a bolted splice. Bolt plate is 18 millimetre; the other plate is 10 millimetre in thickness; it is being pulled in tension.

There is a packing plate which is placed here. The 2 lap plates are 10 millimetres thick each. In addition to that, additional information is given. The bolts are not friction grip bolts, they are snug tightened bolts, 12 millimetre diameter and 10.9, that is high strength bolts are used, but they are not pretensioned, they are only snug tightened. So, in addition to that, the plate is E250, that is 410 MPa, ultimate strength.

The clearance holes are used, standard clearance holes are used meaning that if the bolt diameter is 12 millimetre, the hole diameter would be 13 millimetre. And in this, for simplicity, we are assuming in this example that these edges are far enough from the bolt so that they do not control, that e value does not control the bearing strength of the bolted joint.

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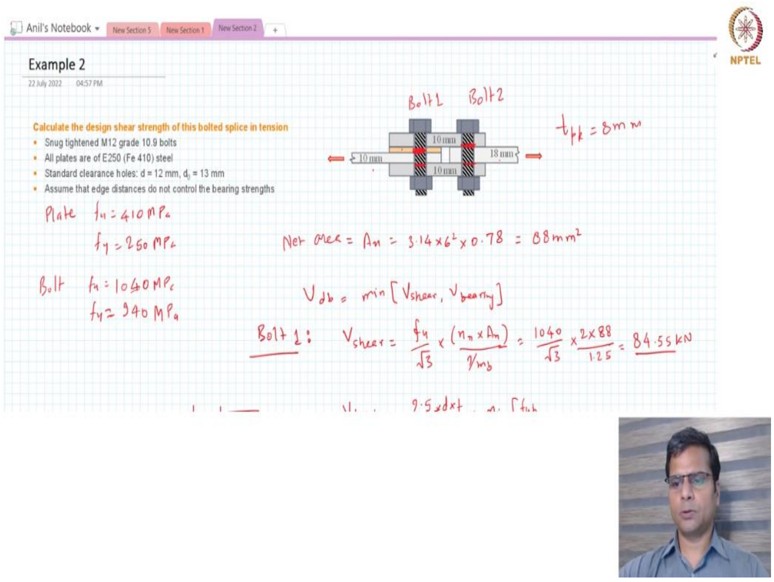

So, we know that this plate is 10 mm thick, this plate is 18 mm thick; so, we know the packing plate is 8 mm thick. I will write as t_{pk} = 8 millimetres. Let me call this bolt as bolt 1 and this as bolt 2. We need to check the design strength of both of them. Now, from this information that is given to us, we know that for the plate, f u = 410 MPa, f y = 250 MPa. For the bolt, f_u = 1040 MPa, and f_y is equal to 90% of that, which is, I have taken it from the appropriate code, which is 940 MPa.

The bolts are both 12 mm diameter bolts. And when they are subjected to shear, the net cross-section area can be calculated as pi multiplied by r square 6 square multiplied by 0.78, which turns out to be 88 millimetre square. And we know that both these bolts are under double shear. This bolt has this shear surface here and here. In this case, this board has 1 shear surface here and another shear surface somewhere in this region.

Both these bolts are under double shear. So, V $_{db}$ we have seen before is actually equal to minimum of V $_{shear}$ and V bearing. We will start with bolt 1 first. For bolt 1, V shear which will be actually equal in, same in both, case of bolt 2 also, but anyway here we will do it for bolt 1 first. V shear would be equal to, design strength would be equal to f u divided by root 3 and n multiplied by A n.

And we are assuming that both shear planes are passing through the threaded portion; divided by gamma mb, which turns out to be 1040 divided by root 3 multiplied by 2; 2 planes; multiplied by 88 millimetre square divided by 1.25. That is 84.55 kilonewton; that is V shear.

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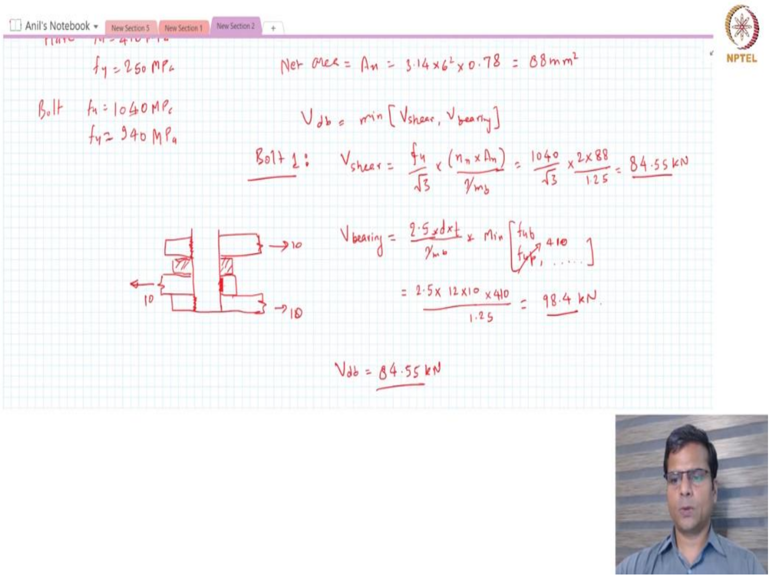

Now, when it comes to V bearing capacity, shear capacity and bearing limit state, we have to look at this joint a little bit closely. So, this is the bolt. Here, this is my 10 millimetre plate which is being pulled this way. Then there is an 8 millimetre thick plate above it. And then there are 2 other 10 millimetre plates. This is an 8 millimetre plate. Then there is another 10 millimetre plate here and one 10 millimetre plate here; both of them are being pulled this way.

This is the packing plate which is not being pulled in any direction. So, if we look at the bearing surfaces, here we would have a 10 millimetre long bearing surface. This thickness is 10 millimetres. So, here we would have a 10 millimetre long bearing surface. Similarly, here we would have 2 10 millimetre long bearing surfaces. So, which of these 2 surfaces would fail first?

Obviously, the surface with only 10 millimetre length would fail first, so, we will design for this one. We will calculate the design strength of this surface. The expression for bearing strength is 2.5 dt divided by Υ_{mb} multiplied by minimum of f_{ub}, f_{up}, and then some other factors which we have already assumed are not going to control because the pitch distance and s distances are not going to control the bearing behaviour.

Now, between f_{ub} and f_{up}, which one is smaller? f_{up} is smaller. That is equal to 410, and this is much greater. So, we will ignore f ub, f ub is 1014, whereas, f up is only 410, so, we will take this one. And the bearing strength will be calculated as 2.5 multiplied by the diameter is 12 millimetres, thickness is only 10 millimetres, only 1, because on this side we have only 1 10 mm thick interface, multiplied by 410 divided by 1.25, which turns out to be 98.4 kilonewton.

This is for bolt 1. Now, this was the shear strength 84 and bearing strength is 98, therefore, V db for bolt 1 is equal to 84.55 kilonewton, minimum of the two. However, we might not have noticed here that there are some correction factors that might have to be applied. So, let us look at those correction factors quickly. There are 3 correction factors we have talked about. One is the correction factor for the length of the joint. So, in this case, the joint does not have any length, it is only a single row of bolts. So, the length of the joint factor does not matter. The other factor; note it down.

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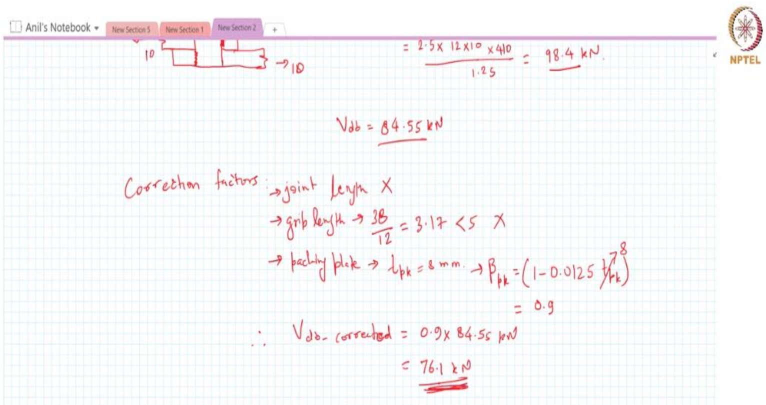

Correction factors: Joint length does not matter, because joint length is very small. Then the second factor is the long grip. And remember that long grip matters only when the grip length divided by the diameter of the bolt becomes greater than 5. So, in this case, what is the grip length? Grip length = 18 millimetre + 10 + 10. So, that is 38 millimetres. Grip length is 38 millimetres and the diameter is 12 millimetres.

38 divided by 12 is only equal to 3.17, which is less than 5; therefore, this factor will also not control the design. This will not reduce the strength of the bolted joint. Now, the third factor that we need to be careful about is the packing plate. If the packing plate is greater than 6 millimetre thick, then it reduces the strength of the bolt. And in this case, we can see that the packing plate is 8 millimetres thick.

If the packing plate is 8 millimetres thick, the correction factor for the packing plate which will turn out to be, this t_{pk} will be 8 millimetres and this will be 0.9. So, this factor is 0.9. Therefore, V_{db} corrected will be 90% of 84.55 kilonewton, which will be equal to 76.1 kilonewton. Now, all this calculation belongs to bolt 1. The question is, what would be the strength of bolt 2? Will it be greater than the strength of bolt 1 or not?

Now, if you look carefully, the shear strength of V shear for bolt 2 will be exactly the same as this shear of bolt 1. There are 2 planes, same cross-section area, everything else is the same, it will not change. The bearing strength now we see; in case of bolt 1, the bearing surface area that was available to us was only 10 millimetre thick. Whereas, in case of bolt 2, we have 18 millimetre available for this plate, and 10 + 10, 20 millimetres available for these 2 plates.

So, the bearing surface area would increase; therefore, this factor, V bearing for bolt 2 will be greater than this value. Now comes the correction factor. So, bolt 1 had a packing plate but bolt 2 does not have a packing plate. So, therefore, there will not be any correction factor that will be applicable to bolt 2. Therefore, overall we can see that bolt 2 is going to have a higher strength than bolt 1. Therefore, we do not have to design separately for bolt 2. The connection strength will be same as the strength of bolt 1, which has been calculated as 76.1 kilonewton.