Design of Connections in Steel Structures
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Module - 1
Lecture - 2
Basic Principles of Bolted Connections

Welcome back to this course on the Design of Connections in Steel Structures. So, we are focusing in the first few lectures on the bolted connection design.

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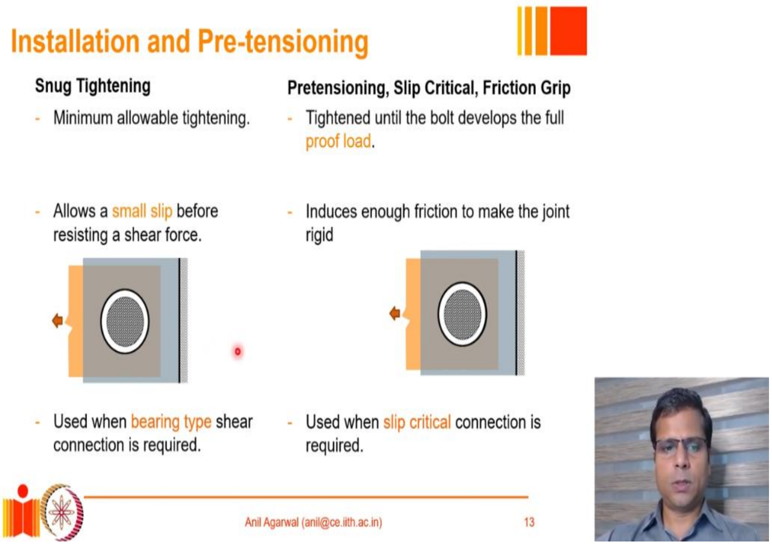

So, bolted connections can be designed or can be installed in 2 different ways. The one commonly used method is the method known as snug tightening and the other method is that of pretensioning. This is also known as a slip critical connection or a friction grip connection. The fundamental difference between the 2 methods of installing a bolted joint is that, in the snug tightened connection, the bolts are tightened only to the minimum allowable tightening.

So, that is basically a spud wrench is used to the maximum manual force, and that is the maximum amount of tensile stress that is introduced in the bolt. So, bolt is not tensioned or the nut is not turned beyond the maximum manual force that can be applied. So, such kind of connections typically allow a small slip. So, when a bolted connection as you can see here is subjected to a shear force demand, this, the 2 plates that are joined together using the bolt, they slip with respect to each other.

However, a pretension connection, that is tightened until the bolt develops a full proof load. So, we had seen a value, proof load value in earlier tables for every bolt; especially for high strength bolts, proof load values are required. And the bolt has to be pretensioned up to, until it develops that level of tension. So, there are various ways on installation. We will talk about that in a minute.

So, the idea here is that when the proof load level of tension force is applied in the bolt, it grips the 2 plates together in a way it introduces enough friction so that the joint behaves as a rigid joint under shear conditions.

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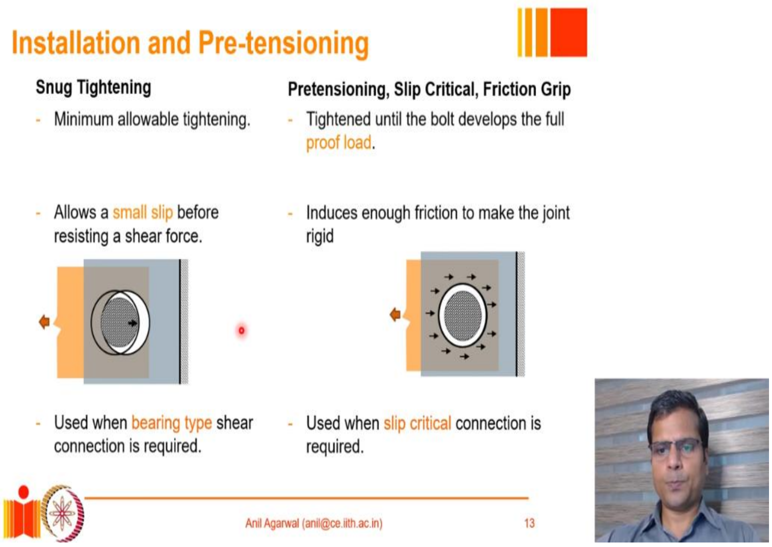

So, here you may see, as the tension force is applied to one of the plates, the grey plate is strained here, while the orange plate was pulled. And as a result, the orange plate slid against the grey plate and also the bolt which had some clearance between the bolt and bolt hole, that clearance closed. And as a result, the force transfer takes place in the form of bearing between the bolt shank and the bolt hole.

So, the force is usually concentrated at that interface between the bolt shank and the bolt hole interface. In a friction grip or in a pretension bolt, typically, there is enough compression applied on the 2 plates together, so that there is sufficient friction available between the plates, so that when one of the plates is pulled; in this particular case, the orange plate is being pulled and the grey plate is strained; there is no slip, there is no effective slip between the 2 plates.

And the force transfer is taking place through friction that is present between the 2 plates. So, this as a result, this type of a connection is a much more rigid connection, whereas this connection has more flexibility.

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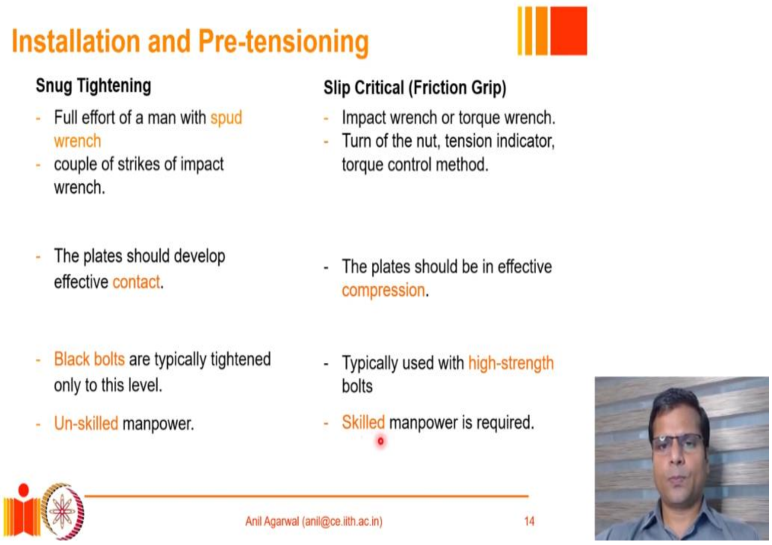

Snug tightening is usually provided by either full effort of a man with a spud wrench, that is a typical wrench that is used for construction. Or otherwise, if an impact wrench is used, so, just a couple of strikes are used using an impact wrench and that is considered sufficient for a snug tightening requirement. However, for a slip critical joint which is also known as pretension joint, impact wrench or a torque wrench is essential.

And usually, we measure the amount of tension force that is developing in the bolt by one of these 3 methods. The first method is turn of the nut method, which is the most common type of method. Otherwise, there are some types of nuts and some other washers available which will give an indication of the tension force developing in the bolt. Otherwise, we have to measure the amount of torque that we are applying on the nut.

And some calibration charts have to be used to correlate the torque with the tension force developing in the bolt. Most of these products, the second and the third ones are proprietary items which can be bought from the market. The idea behind a snug tightening is that just that the 2 plates that are being tight together, they should develop effective contact, they need not be in effective compression together.

Whereas, in a slip critical bolt, bolted joint, the plates should be in effective compression. Not only they should be in effective compression, they should be also having sufficient friction so that the joint behaves as a rigid joint. Typically, black bolts which are normally strength bolts up to 600 MPa strength bolts, they are tightened only to the snug tightening level. Whereas, high strength bolts are usually tightened up to the slip critical or friction grip level.

Snug tightened bolts require a unskilled manpower typically. Any manual labour that is available should be able to install snug tightened bolts, normally strength bolts. Whereas, the high strength friction grip bolts installation requires skilled manpower.

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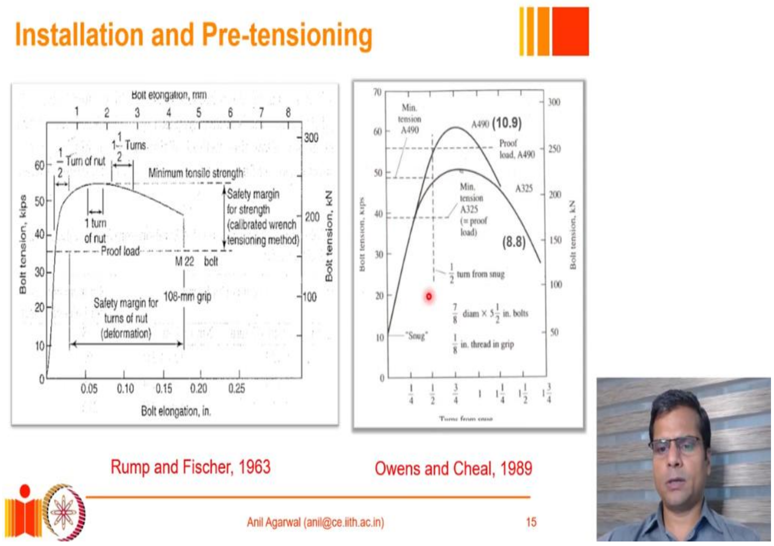

It is important also for us to understand the bolt behaviour with respect to number of turns as we introduce. So, how the bolt undergoes tension and how the bolt failure takes place. So, many researchers have conducted, have studied this behaviour of high strength bolts. So, this graph I have taken from some of the research papers which are published and are available in the public domain.

So, this is a high strength bolt. As it is elongated on the horizontal axis, you will see the bolt elongation. And on the vertical axis, you will see the tension force developing in the bolt. As you can see, as the high strength bolt is elongated, it does not have a very clear yield line. It gradually goes into plasticisation. And what you might notice is that the proof load level is approximately the level at which it starts to plasticise significantly.

And, also the same behaviour can be plotted by marking the turn of the nut on the horizontal axis. So, in this particular graph, the vertical axis represents the tension force in the bolt, but the horizontal axis represents the turn of the nut instead of the bolt elongation directly. So, both elongation and turn of the nut are not necessarily linearly proportional. So, here you might see that they start counting the turn of the nut from the snug tightened level.

So, at the snug tightened level, which was just manually applying the force, the bolts were under a very small tension force. But as the nut is tightened further, the tension force in the bolt increases. Initially it increases linearly and beyond a point it starts to turn into nonlinear. These are the 2 plots for 2 different strengths. This is for 8.8 grade bolt and this is for 10.9 grade bolt. So, you might see that for both of these bolts approximately at about half a turn beyond the snug tightened bolt, they start to develop the proof stress level.

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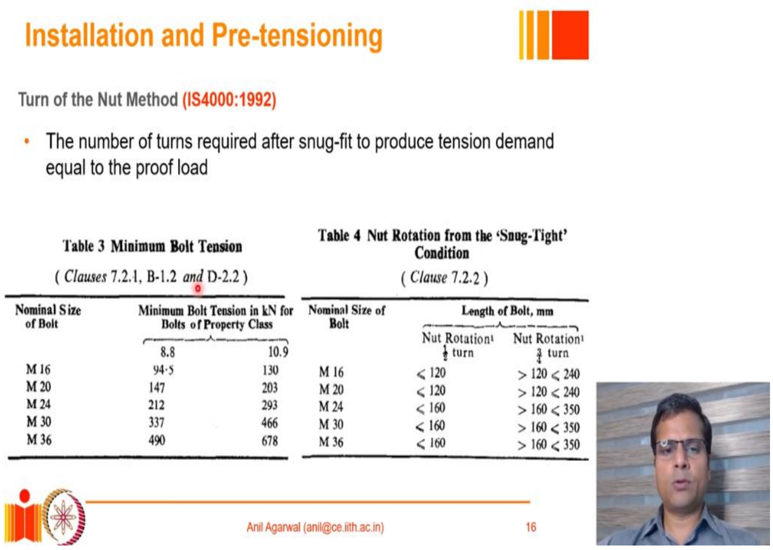

So, the turn of the nut method, actually IS 4000, it prescribes a way for us to calculate the number of turns required in order for us to be able to develop the full proof stress level in a bolt. So, if you go to table 4 of IS 4000, for different size bolts, M16, M20, M24 and so on, and for different lengths; so, length less than 120 or greater than 120 but less than 240; so, for 2 different lengths and for different diameters, this table provides us the number of rotations required to develop proof stress level load in a bolt.

Also, the expected proof stress or proof load in a bolt of a different diameter and different strength are also given in the same IS code. So, if you are going to use some different method other than the turn of the nut method, then you can directly refer to this table and make sure that you are developing sufficient amount of proof stress for it to be a slip critical bolted joint. Alternatively, we can just follow this method. It provides sufficient number of turns so that we develop a slip critical joint.

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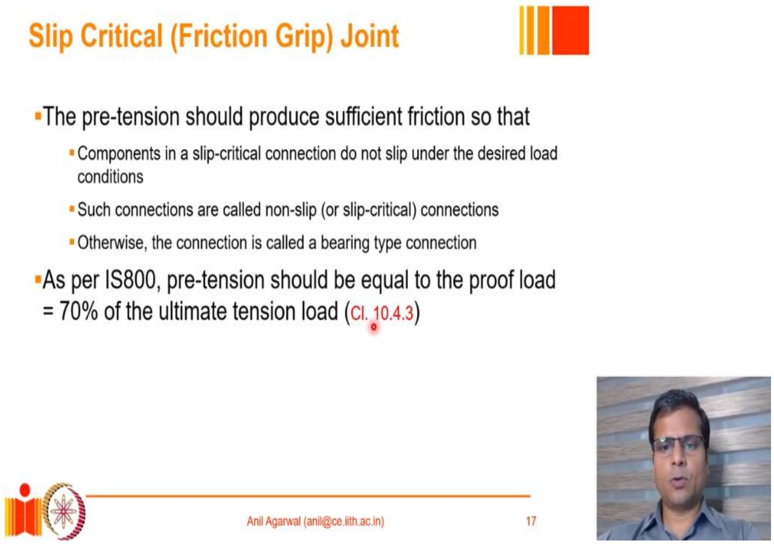

The idea behind developing a slip critical or friction grip joint is that a slip critical joint should produce sufficient friction between the 2 plates so that under the desired load conditions, whatever the desired load conditions, the 2 plates do not slip. So, such connections would be called non-slip or slip critical connections. If the sufficient force is not developed or if for some reason sufficient friction is not developed, in such a condition, it would be called a bearing type connection.

We have seen that already through that animation that in a bearing type connection, there is some, the clearance between the bolt and the bolt hole allows for that slip to happen, and that slip turns the bolt into a bearing type connection. So, we have seen that IS 4000 provides us the pretension or proof load level for a bolted joint that is required during the installation. However, IS 800 recommends that we do not have to refer to IS 4000 for each specific bolt what is the level of proof stress that we have to develop.

For the design purposes, we can assume the proof load to be approximately 70% of the ultimate tensile load of the bolt and that is acceptable. We can go to IS 800, clause number 10.4.3 and there it is mentioned.

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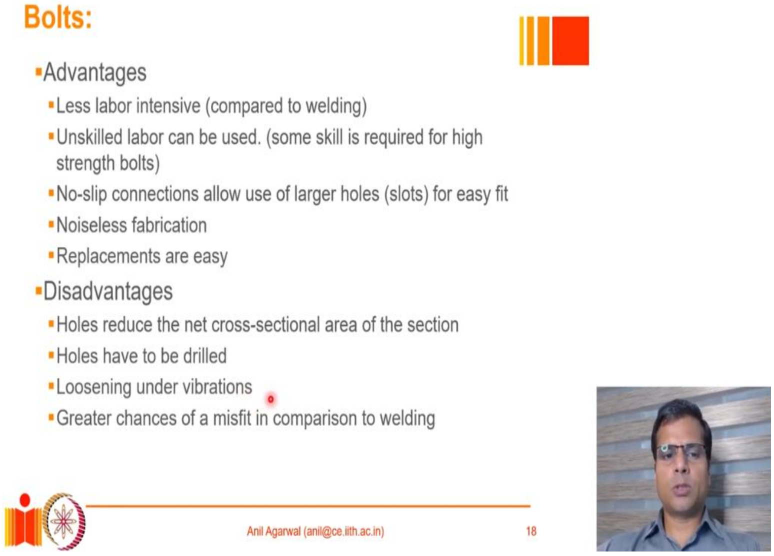

So, bolted joints have various types of advantages and disadvantages in comparison to welded joints; here I am listing a few. Generally, bolted joints are less labour intensive, especially unskilled labour can be used to install bolted joints. That is true especially for normal strength bolts. For high strength fishing grip bolts, we may have to require more highly skilled labour for installation.

Generally, if we are going for a no-slip type of a connection, that is a high strength no-slip connection, we can even provide larger holes which will allow us an easy fit during the fabrication and during the installation erection. And later on, the connections can develop good rigidity. The fabrication process is not very noisy and does not produce lot of pollution, so, it can be done indoors, it is not a problem; and replacement of such bolted joints is easy.

Some of the disadvantages of bolted joints in comparison to welded connections are: Bolted joints require hole to be drilled and those holes reduce the cross-section area of the section which effectively reduces the strength of the cross-section. The drilling process is very time consuming and labour intensive; so, that adds to extra cost. Fabrication has to be done very carefully, because, if there is any small misfit, it can lead to inappropriate connection. And there is also a possibility of loosening of these bolted joints under vibrations.

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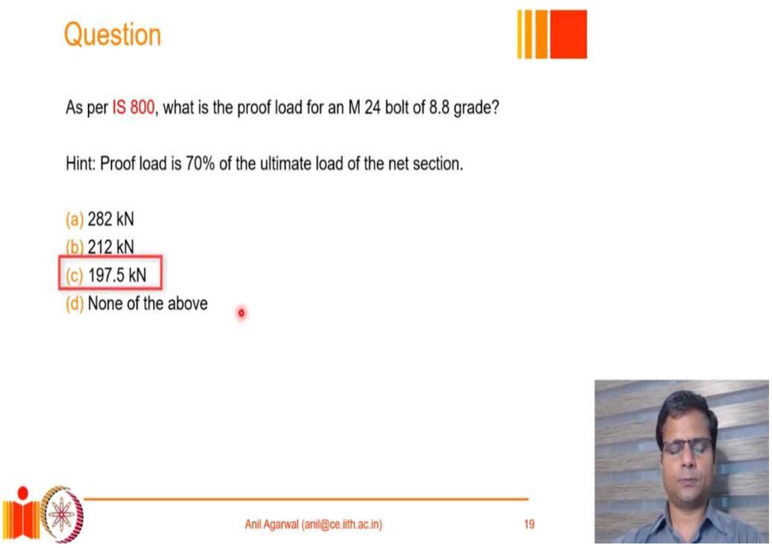

So, let me ask a question first. What is the proof load of an M24 bolt of 8.8 grid as per IS 800? Please mind that I am not asking as per IS 4000. As per IS 800, for the design purpose, what would be the proof load? I have given a hint also; the proof load is 70% of the ultimate load of the net section. So, for an 8.8 grade bolt, you know what is the ultimate stress; you know for that we can calculate what is the proof stress; and also we can calculate what is the net section of an M24 bolt. Based on that, we need to find out what is the proof load value. Please click the correct answer.

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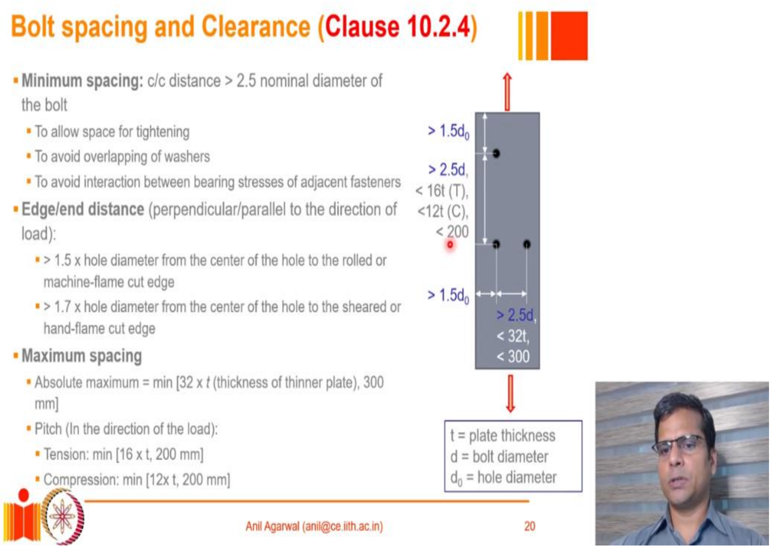

So, moving forward, when we provide bolted joint, there are various constraints that we need to satisfy with regards to the location of the bolts. So, there are various constraints with regards to how close 2 consecutive bolts can be in a bolted joint. And also there are some constraints of how far apart 2 consecutive bolts can be. So, first, we will talk about the minimum spacing requirements.

Whenever we provide bolts close to each other, the bolts should not be too close to each other. There are some obvious constraints such as, if the bolts are too close together, it will be difficult to access the bolt nuts for tightening. So, we should have enough space so that a wrench can be placed around the bolt and nut and it can be tightened, it can be rotated with ease.

Also, when we use washers, the washers require larger area, so, the bolt holes should not be so close that the washers start to overlap. Also, one might be mindful of the possibility that the stress zone of one bolt should not start to interfere with the stress zone of another bolt. Here what I am showing you for example is, let us say there is 1 bolt here, 1 bolt hole is here and there is a bolt placed inside this.

And then, when the bolt is subjecting this bolt hole to a tension force demand, most probably this area of the plate will be under stress. Now, this area under stress, if we place another bolt hole right next to it, that bolt hole will be under the influence zone of the bearing area of this bolt hole. Therefore, it is not advisable to provide bolts at very close intervals. And general minimum requirement is that is marked in blue colour here in this diagram.

So, in the direction of the load, typically, it is limited as it should be at least 2.5 times the diameter of the bolt, that much of space has to be left, whether it is in this direction or in the direction perpendicular to the load. This is just to avoid the bolts getting too close together. Also bolt holes should not be placed very close to the edge or the end of a plate. Again similar constraints are in plane.

So, when the edge or these edges are machined or they are hot rolled, in such a case, this edge distance or end distance can be anywhere up to or greater than 1.5 times the hole diameter. And I am talking about the distance from the centre of the hole to the edge. But when the edge is not machined, if it is cut using a hand flame or if it is sheared, in that case, the edge will not be a smooth edge.

And in such a case, the centre of the hole should be at least 1.7 times the hole diameter away from the edge. And this is true for both the edge, side edge as well as the end edge. Also, there are various constraints on the maximum amount of spacing that is allowed in between 2 consecutive bolts in a bolted joint. So, if 2 bolts have to be counted as a part of a single bolted joint, they cannot be too far apart.

So, the absolute maximum limit in all possible directions is given as 32 times the plate thickness of the thinner plate. So, if there are 2 or 3 plates joined together, the thinnest of those 3 plates would be taken; its thickness multiplied by 32, that is the maximum distance between the 2 consecutive bolts; and also 300 mm. So, if the 2 bolts that are more than 300 millimetres apart, they cannot be counted as a single bolted joint.

Now, in the direction of pitch; now, the direction of pitch is basically the direction in which the load is acting. So, the pitch distance has more, strict constraints with regards to maximum distance between the bolted joints. If the load is tensioned in the plate, in such a case, the distance between 2 consecutive bolts in the direction of the load should not be more than 16 times the plate thickness or 200 millimetres, whichever is less.

If the plate is in compression however, this limit is even more stringent, and the distance between the 2 consecutive bolts should not be more than 12 times the thinner plate thickness or 200 millimetre, whichever is less. Now, obviously, this begs a question. Why is limit less in case of compression but it is greater in case of tension? I will give you a minute to think about it. Do you have some ideas, some clues?

So, the reason for that is that if the plate is under compression and these are the locations let us say where the bolts are restraining the plate, in between the plate can buckle. So, if we increase this distance too much, the plate can buckle in compression. However, in tension, there is no such possibility of buckling. However, still in tension, if we separate the bolts too far apart, in that case, the force distribution between these two bolts cannot be assumed to be equally divided, because the flexibility of the plate will start to play a very significant role.

Therefore, there is a limit of 16t in case of tension. But in case of compression also there is a fear of buckling; therefore, the limit is 12 multiplied by the plate thickness.