Design of Connections in Steel Structures

Prof. Anil Agarwal
Department of Civil Engineering
Indian Institute of Technology - Hyderabad

Module - 3
Lecture - 14
Design Example of a Bolt Group

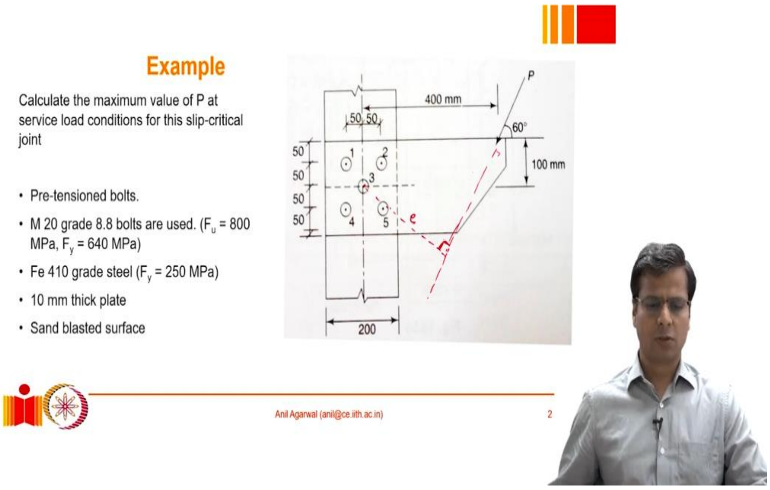
Hello. So, we are learning about Designing of Connections in Steel Structures. In the previous 2 weeks, we have discussed the basic principles of designing of bolts and welds, and what are the manufacturing aspects and some of the various dimensional restrictions, etcetera that we have to follow. In addition to these, now we will get into some real design problems and we will see how those principles are actually applied in a real life design problem.

So, today we will start with a few examples. And basically these examples would involve some of the basic concepts that we have learnt about calculating the design strength of individual weld or an individual bolt. In addition to that, there will be some basics of structural mechanics that will be involved, because we have to calculate the demands in individual bolts and welds for a given set of loads.

And that part, it is very difficult to cover it through theory because every single weld group or every single bolt group or every single connection has its own peculiarity. And basic concepts, basic understanding of mechanics is what is required, which is not necessarily within the scope of this course. So, we will learn it through examples. I think that would be the ideal approach.

So, we will do a few examples of different types of bolt groups and different types of weld groups and try to understand how to design them for various types of loadings. So, the first example we will take today is of the designing of a bolt group.

(Refer Slide Time: 01:54)



So, this is the example that we have taken. Here you may see, this is a column which is supporting a bracket. The bracket has a load P acting at an angle of 60 degree from horizontal. So, the connection between the column and the bracket is shown here, which basically specifies that there are 5 bolts. 4 of these bolts are at the periphery and 1 is at the centroid.

The spacing between the bolts is 50 millimetres each, in horizontal as well as vertical direction. So, this direction also, the spacing is 50 millimetres. And this load, the way it is applied, it is not passing through the centroid of the connection. If this load were to pass through the centroid of the connection, the design exercise would have been very simple; we would have simply calculated the total force on the bolt set divided by 5.

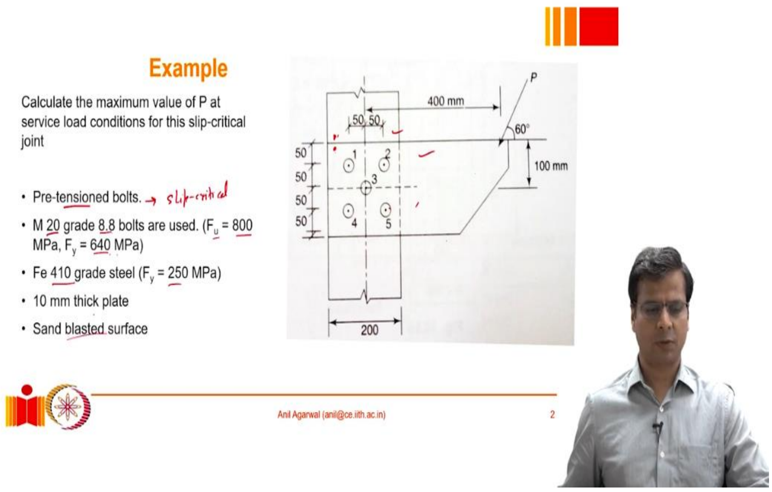
So, each bolt would have carried exactly one-fifth of the total load. And that would have been the demand on each bolt. Subsequent to that, we would have simply calculated the capacity of each bolt based on various parameters that are specified here. And we would have compared the two, and that would have been the end of the exercise. However, in this particular case, the load is not passing through the centroid of the bolt group.

And it is noticing here that this connection or bolt group is symmetric. So, that makes life a little bit easier. So, it is symmetric about the vertical axis; it is also symmetric about the horizontal axis; also it is symmetric about the axis which is at 45 degrees. So, that makes the life bit easier, but still we have to worry about the eccentric effect. So, if we may see here in this particular case, the way this load is applied, if I extend the line that is passing to this load, let us say it passes from here.

So, then, from the centroid, it has some net eccentricity which will be the perpendicular line drawn from the centroid to this extension line. So, this angle will be 90 degrees. And we need to find out how much that eccentricity is. And that eccentricity multiplied by the force value will be the moment that also has to be resisted by these bolts. So, these bolts will not be resisting only the force that is applied directly, which is P divided by 5, but also they will be resisting the moment component of it.

So, that is the design philosophy that we will follow. We will go into the detail example in a minute. In addition to this, there is also this information provided that these bolts are pretensioned bolts.

(Refer Slide Time: 04:48)

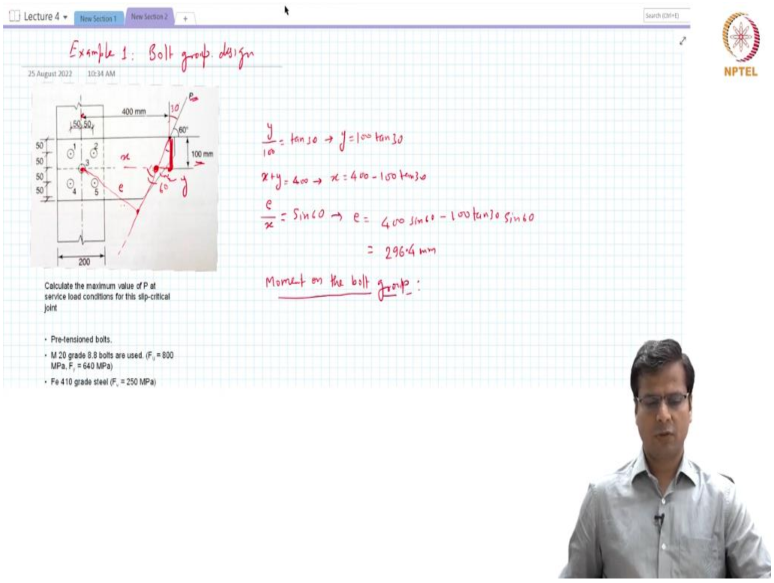


What does it mean? It means that we need to design them as slip-critical connections. When we design it for slip-critical connection, it is not a bearing type of bolt, it is basically slip-critical. So, its strength is dependent on the strength of the friction, the friction resistance. So, that is what we need to design it for. These are M 20 bolts. So, M 20 bolts means the diameter is 20 millimetres, radius is 10 millimetres.

Grade 8.8, that means F_u ultimate stress is 800 MPa; and F_y is also given, which may not be immediately required. The steel that this column and the bracket are made of is Fe 410 grade steel, which means that it has a unit stress of 250 MPa and the ultimate stress of 410

MPa. And the plate is 10 millimetre thick, the bracket plate. And the surface between the 2 plates basically offers very good friction. The reason for that is that these surfaces are, the plate as well as the column surface, they are both sand blasted. Sand blasted gives us very high level of friction resistance.

(Refer Slide Time: 05:59)



So, we have just described the problem that we need to solve. The question is that we need to calculate the maximum value of this force P that can be resisted safely by this bolt group. We know the eccentricity; we know these different dimensions. This dimension is 100; this spacing is 100 millimetre and this distance from the centroid of the bolt to the loading location, horizontal distance is 400 millimetres.

And as we had discussed before, we need to calculate this eccentricity. So, this is e value, this length. This is the eccentricity that we need to calculate. So, we can use some simple geometry principles to calculate the eccentricity. This angle is 60 degrees, so, this angle would be 30 degrees. Therefore, this angle will also be 30 degrees. And this angle will again be 60 degrees. We know that this height is 100 millimetres, it is given here.

And we know that this length from the centroid to this point where the load is acting is 400 millimetres. Now, if we want to know e, we can first calculate; let us call this distance from the centroid, that is bolt number 3 to this point x; let that distance be x and let this distance be y. Now, we can calculate the relationship between y and this distance 100 millimetres as y divided by 100 is equal to tan(30).

And from there we can calculate y to be 100 tan(30). Now, we know that x + y = 400 which means that x = 400 - y, and y is equal to 100 tan(30). So, we can calculate the value of x. Once we know the distance x, we can calculate distance e, because the relationship between e and x is sin(60). e divided by x will be equal to sin(60). Therefore, e will be equal to 400 sin(60) - 100 tan(30) sin(60,) which we can calculate to be equal to 296.4 millimetres.

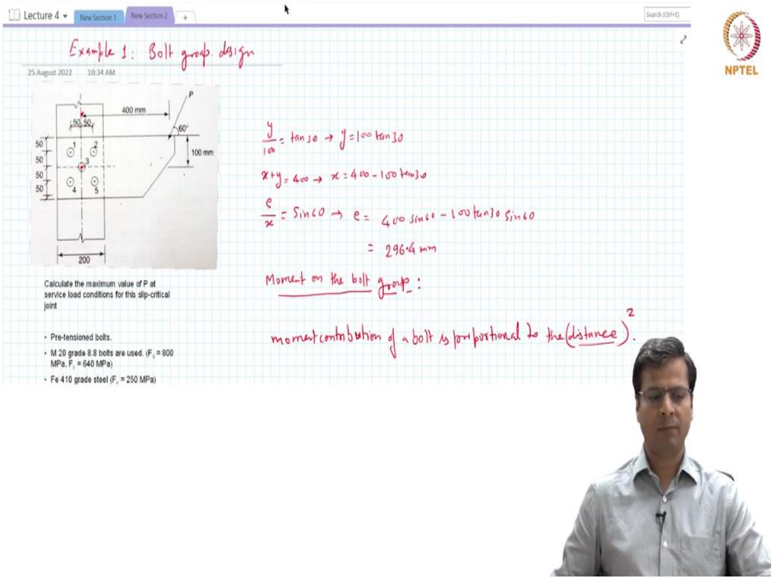
So, the eccentricity is this much. And if the eccentricity is known, we know how much moment is acting. So, about which point should we calculate the moment? Should we calculate the moment about the point, about the location where the bolt 3 is working, or should we calculate it about any other point? What is your answer? Please think about it. So, the answer is that we should calculate the moment about 0.3, because 0.3 is the centroid of this bolt group.

How do we know that it is the centroid of the bolt group? Because the bolt group is perfectly symmetric about the x axis as well as the y axis. Therefore, that is the centroid; that is where the neutral axis is. And when we apply a pure moment, there will not be any stress developing in bolt 3 which is with the assumption that each bolt has equal stiffness. So, if each bolt has equal stiffness and each bolt is equally far from the centroid, then the centroid will be at bolt 3.

However, if each bolt was not equally far from bolt 3 or if there was any other kind of an asymmetry, then the new centroid location had to be calculated manually; it would not be obviously known that it is at the centre. So, geometric centroid could be different from the centroid of the stiffness. In this particular case, both are same. But, if let us say 1 bolt was slightly stiffer or 1 bolt was slightly farther, then the centroid would shift its position.

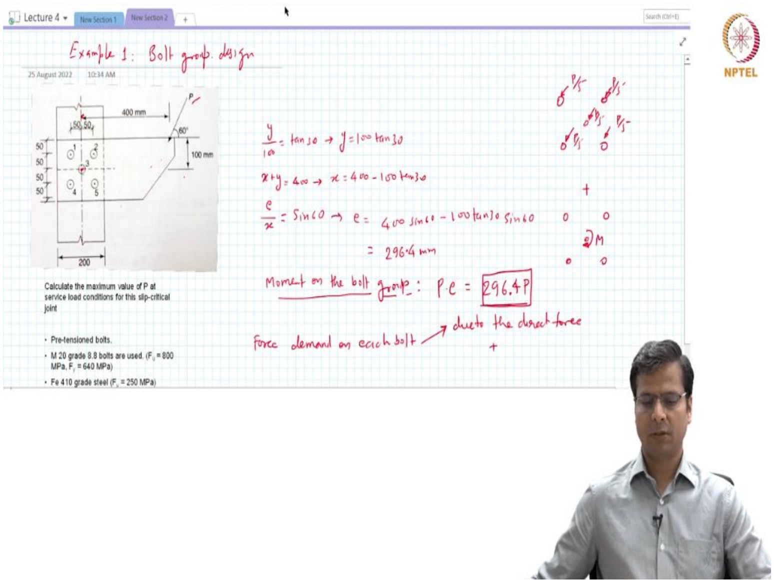
And the principle that we need to follow for that is that, if the force that 1 bolt would resist will be proportional to its distance from the centroid, that is one. Then, in addition to that, the moment contribution from that bolt will again be proportional to, in addition to the force, the distance from the centroid, which essentially means that moment contribution or contribution towards resisting the moment from a bolt or of a bolt is proportional to the distance from the centroid.

(Refer Slide Time: 10:57)



When I say distance, I mean distance from the centroid. And when I say centroid, I mean centroid of the stiffness squared. In this particular case, since all 4 bolts are equally distant and bolt 3 has 0 distance from the geometric centroid, therefore, the moment will be distributed proportionally or equally between bolts 1, 2, 4 and 5; and bolt 3 will not resist any moment. And we will get there in a minute.

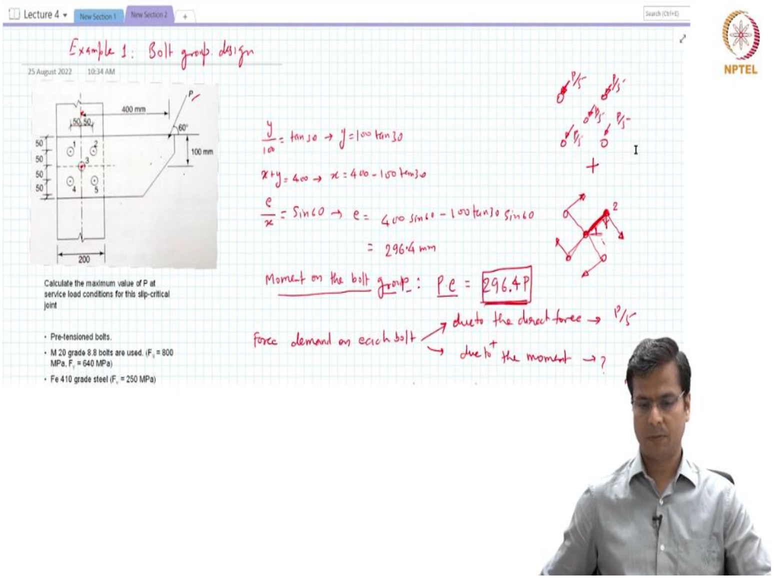
(Refer Slide Time: 11:54)



So, moment on the bolt group is P multiplied by e, that is 296.4 P. And the force demand on each bolt; first we will calculate due to the direct force, as if the force was acting at the centroid. You can imagine that this particular configuration can be thought of as a combination of these 2 configurations. In the first configuration, the force P by 5 is applied to each bolt in the direction of the force that is applied at that angle.

Each bolt would be resisting P divided by 5. Then there is a moment applied on this bolt group which is equal to 296.4 times P. And because of that moment application; I will just erase it for a minute.

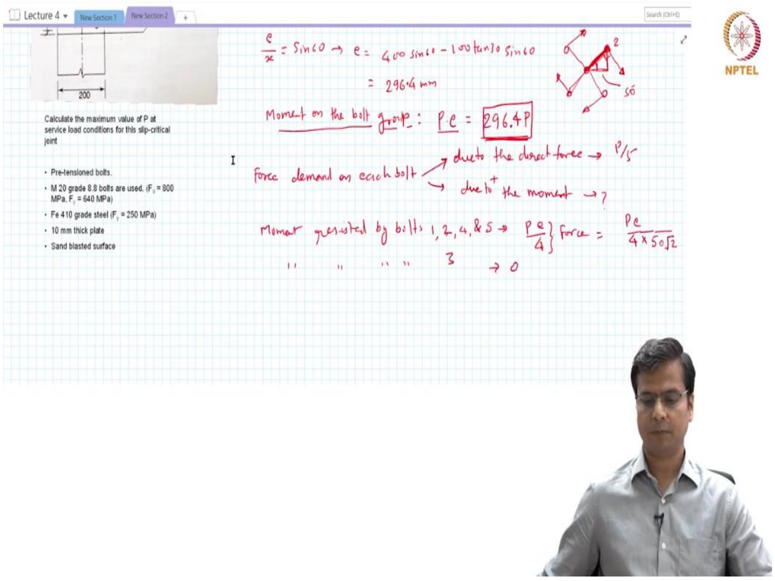
(Refer Slide Time: 13:10)



Because of that moment applied, that we are applying, each bolt will be resisting that moment in the direction perpendicular to its distance from the centroid. So, let us say bolt 2; this is bolt number 2; it is at this angle from the centroid, that is the line that is drawing the radius from the centroid to bolt 2. And the force because of the moment on bolt 2 will be perpendicular to that line. That is understandable; that is how it can resist the moment.

So, now, since all 4 bolts are equally distant, they have same stiffness, they have cross-sections; therefore, they will be offering equal amount of resistance against the moment. So, if the total moment was this much, one-fourth of that will be resisted by each bolt. So, what we are talking about is that the force, the direct force because of the external force that is applied plus the moment effect that we need to account for. And that is how we will calculate the total force demand in each bolt.

(Refer Slide Time: 14:26)

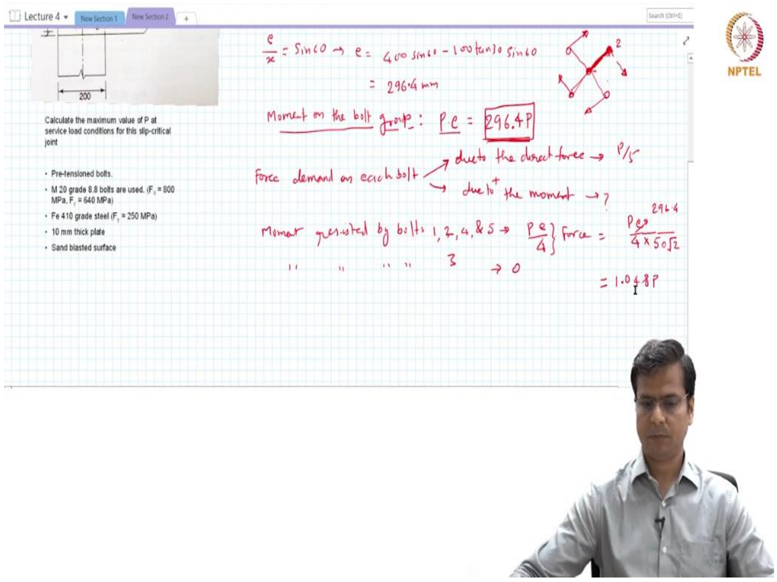


First was due to the direct force and due to the moment. Now we know that; how much is the force in each bolt due to the external load? That is P divided by 5. How much is the force in each bolt due to the external moment? So, first we know the external moment. That is P multiplied by e. Now that moment has to be resisted. So, moment resisted by bolts 1, 2, 4 and 5; how much is the moment resisted by each bolt? P divided by 4.

And what is the moment resisted by bolt number 3? 0, because it is at 0 distance from the centroid. So, each bolt will be resisting, 1, 2, 4 and 5 will be resisted P by 4 moment. And how much force will it introduce in each member or in each bolt? Because of this, the force will be equal to Pe divided by 4 divided by the distance of the centroid from the bolt. What is that distance?

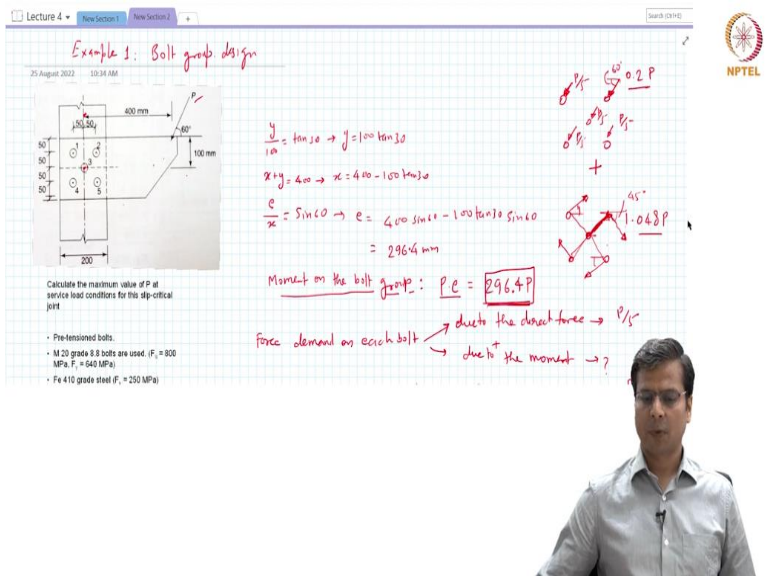
We know horizontal distance which is 50 millimetres; and vertical distance is also 50 millimetres; therefore, this angle is 45 degrees. And the actual distance from the centroid would be 50 multiplied by √2. So, now we know that the force here, we can actually calculate this value.

(Refer Slide Time: 16:25)



We can substitute the value of e which is 296.4 and then calculate this value. It turns out to be 1.048 times P.

(Refer Slide Time: 16:42)

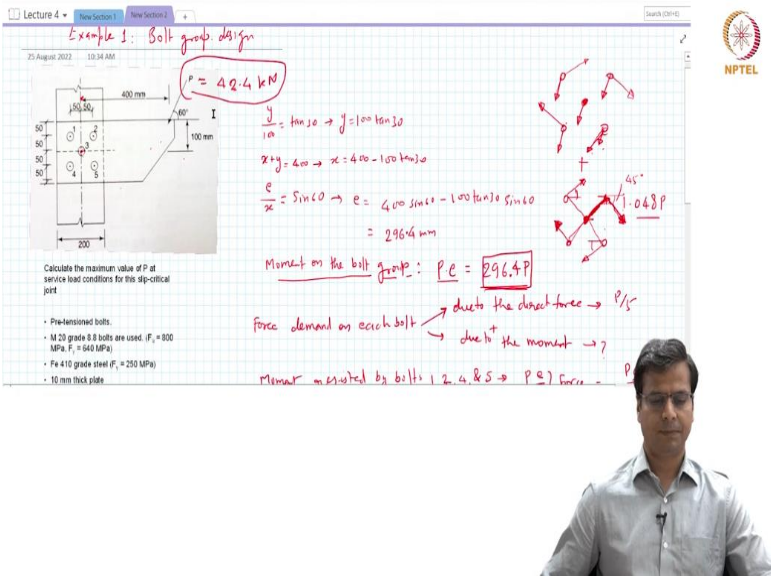


So, now, here we know that this value is 0.2P which is acting at a 60 degree angle from horizontal. This angle is 60 degrees. And this force is basically 1.048P, and this is acting at 45 degree angle from horizontal but at different angles. All of them are 45 but in different directions. We need to find the total force demand on each bolt and make sure that each bolt is safe. But do we really need to do that?

Here we can see the direction of each of these forces. And can we directly conclude from here and make sure that the bolt that is subjected to the largest total force, that is safe? If as long as we make sure of that, we do not have to design the other bolts, the bolts that are carrying less load. So, which of these bolts would be carrying the largest load? Due to moment, each one of them is carrying the same load.

Due to direct force, each one of them is carrying the same force. However, if we look closely, we will see the direction of forces. So, let me mark; let me remove the values here, so that it is easier to see.

(Refer Slide Time: 17:56)

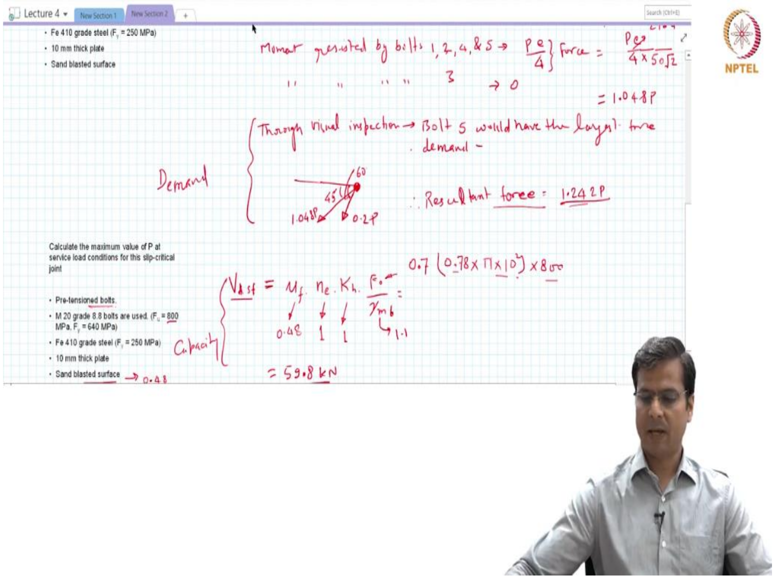


So, these are the forces directly due to the applied load, and these vectors are the forces that are because of the moment. Now, the maximum force would be in the bolt where these 2 forces are almost aligned or almost parallel or perfectly parallel. So, is there any bolt? Let us look at bolt 3. In bolt 3, the force is only 0.2P. So, it does not qualify. There is no effect of moment. Let us look at bolt 1.

In bolt 1, direct force is in this direction. The force due to the moment is in this direction. So, the net effect will be small, because they will try to cancel each other out there, almost in the opposite direction. Bolt 2, they will be like this. Bolt 3, again we discussed, there is no force because of the moment, so, the total force demand will be very low. In case of bolt 4, this is this direction; this is this direction.

So, again the angle is very large between the 2 forces. Therefore, the net component may not be the largest. How about bolt 5? The direct action is at 30 or 60 degrees from horizontal and the effect of moment is at 45 degrees from horizontal. They are much better aligned than all the other bolts. And therefore, they will have a much more significant combined effect than any other bolt.

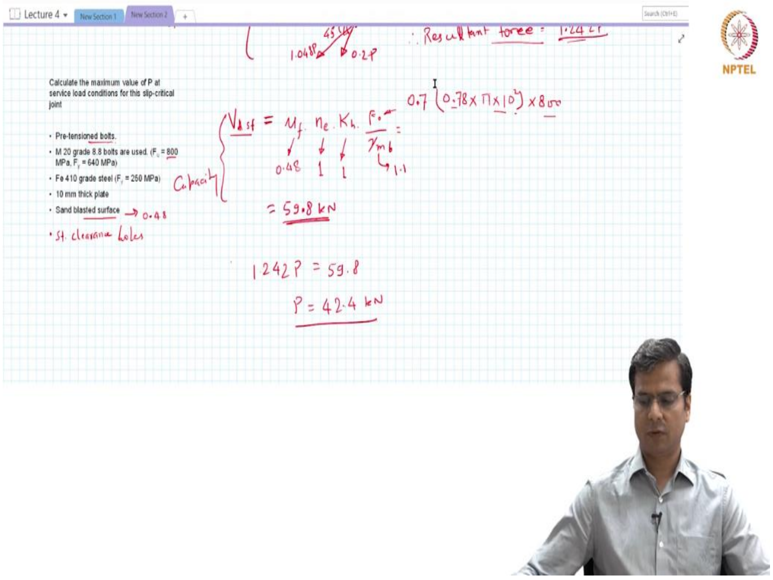
(Refer Slide Time: 19:25)



So, we can simply say, through visual inspection, we can say that bolt 5 would have the largest force demand. How much demand would that be? There is a force of 0.2P which is acting at 60 degrees from horizontal, and there is a force of 1.048P acting at 45 degrees from horizontal. So, once we know these 2, we can take their horizontal and vertical components and add them and again take the resultant.

So, the resultant force will be equal to 1.242 times P. So, what does that mean? When we apply a force P, external force P, bolt 5 will be resisting most amount of it. And it will be actually, the bolt 5 itself will be subjected to 1.242 times the P value, the external load. Now, we have calculated the demand on the bolt, maximum demand on any bolt. Now we need to look at the capacity side of it. So, let me move this information line.

(Refer Slide Time: 21:11)



So, capacity will depend on what type of bolt it is and what type of pretension we have applied and what type of surface it has. So, if you remember, V_{dsf} which was the expression, which was the term which was used for calculating the design strength of a friction grip bolt. d stands for design, s stands for slip and f stands for friction. So, the expression here was μ_f multiplied by n_e multiplied by K_h multiplied by F_0 divided by γ_{mb}.

Now, μ_f here is the friction coefficient which for a sand blasted surface, we can check in the code. It turns out to be 0.48 can be used. So, this value is 0.48. And e is the number of surfaces which are offering the friction resistance. Here, in this case, it is only 1, so, we will put 1. K_h is the factor that controls the effect of larger size holes. In this case, let us assume clearance holes, standard clearance holes.

So, if that is the case, K_h will also be equal to 1. F_0 is the proof stress or the proof load in the bolt, which is basically the definition of pretensioned force; so, which again will be equal to 70% of the ultimate load. So, 70% is 0.7. What is the ultimate load in tention for a bolt? Which will be the net cross-section area. First we need to calculate the net cross-section area is 78% of the gross cross-section area, multiplied by πr^2, that is 10 squared.

This is the area, multiplied by the ultimate stress capacity, that is 800 MPa. So, this part is the ultimate strength or ultimate load capacity of the bolt. Multiplying it with 0.7 makes it the proof load. So, this is the proof load. And γ_{mb} value can be taken as 1.1 for a slip-critical bolt. And when we substitute all these values, this turns out to be 59.8 kilonewton. The design capacity of one of the bolts, any bolt in this assembly is only 59.8 kilonewton.

And the demand was 1.242 times P. So, we can calculate, we can equate the two. This is the capacity and this was the demand. When we balance the two, match the two, what do we get? $1.242P = 59.8$. That is, $P = 42.4$ kilonewton. And that is the value that we can use for our bolt. So, that is the maximum force that we can apply. P will be equal to, P max will be equal to 42.4 kilonewton for the bolt assembly to be able to resist this load safely.