Process Equipment Design
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Lecture –58
Distillation Column: Mechanical Design-3

Hello everyone. Welcome to the 3rd lecture of 12th week of the course Process Equipment Design and this is basically 58th lecture of this course and here we are going to discuss design of distillation column and we will consider mechanical design over here. If you remember last two lectures of this week there we have discussed mechanical design and we have considered different stresses which are generated due to different loads in the shell.

So, those two lectures were devoted to shell and now we will focus on the support. So, let us start this lecture.

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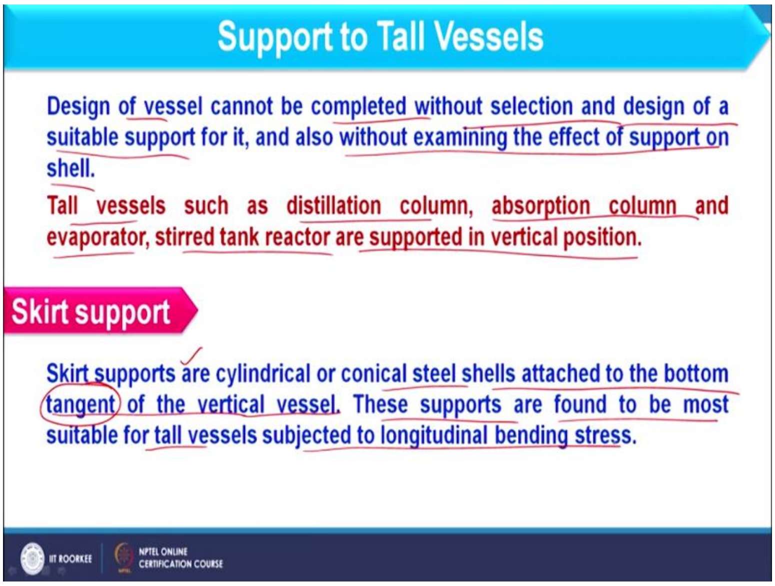

So, when we consider design of the vessel that cannot be completed without selection and design of the suitable support for it and also without examining the effect of support on the shell. So, in this way design of support is also as important as design of tall vessel or design of vessel. So, tall vessels when we consider these are basically distillation column, absorption column and evaporator, stirred tank reactor and these are supported in vertical position.

So, some of the vessels are usually placed horizontally so for that we need horizontal support, but that is not in the category of tall vessels. For tall vessels which are placed always vertically we consider the vertical support. And the vertical support available which is used for such tall vessels is basically the skirt support. Skirt supports are cylindrical or conical steel shell attached to the bottom tangent of the vertical vessel.

Bottom tangent means where shell is attached to the head and we consider that where shell ends because that is basically the tangent to the shell. So, these supports are found to be most suitable for tall vessel subjected to longitudinal bending stress. So, let us see how to design the skirt support and you understand that if I say design of skirt support or design of tall vessel it means I am focusing on the thickness of that particular part of the vessel.

So, here also we will focus on thickness of the skirt support and if I speak about the thickness of skirt support it means thickness of the wall or the metal sheet by which this support is prepared.

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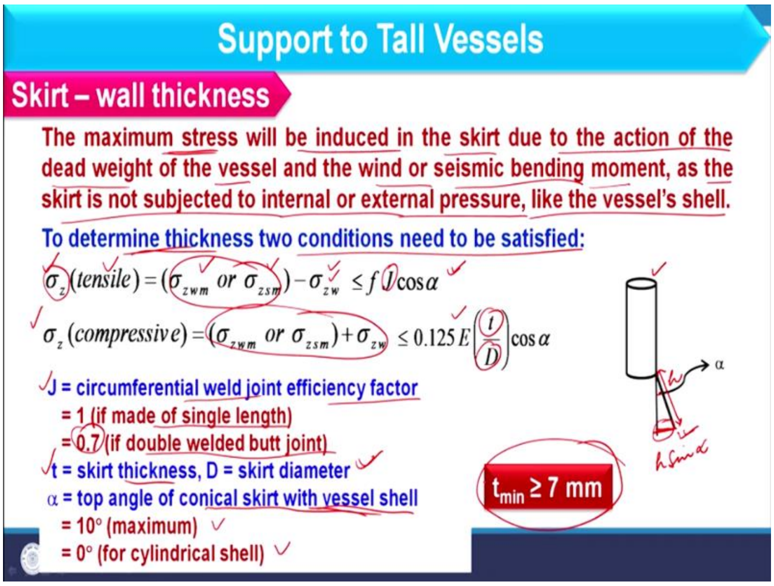

So, the maximum stress will be induced in the skirt due to action of dead weight of the vessel and wind or seismic bending moment as the skirt is not subjected to internal or external pressure like the vessel shell. So, if you recall the last lecture where we have discussed the resultant longitudinal stresses there we consider stresses generated due to dead load, due to operating pressure and due to wind load or seismic load.

So, all these stresses will work equally to the support except the stress generated due to pressure because support will not have any operating pressure as the case will be with the vessel. So, apart from the stress generated due to pressure we consider all other stresses to design the skirt. So, let us consider that. To determine the thickness two condition should be satisfied.

The first is when I consider the tensile stress and sigma z is the resultant tensile stress and that should be generated in the support. So, here we have this expression sigma z w m or sigma z s m we will consider maximum of these two and minus sigma z w that is because of the dead load and minus because this I am considering as tensile condition and this dead load gives the compressive stress.

So that should be less than or equal to f J cos alpha. Further I consider compressive stress that is sigma z compressive and in that case all these stresses are positive and that should be less than or equal to 0.125 E t / D cos alpha. So, in this way we calculate the thickness of support. Usually we consider the thickness of the support using these two conditions and wherever I am finding the larger thickness that I will choose as the final shell thickness.

So, now we will consider the parameters which are associated with these expressions like capital J that you can see over here it is circumferential weld joint efficiency factor and it is one if made by single length and it is 0.7 if double welded, but joint is considered. So, you can consider when I make the shell with a single metal plate and we role it and we weld at one side only we consider J as 1.

If I am having different parts of it so at multiple points we will weld it and therefore we will consider J factor as less. And that welding we consider as double welded, but joint. So, let us see other parameters. Here I am having the t which is basically skirt thickness D is the skirt diameter how to find this that we will discuss alpha is top angle of conical skirt with vessel shell.

If I am having the shell like this alpha is basically this angle. So, it is 10 degree maximum and 0 degree for cylindrical shell. So, usually what happen when I am having the cylindrical shell we consider support which is also cylindrical and that is simply welded at the bottom. So, in that case inner diameter of the support will be equal to outer diameter of the shell and if I am having the angle alpha in that case you already know the height of this support.

And you know this angle so this distance you can consider by let us say height is basically small h so h sin alpha that will give this distance and twice of this we can add to outer diameter of the shell to find out the diameter of the skirt. So, in this way you can find out the skirt diameter. Now whatever thickness we will calculate for the skirt that thickness should never by less than 7 mm.

If it is less than 7 mm we consider thickness at least 7 mm for the skirt support. So, this criteria you should check at the end of the calculations.

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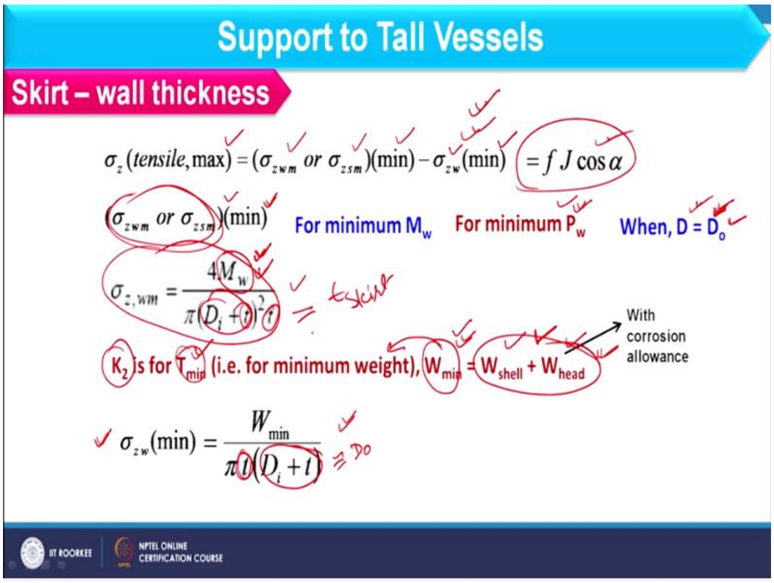

So, let us start the skirt wall thickness calculation. First of all, I am considering tensile stress so this is the expression. Now here you should understand the fact that so if I am focusing either on tensile stress or compressive stress I am basically considering the extreme condition. So, when that tensile stress will be maximum if I am having this shell right and column is available over it.

So, when the tensile stress in this support is maximum when whatever load is falling on this support is should be minimum then only this tensile stress would be maximum because tensile stress would be in this direction or in this direction, but it should not compress. So, in that case all stresses generated into this should be minimum. So, we should consider this expression that sigma z tensile maximum should be equal to sigma z w m or sigma z s m and this should be minimum.

And this dead load stress that should also be minimum and that should be equal to f J cos alpha. So, here we are calculating the stress thickness so how that t term will appear because if you see no t term is there. So, if we further consider each of these stresses sigma z w m or sigma z s m minimum I have to choose. So, let us say if I consider sigma z w m depending upon this you can consider the required expression.

If I consider this then at what condition this will be minimum when I am having Mw minimum and when this Mw or the moment generated due to wind or the bending moment generated due to wind will be minimum at this condition when I am having P w minimum. Pw is basically the wind load and when this would be minimum? When I am considering D should be equal to D 0.

If it is falling only on the shell we consider that Pw should be minimum otherwise you can imagine the P w that is K 1 K 2 h 1 p 1 all these factor will be fixed only the change will occur when I change the diameter. So, in this case you can consider D should be D 0. And I am assuming over here that insulation is not available. So, in this way you can find the stress generated due to wind load should be minimum.

Now, we will see sigma z w minimum and that would be minimum when I consider minimum weight and minimum weight will include the weight of shell as well as weight of head only. And here I am not including any attachment or weight of the liquid etcetera. This is the minimum possible load because vessel will include at least these two parts and when we consider the wind stress there K 2 should be computed at T minimum and T minimum means at W minimum.

So, if I calculate the minimum weight I should consider the minimum longitudinal stress through this expression W minimum / pi t D i + t. Now what is this t? This t is basically t of skirt not the t of shell. Now because all these stresses are falling in support only. So, in this case this complete expression you can equate to D 0 and this t will be of skirt support. In the similar line this D i + t you can replace with D 0 and this t you can consider as t of skirt.

So, when we put all these expression over here you can find the t parameter and that you can calculate while considering this condition. So, in this way we can calculate support thickness when tensile stress is maximum and let us see how to calculate the skirt thickness when compressive stress is maximum.

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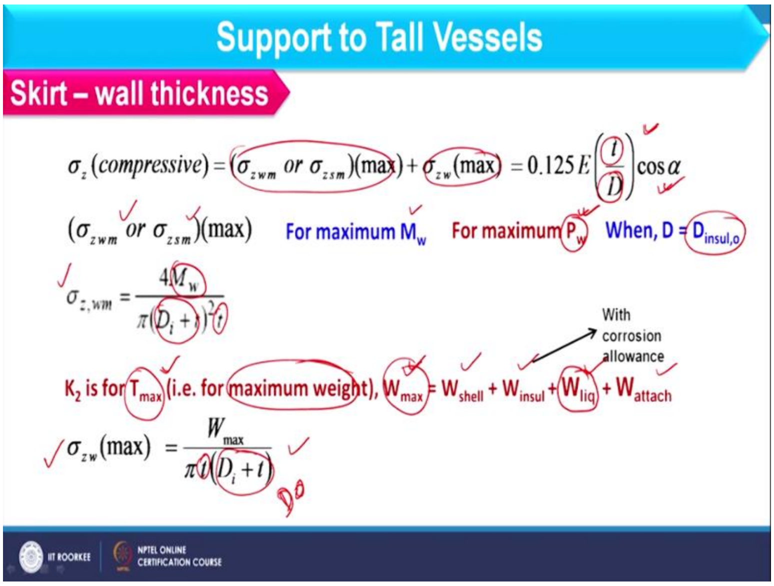

So, this is the expression we can have maximum compressive stress when this would be maximum and this would be maximum and that should be equal to 0.125 E t / D into cos alpha. So, you can understand that when compressive stress will be maximum if this is the support and I am having shell over here. So, whatever the maximum possible load will fall on this support compressive stress in this support would be maximum.

So, considering this fact let us calculate the shell wall thickness. So, we have to maximize sigma z w m and sigma z s m either of these two. So, if I am having this expression for sigma z w m I should maximize this. So, I have to calculate maximum M w and when this would be maximum if I am having maximum P w and when this P w would be maximum when I am considering D insulation outer instead of D o.

In this way we can consider the stress generated due to wind load and here we have another factor that is K 2 and K 2 will depend on period of vibration and in this case we should calculate maximum period of vibration depending upon the maximum weight and maximum weight how I can calculate? Weight of shell, weight of insulation, weight of liquid and weight of attachment all weights we have to include over here, but here you should keep in mind that what is this W liquid.

This is basically weight of the liquid and at maximum possible condition what we can consider? We can consider that complete vessel is filled with the liquid. So, previously when you have designed the shell you have considered that liquid is available only on the trays, but now you should consider that complete column is filled with the liquid. So, in that case weight of liquid should be simply rho g h and h is the total height of the shell.

It will not include height of the support and for the obvious reason. So, once I am having W max I can calculate sigma z w max using this expression. And here again this you have to replace with the D o of the skirt support, D o of the shell if I consider the cylindrical support in the similar line this can also be represented D 0 this t is the support thickness and this t is also the support thickness and this D is the diameter of the skirt support.

So, in this way you can calculate the skirt thickness and wherever you are finding the larger value from maximizing the tensile stress and maximizing the compressive stress you can choose that value, but you should check that the chosen value should be greater than at least 7 mm otherwise you have to consider 7 mm as the skirt thickness.

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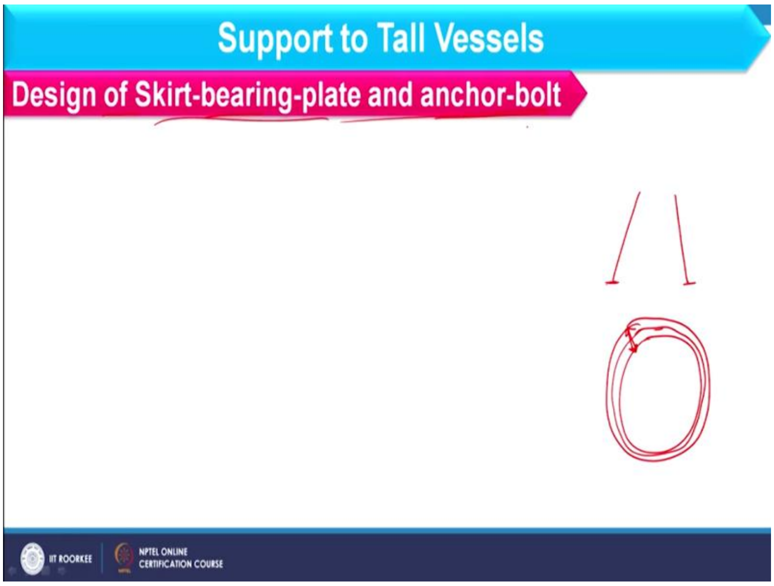

Now, we will consider few more parts as far as support of the tall vessel is considered. So, here we are considering design of skirt bearing plate and anchor bolt. So, what is bearing plate? When I consider shell like this at the bottom it is basically attach with the ring that is basically the metal ring. If you see the top view of this is basically the metal ring and shell is welded at the center of it or at one edge of it.

So, this is basically the shell and this is the complete width of the bearing plate. So, we also have to consider skirt bearing plate as well as anchor bolt. What is this anchor bolt that also we will discuss.

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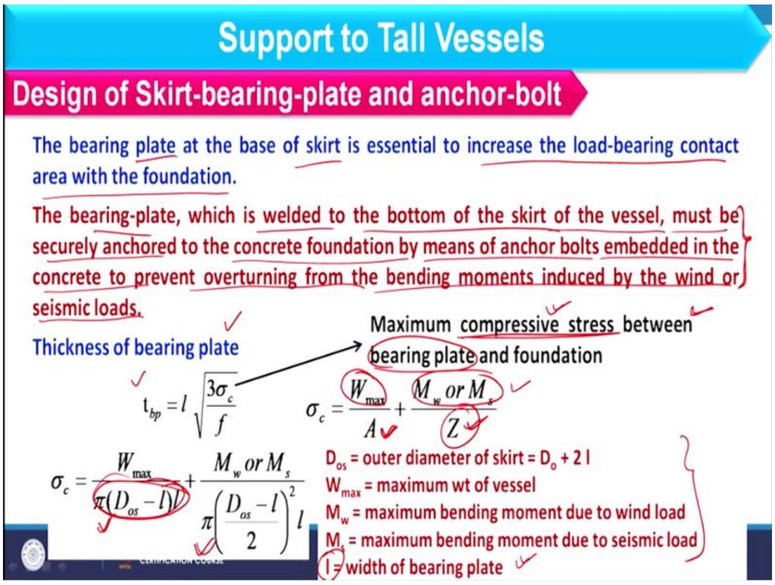

So, the bearing plate at the base of the skirt is essential to increase the load bearing contact area with the foundation because when you attach the skirt with the foundation or support with the foundation you are basically attach support with the bearing plate and then that bearing plate is attach with the foundation. So, bearing plate design is very important as far as support design is concerned.

So, bearing plate which is welded to the bottom of the skirt of the vessel must be securely anchor to the concrete foundation by means of anchor bolt embedded in the concrete to prevent over turning from the bending moment induced by wind or seismic load. So, that point we should consider to make the skirt support strong, but what is this anchor bolt and over turning all these we will discuss in subsequent slides.

But first of all we should calculate the thickness of bearing plate and that we can calculate by this expression t b p which is equal to l root over 3 sigma c / f. So, here sigma c is basically the maximum compressive stress between bearing plate and foundation. It means that what is the maximum possible stress bearing plate bears and that should be the compression stress. And we can calculate this by this expression where I am considering maximum weight and maximum of bending moment due to wind as well as seismic load.

And A and s we can calculate by these terms where Z is basically the modulus and A is the area which you can find through this term. So, in this way I can calculate sigma c and whatever maximum compressive load is falling on the bearing plate we should consider that to find out the thickness of the bearing plate and here we have some of the nomenclature which you can see where l is basically width of the bearing plate. How to decide this l that also we will see.

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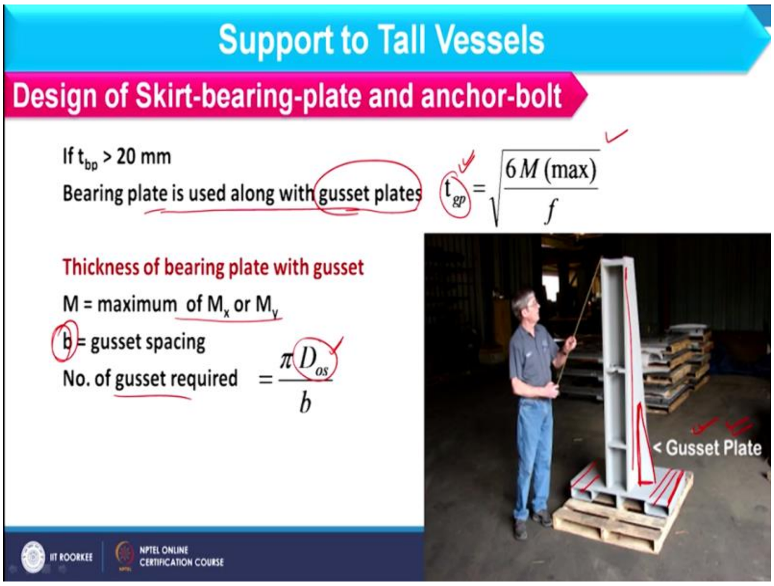

Now here we should check the thickness of bearing plate if thickness of bearing plate is more than 20 mm so what we have to do? In that case we should consider bearing plate along with the gusset plates. So, bearing plate you know if I consider this support so this is attach with this plate and this plate is basically called as the bearing plate. And we can put a metal plate in a triangular shape with right angle.

And this we can attach over here and this is basically called as the gusset plate. So, whatever load is appearing on the bearing plate some of the load this gusset plate bears. So, if thickness of bearing plate is more than 20 mm we should consider gusset plate and if I am using the gusset plate I have to calculate bearing plate thickness again. So, that we can calculate considering this expression where t g p = 6 M max / f.

This g p is not the gusset plate thickness this is the bearing plate thickness only when gusset plates are used where M is the maximum of M x or M y what is that M x or M y? That we will see. Here, I am using this b which is basically the gusset spacing and if I know the gusset spacing I can calculate number of gussets and that is pi D o s / b pi D o s is basically the outer diameter of the skirt support.

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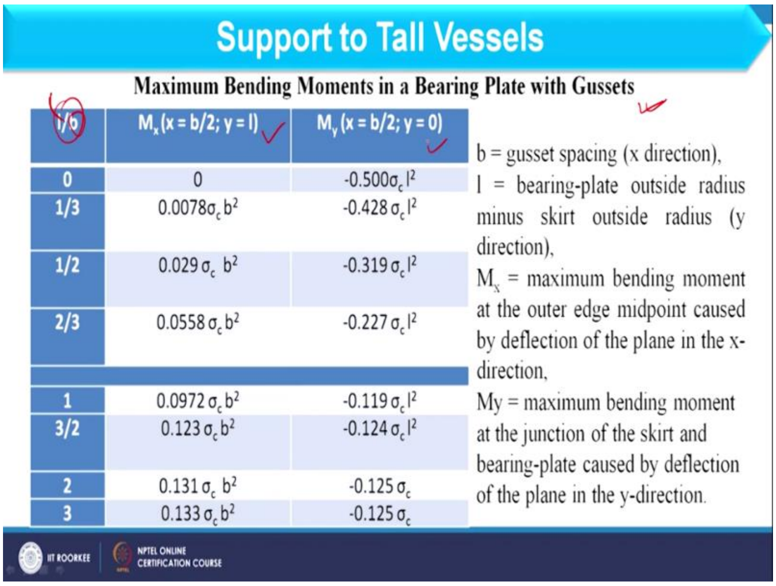

l/b	$M_x (x = b/2; y = l)$	$M_y (x = b/2; y = 0)$
0	0	$-0.500\sigma_c l^2$
1/3	$0.0078\sigma_c b^2$	$-0.428\sigma_c l^2$
1/2	$0.029\sigma_c b^2$	$-0.319\sigma_c l^2$
2/3	$0.0558\sigma_c b^2$	$-0.227\sigma_c l^2$
1	$0.0972\sigma_c b^2$	$-0.119\sigma_c l^2$
3/2	$0.123\sigma_c b^2$	$-0.124\sigma_c l^2$
2	$0.131\sigma_c b^2$	$-0.125\sigma_c$
3	$0.133\sigma_c b^2$	$-0.125\sigma_c$

So, as far as this M x M y or b is concerned and l is concerned we should refer this table. You can see here I am having l / b where l is the width of the bearing plate. And b is the gusset spacing M x and M y you can calculate whichever is maximum that you have to use to find out bearing plate thickness when you are considering the gusset plates.

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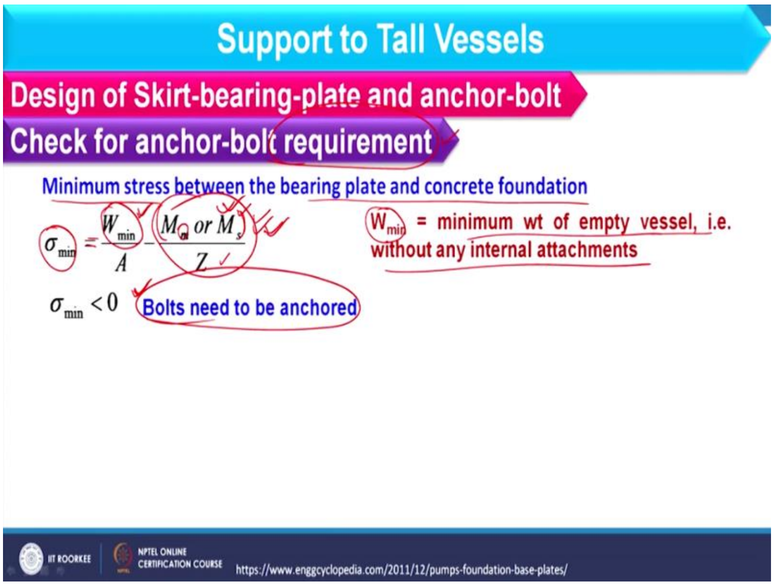

So, now we will focus on the anchor bolt and for that first of all we have to check whether anchor bolt is required or not. So, first of all let us see what is anchor bolt? Anchor bolt is basically the bolt which is attach with the concrete foundation. It means some part of the bolt is attach with the concrete foundation and upper part of that is attach to the bearing with the nut.

I will show the image related to that so that it will be clear to you, but first of all we should check whether anchor bolt is required or not and that we can check through this equation which equates minimum stress between bearing plate and concrete foundation to these parameters. Now, here I am considering minimum stress. If you see its expression it includes W minimum / A M m or M s / Z.

This should be W. So, in this way you can consider W minimum which is the minimum weight of empty vessel without any internal attachment. It means this W minimum considers only the shell as well as head. So, when we consider this sigma minimum what it shows basically? If you see it is equating to W minimum and M w as well as M s. So, what is the meaning of this?

It is counting the over turning if I am having the support as well as vessel and here at the bottom I am having the bear plate. So, to check whether anchor bolt is required or not I should consider the extreme case. It means I am assuming that it will overturn. In that case minimum weight which is falling over this that I am considering. What is the point over here to understand that if I am considering maximum pressure in that case what will happen?

It will be more stable and that I do not want because I am checking the anchor bolt condition. So, to check that extreme condition will be that over turning is possible. So, in that case I am considering minimum stress. Now to calculate that this W minimum should be considered. Now, what about that? Here you understand that bending moment and moment due to seismic load should be maximum because when it will be maximum then the vessel will overturn or then the vessel will fall.

So, this should be minimum, but this should be maximum, but this should be maximum that condition you should check and so if I am having sigma minimum value if it is less than 0. What is the meaning of this? It means this will dominate and it will let the vessel fall. So, if this sigma minimum value is less than 0 it means bolt must be anchored.

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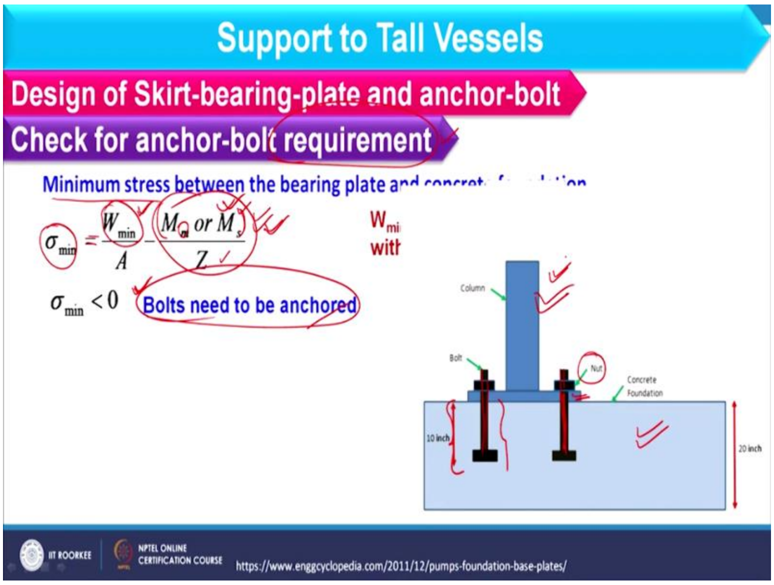

In that case let us see what is anchored bolt? If you consider this I am having the bolt and maximum part of this bolt is inside this concrete foundation and we can have some upper section also where this bearing plate is attach with this nut and here I am having the column with the support. So, we can understand that anchor bolts are required to remove or to avoid falling of the column or to avoid overturning of the column.

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So, you can see the anchor bolt and size of these in this image detail you can find over here.

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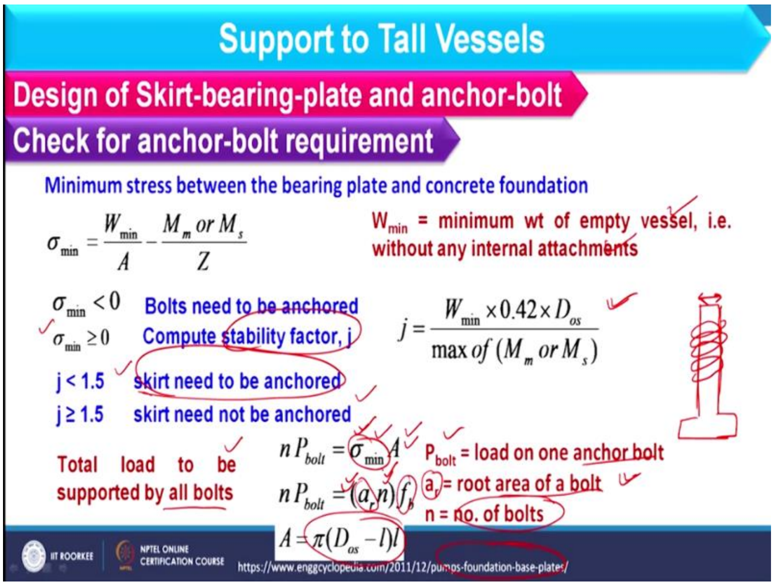

Further, if sigma minimum is greater than or equal to 0 in that case we should consider the stability factor j and j we can calculate by this expression. If j is less than 1.5 it means anchoring is required if j is more than or equal to 1.5 anchoring is not required. So, in this way you can check whether anchor bolts are required or not. Now, once it is required you have to calculate number of bolts as whatever total load is available that should be supported by all bolts.

In that case n P bolt should be equal to sigma minimum and A. Further n P bolt we can find out as a r n into f b and a we can find out by this expression. So, let us see the parameter P bolt is the load on one anchor bolt a r is basically root area of the bolt if I am having the bolt like this each bolt has some threads. So, root area is basically this area. So, you know, the size of the bolt so this parameter will be known to you.

So, you can calculate area of that section and that will be nothing, but the root area n is the number of bolts. So, how you have to calculate? This you should equate with this because you already know the sigma minimum and A and a r for a given bolt you can find out f b is the allowable stress of the bolt material and so you can find out number of bolts. So, in this way you can complete the design of skirt support and we will see the design of tall vessels as well as it support in subsequent lectures. So, that is all for now. Thank you.