Process Equipment Design
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Lecture –60
Distillation Column: Mechanical Design-5

Hello everyone. Welcome to the last lecture of this course that is 60th lecture of the course Process Equipment Design and here we will consider the distillation column and mechanical design of it. If you recall the last lecture there we have discussed one example in which mechanical design of distillation column is discussed where we have focused on design of vessel. It means design of shell of the vessel.

We have calculated the thickness of the shell and then we check all stresses which are available in that shell. And in this lecture also we will consider the same example, but here we will design the support for the distillation column.

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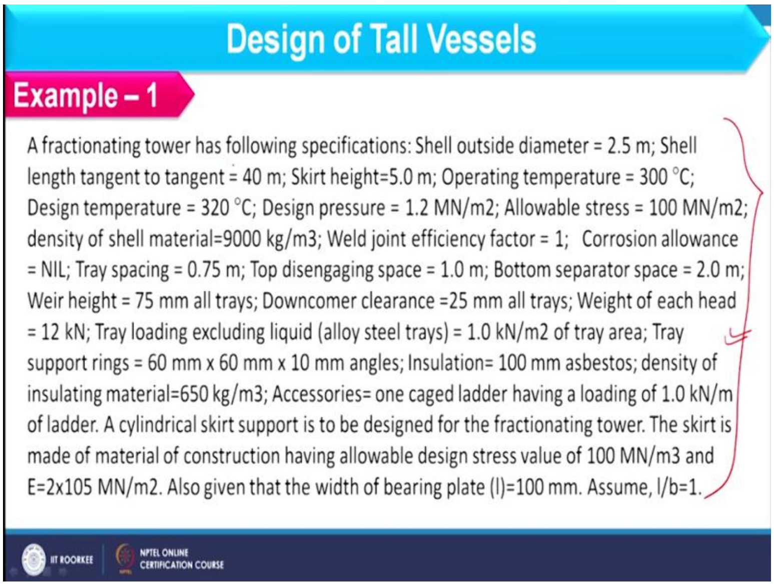

So, let us start with the same example. So, if you see this is the same example I am not going to into detail of that because that I have already discussed in previous lecture. So, you can refer that. Now for this problem we will calculate other parameters which are related to the support design. So, let us see that what we have to calculate.

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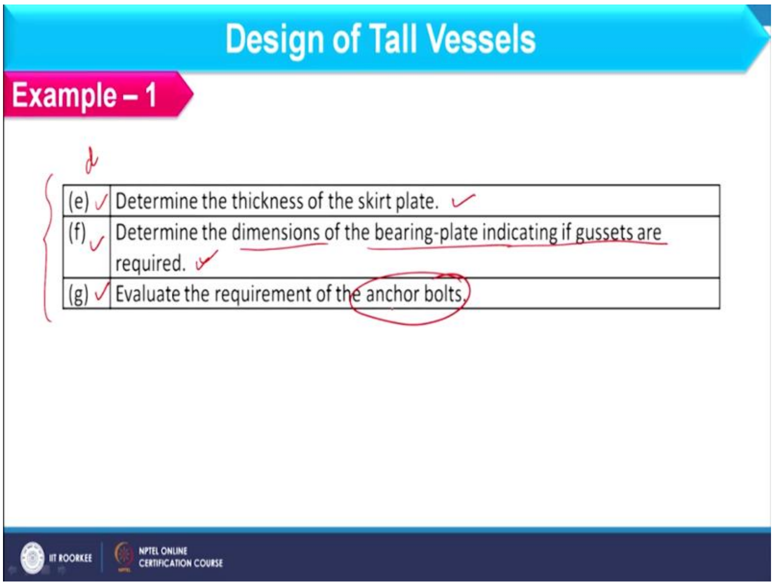

If you recall in the previous lecture we have covered up to part d. So, from here I am starting from part e. So, part e is basically determine the thickness of the skirt plate then f determine the dimensions of the bearing plate indicating if gussets are required or not. And finally we have to evaluate whether anchor bolts are required or not. So, let us start with part e of this that is design of skirt plate and in this we will calculate the thickness of the plate. So, let us start that.

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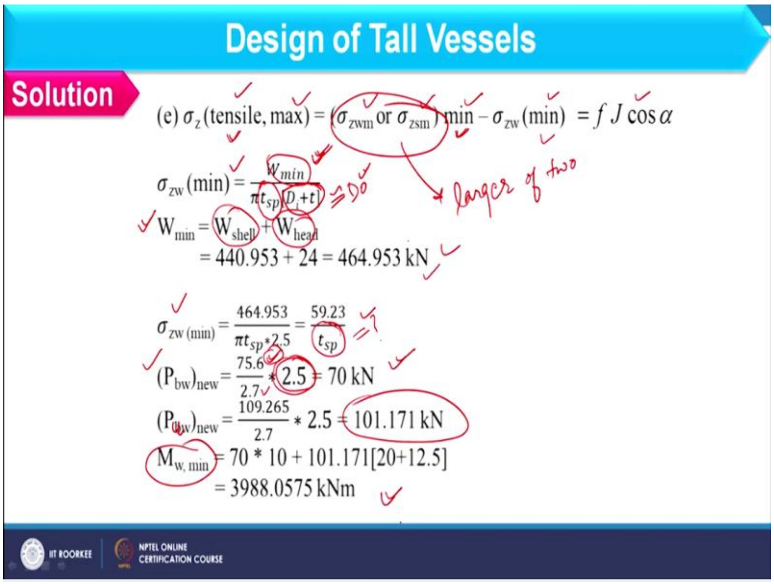

Now, if you recall the third lecture of this week there we have discussed detailed design of the support in which we focused on two stresses that is tensile stress and second is compressive stress. We will consider maximum condition of these stresses and then we have to calculate the stress for these conditions individually and whichever is larger among this that we have to choose as final support thickness.

So, let us start with the tensile stress. If you recall this is the expression sigma z tensile maximum we have to consider and in this case sigma z m and sigma z s m and we have to choose minimum of these two because this tensile stress we have to maximize. And further sigma z w that is the stress generated due to weight and that should also be minimum and that should be equal to f J cos alpha.

Now, what about this? This I have to consider at minimum condition, but this should be larger of two. So, we have to calculate sigma z s m and sigma z w m and larger value I have to choose. However, both of these stresses are corresponding to minimum possible condition. So, let us see how to consider that, but first of all we will focus on sigma z w. So, sigma z w minimum should be equal to W minimum that is the minimum weight divided by pi t D i + t.

So, as far as this t is concerned this we are considering this we are considering for support plate therefore t s p is used over here. Further this D i + t we are equating this to D 0 for simplification only. So, let us calculate minimum weight and minimum weight means weight of the shell as well as the head because when I am considering the tall vessel at least these two parts will be required shell as well as head if I am not considering any attachment.

And for minimum weight I should not consider any attachment or weight of the liquid etcetera. So, W minimum should be 464.953 kilo Newton. Considering this I can find out sigma z w minimum and that should be equal to 59.23 / t s p because I have to calculate thickness of the support plate. So, this value remains unknown for now and then we will find out sigma z w m and sigma z s m at minimum condition.

So, let us see how to consider that. To consider the minimum values of these stresses we have to consider the minimum moment due to these and minimum bending moments means minimum wind load and that wind load we have considered in bottom part as well as upper part, but how we consider the minimum load of that. Minimum load means when insulation is not available.

As I am considering here the minimum weight as weight of shell only not the insulator. So, in that way P b w and P u w should be considered based on D 0 of shell not as D 0 of insulation I hope it is clear. So, P b w new value should be because this we have already calculated in the last lecture. So, you can refer this value there divided by 2.7 because this is based on 2.7 and now I have to consider outer dia of the shell. So, this P b w should be 70 kilo Newton.

In the similar line I can revise P u w and that should come out as 101.171 kilo Newton. So, bending moment due to wind action should be 3988.0575 kilo Newton meter and when I am calculating the wind load you should also consider the period of vibration so that check is also required.

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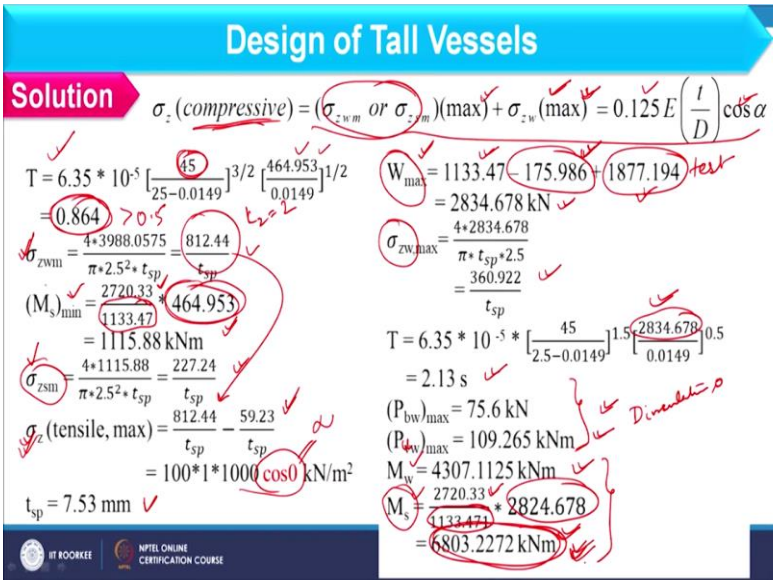

So, that we can calculate through this expression where total height we are considering including the height of the support and this 464.953 is the weight we are considering now. So, considering this T should come out as 0.864 and it is more than 0.5 seconds. So, K 2 value will always be 2. So, in this case P b w and P u w values are not changing only that will change with respect to the diameter that we have already discussed in the last slide.

So, sigma z w m we can obtain as 812.44 / t s p and further we consider the bending moment due to seismic load. And if you consider the previous lecture there we have calculated this bending moment considering the total load and now we can divide this with total dead load and multiplied this with minimum weight. So, considering this M s minimum can be obtained as 1115.88 kilo Newton meter stress due to this can be obtained as 227.24 / t s p.

So, when we consider the tensile stress expression we can choose higher value from this as well as from this. So, we can choose this value you can see here and after that we consider the stress generated due to minimum weight. So, that we can equate to f J cos alpha and alpha is 0 over here because here we are considering the cylindrical support. So, total thickness of the support is coming out as 7.53 mm.

So, in this way you can obtain the thickness of support considering tensile condition. So, now we will focus on compressive condition so what is that? Sigma z compressive we can consider using this expression where sigma z w m or sigma z s m maximum should be consider. So, among this we should consider the larger value for maximum sigma z w maximum I should consider and that should be equal to 0.125 E t / D 0 cos alpha.

So, let us focus on sigma z w first. So, this should be maximized and how it will be maximized? When I consider the maximum possible weight and maximum possible weight we can calculate is the total weight which we have considered in the last lecture that you can refer. From this we will deduct the weight of the liquid because this is available at operating condition.

However, when I am calculating the maximum possible load I should consider the weight of liquid at test condition. And this value can be obtained that you can see in the last lecture. So, maximum weight we can obtain as 2834.678 kilo Newton and corresponding to this we can find out sigma z w and that should be come out as 360.922 / t s p. Now, next we have to find out sigma z w m and sigma z s m at maximum condition.

So, for that we have to calculate period of vibration. So, you can see that through this expression where I consider the maximum possible weight and the value of T should come out as 2.13. And this P b w and P u w maximum you can consider as we have calculated in the last lecture because that is based on D insulation only outer. So, in this way P b w and P u w will remain same.

Next is bending moment due to this that you can calculate and further we will calculate the bending moment due to seismic condition. So, this we have already calculated in the last lecture it will be divided by the load which we have considered and multiplied by the maximum load which we have considered now. So, Ms should come out as 6803.2272. Now, if you compare these two that is bending moment due to wind as well as seismic we should choose this value because this is higher amongst the two.

Now, if you see the expression of z w m and z s m it is basically the same expression. So, we can decide the larger value depending upon the bending moment. So, in that case we consider M s value not M w value.

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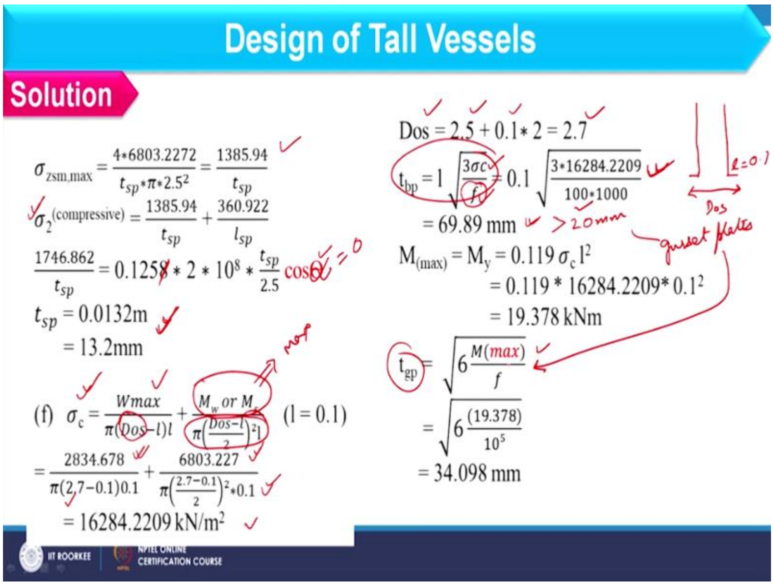

Further, sigma z s m we can obtain as 1385.94 / t s p. So, after that we can consider sigma z compressive that is the expression to calculate the thickness it should be equated to 0.125 8 will not be here into 2 into 10 is to the power 8 t s p / 2.5 cos theta or we can consider this as cos alpha which will be 0. So, t s p we can obtain as 13.2 mm. So, if you compare the thickness of support plate for compressive as well as tensile.

It is more for compressive so we can select 13.2 mm is the thickness of support plate. So, next value than this you can choose as the final thickness of skirt support. Now here you should also check that this value whatever you have finalized it should be more than 7 mm. In this case it is coming already more than 7 mm, but if it is not you should choose at least 7 mm as support plate thickness.

So, once I am having this value we can calculate the bearing plate thickness and other parameter. So, let us start that. So, to calculate bearing plate thickness we should consider this expression where t b p is equal to L root over 3 sigma c / f and sigma c value you can obtain from this expression. W max we have already calculated so that value we can put over here. Now below this we have pi D o s – l into l.

So, what is this D o s? This is basically the diameter of the support. Now that we can calculate over here. So, if you consider the support where it should be attached to the shell at bottom section where head is attached to the shell. So, its diameter should be equal to the diameter of the shell because here we are considering cylindrical support. So, it will be in line with the shell only.

Further, if you see D o s is basically if this is the support we can have bearing plate at the bottom and width of the bearing plate l is given as 0.1. So, this value we can consider as D o s and that should be 2.5 + 0.1 into 2. So, 2.7 we can obtain like this. So, this we can use over here and now from this M s and M w we can choose the maximum value and that should be 6803.227 for M s.

And this modulus you can consider here also so sigma c we can obtain as 16284.2209 kilo Newton per meter square. Considering all these values here we can obtain thickness of bearing plate. Now, if you see f is basically the allowable stress of the material of support plate and that is given as 100 mega Newton per meter square if you see the problem. So, that value we can use here also.

Considering this bearing plate thickness we can obtain as 69.89 mm and here we have to check this value if this value comes more than 20 mm we should choose gusset plates. So, if gusset plates are used we have to recalculate the thickness of bearing plate and we can use this expression for that, that is root over 6 M max / f.

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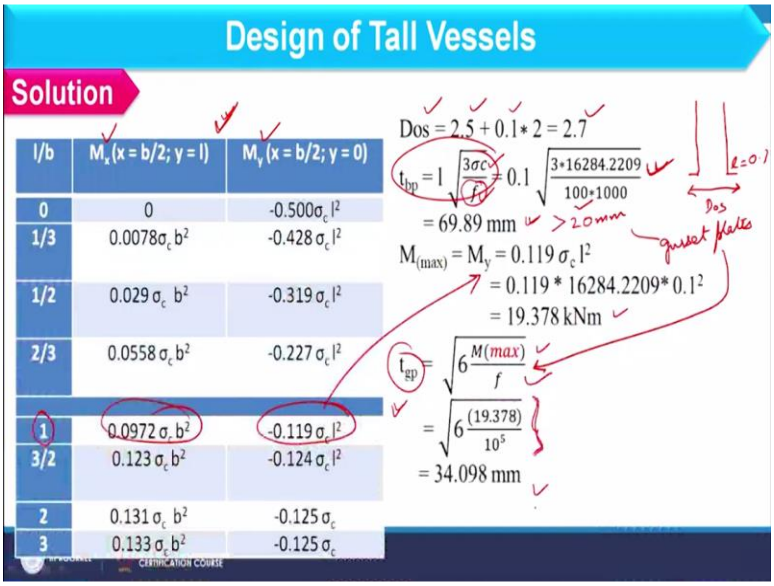

So, how I can choose this value? You can refer this table where l / b is given. Now, if you see this problem here l / b is given as 1. So, we have to choose maximum of M x or M y. If you compare these two expressions so M y will be maximum and that I can choose over here. So, M max value should be 19.378 kilo Newton meter. So, considering this you can obtain the thickness of bearing plate as 34.098 mm. So, next value in standard you can consider as thickness of bearing plate.

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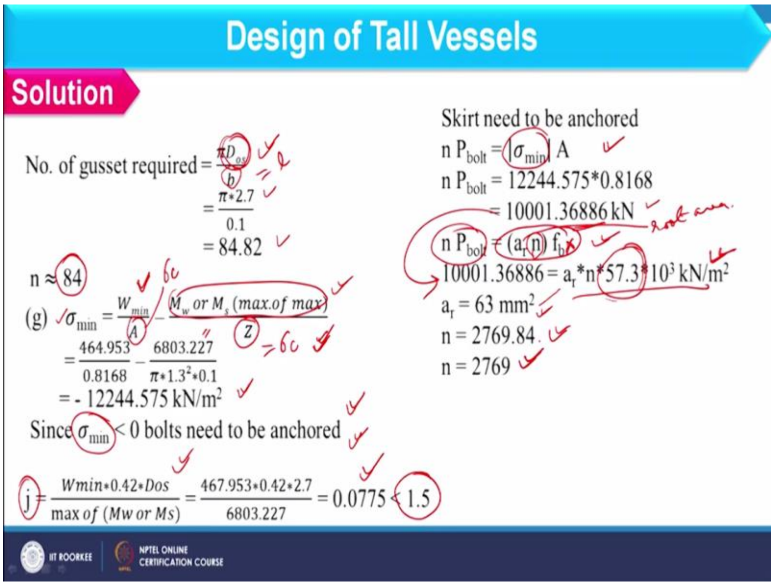

Now, if I am using the gussets we should also calculate the number of gussets and that we can calculate using this expression pi D o s / b, b is the gusset spacing and which is equal to l. So, pi D 0 / 0.1 we can consider 84.82 as number of gussets. So, final number of gusset should be equal to 84 because diameter of the support should be same. So, next part is we have to find out whether anchor bolts are required or not.

So, in this case we consider sigma minimum and that should be given by this expression you see here I am having W minimum which we have calculated in previous slides and this A is basically given in the expression of sigma c in the last slide so that you can refer. Similarly, I am having M w and M s and maximum of these we have to choose so this should be 6803.227 and this Z value we can also see in sigma c expression the previous slide.

So, considering all these values we can obtain sigma minimum as – 12244.575 kilo Newton per meter square. So, we can find that this sigma minimum is less than 0. So, it means that anchor bolt must be needed. So, let us calculate further. We can also check that with j factor that is basically the stability factor using this expression and this value should come out less than 1.5.

So, here it is coming so in this way we can also say that anchor bolts must be required. So, now we will focus on number of bolts how we should calculate that. So, let us see that. This is the expression for that n P bolt should be equal to sigma minimum A. So, this sigma minimum here we are considering as the modulus. So, in this way we can obtain sigma minimum and A value which is coming out as 10001.36886 kilo Newton and that should be equated to this term that is a r n f b where a r is basically the root area.

And n is the number of bolts f b is the allowable stress for the material of the bolt. So, this value we can put over here it should be equated to this. So, in this we consider 63 mm square as the root area and 57.3 mega Newton per meter square as allowable stress of the bolt material. Considering all these we can find number of bolts as 2769. So, in this way we can calculate number of bolts for tall vessel.

So, considering previous lecture and this lecture we can complete the design of tall vessel as far as mechanical aspects are concerned. And in this lecture we are also calculating the plate hydraulic design it means we are computing the plate design which is basically the process design of the distillation column and here we are considering one example. Details about this we have already covered in 11th week so you can refer those lectures.

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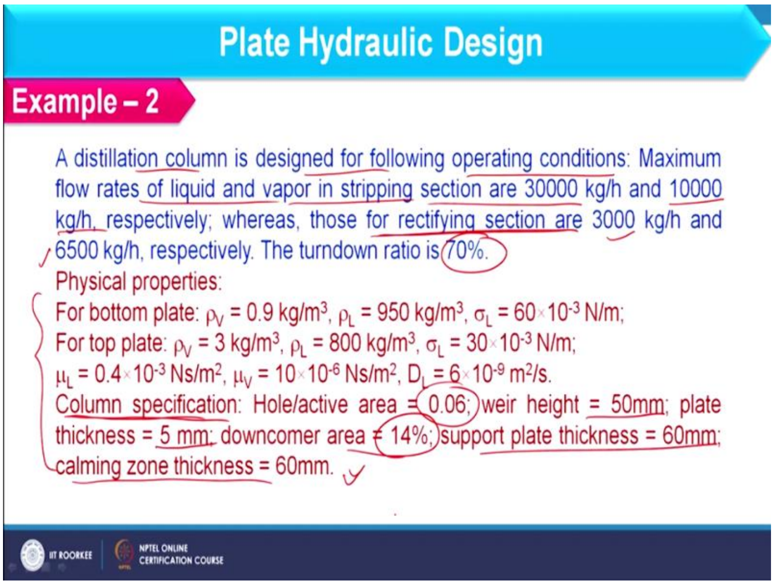

So, in this example a distillation column is designed for following operating conditions that is the maximum flow rate of liquid and vapour in stripping sections are 30,000 and 1,000 kg per hour whereas that is in rectifying section as 3,000 as well as 6,500 turndown ratio we can consider as 0.7. These are the physical properties and along with that we are given some column specification such as hole to active area is 0.06.

Weir height 50 mm, plate thickness 5 mm downcomer area is 14% and support plate thickness is 60 mm. We are also given the calming zone thickness that is 60 mm. In this way different parameters are given to us. Now, let us see what we have to calculate.

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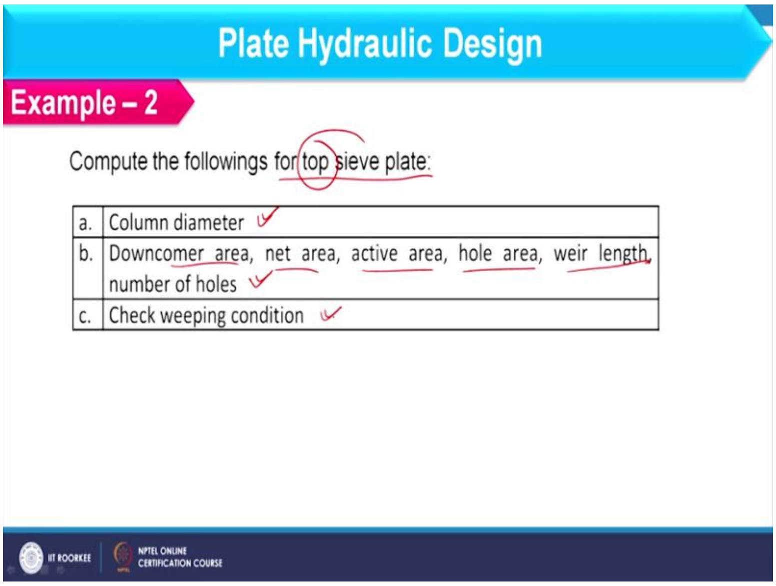

We have to calculate different parameters for top sieve plate. So, position you should understand it is available above feed or we can consider the top of the column. What we have to calculate is the column diameter, next downcomer area, net area, active area, hole active, weir length and number of holes and after that we have to check with the weeping condition. So, let us start the solution of this problem.

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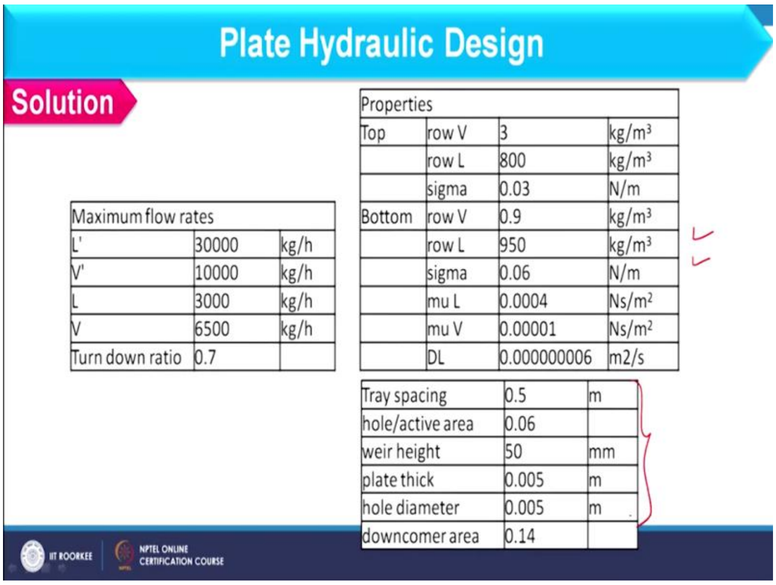

Maximum flow rates		
L'	30000	kg/h
V'	10000	kg/h
L	3000	kg/h
V	6500	kg/h
Turn down ratio	0.7	

Properties			
Top	row V	3	kg/m³
	row L	800	kg/m³
	sigma	0.03	N/m
Bottom	row V	0.9	kg/m³
	row L	950	kg/m³
	sigma	0.06	N/m
	mu L	0.0004	Ns/m²
	mu V	0.00001	Ns/m²
	DL	0.000000006	m2/s

Tray spacing	0.5	m
hole/active area	0.06	
weir height	50	mm
plate thick	0.005	m
hole diameter	0.005	m
downcomer area	0.14	

In this slide, different parameters are given which we have just discussed all these are the known parameters.

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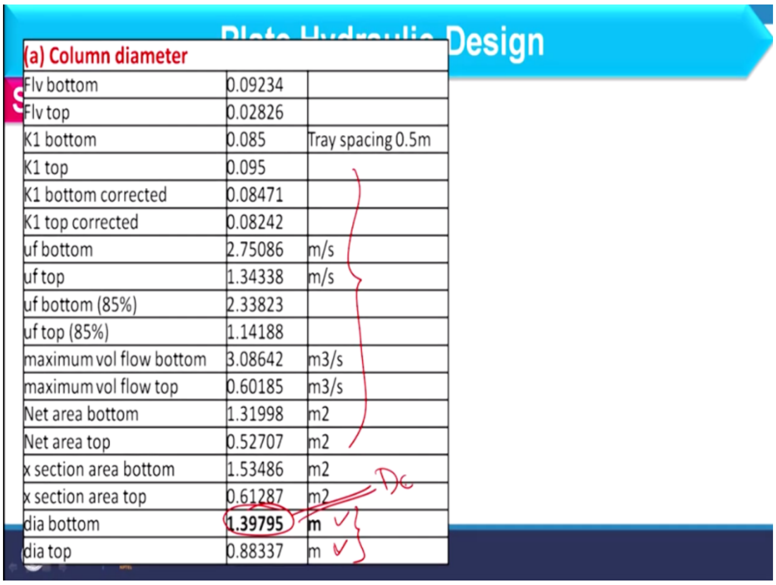

(a) Column diameter		
Flv bottom	0.09234	
Flv top	0.02826	
K1 bottom	0.085	Tray spacing 0.5m
K1 top	0.095	
K1 bottom corrected	0.08471	
K1 top corrected	0.08242	
uf bottom	2.75086	m/s
uf top	1.34338	m/s
uf bottom (85%)	2.33823	
uf top (85%)	1.14188	
maximum vol flow bottom	3.08642	m3/s
maximum vol flow top	0.60185	m3/s
Net area bottom	1.31998	m2
Net area top	0.52707	m2
x section area bottom	1.53486	m2
x section area top	0.61287	m2
dia bottom	1.39795	m
dia top	0.88337	m

Now, we can first calculate the column diameter and for that you need FLV and K 1 value at top and bottom and once you know the FLV value you can find out K 1 value depending upon the plate spacing. So, all these points we have already discussed in 11th week lectures so that you can refer. So, when we calculate all these parameters we can find out the column diameter at bottom as 1.3979 and at the top it is 0.88337.

So, if you compare these two this is larger value so this would be the diameter of the column. So, if you consider here we have to design the top plate, but as far as diameter is concerned we can choose the larger diameter whether it is available at the top or at the bottom. So, as far as column diameter calculations are concerned it is irrespective of the position of the plate for which we are calculating the hydraulics. From now onward all calculation will depend on the position of the plate.

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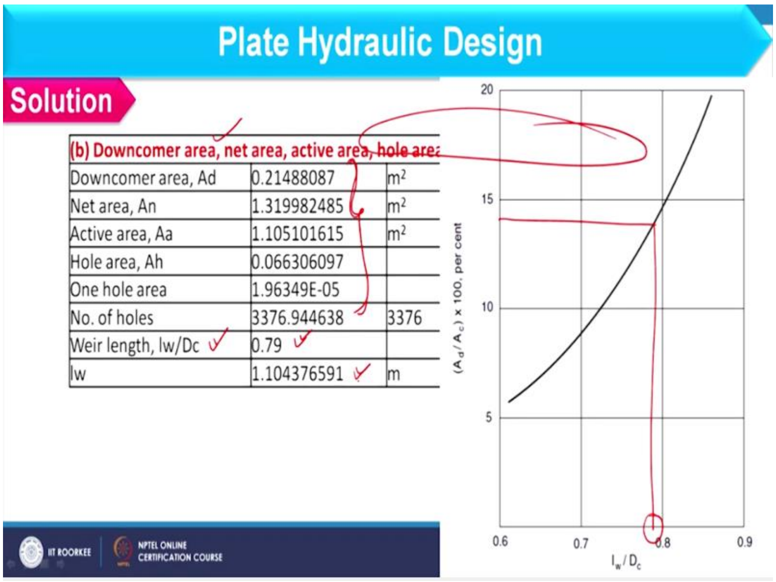

So, part B is we have to find out different areas and it will also depend on the column diameter. So, accordingly you can calculate this. Details of all these we have already discussed in 11th week. So, you can refer I am showing the values of this example here. So, as far as this weir length is concerned this is corresponding to 14% column area and that we can see from this graph.

If you see here I am having 14% and if we consider this lw / Dc we can obtain as 0.79 and so chord length you can obtain as 1.1 meter.

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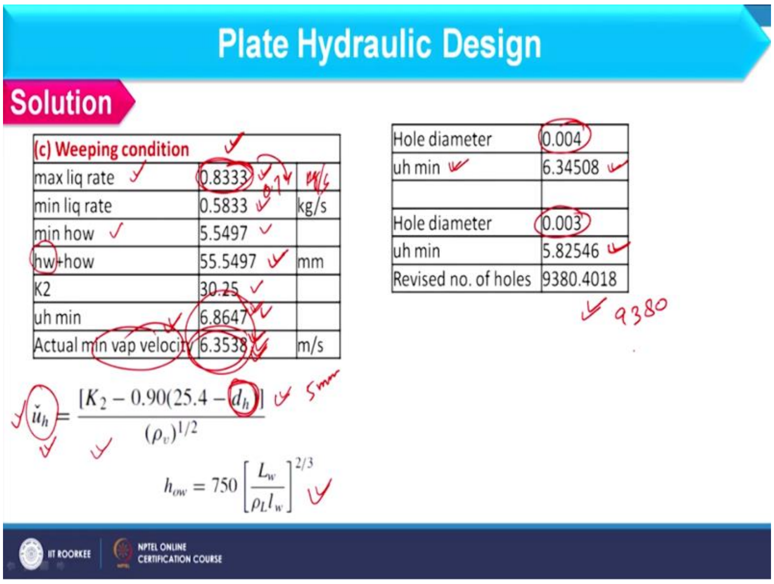

And next we have to check the weeping condition and here we should focus on the position of the plate and that is the top. So, as far as this weeping condition is considered we have to take the flow rate which is available at the top. So, maximum liquid flow rate we can obtain like this 0.8333 kg per second. This is based on the flow rate of liquid which is available in top section that is above feed.

So, this value you can already refer from the example and next we have to consider the minimum liquid rate for weeping condition so that should be 0.7 into this. So, minimum h w we can obtain using this expression and it will come out as 5.5497 mm and weir height is given as 50 mm. So, h w + how you can obtain accordingly.

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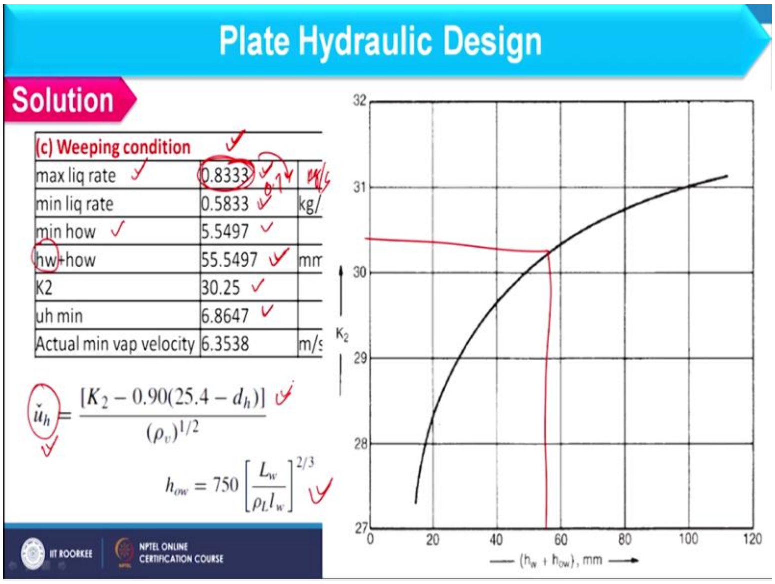

And once you know this value you can find out K 2 from this graph. So, this is basically like this you can calculate. So K 2 value you can obtain as 30.25. Now, once you have the K 2 value you can calculate the minimum vapour velocity at which weeping will occur and this is this value and this expression you can use. So, you can find the value as 6.8647. So, this is the minimum vapour velocity at which weeping will occur.

Now, we will check the actual vapour velocity actual vapour flow rate in top section is already given to us. We will consider that as maximum vapour flow rate and that we converted into volumetric flow rate it would be divisible by hole area which is 6% of the active area considering all these you can find actual minimum vapour velocity. And how you consider the minimum velocity because based on the given flow rate you have already calculated the volumetric flow.

Consider 70% of that you can find as the minimum volumetric flow rate and that should be divided by hole area. So, you can obtain actual minimum vapour velocity as 6.35. Now here if you compare these two condition is not met because this value should be more than this. However, it is coming lesser than this so what we have to change over here because you cannot change this, you cannot play with the volumetric flow or the mass flow rate.

However, you can change this minimum flow rate because it will depend on hole diameter. Initially we have consider 5 mm as hole diameter. Now, I will reduce this value to 4 and we will calculate uh minimum and this value will be very close to this. So, we consider that weeping may occur if slight change will occur in the operation. Next, we should consider slightly lesser value of hole area.

And for that uh minimum is very low in comparison to the actual minimum vapour velocity. So, in this case we consider that weeping condition is satisfied. Now, what diameter of hole you have chosen. It is basically 3 mm so we have to again calculate the number of holes which we have already calculate in the last part. So, revised number of hole should be 9380 that you can simply calculate. And so we are ending this lecture.

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And here we are having some of the reference and now we are summarizing the video.

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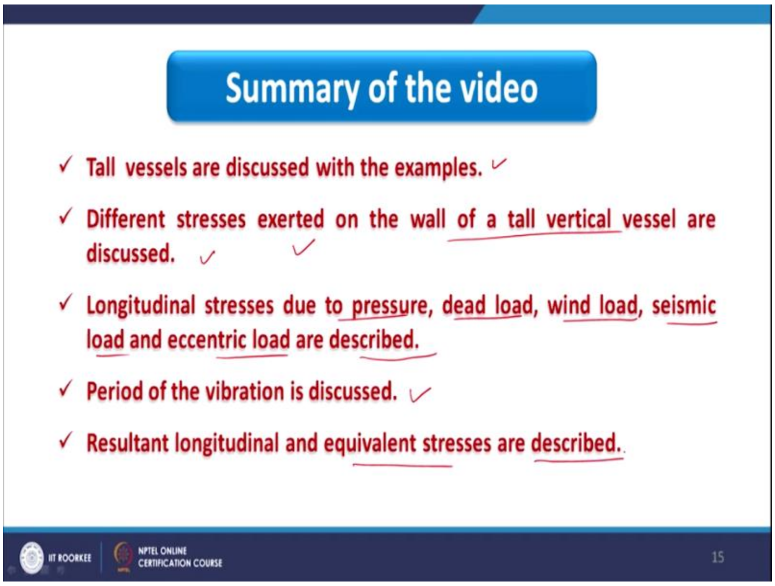

And this is basically the summary of all 5 videos available in this week. So, let us see that. In this tall vessels are discussed with examples. Different stresses exerted on the wall of the tall vertical vessel are discussed. Longitudinal stresses due to pressure dead load, wind load, seismic load and eccentric load are described, period of vibration is discussed, resultant longitudinal and equivalent stresses are described.

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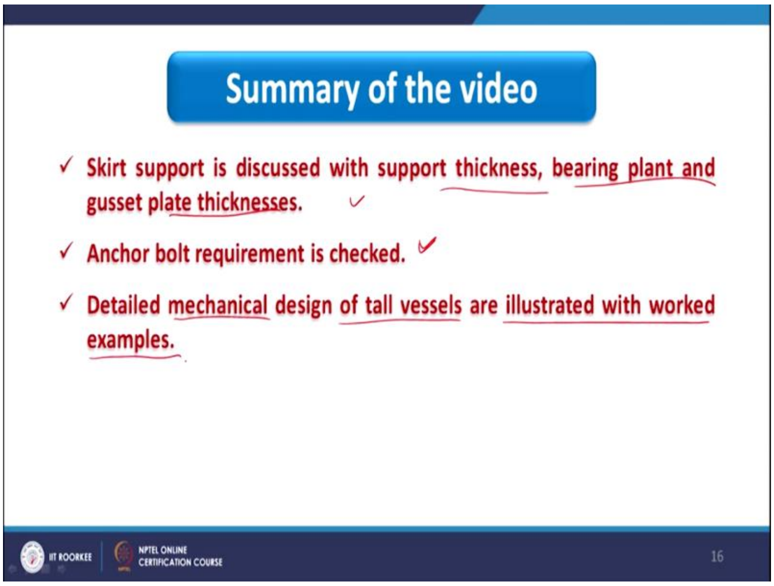

And further skirt support is discussed with support thickness, bearing plate and gusset plate thicknesses. And then we have checked whether anchor bolts is required or not what is the condition that we have discussed and finally detailed mechanical design of tall vessels are illustrated with worked example and after that we have carried out one exercise for plate hydraulic design.

So, this is basically all about this course. Now here we will going to summarize this course that basically what we have considered over here. So, as far as different equipment which we have considered over here these are concerned these are basically shell and tube heat exchanger, condenser reboiler, crystallizer, evaporator, distillation column and packed column.

And as far as the uses of these equipment in chemical plant is concerned we can refer the onion diagram which we have discussed in the first lecture of this course because this is clearly representing the chemical plant. So, as far as designing of these course you can address different layer and you can contribute in different layer of chemical plants. So, in this way we have considered process design of all these equipment along with the mechanical design of tall vessel and that is basically the distillation column.

So, here I am ending this course I really thank you all for attending this course and I wish you success in the upcoming exam. So, thank you all. Thank you very much for joining me in this course. Thank you.