Process Equipment Design
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Lecture –59
Distillation Column: Mechanical Design-4

Hello everyone. Welcome to 59th lecture of the course Process Equipment Design. In this lecture, we are going to discuss distillation column and mechanical design for the same. Now, if you recall the previous lectures of this week there we have designed distillation column considering mechanical aspects. And as far as this design is concerned we have basically designed the tall vessel and distillation column falls in that category.

So, as far as mechanical design is concerned or mechanical aspects of design is concerned it means that we need to calculate thickness of shell as well as support which can sustain all stresses which are available while operating the system as well as when operations is not going on. So, we have considered different stresses depending upon the operating conditions as well as without operating condition.

Such as wind, seismic and dead load etcetera. So, we have to calculate thickness of shell as well as support accordingly. Now, in this particular lecture we will illustrate that design with the help of example. So, let us start this.

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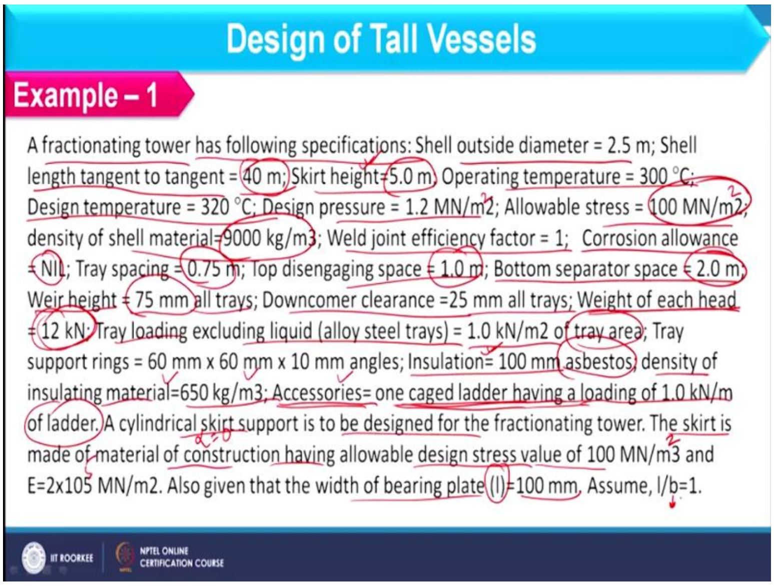

So, in this example a fractionating tower that is the distillation column is to be designed with the following specification that is shell outside diameter is 2.5 meter. Shell length tangent to tangent it means shell length tangent to tangent is 40 meter. What is the meaning of this that above that the complete length of shell. So, tangent to tangent means when the head is attached to the shell there it makes tangent with the shell.

So that we consider as tangent to tangent length or it means the complete length of the shell. So, that is 40 meter, skirt height is 5 meter. It means this is the height of the support and as you understand that for tall vessel we basically consider only one type of support and that is the skirt support. Further, we are given that operating temperature is 300 degree Celsius, design temperature is 320, design pressure is 1.2 mega Newton per meter square.

Allowable stress is 100 mega Newton per meter square, density of the shell material is 9,000 kg per meter cube. Weld joint efficiency factor is 1 and along with this we are given corrosion allowance as 0 it means we are not considering this, tray spacing 0.75 meter, top disengaging space that is 1 meter. Now what is this top disengaging space because when I consider the distillation column when vapour exits the first tray from the top. So, when the vapour exits it means it contain some liquid droplet with it.

So, some space is required for vapour liquid disengagement. So, that we consider as top disengaging space which is given as 1 meter in this problem. Next, I am having bottom separate space that is 2 meter and why we are providing this bottom separator space because at the bottom we have liquid which is entering into the reboiler and then vapour form there and vapour liquid mixture enters into the distillation column.

So, at the bottom we again need some space for vapour liquid separation. So, at the bottom liquid availability and vapour liquid separation should be ensured by bottom separator space and that is given as 2 meter in this problem. Further, we are given weir height as 75 mm for all trays, downcomer clearance 12 mm all trays, weight of each head is 12 kilo Newton and usually we have two heads.

So, we have to consider the weight of head accordingly. Further, we are given tray loading excluding liquid and that should be 1 kilo Newton per meter square of tray area, tray support ring that is 60 mm and 10 mm angle. Further, insulation of 100 mm is required which is of asbestos and that insulation is basically placed at the outer surface of the shell. Density of the insulating material is given as 650 kg per meter cube.

Other accessories are one caged ladder is used which is having the loading of 1 kilo Newton per meter of ladder. Next, cylindrical skirt support is to be designed. So, here I am considering alpha 0 if you recall the last lecture. The skirt is made of the material of construction having allowable design stress value as 100 mega Newton per meter cube. This is basically per meter square.

And that will be equal to the material which we are using for the shell. Further, elasticity coefficient is given as 2 into 10 is to the power 5 mega Newton per meter square and width of the bearing plate is given as 100 and that is basically small l and small l / b that is basically the gusset spacing that should be equal to 1. So, in this way different parameters are given to us and now we will focus on different points what we have to calculate. So, let us see that.

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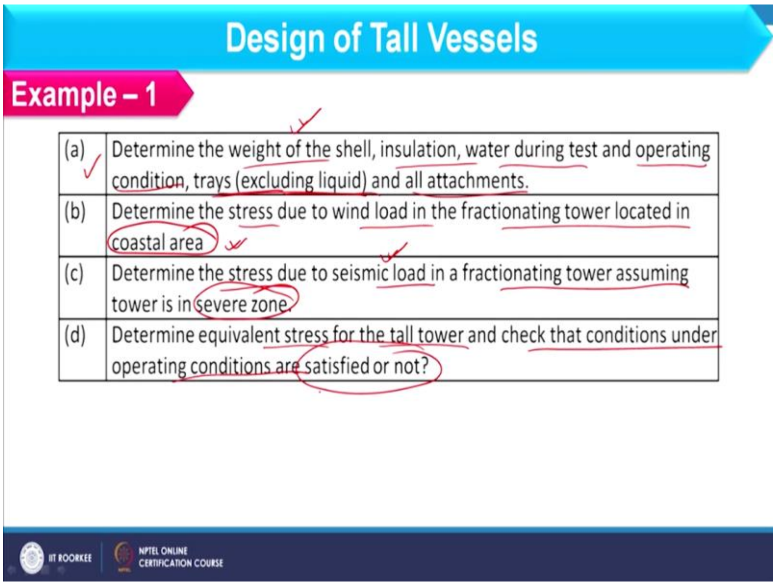

First of all we have to determine the weight of shell insulation, water during test and operating conditions, trays excluding liquid and all attachment. So, we have to find out weight of all these components. Second is we need to determine the stress due to wind load in fractionating tower located at the coastal area. So, accordingly you have to design. Third, what we have to consider is determine the stress due to seismic load in fractionating tower considering severe zone.

So, accordingly we have to consider the stress generated due to earthquake. And finally we have to determine the equivalent stress of tall vessel or basically the fractionating tower and check that conditions under operating conditions are satisfied or not. So, we have to design the tall vessel considering all these factor. So, let us start the design of tall vessel.

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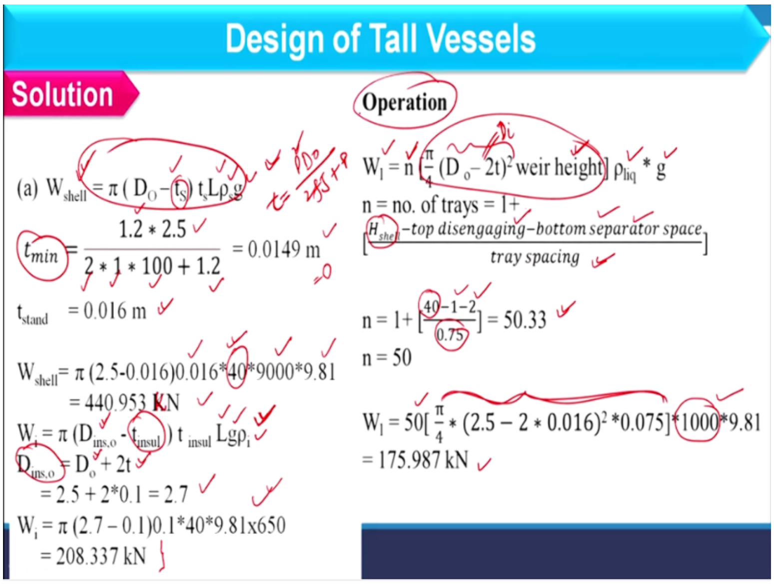

As you know the first point is we have to find out weight of different components. So, first of all I am considering shell. So, this is basically weight of shell which is equal to pi D 0 – t s into t s L rho s and g. Derivation of this expression is explained in first lecture of this week that you can refer. So, as far as this t s is concerned this is basically the standard thickness of the shell and how I can find out the standard thickness of the shell.

This thickness can be obtained considering operating conditions. It means the pressure at which the system is being operated. So, once I am having the operating pressure I basically consider design pressure to find out thickness of shell. So, let us see what is the expression for that. So, that thickness expression is P D 0 / 2 f J + P. So, this P is basically the design pressure which is given as 1.2 mega Newton per meter square and D 0 is given as 2.5 divided by 2 f J + P.

All these values are given to you so we can obtain 14.9 mm as minimum thickness of shell. So, in this way we will not add any corrosion because that value is given as 0. So, standard thickness we can obtain as 16 mm. Now I am having the standard thickness of the shell we can further calculate the weight of shell. So, let us see that. Now all component in this expression are known to us.

So, we can simply put the values of each component so that should be thickness we can consider as 0.016 40 meter is the total length of the shell, 9,000 is the density of the material by which shell is made and 9.81 is the g value. So, 440.953 kilo Newton we can consider as weight of shell. So, here it should be small. Now, once I am having the weight of the shell in the similar line I can obtain weight of the insulation also.

So, let us see that. We can consider the same expression as we considered for shell, but only difference is instead of D o we will consider outer diameter considering insulation. And here it should be the thickness of insulation material. Length will be same g will be same, rho i will differ. So, first of all let us see D insulation outer and that should be outer diameter of shell plus 2 into thickness of insulation. So, 2.7 meter we can obtain D insulation.

So, considering all these parameter we can find out the weight of insulating material as 208.337 kilo Newton. And after that we have to find out weight of liquid at operating condition and at test condition. So, first of all let us focus on operating condition. Now as in this case we are considering fractionating column that is basically the distillation column where trays are available.

So, as far as operation is concerned whatever liquid I am considering that will stay over the tray. So, first of all I have to find out the number of trays and then we will calculate the weight of liquid on these trays. So, let us see that. So, here I am having weight of liquid that is W l which is equal to n that is number of trays and pi / 4 D o – 2 t square. So, that is nothing, but inner dia because tray will be placed at inner side of the distillation column.

And whatever liquid is available over the plate it will be decided by the weir height. So, this is basically the volume which is available over one plate multiplied this by number of trays into rho of liquid into g. So, let us see how to find out number of trays. For this we have the expression like 1 + H shell that is height of the shell – top disengaging space – bottom separator space divided by the tray spacing.

So, all these parameters are known to you that is 40 meter is the shell height. One meter is top disengaging space and 2 meter is bottom separator space 750 mm is the tray spacing. So, considering this we can find out number of trays as 50.33. Now here what you have to do?

Number of trays will be the total number. So, we will round it off because length of the shell is fixed. So, we will consider number of trays as 50 instead of 51.

So, considering 50 number of the trays and above expression we can find out weight of liquid as 50 into all these components are known to you. We can simply put it and we are considering 1,000 as the density of the liquid because we are considering that as water. So, its value should come out as 175.987 so that is at operating condition.

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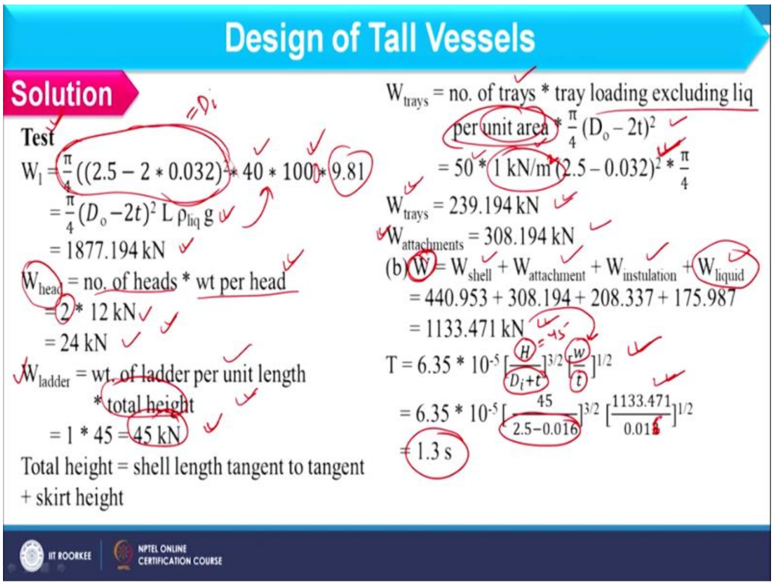

Now, let us see how to find out weight of liquid at test condition. Now, as far as this test is concerned what is the meaning of that? Usually, when we consider the test condition it means that is the extreme possible condition. And when I am considering weight of liquid what could be the extreme possible condition? The extreme possible condition should be when complete column is filled with the liquid not only the trays.

So, that can be considered while calculating the weight of liquid during test condition. So, let us see that. So, here I am having the cross sectional area of the column considering D i into 40, 40 is the total length of the shell and rho is basically 1,000 over here and 9.81 is the g value this is the expression and before I have put the values. So, 1877.194 kilo Newton is the total weight of liquid during test condition.

So, I hope you understand the difference between operating condition and test condition and along with this we will calculate weight of other parts. So, first of all let us focus on weight of head. So, weight of head will be number of heads into weight per head. So, that I know already weight per head is 12 kilo Newton and total head are basically 2. So, 24 kilo Newton is the weight of head and further we can find out weight of ladder.

Weight of ladder per unit length into total height. Now, what should be the total height in this case? Because when you put the ladder is basically placed from the foundation not only in the shell. So, in that case we will consider total height of the ladder from the foundation. So, in this case total height would be the height of shell plus height of the support. So, 5 meter is the height of the skirt and 40 meter is the height of the shell.

So, total 45 meter we have consider so 45 kilo Newton will be the weight of ladder and along with this we can consider the weight of trays as these are available inside the column and it will also put load on the shell. So, let us see weight of trays. So, that is the simple calculation number of trays into tray loading excluding liquid per unit area. So, what is the area of tray? It will depend on the cross sectional area of column.

So, usually tray is available inside the column. However, in that case downcomer area is also included. However, in this case we are assuming that downcomer area is negligible which is not possible, but we are assuming that. So, we are assuming that tray is available in complete cross section area of the column. So, it will basically give slight over weight of the trays, but that we can consider.

So, 50 will be the total number of trays 1 kilo Newton per meter square is the load of tray for the unit area and then this will be basically the cross sectional area and then this will be the cross sectional area. So, total number of trays will be 239.194. In this way, we can find out weight of attachments as weight of trays plus that of ladder plus that of heads. So, total weight of attachment is 308.194 kilo Newton.

So, in this way we complete the first part of the problem. Now, we will focus on the second part where we have to consider the wind effect. So, in this case total weight that we consider as the dead load it should be addition of weight of shell attachment, insulation and liquid which is available at operating condition. So, total dead weight is 1133.471 kilo Newton and this is required to find out period of vibration which we can calculate using this expression.

So, this H is the total height of the column from foundation so that should be equal to 45 and this weight is total weight. So, considering this we can find out the period of vibration which is coming out as 1.3 second and in this you can consider D i + t as D o – t also. And this t should be the standard thickness so here it should be 0.016. So, in this way period of vibration you can obtain as 1.3 which is more than 0.5.

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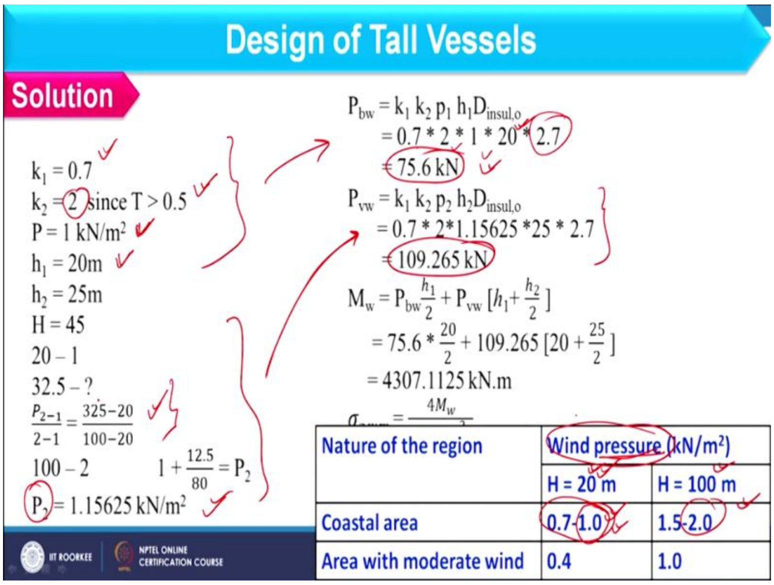

So, accordingly we can choose the k factor that is k 2 and that should be equal to 2. Similarly, k 1 we can consider as 0.7 because cylindrical shell is considered over here and further we can find out the wind pressure and that should be 1 kilo Newton per meter square. So, if you understand the wind effect in hole shell along the length you can recall the previous lectures where we have discuss that the complete wind action or complete wind load we can consider in two parts.

First is up to 20 meter height and then above that. So, in this problem we can first consider the bottom section where H is basically 20 meter. And if you focus on this problem the column which we are considering it is available in coastal area. So, here we should consider this particular region. So, up to 20 meter height pressure should be 1 kilo Newton per meter square because we design for the extreme possible condition.

So, therefore the value of P is considered as 1 kilo Newton per meter square h 1 should be 20. So, considering these we can find out wind load at bottom section and that should be up to 20 meter height. So, 0.7, 2, 1 and then 20 and 2.7 is the outer diameter with insulation and hole wind load at bottom section should be 75.6 kilo Newton. So, in this way you can consider the wind load at bottom section.

Now, how I should consider that in upper section? When I consider the upper section which height I should consider, what should be the value of h 2? H 2 should be 25 meter because we are considering height of the column from foundation not of the shell only. So, 45 is the total height 20 we have already considered so in that case h 2 should be 25. Now, how I should consider the P 2 value that is basically the wind pressure in upper part.

To consider that P 2 is acting at the middle part of upper section, upper section is basically 25 meter long and middle point of that should be 12.5 and from foundation it is 20 + 12.5 so 32.5. So, we can calculate P 2 accordingly like wind pressure up to 20 meter height is 1 and for 100 meter height it is 2. So, what should be the value of wind pressure at 32.5 meter that we can calculate using interpolation as you can observe here.

This is basically 32.5. So, total P 2 should come out as 1.15625 kilo Newton per meter square I think interpolation you all can carry out there is no issue. So, considering all these value we can find out wind pressure at upper section and that should be 109.265 kilo Newton. So, once I am having P b w and P u w this should be P u w we can find out bending moment due to wind action and this expression I can put values over here and Mw we can obtain as 4307.1125.

And so we can calculate the stress generated due to bending moment and this is the expression for that. We can put the values over here. Now, if you focus here t is basically the thickness of shell, but here I am considering minimum thickness of shell. Now why it is so? Because whatever stresses are generated that we will check with minimum thickness. If minimum thickness is able to satisfy the design conditions it means the standard thickness can also sustain. So, all stresses we are considering based on minimum thickness of the shell. So, here sigma zwm we can obtain as 59.59 mega Newton per meter square.

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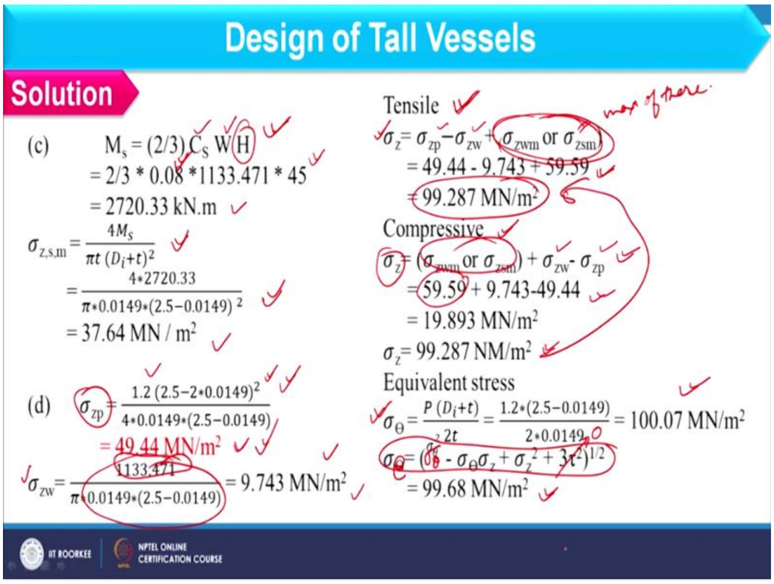

And next we have to check the seismic condition and the bending moment due to seismic condition or the earthquake can be shown by this expression 2 / 3 Cs W H Cs is basically seismic coefficient which you can see from here. So, we are given the severe zone where t is 1.3 which is more than one second. So, C s value should be 0.08 as we can see here. Total W is the weight which is 1133.471, height is the height of the column from foundation so that is 45 meter.

So, total Ms 2720.33 considering this expression we can find out sigma z s m as 37.64 mega Newton per meter square. So, in this way you can find out stress generated in the shell considering seismic zone and next we have to find out the equivalent stress and we should check the design condition so let us see that. To find out the equivalent stress we have to consider the stress which is generated due to pressure as well as due to dead load.

So, first of all we will see the stress which is generated due to pressure. So, in this expression we can find out sigma z p where 1.2 is the design pressure of the vessel and other parameters are given to us so we can consider 49.44 mega Newton per meter square as the stress generated in the shell due to design pressure and sigma z w is basically due to the dead load which is 1133.471.

Considering this expression we can find out sigma z w as 9.743 mega Newton per meter square. Now after this we will consider resultant stress and that we calculate for two conditions that is tensile as well as compressive. So, let us focus on tensile stress when column is operated under internal pressure. So, this is basically sigma z that is resultant stress so sigma z p – sigma z w and these term.

So, we consider maximum of these. So, sigma z p 49.44 sigma z w 9.743 and you see among this when we compare sigma z s m as well as sigma z w m sigma will be maximum so we consider that value over here. So, sigma z should be 99.287. In the similar line I can calculate for compressive stress. So, this is the resultant stress and the expression for compressive stress is given like this and here I am having 59.59 that is maximum of these two sigma z w and sigma z p values are given to us.

So, we can find out resultant stress considering compressive condition as 99.287. So, you can consider these two. Now, next we will calculate the equivalent stress and in this case sigma z should be maximum of tensile and compressive. In this case both are equal, but if it differs we can consider maximum of these two. So, equivalent stress can be obtained by this. Here I am having sigma theta.

So, you see sigma theta is basically the hoop stress which we can find using this expression. So, that comes out as 100.07 mega Newton per meter square. This tau is basically torque which we neglect and so we can find out equivalent stress that is basically sigma e and it comes out as 99.68 mega Newton per meter square. So, in this way we can have tensile stress, compressive stress and equivalent stress and now we will see whether design is safe or not. So, let us check that.

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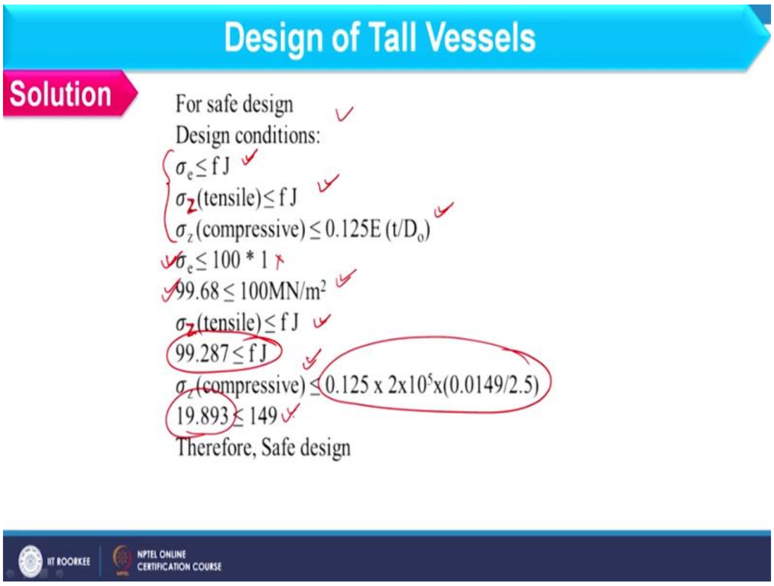

For safe design we have to follow these conditions that is equivalent stress should be less than or equal to f J sigma z for tensile should be less than or equal to f J sigma z compressive should be less than or equal to 0.125 E t / D 0. So, let us see first for equivalent stress so that value is 99.68 it should be less than 100 into 1. So, it is already less than that. So, design is satisfied. Further sigma z tensile should be less than or equal to f J.

This condition is also satisfied and for sigma z compressive value is coming as 19.893 and if we calculate this it will come out as 149. So, in this way we can consider that all stresses are below the permissible limit and design is safe. Now, if somehow these stresses will not come within the permissible limit then what we have to do? We can change f value that is the material of construction because in that case you can change the thickness of the shell, but that thickness will again depend on the material.

So, you have to change the value of allowable stress and accordingly the thickness of the shell and further you can carry out the whole calculation as we have discussed in this example. So, that is all for now. Thank you.