Equipment Design: Mechanical Aspects
Prof. Shabina Khanam
Department of Chemical Engineering
Indian Institute of Technology - Roorkee

Lecture 19
Vessel under external pressure

Welcome to the fourth lecture of week 4 and in this lecture we will discuss vessel under external pressure. So in the last lecture we have started discussion on this topic, where we have discussed different conditions where failure will occur in external pressure vessels and what are the measures to avoid that and what should be the design procedure for such type of vessel. Now in this lecture we will discuss a few examples so that whatever we have discussed in previous lecture those concepts will be more clear to you. So let us start with example 1.

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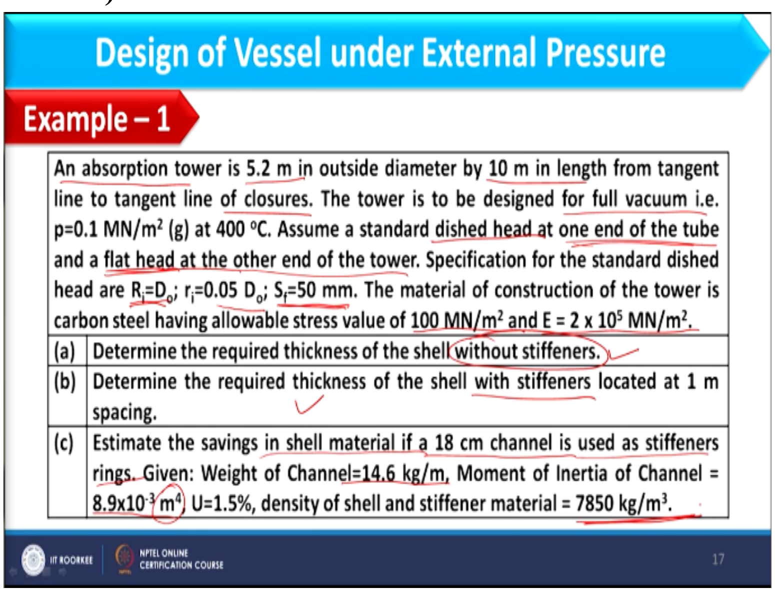

So this example says that an absorption column of 5.2 meter outside diameter and 10 meter length from tangent to tangent line of closures. So I guess you understand what is the meaning of tangent to tangent line that is nothing but the length of the shell. This tower is to be designed for full vacuum that is 0.1 meganewton per meter square at 400 degree Celsius. Assume a standard dished head at one end of the tube or tower and a flat head at another end of the tower.

So once I discovered with form section or dished head and another side is covered with flat head. Specification for standard dished heads R i = D O, r i = 0.05 D O, S f 50 mm. The material of construction of the tower is carbon steel with allowable stress value of 100 meganewton per meter square and this is the modulus or modulus of elasticity value. For this example I have to determine the required thickness of shell without stiffener and then I have to find out the thickness of shell with stiffener located at 1 meter spacing.

So here we have to find out thickness without stiffener and with stiffener, so that you can have idea that how stiffeners are beneficial for such conditions. And in part C I have to estimate the saving in shell material if 18 cm channel is used as stiffening rings. Weight of the channel is 14.6 kg per meter, moment of inertia of channel is 8.9 times 10 power -3 m power 4 because this is area moment of inertia, U 1.5% is given and density of shell and stiffener material is given as 7850 kg per meter cube.

So as far as design of shell for external pressure condition is concerned, this we do for elastic failure condition first and then that condition or that thickness will be checked for plastic failure condition okay. So for elastic failure condition if you remember the expression there I need values of constants K and m, and for that values of constant I have to find out D O/L because it is the function of D O/L, and L here is not the length of shell it is basically the effective length.

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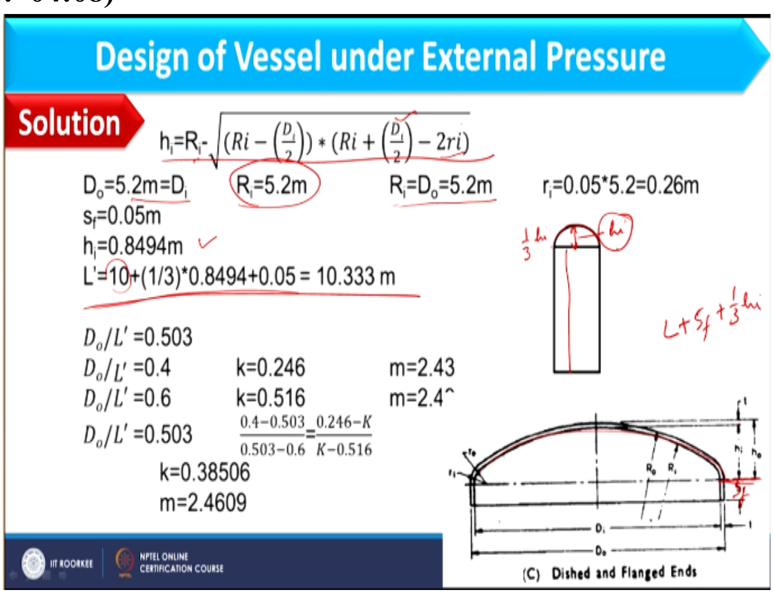

And as you have seen the example that in this vessel one side have flat head and another side has domed section or form section. As you can see from this diagram, here we have this is shell and this is form section. Now this height of form section is hi and to consider this domed section in effective length I am considering one-third of hi here okay. So first of all I have to determine what is hi, so hi you can find out through this expression.

Here we have R i and r i and D i, and D O is given as 5.2, which I am taking as D i for initial guess, and R i = 5.2. R i = D O which is equal to 5.2 and therefore I have taken R i = 5.2. S f is given as 50 mm. So considering all these parameters I can find hi as 0.8494, and further we can calculate effective length that is L dash which is equal to 10, which is basically the length of shell plus one-third into hi + S f okay. So what is SF.

If you consider this domed section okay, hi is considered from here okay and S f is basically the straight section available in head. So effective length will include L + S f + 1/3 hi. So effective length will include L that is length of shell, S f that is the straight part in head and then 1/3 of hi, which is already we have written here and then that L dash comes as 10.333 meter okay. For example, if I am having domed section here also then instead of one-third we will consider two-third of hi.

So here D O is 5.2 that is outer diameter of shell and effective length is 10.333 meter. Considering these two values we can find out D O/L dash which comes at 0.503.

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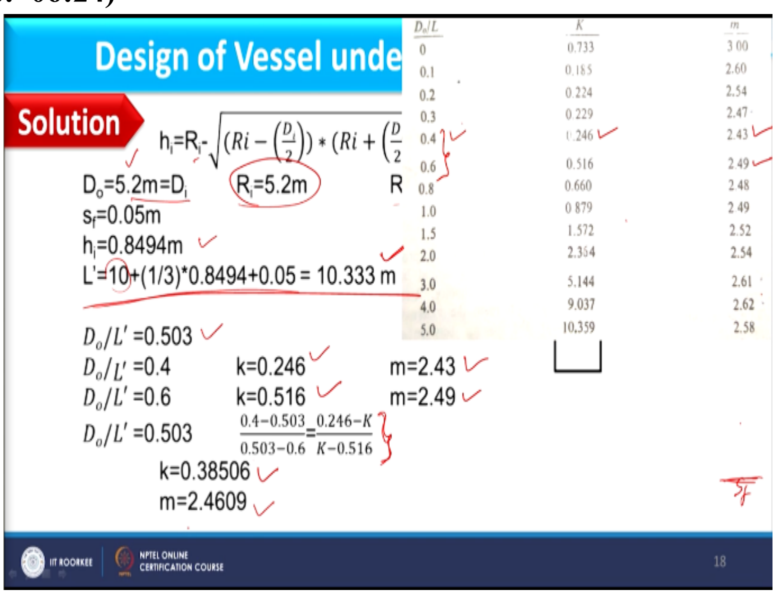

And if you remember this table 8.2 in book given by B. C. Bhattacharya, here D O/L dash is 0.503, which is falling in this region. It means I have to interpolate between 0.4 and 0.6 to obtain value of K and m at 0.503. So at 0.4 value of K is 0.246, which is given over here, and m is given as 2.43. And similarly corresponding to 0.6 K comes as 0.516 and K 2 2.49 as it is written here.

So for interpolation at 503, we calculate K value and here 0.4 - 0.503/0.503 - 0.6, which is equal to 0.246 - K/K - 0.516. So interpolation is nothing but we equate the slopes okay. So solving this equation we can find K as 0.38506 and in the similar line we can calculate m as 2.4609.

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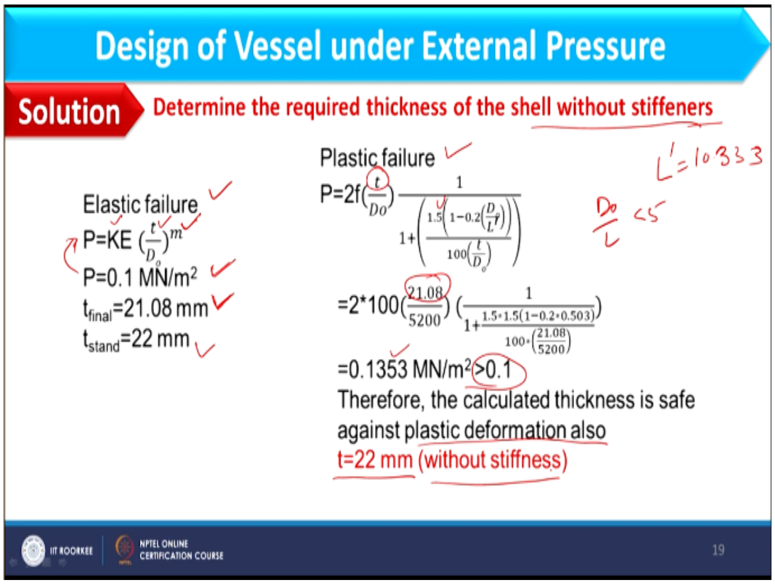

So after computing value of K and m we have to determine the required thickness of shell without stiffener, and without stiffener means we have to consider L dash as 10.333 okay that is without stiffener. So as far as computation of thickness is concerned first we will go for elastic failure and then we will go for plastic failure. Elastic failure expression is P = K et/D O (m). K and M we have already found out in previous slide and P is basically the safe pressure, it means whatever would be the design pressure we are assuming that as a safe pressure and then corresponding to this we will find out the thickness.

So P I will put over here and then all parameters I know and further I can find out t, which comes out as 21.08 and then standard is available as 22 mm in table B1. So once I am having this thickness, I have to check whether it suits for plastic failure or not because I have to keep my vessel safe from elastic failure as well as plastic failure. So as D not/L is less than 5 I will use this expression.

Here I should write U also which is 1.5% and then I will write all parameters and t whatever I am having that t should be the minimum thickness because when vessel satisfies the condition for minimum thickness, it can satisfy or it can withstand with standard thickness also. So here we are considering 21.08. Solving this equation gives value of P as 0.1353 and which is greater than 0.1, which we have considered as safe pressure.

It means a plastic failure will occur beyond elastic failure condition and that is the true condition, and therefore calculated thickness is safe against plastic deformation also. And further we can consider t as 22 mm as final thickness for without stiffening condition. Let us discuss computation of required thickness of shell with stiffeners, which are located at 1 meter spacing.

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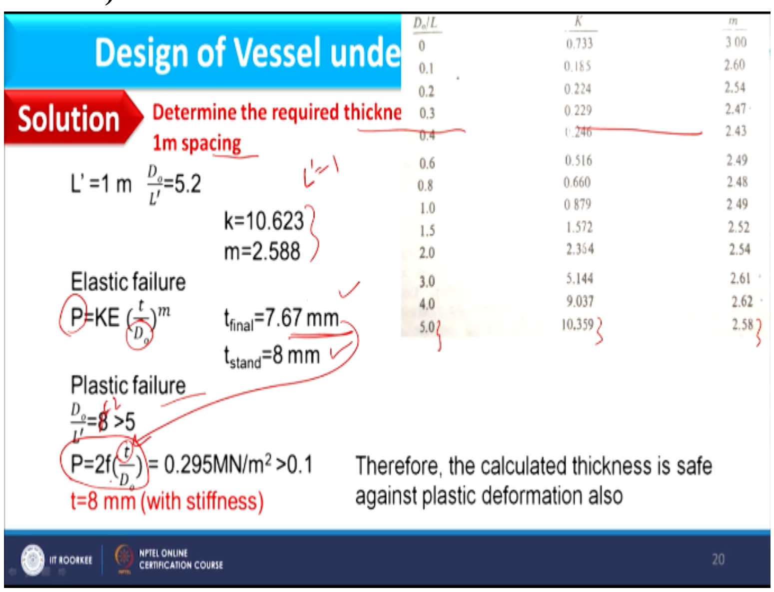

So when stiffeners are located at 1 meter spacing, it means that effective length would be 1 meter in this case. So D O/L dash comes as 5.2 okay. And here I am having the elastic failure and here corresponding to D O/L dash = 5.2, I can find out value of K as well as m from this table and here you see value is available slightly higher than this. So it is very close to 5, so here we can extrapolate the values to know the values of K and m. And K we can find out as 10.623 and m as 2.588.

For elastic failure condition, P should be equal to K E (t/D not) m okay. Now putting P as 0.1, K and m are given here, E value I already know and D not is given as 5.2. Considering this value t comes out as 7.67 mm okay and standard for that is 8 mm. Now for this minimum thickness we will check plastic condition. In that case as D O/L dash is 5.2, here it is not 8, this should be 5.2, and that is greater than 5, so we will use this expression and here t we will use this value. I hope I am clear.

And then we will find out pressure and that comes out as 0.295, which is greater than 0.1. So 8 mm we can consider thickness of shell with stiffeners. So if you consider the situation where we were not using stiffener, the thickness of shell comes as 22 mm and here we are using the stiffener and thickness comes as 8 mm. So you can see the difference of using stiffeners.

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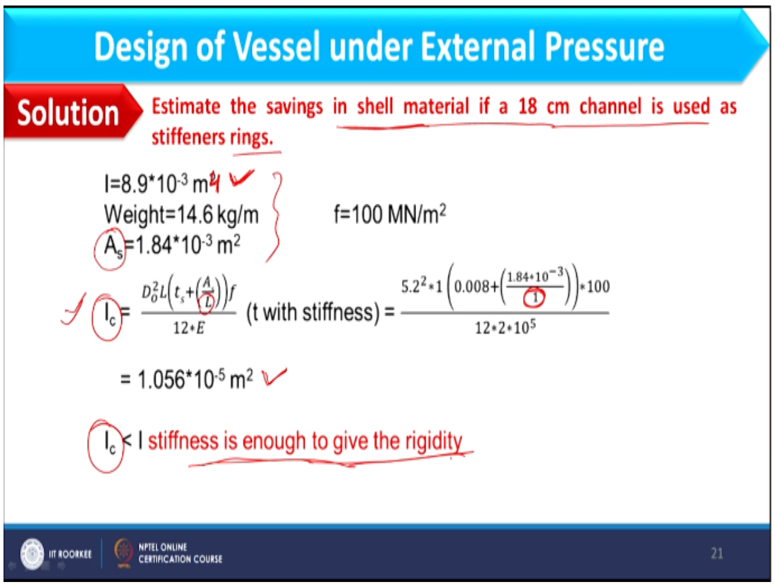

And now I need to estimate the savings in shell material if 18 cm channel is used as stiffening ring. For this channel, value of moment of inertia is given as 8.9 times power -3, here we have meter power 4 okay, and weight of stiffener is 14.6 kg per meter, f is given like this and here we have the sectional area A S, which is 1.8 times power -3 meter square. Considering all these values we will find out I C, which is basically the moment of inertia for the structure with circumferential ring.

So that is given as D O 2 L (t s + (A S/L)) * f/12 E. So putting all these values over here okay and if you see here L we have taken as 1 not 10 meter, and why it is so because when I am using stiffening ring then only I need to find out I C and then effective length would be 1 not 10 okay. So considering these values I can find I C as 1.056 * times 10 power -5.

Now if you compare this value with this. So it means that the given value of I is greater than whatever is required for structure and therefore stiffness is enough to give the rigidity. So the condition should be whatever we have discussed just now that moment of inertia for the structure should be less than then that for ring. Therefore, if this condition satisfy whatever channel I am considering that is rigid enough to avoid the collapsing.

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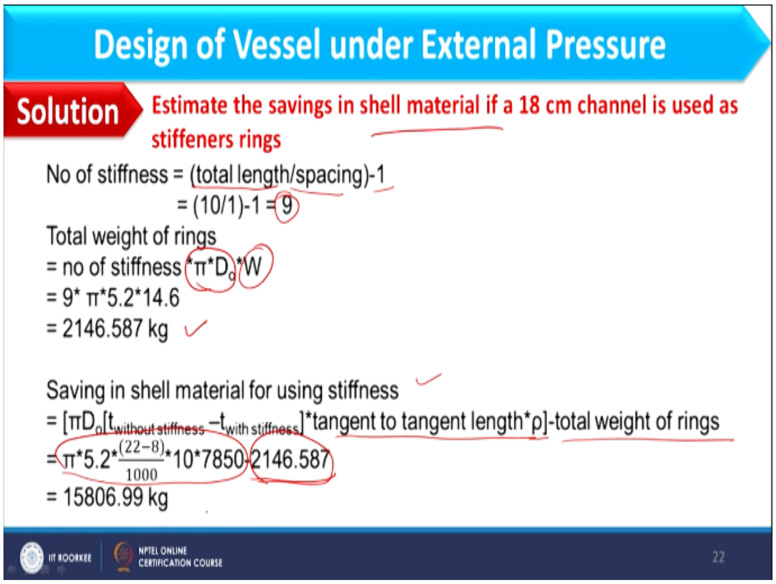

And then I have to find out saving in the shell material. So as far as saving in shell material is concerned how I can calculate this because when I am not using stiffeners the thickness was 22 mm. And when I am using stiffeners thickness becomes 8 mm, but at the same time I am investing in stiffeners also okay. So first of all I have to find out number of stiffeners and how much material will be required for these stiffeners.

So we have number of stiffeners as total length by spacing – 1. So 10 is the total length of the shell divided by 1 because 1 is the spacing -1, so 9 stiffeners I have to place along the length at the spacing of 1. So total weight of the stiffening rings are number of stiffeners into Pi * D O that is the periphery because weight of unit length is given so I need to know the periphery. So putting all these values we can find 2146.587 kg as total weight of the rings.

Now saving in shell material for using stiffeners equal to Pi D not that is the periphery, t without stiffness, -t with stiffness that is the saving in thickness into tangent to tangent length into Rho minus total weight of the rings. So this much saving I have observed in shell, however, this much I am investing in stiffeners. So solving this we can find that 15 tons of material can be saved while using stiffeners. So in that way we calculate the thickness of shell with or without using stiffeners.

And here I am having another example that is example 2, which will give more clarity on the topic.

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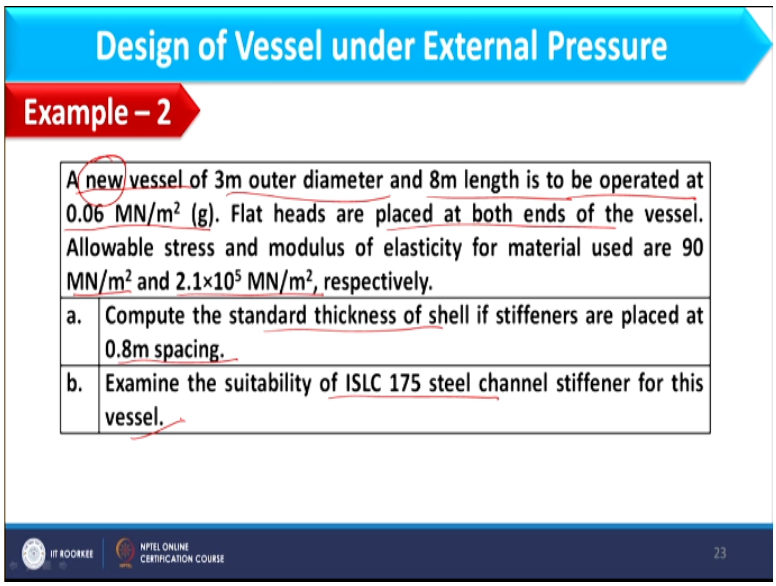

And this example says that a new vessel of 3 meter outer diameter and 8 meter length is to be operated at 0.06 meganewton per meter square in gauge. So here you see I am considering new vessel okay. So this hints that out of roundness should be considered as 1.5 because for new vessel it is assumed as 1.5 okay. And flat heads are placed at both end of the vessel. Allowable stress and modulus of elasticity for the material used are 90 meganewton per meter square and 2.1 times power 5 meganewton per meter square respectively.

What I have to find is the standard thickness of shell if stiffeners are placed at 0.8 meter spacing. And then I have to examine the suitability of ISLC 175 steel channel stiffener for this vessel okay. So these two partS I have to compute, so let us start with part A.

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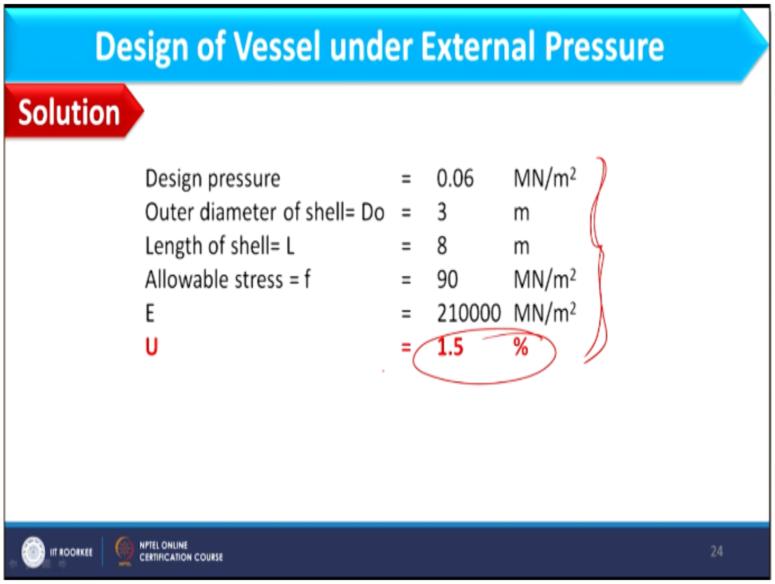

Now here I am having the parameters know to me to solve this problem, design pressure, outer diameter of shell, allowable stress and U I am taking as 1.5. Why I am taking that I have already explained.

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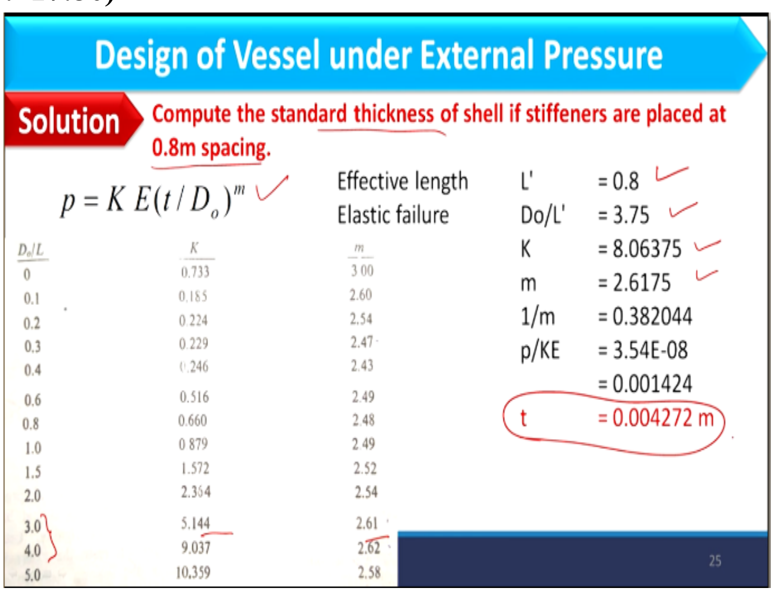

So let us start the computation of standard thickness of shell. And if you say that stiffeners are placed at 0.8 meter spacing, L dash can be taken as 0.8, outer diameter of shell is 3 meters, so D not/L dash is considered as 3.75. K and m I can see from the table corresponding to 3.75, so it will lie here and we can find value of K as well as m using interpolation and that I have already explained in the previous example. Considering this we can solve this equation and then we can find out t as 0.004272 meter. So 4.25 mm we have considered as minimum thickness.

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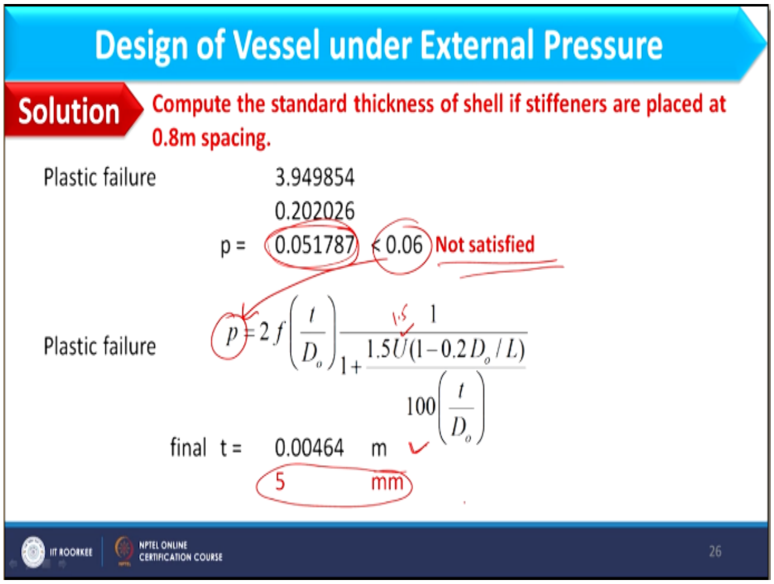

And then we will go for plastic failure condition. This gives me the pressure for plastic failure considering 4.27 mm thickness, and if you see this is less than the design pressure, design pressure was 0.06 and in plastic failure condition it is coming lesser okay. So it will not satisfy the condition. So for that purpose we will consider p as 0.06 and which will be given by this whole expression where U should be 1.5 as we have discussed earlier.

And solving this equation and this is basically hit and trial because t is coming at two places, so you can find out the value of t while solving this equation, which comes out as 4.64 meter. And further I do not need to recheck for elastic condition because once it satisfy the plastic condition, it will satisfy elastic condition also. So 5 mm I can consider as standard thickness for this vessel.

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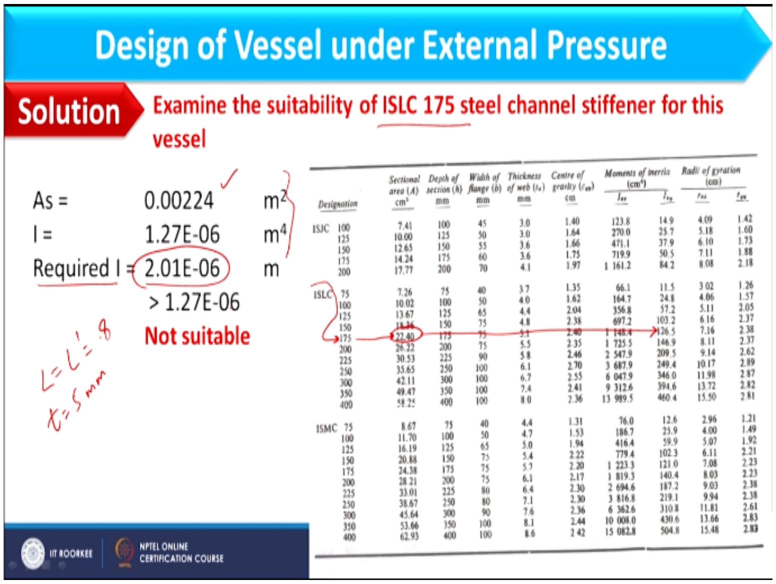

Next I need to examine the suitability of ISLC 175 steel channel stiffener for this vessel okay. Now if you consider this is the table for channel and here I am having ISLC 175, so this you see ISLC 175 okay. So this value you can take as sectional area or A S and this value like 126.5 cm power 4 you can take as moment of inertia. So this A S as 22.4 meter square and I we can consider as 1.27 times power -6 meter 4, so these value I can see from table C3.

And I can calculate required moment of inertia. The expression for this we already know where L should be L effective and this is 0.8 meter and t should be 5 mm okay. So considering all these values along with A S we can find out required moment of inertia as 2.01 times power -6 and that is greater than 1.27 times power -6. So as far as condition is concerned, required moment of inertia for the structure should be less than the moment of inertia of the stiffener.

However, in this case it is coming larger, therefore, the channel which is given in this problem is not suitable for the vessel okay. So therefore this is found not suitable. So here we have solved two examples to illustrate you how to carry out computation for pressure vessel under external condition and for such vessels, which is operated under external pressure how you need to choose the correct stiffener that also we have discussed. So for that purpose you can refer table C2 and C3 in book given by B. C. Bhattacharya.

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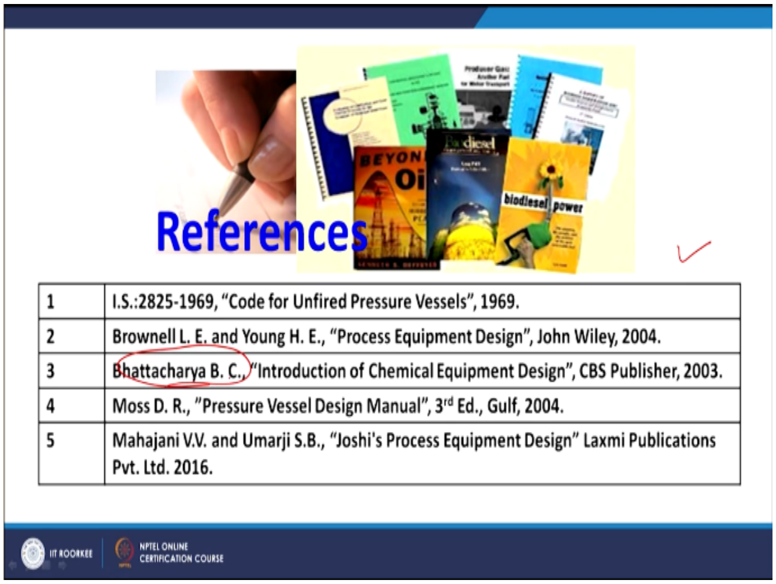

And here I am closing this lecture, and further these books along with B. C. Bhattacharya you can use to study about the topic in detail.

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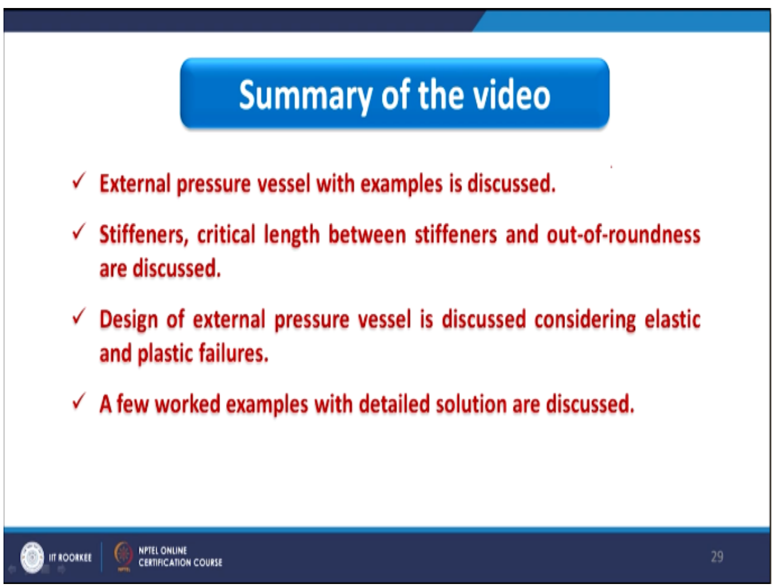

And here I am having the summary for lecture 3 as well as 4 and it goes as external pressure vessel with examples is discussed, stiffeners, critical length between stiffeners and out of roundness are discussed. Design of external pressure vessel is discussed considering elastic as well as plastic failures. A few worked examples with detailed solution are discussed for better illustration. And that is all for now, thank you.