Equipment Design: Mechanical Aspects
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Lecture 08
Design of Heads

Welcome to the third lecture of week 2 and here we are discussing design of heads. In lecture 1 and lecture 2, we have covered the theory part related to this and in this lecture we will discuss a few examples to make you understand how design of different types of heads will be carried out. So, let's start with example 1.

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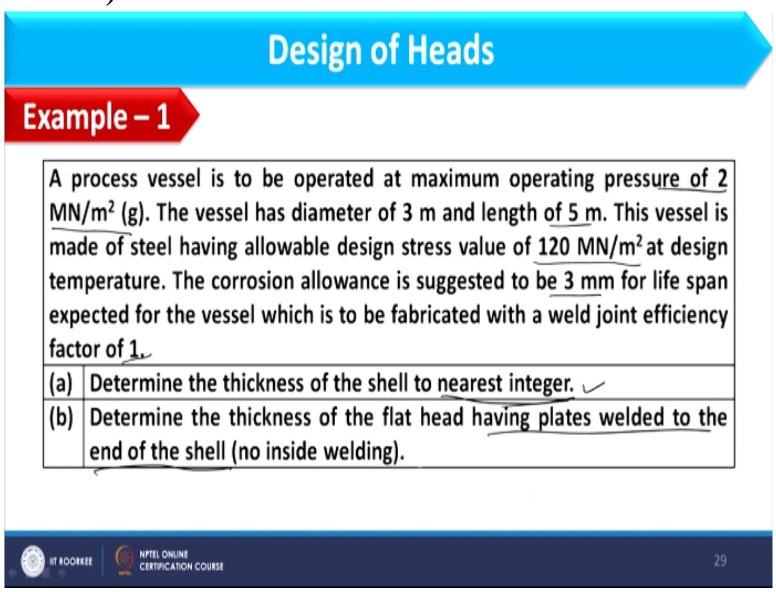

In example 1, a process vessel is to be operated at maximum operating pressure of 2 mega Newton per metre square gauge. Vessel has diameter of 3 meter and length of 5 meter. This vessel is made of steel having allowable design stress value of 120 mega Newton per metre square at design temperature, corrosion allowance is 3 mm and joint efficiency factor as 1.

And in this problem, we need to determine the thickness of shell to nearest integer, so this we have to consider nearest integer and second part we need to determine thickness of flat head having plates welded to the end of the shell. No inside welding. So, in this A and B we have to design the shell as well as flat head and in part C, we have to determine the thickness of conical head when apex angle is 120 degrees Celsius.

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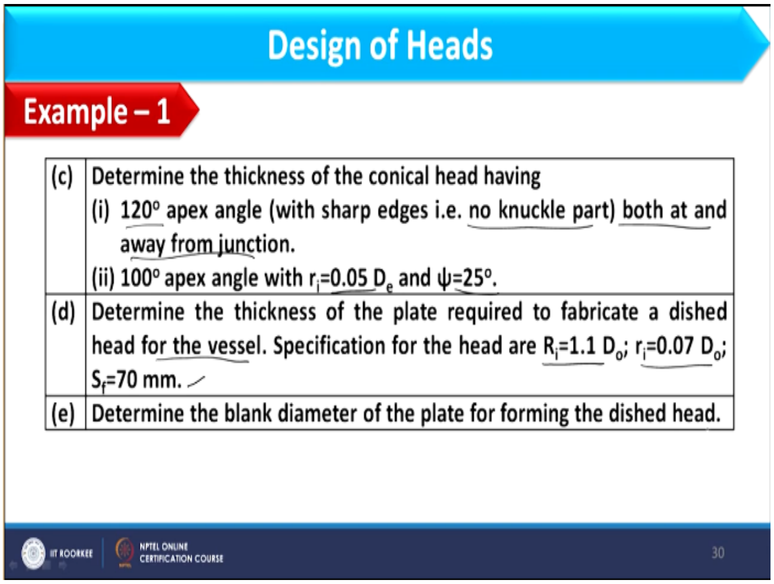

No knuckle part is there and we have to find out thickness both at and away from the junction. In the similar line, part 2 is there we apex angle is 100 and here we have SI value which is different than the alpha and here I am having the knuckle part also. So, considering these variations, we will demonstrate how the thickness of conical head will be carried out. Further, in part D, we need to determine the thickness of plate required to fabric a dished head for the vessel.

Specifications of the head are RI is 1.1 D o, ri is 0.07 D o and SF 70 mm, and finally we have to determine the blank diameter of plate for forming the dished heads. So, in all these 5 sections, we need to determine different types of heads, so let's start with part A where we need to find out thickness of shell.

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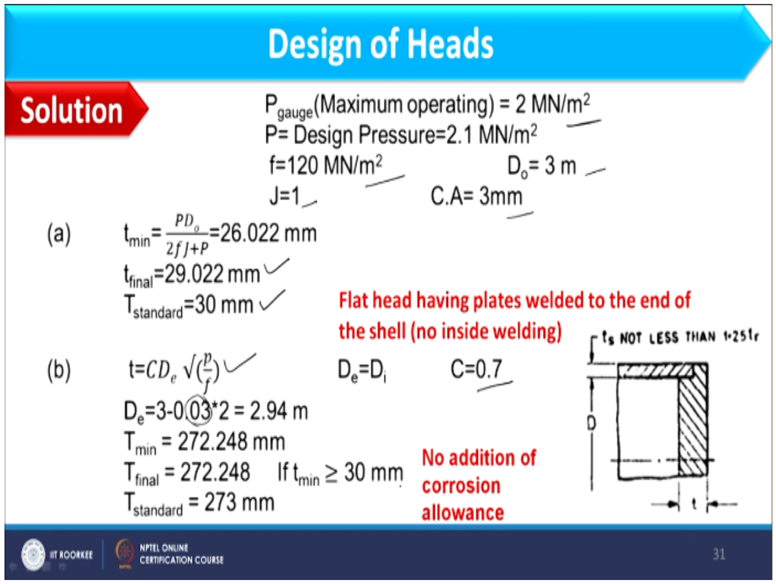

Now, to find out thickness of shell, we have to calculate the design pressure. Maximum working pressure in gauge is given as 2 mega Newton per meter square, design pressure would be 5% extra to that.

Allowable stress value, J value, corrosion allowance and outer diameter, all these values are known, and here this is the expression for minimum thickness of shell, PD o/2FJ plus P, so putting all these values in this, we can find out 26.022 mm minimum thickness of shell. We will add corrosion allowance into this to get the thickness as 29.22 and as it is mentioned part A. that we need to find out thickness for nearest integer, we can consider 30 mm as next integer value to this. so, in this way we compute thickness of shell as we have already demonstrated in fifth lecture of week 1.

Further, in part B, we have to find out thickness of flat head, so let's discuss that. So, this is the expression for calculation of thickness of flat head where C, D, E and root over P/F, all values we need to extract first. P and F we already know. DE and C will depend on type of attachment and type of attachment is flat head having plates welded to the end of the shell, no inside welding. So, this type of connection is there where D = DI, that is inner diameter of shell and C in this case is 0.7.

So, DE how I can find out, that is 3 meter is the outer diameter of shell minus 2 x 30 mm, 30 mm is the standard thickness of shell. So, considering these two, 2.94 is the value of DE. C value, as

I have discussed, it is 0.7, so T minimum we can find out as 272.248 mm and further we will not add any corrosion allowance at T minimum is greater than 30 mm. So, if you remember the terminology lecture, that is lecture 4 of week 1, we have discussed that when thickness is greater than 30 mm, we will not add corrosion allowance into this. Therefore, in this case also, it will not be added.

Standard value will be next integer value to this value. So, final thickness value for flat head is 273 mm, which is quite high.

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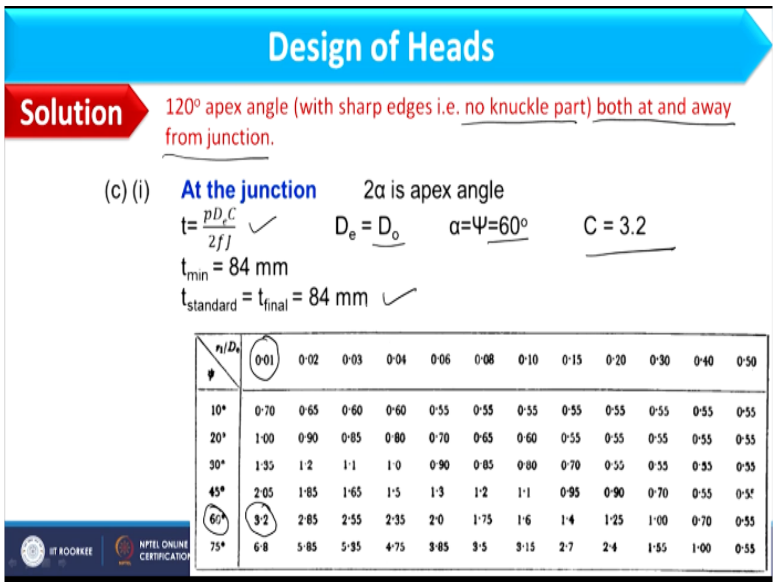

ψ \ r_i/D_e	0·01	0·02	0·03	0·04	0·06	0·08	0·10	0·15	0·20	0·30	0·40	0·50
10°	0·70	0·65	0·60	0·60	0·55	0·55	0·55	0·55	0·55	0·55	0·55	0·55
20°	1·00	0·90	0·85	0·80	0·70	0·65	0·60	0·55	0·55	0·55	0·55	0·55
30°	1·35	1·2	1·1	1·0	0·90	0·85	0·80	0·70	0·55	0·55	0·55	0·55
45°	2·05	1·85	1·65	1·5	1·3	1·2	1·1	0·95	0·90	0·70	0·55	0·55
60°	3·2	2·85	2·55	2·35	2·0	1·75	1·6	1·4	1·25	1·00	0·70	0·55
75°	6·8	5·85	5·35	4·75	3·85	3·5	3·15	2·7	2·4	1·55	1·00	0·55

Now part C I am having where 120 degree apex angle with sharp edge that is no knuckle part is there and we have to find out thickness at and away from the junction, so at the junction, apex angle is 120, so alpha in that case would be 60. This is the expression to find out the thickness where P is the design pressure, DE is the outer diameter of head, but here we can consider for shell because it will be almost equal, so we can assume the equality between the two.

C we need to find out through table 3.6. For C value, I have to find value of SI and SI would be equal to alpha which is 60 in this case, okay. Now, if you focus on this table, this is table 3.6 where SI is given as 60 degree, okay. As no knuckle part is there, we have discussed in lecture 2 that if no knuckle part is there, then R i/D e should be equal to 0.01. So, corresponding to 60 degrees, we can find out C value is 3.2 as already mentioned over here.

So, considering these values, we can find out thickness of conical section at the junction and as it is greater than 30 mm, we will not add corrosion allowance into this. So, final thickness we can consider as 84 mm. So, in this way we find out thickness at the junction when no knuckle part is there. Let us continue for the thickness away from the junction.

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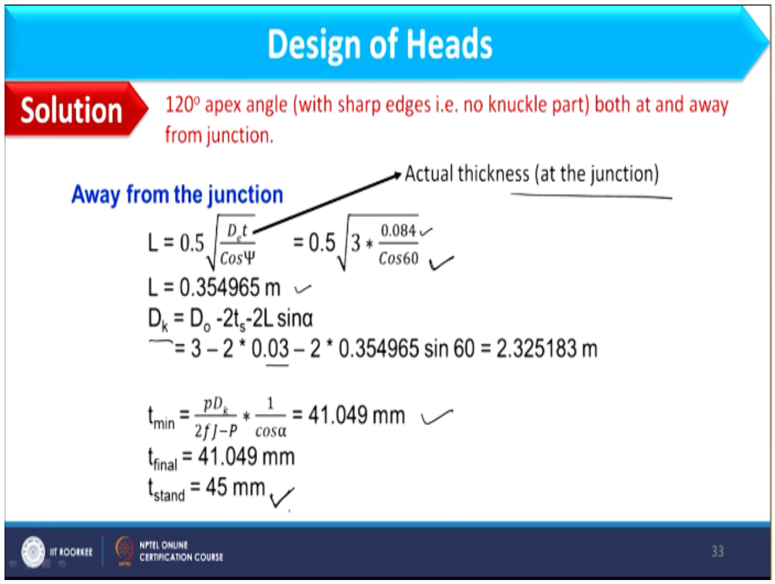

So, thickness away from the junction that can be found out L distance away, so in this case L would be 0.5 root over De t/Cos Si. So, D e is the outer diameter of shell as we have discussed that would be 3 metre and T is the actual thickness at the junction and here we have computed the thickness as 84 mm. So, in this case 0.5 root over 3 x 0.085 divided by Cos 60.

So, considering all these values we can find out L as 0.354965 meter. Putting this value in expression, we can find out value of D k and that would be 2.325183 meter and here in this D k expression, this t s will be nothing but the standard thickness of shell, which we have found as 30 mm. So that value we have kept over here. Considering value of D k, P f J and alpha, we can find out minimum thickness of conical section away from the junction and that comes out as 41.049 mm, again it is greater than 30 mm, so we will not add corrosion allowance.

So, final T in this case will be 45, so here we can consider the thickness of conical section at the junction and away from the junction. And in next part, we will discuss thickness of conical section at the junction and away from the junction when knuckle part will be there. In first part, we have not considered any knuckle part.

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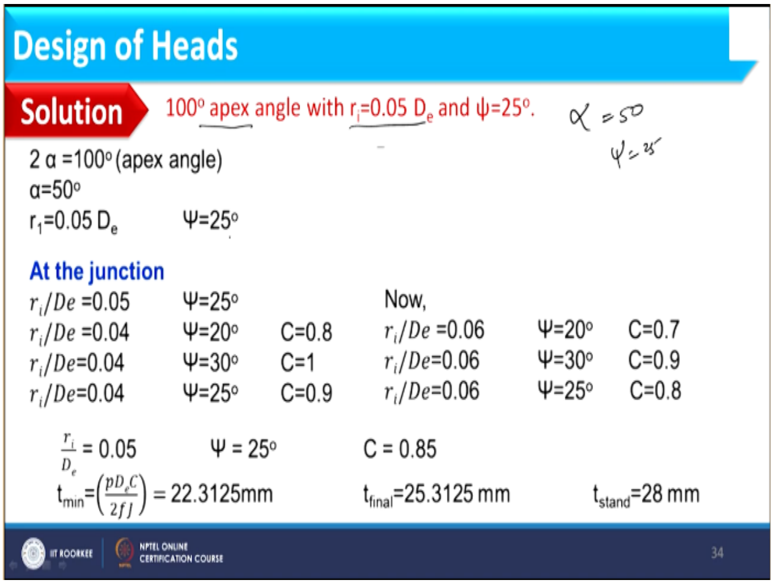

So, in this part, 100 degree apex angle is given where RI is 0.5 DE, when knuckle part will not be there, it is 0.01 * DE as we have considered in last slide and SI is equal to 25. So, in this case if you consider alpha would be 50 and SI would be 25, so these both angles are different. So, two alpha is 100, alpha is 50, then RI 0.05 DE and SI 25. So, for this combination, I have to find out the value of C.

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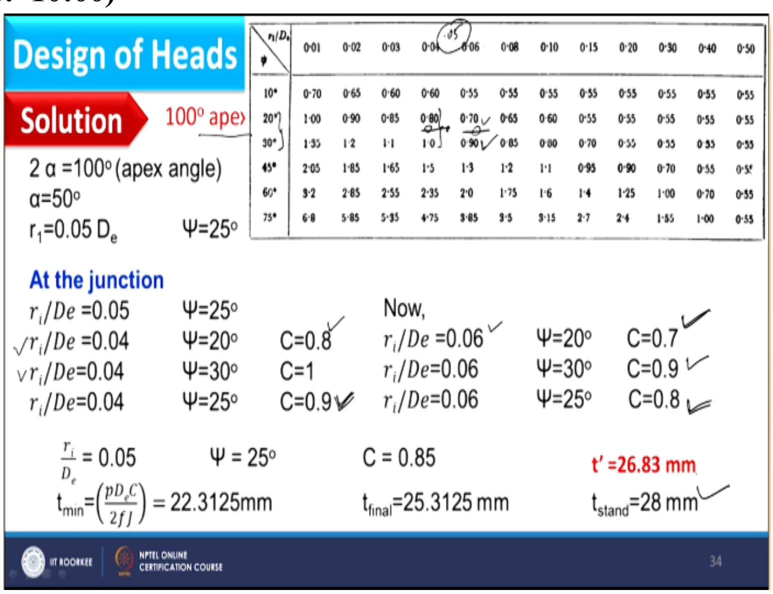

Further, if you focus on table 3.6, R i/D e is given as 0.05, which is falling between 0.04 and 0.06, okay, and Si will be given as 25, which is falling between 20 and 30. So, at the junction, we need to find out value of C for a particular combination that is R i/D e that is 0.05 and Si 25.

So, for that case, we will consider R i/D e as 0.04 and value of C at 20 degree Si is 0.8, and further, if I am having R i/D e 0.04 and SI value is 30, so C in that case would be 1. So, what I am finding is value of C for 0.04 and 0.06 at Si equal to 25. So, R i/D e 0.04 if I am considering and SI I am taking as 25, so value will lie in between these 2, so that value we can consider as 0.9. Otherwise, if SI value is 28 degree, in that case, C value can be obtained interpolation. In this case, it is directly in between or middle value of these 2, because SI is lying in between 20 and 30.

So, SI is 25, so directly we can take value of C at middle point of 0.8 and 1 and then th3e value of C becomes 0.9, okay. In the similar line, I need to find out C value for R i/D e 0.6 and at 20 degree Celsius, so that value comes at 0.7 and again for 30 degree Celsius, I need to find value of R i/D e at 0.06, so at 0.06 at 20 degree SI value of C comes as 0.7, and at 30 degree, we have value of C as 0.9. So, at 0.06 and 25 degree, value of C I can consider as 0.8. So, what I have found, value of C here and value of C here.

Now, we have to find value of C at 0.05, so that value will be middle point of these 2 values. So, considering that, R i/D e 0.05 and Si 25, we can find C value as 0.85, which is in between this and this. So, in this way we find the value of C and then putting that value of C in this expression, we can compute as T as 22.3125 mm, further because it is less than 30 mm, we had to add corrosion allowance. So, here I am getting the value after adding corrosion allowance as 25.3125 and further we have this value T – that is 26.83 mm.

How this 26.83 mm comes? Because I have to add 6% in this value, okay? If you remember the lecture 2, there we have discussed that wherever I am having forming sectio, I need to add 6% extra, okay. So, that because it is with knuckle at the junction, here I need to add 6% extra, so 1.06 x 25.3125 gives this value that is 26.83 mm and then we can take standard value than this from table B1. So, in this way we calculate thickness at the junction, now for away from the junction, we will follow the usual method, which we have observed in previous part.

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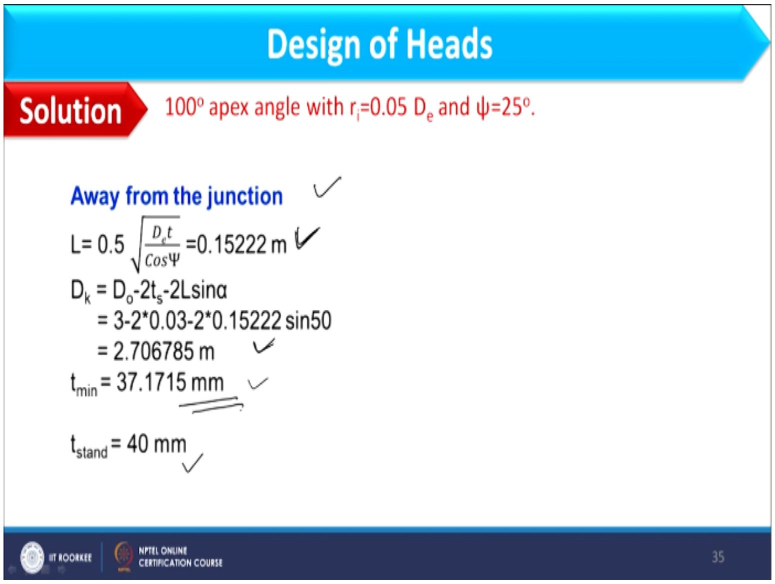

So, away from the junction, we will find out L value, we will find out D k, and putting all these values in the expression of minimum thickness and then it comes as 37.1715 mm and then we can see standard thickness from table B1 which comes out as 40 mm. Here, we have not added any corrosion allowance, not 6% extra because away from the junction all parts are straight parts, so there is no need to add 6% extra. So, in this way, we calculate thickness at the junction and away from the junction in conical head when knuckle part is there and when knuckle part is not there.

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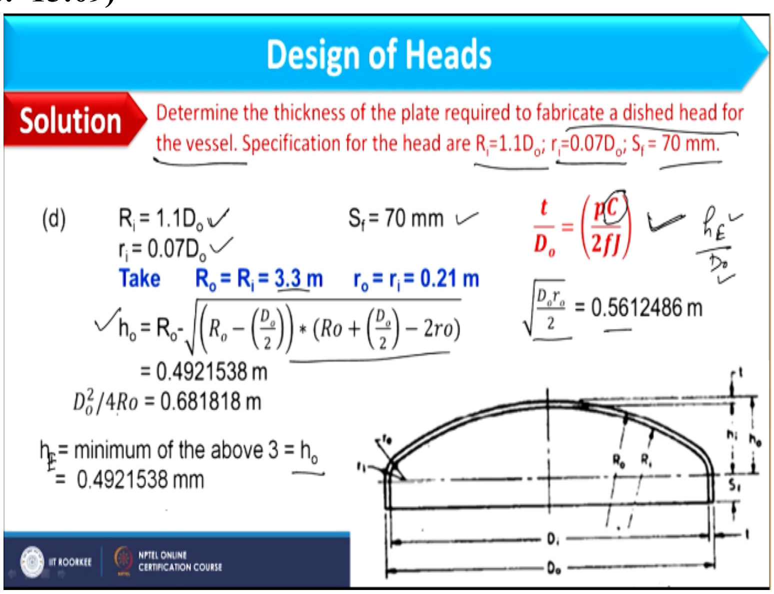

Now, next part of the problem is, to determine the thickness of plate required to fabricate dished head for the vessel and specifications are R i is given as 1.1 D o, ri 0.07 D o and S f as 70 mm.

So, considering this we have R i and r i, S f value 70 mm I am having and this is the expression to find out thickness of dished head where main concern is about factor C, okay. Now, if you remember, how we can find out factor C? For this, first of all we need to find out value of H e/D o.

D o I already now, to calculate H e, we have 3 different expressions and whatever would be the minimum value among that, that we will select as H e. So, to compute 3 values of H e, we assume that R o is equal to RI which is 3.3 metre, because RI is 1.1 D o, so that should be 3.3 metre, and similarly we will assume r o equal to ri which is equal to 2.01 metre. Now, why I am assuming RI is equal to RO because thickness of head should be added to RI to calculate RO, but at present I am not having thickness of head, and therefore for computation purpose, I am taking RI and R o both are equal and further we will resolve that.

Considering this, we can find out H o based on this expression, which comes out as 0.49215 and DO square by 4 R o square we can compute as 0.681818 and similarly root over D o, R o by 2 is 0.56125. In that way, we can find out all 3 values and H e is minimum of above three and that should be equal for H o, so here it should be HE. So, H e should be equal to minimum of above three and which we can find for H o and which comes out as 0.4921538, so in this way we can find out value of H e.

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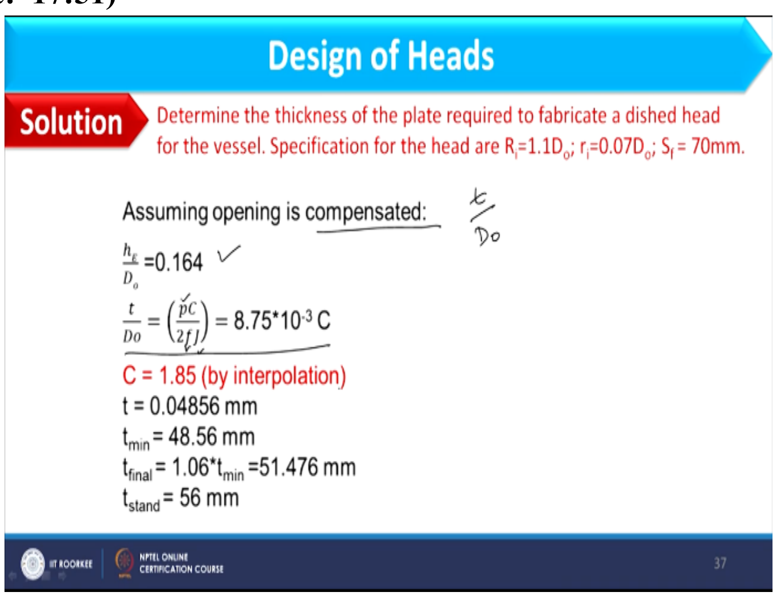

Once I am having value of H e, I can find out H e/D o as 0.164 and I am assuming opening as compensated, okay. So, in that case I can use values of t/D o, so this is the whole expression and if I am having t/D o, I can having P value, F value, J value, all these values are constant and which gives collectively 8.75 times power minus 3 x C. So, I need to select t/D o and see corresponding to H e/D o 0.164 in such a way so that this expression should be satisfied and the corresponding value of C I am getting as 1.85, that I have found through interpolation, and how I can find this, let's discuss that.

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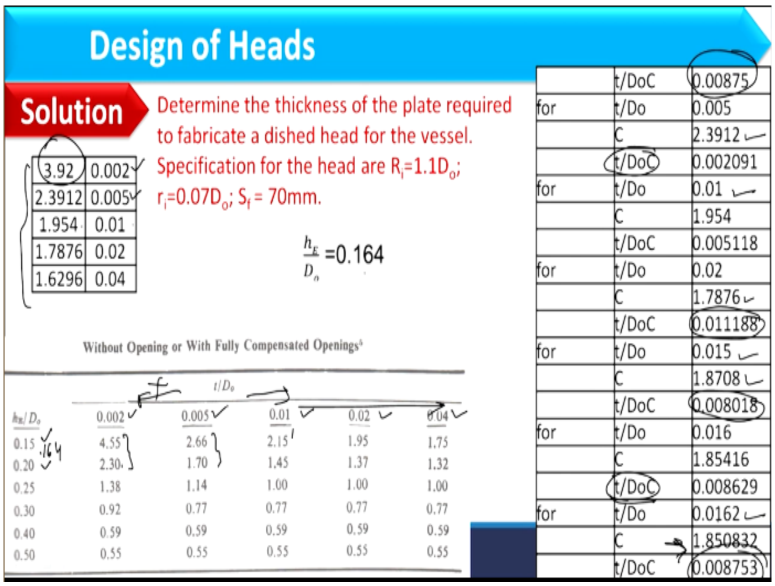

To find out that value, I will consider table 4.1A from B. C. Bhattacharya book and here HE/D o is 0.164. If you consider this table, here I am having HE/D o 0.15 and 0.2 and T/D o have different values which varies from 0.002 to 0.04, okay. So, corresponding to 0.164 value, I have to find C factor for all T/D o values, okay. So, for example, T/D o is 0.002, corresponding to 0.15 value comes as 4.55 and corresponding to 2, value comes as 2.3.

So, corresponding to 0.164, value will lie in between these 2 and that value we can find through interpolation and that comes out as 3.92 and similarly for 0.005 value, we can find C value in between these two, which comes out as 2.3912 and in the same line we can find value of C corresponding to 0.164 for 0.01, 0.02 and 0.04 and these values are summarized or mentioned over here. Now, to find out value of C for HE/D o, I will consider all these values, okay. Now, how I need to compute this, if I am having T/D o, C as 0.00875 that we have already found in the last slide and to start computation, I am starting with T/D o as 0.005, okay?

So, corresponding to T/D o 0.005, C value comes as 2.3912, which is mentioned over here. Considering this value, we can find value of this expression T/D o C as 0.00209. Now, here you need to see that what I have to find was 0.00875 and I am getting very less value than this. It means what? It means that if you consider the expression T/D o C, C is coming in denominator. So, expression T/D o C comes as 0.00209 and I want to find the value equal to 0.00875. What is the meaning of that? This expression has to increase its value from 002 to 0.00875, okay? How can I increase the value, to reduce the value of C, okay. So, further in which direction I have to move? That we can decide while comparing value of T/D o * C.

So, what we can see that, now I have deal with lesser value of C and if you consider this table, what I can observe that, as I move towards higher value of T/D o, I am getting lesser value of C. It means I have started from here, so correct direction would be this, not this, okay. So, next value of T/D o I am considering as 0.01 and corresponding to this value of C, I am getting as 1.954 and putting this value in the expression, I am getting T/D o C as 0.005, which is coming close to this, but still it is very far. So, further I need to reduce the value of C and therefore I need to increase the value of T/D o.

So, further I am considering T/D o as 0.02, corresponding value of C is 1.7876 and corresponding value of T/D o C is 0.01118, okay. So what is happening over here, that now for T/D o, whatever value I am getting for T/D o C, it is increasing than whatever I was expected to get. It means further I need to increase the value of C. So, what is the main point over here, that when I am having value of T/D o as 0.01, I am getting lesser value of T/D o C, but if I am having T/D o as 0.02, I am getting higher value of T/D o C.

So, exact value of C will lie between T/D o 0.01 to 0.02. So, next value I am considering as 0.015 and C value I am getting 1.8708 through interpolation and then T/D o C I am getting as 0.008, and further it has to increase, so T/D o I am considering as 0.016, corresponding value of C 1.85416 through interpolation and further value of T/D o C is coming as 0.0086, which is increased, so further I need to take another value of T/D o, which is I am taking as 0.0162 and finally I can get T/D o C as 0.00875 at C value 1.85.

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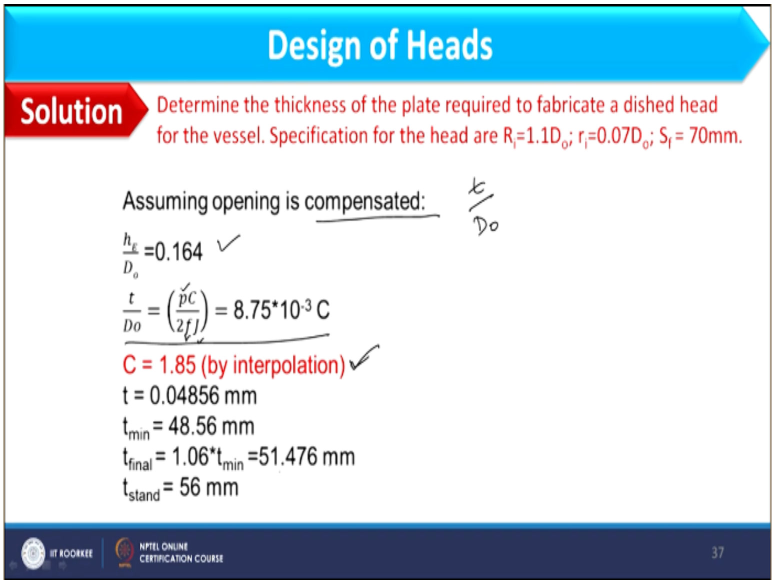

So, this 1.85 I have taken over here and then corresponding value of T I can find as 0.04856, which is 48.56 mm. I have to add 6% extra to this and the value comes as 51.476 and next standard value coming as 56 mm. So, in this way, I can find thickness of dished heads.

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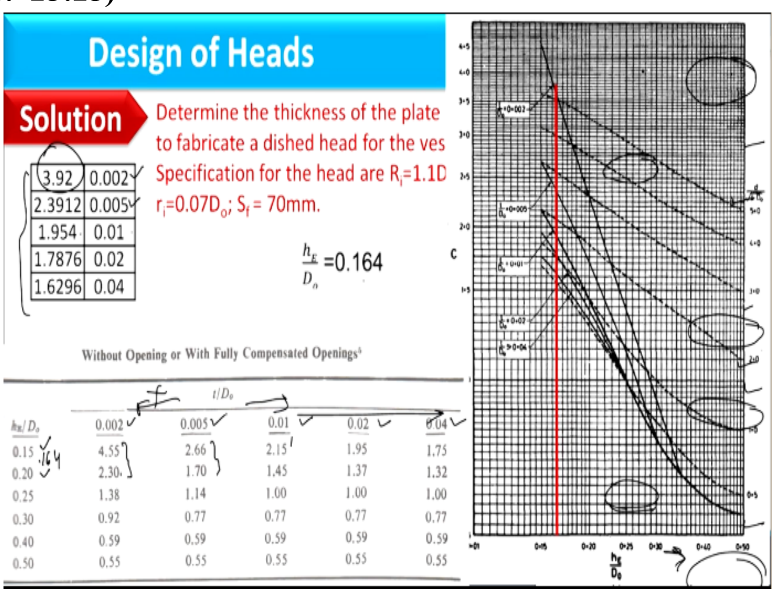

Further, you can find out value of C from this graph which is figure 3.7 in code. Here, HE/D o 0.164, so you can draw a line of 0.164 and then you need to choose different value of T/D o and C in such a way so that it satisfies the expression of T/D o C as we have explained through table 4.1.

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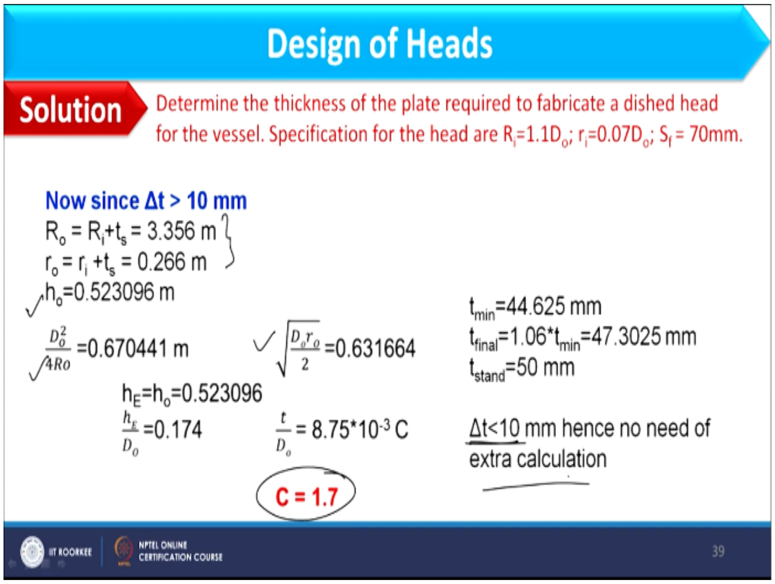

Now, here, further you need to consider that when we have started the computation of dished heads, we have assumed that RO should be equal to RI, and while assuming this, I have considered T should be 0. Then only it is possible. So, when T equal to 0, RI should be R o, okay, and next value of T I am getting as 56. So, if difference of these two consecutive values will be greater than 10 mm, I have to repeat the whole calculation.

So, in this case, repetition is required, so for that purpose R o is considered as RI plus TS that is 56 will be added over here and the value comes as 3.356 and similarly r o we can find out. So, for revised value of R o and r o, HO value, this expression value and this expression values are found out and then HE/D o we can consider as 0.174. Now, HE/D o corresponding to 0.174, I have to find out value of C, which comes out as 1.7 based on the method which I have explained in last slide.

So corresponding to C 1.7, you can find out T minimum 44.625, 6% will be added to this and then final value would be 50. So, previous thickness was 56, now thickness is 50, so that difference is less than 10 mm, hence no extra calculation will be required, so final thickness of dished head can be considered as 50 mm.

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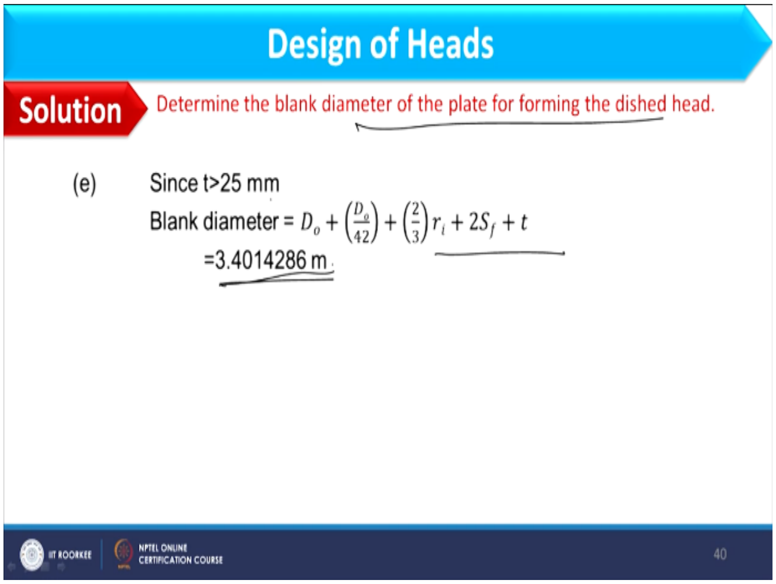

Now, here I am having the final part of this example where blank diameter needs to be determined. Since thickness is greater than 25 mm, we will use this expression as blank diameter we can find as 3.4014 m.

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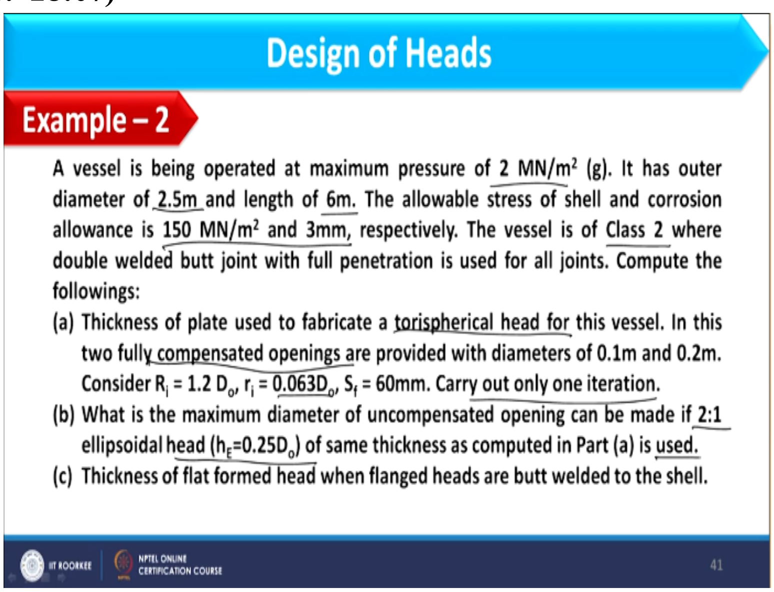

Here, I am having example 2. In this example, a vessel is being operated at a maximum pressure of 2 mega Newton per metre square, outer diameter 2.5 metre and length is 6 metre we have. Allowable stress and corrosion allowance are given like this and it is made of class 2 where double welded butt joint with full penetration is used for all joints. What we need to find is, thickness of plate used to fabricate the torispherical head for this vessel and here we have fully compensated openings.

So, compensated openings are provided and we need to consider RI as 1.2 D o and ri as this and I have to carry out only 1 iteration, okay, that is part 1. In part B, what is the maximum diameter of uncompensated opening can be made if 2:1 ellipsoidal head of same thickness as computed in part A is used and finally we need to find out flat formed thickness where this connection is made.

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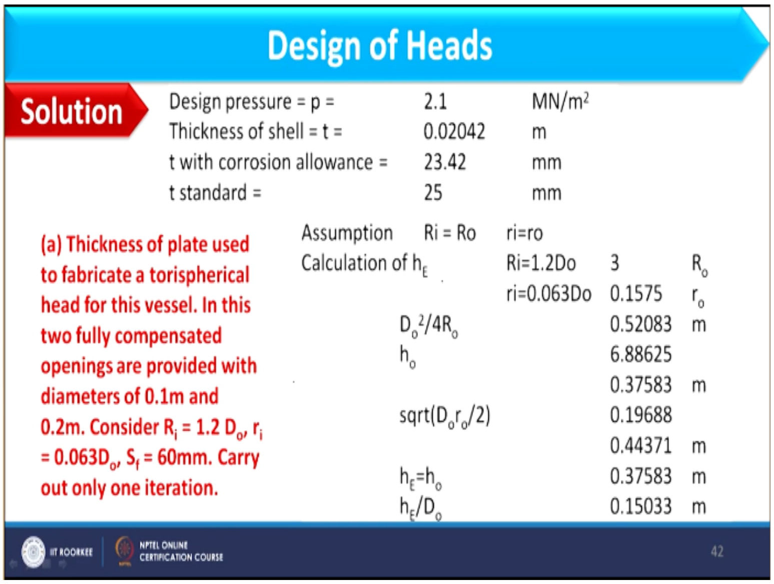

So, part 1 is calculation of torispherical heads, so it is computed as based on same method as we have explained in the last example. So, for that purpose, we need to calculate RI and ri and then HE we can find out using the method explained in previous example, which comes out as 0.15.

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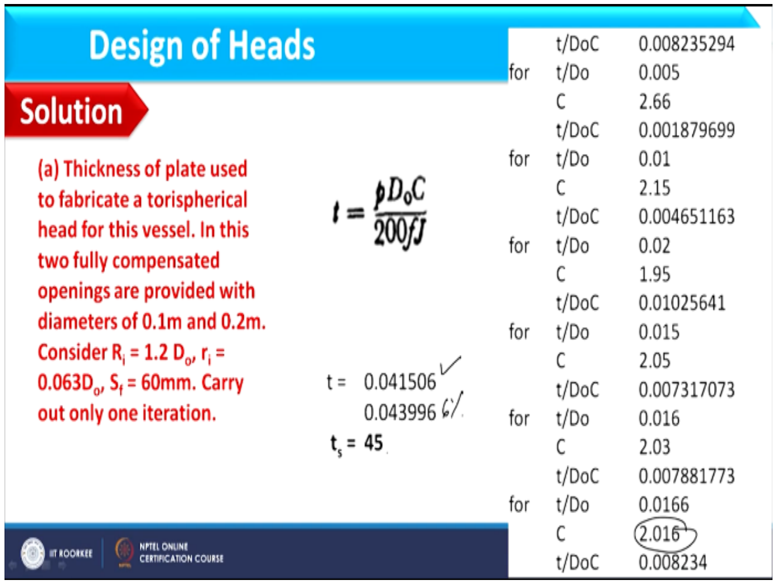

Following the table 4.1A, we can calculate value of C corresponding to HE/D o as 0.15 and which comes as 2.016 and corresponding to this we can calculate thickness as 0.4156, 6% extra I have taken over here and then we can take that standard from table B1. So, in this way we calculate the thickness of torispherical heads.

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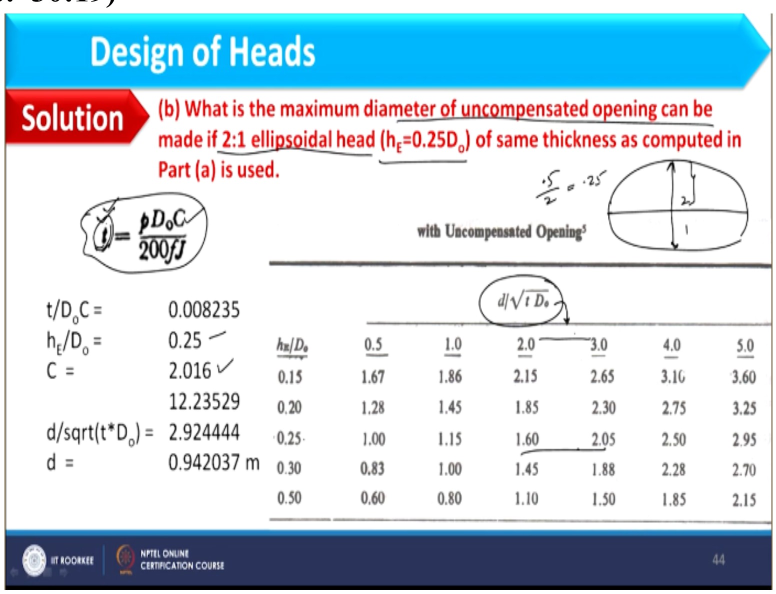

Now, main point over here is part B where I have to find out the maximum diameter of the uncompensated opening for 2:1 ellipsoidal head where HE/D o is 0.25, okay, of same thickness as computed in part A. So, this is the repression for ellipsoidal head, the same we have used for torispherical head and thickness we have found out as 45 standard, so here corresponding minimum thickness I have to put, so once this T will be same, it means C will also be same.

So, C I am taking 2.016 and He/D o comes as 0.25. How it comes as 0.25? because if you see torispherical head, okay, this is 2 and this is 1 ratio. So, if am considering this particular section, that should be 0.5 divided by 2, so it is 0.25, so corresponding to 0.25 HE/D o and C value, I have to find value of this expression.

This is table 4.1E. Here it is 0.25 and value is lying between 1.6 and 2.015. If you see value 2.016 is lying between 2. So while interpolating value of C, we can find out value of this expression between this, which comes out as 2.94244 and here D would be uncompensated opening diameter, which comes out as 0.94. So, in this way we calculate the maximum diameter of uncompensated opening.

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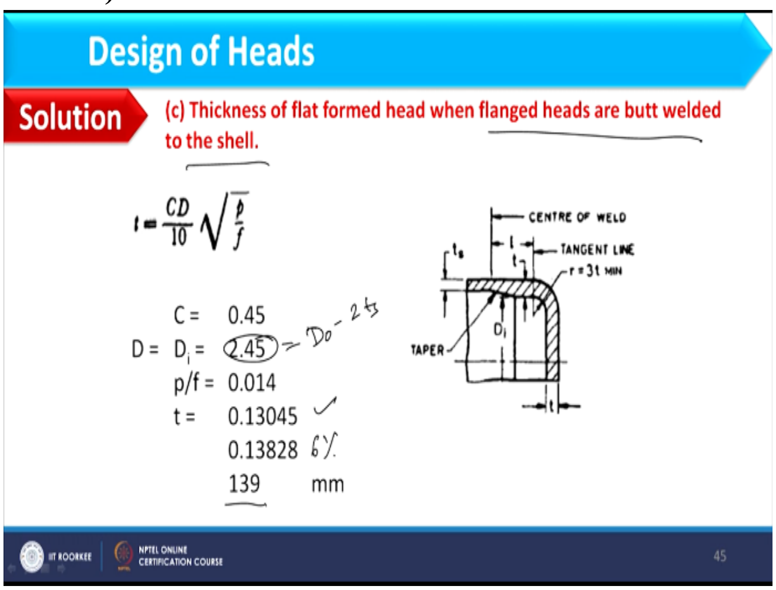

Part C is very simple that is flat formed head where C for this type of connection is 0.45, D is equal to DI, how I can find this? it is D o that is 2.5 minus 2 TS. TS we have found as 25 mm. Considering this value, we can find out T as 130.45 mm and then I have to add 6% extra in this because it is formed section, so final value comes as 139 mm. So, that is for example 2.

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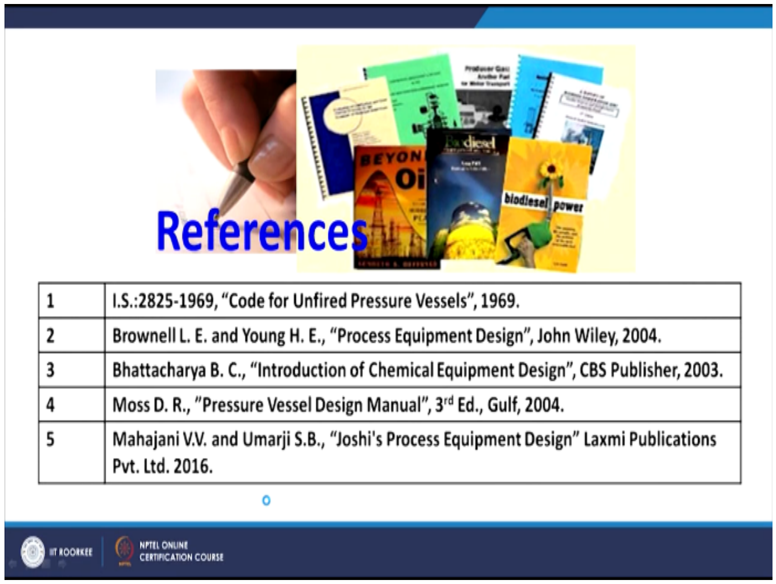

And here I am having some of the books which you can refer to study this topic.

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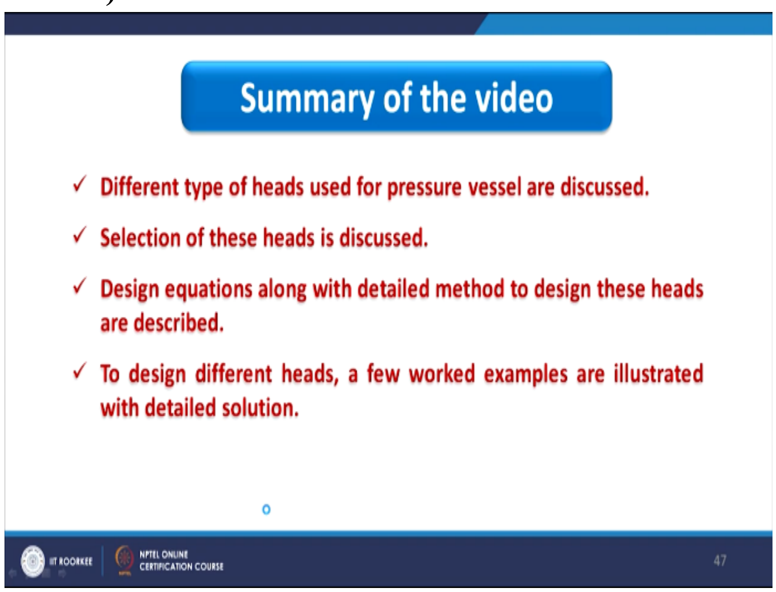

And now we have the summary of video, and here I am combing summary of lecture 1, lecture 2 and lecture 3 as different types of heads used for pressure vessel are discussed. Selection of these heads is discussed and design equation along with detailed method to design these heads are described and to design different heads, a few worked examples are illustrated with detail solution. And that is all for now, thank you.