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

Lecture 07
Design of Heads

Welcome to the second lecture of week 2 and here we are discussing design of heads. This topic we have started from the previous lecture where we have discussed different types of heads and in this particular lecture, we will discuss procedure to design these heads. As flat head is the simplest one, we will start design from that and then we will proceed towards conical head and then for dished heads okay. So, let us start with design of flat heads.

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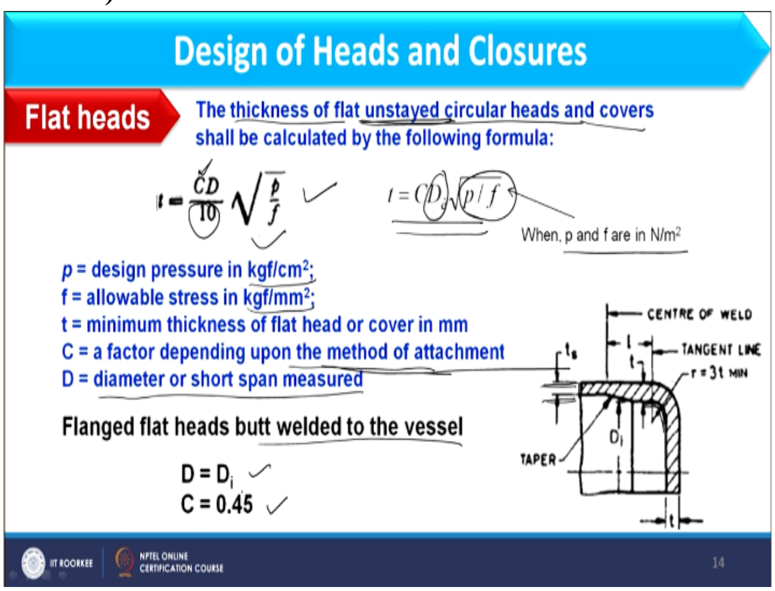

Now, in this case, we will calculate thickness of flat unstayed circular heads and curves, okay? So, you see here we have one term that is unstayed circular heads, what is the meaning of unstayed circular head? To illustrate this or to make you understand, I am taking the example of this glass, now if you see this glass, this is open part of this glass where I need to cover, so what is the meaning of unstayed. To understand this, let us first discuss what is stayed.

So, stayed means, when this is the opening which I need to cover, so what I do, I put some of the metal strip and those strips will be welded at its edges. For example, I am taking one strip of this much diameter, I hope you are getting this, one section will be welded over here, another would be welded over here. Similarly another strip of same diameter and another strip diameter and this way, I will put different strips and over this the head will be stayed. So, it basically gives more strong positioning of head, but here we are discussing unstayed where this type of structure or this type of support is not available to the head.

Even that type of structure can be used in the shell also to keep its geometry regular. For example, if I am having this glass and this is the whole length of the shell, so that type of the structure, it means when we weld the strip at two edges, when we keep the weld of those strips equal to the diameter of shell, so it means when we weld it, it will keep its shape circular only, okay? I hope you are getting it.

So that type of structure is usually used in pressure vessel when it is having larger diameter, but it does not interrupt the process because in between it has open space for fluid to move, okay. So, here, as far as design is concerned for flat head, we are considering design of unstayed flat heads. So, to calculate thickness of flat head, we can use the following expression, as you see, this is the expression which we will use. Here T is the minimum thickness of flat head and that is equal to CD/10, root over P/f where P is the design pressure in kg force per centimeter square and F is the allowable stress in kg force per mm square and due to this here we have the term 10.

If I am considering pressure and allowable stress in same unit, that is Newton per metre square, then this 10 will not appear. In this formula, T which is the minimal thickness is found mm and C is the factor that depends on the method of attachment to the shell. It means how this head is attached to the shell, accordingly value of C varies okay. And further D is the diameter or short span measured. It means D is not always the diameter, you can consider this as an effective diameter, which will depend on how head is attached to the shell.

Here I am having this expression where T = CD root over P/F where both pressure and allowable stress are Newton per meter square, so in books you can find this expression. This expression is available in IS: 2825-1969 code. So, here in book instead of D it is D e is mentioned, where it is called as effective diameter, C is the factor. Depending upon different attachments, now we will see how to find out the value of factor C as well as D that is the effective diameter. So, let us start that with flange flat head butt welded to the vessel. For this connection, we will see the value of factor C as well as diameter.

Now, if this is the image where you consider this particular section is resembling to the shell and over the shell, head is attached. So, if I consider placement of this, that placement is horizontal, okay. So this head is attached to the horizontal shell, okay. TS is the standard thickness of shell and this T is the thickness of flat head which we need to find and here you see, in this particular section, this is basically the curved part of formed section. This is not flat section.

This is flat formed section, okay? In that case, D will be DI. D iis what? D ibasically inner diameter of head, okay, and C is the factor which has the value 0.45. so, when we have flange flat head butt welded to the vessel, we can consider C and D in this way and these values we can put in this expression to calculate the value of thickness.

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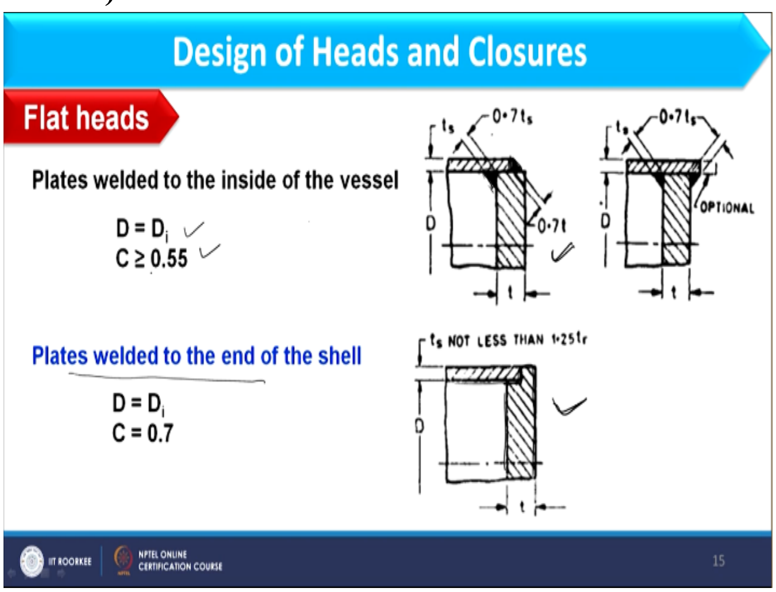

Now, further, we have another attachment or another connection, and that is plates welded to the inside of the vessel, so how it looks like? Here, I am having this shell and inside this shell head is attached. If you consider the previous diagram, there head is attached to the shell through butt welding. I hope you remember different types of welding which we have discussed in lecture 4 of week 1 in weld joint efficiency factor, okay.

So, here we have this flat head which is attached inside to the shell, here also and in this diagram also. Now what we need to focus on that if you consider this section, okay, why this section is so black, okay. This section is so black because when we are welding it, the material through which it is welded, like iron, that is filled inside the corner and when that filling is higher, we call that as fillet. So, this black spot in this diagram as well as in this diagram, these are nothing but fillet us. It has a particular thickness as 0.7 x TS.

If it is more thick, it will be called fillet, otherwise that will be simply looking like a joint, okay. So, when this type of connection I am having, D should be equal to D iand C value should be greater than 0.55. Now, if you compare this image with the previous one, previous figure has formed section. So, there C value was 0.45, but in this particular case, formed section is not there, flat head is directly attached, so C will have greater value than 0.45 and if you remember the expression for thickness, thickness is directly proportional to C.

So, when C value will be small, T will also be small, so in formed head we can have less thickness in comparison to flat head as we are discussing now. Next, we have is the plate welded to end of the shell. For example, if it attached like this, like this is the shell and here we have this attachment of head, so if head is welded at the end of shell, in that case D would be D iand C would be 0.7, okay. Now, if you compare this image as well as this image, in this image, I am not having any fillet.

However, in this case fillet is made and that fillet will give slight curvature to this sharp corner and here stress distribution will be more uniform in comparison to this figure and therefore C value would be 0.7 over here, but here minimum C value would be 0.55. So, if it can work with 0.55, keep that value, equal to 0.55 only.

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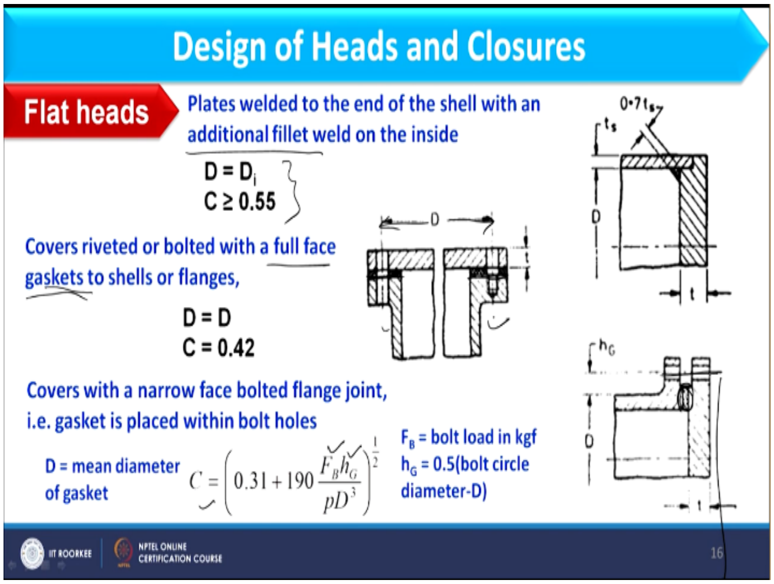

Now next connection I am having is plate welded to the end of the shell with additional fillet weld on inside, okay. So, this is noting but the previous diagram only. At the end of shell, head is attached with fillet. So, you can see the value of C and D would be D in this case. Now, next I am having is curves R iveted or bolted with full face gasket to shells or flanges.

So, this connection is looking like this, where if I am having this flange section, okay. Flange is basically used to joint two parts having same diameter. In detail, the flange design will be discussed in week 3, okay, but for the time being you can understand that it will be used to connect pipe of same diameter. Here, in this diagram you see, this is one section of flange and over this we have flat head, so this flat head is connected to the flange, now here you see full face gasket.

Full face gasket means, this whole surface of the flange is covered with gasket, so if I am having circular pipe, this particular section is placed around the pipe and this section will also be circular. So, circular gasket of this much diameter will be kept over here and therefore it is called full face. Now, if I need to attach this flange with flat head, here these 2 assemblies connected through bolt, so one bolt is available here, another is available here and around the periphery different bolts are available and it gives the diameter that we are showing as D in this diagram and which is called as bolt circle diameter.

Now, if this is the case, D would be D as it is shown here and C would be 0.42. Further, if we have covers with narrow face bolted flange joint, that is gasket is placed within the bolt circle, now how it will look like, if you see, here it is horizontally placed, here we have demonstrated vertically placed head with the flange. Here head is placed with the flange in horizontal manner. Now, if you see this particular section, this is basically the gasket which is placed within the bolt circle.

Bolt circle, one is this and second edge will be up to here, so within that bolt circle, this gasket is placed. So, here we have different dimensions like D h G that you can observe from this figure. So, D is basically mean diameter of gasket, C you can observe from this which is equal to 0.31 plus 190 F B h G/p D cube power 1/2, so here F B is basically bolt load in kg force, h G is 0.5, bolt circle diameter minus D and half of that will be equal to h G. So, in this way, you can find values of C as well as D for different connections and whatever connection is present in your case, you can compute the thickness of flat head for that case, okay.

So, in this way, we design the flat heads, okay.

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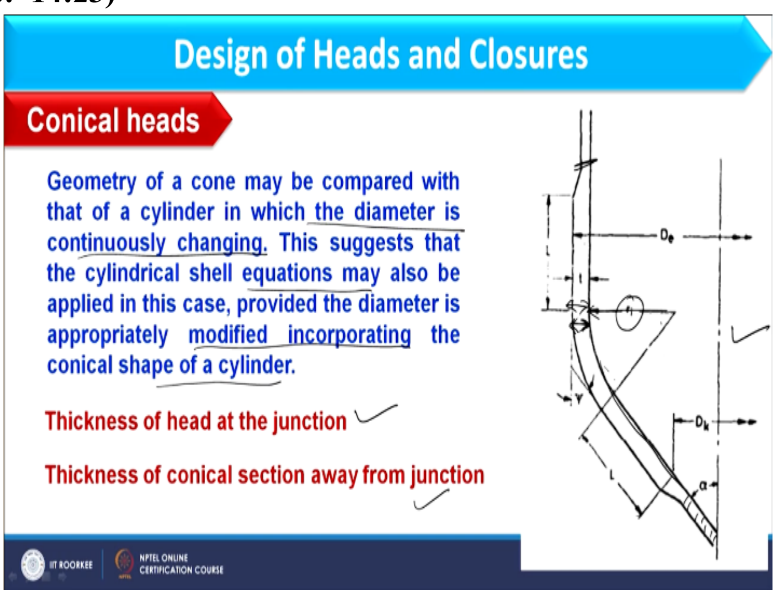

Next head I am having is the conical head. Now geometry of the cone may be compared with that of cylinder in which the diameter is continuously changing, okay? So, conical shape if I am considering, it is like this, so diameter is continuously changing from top to bottom. This suggest that cylindrical shell equation can also be used in this case provided the diameter is appropriately modified incorporating the conical shape of the cylinder.

So, as this diameter is continuously changing, we usually design conical head in two ways, first is we compute thickness of head at the junction, now what is junction. Junction is basically the part where it is attached to the shell. For example, if I am having this conical shape, you can see this image where the conical shape is there, you see, this is the conical shape which is attached to the shell. So, if the curved part is not there, it will be directly attached to the shell.

So, at the junction means, at this part where it is attached to the shell. For example, if I am having this curved section, then this curved section will be part of conical head and somewhere here it will be attached to the shell. So, in that case, at the junction means, wherever this curvature occurs, and if that curvature will not be there, it is directly attached to the shell, so at this point we compute the thickness of conical head at the junction, so at the junction means this part, whether it is attached to the shell over here or not, okay.

Thickness of this part we will compute as that at the junction. So, one thickness is at the junction, second thickness is away from the junction as diameter is continuously changing, okay. So, we will compute thickness away from the junction, away from the junction means, to this side, okay, if I need to calculate the thickness for this section. So that will be calculated away from the junction, away from the junction means L distance away from the junction.

So, what is that L?, how it will be computed? That all we will discuss. Now, if you see this diagram, here a few more points I need to focus. If you consider this R i, what is R i that is the radius of knuckle part. If knuckle part is there, because if you remember we have discussed in conical head, that if apex angle exceeds 60 degrees, it means the conical section should have curved or knuckle part, so that knuckle part must have the radius R i okay.

So that you can see in this diagram. D e if you see, D is basically outer diameter of head and here we have D k, D k is basically the diameter where I am computing the thickness and alpha is half of apex angle. Usually this section is defined as apex angle, so alpha is half of apex angle and in this case, angle size is also given. So, for this case, Si is equal to alpha. So, why these 2 terminologies are used for same purpose because there are some cases where Si is not equal to alpha. We will discuss that case also. So, to distinguish the two cases, alpha and SI are two different angles which are used in conical heads.

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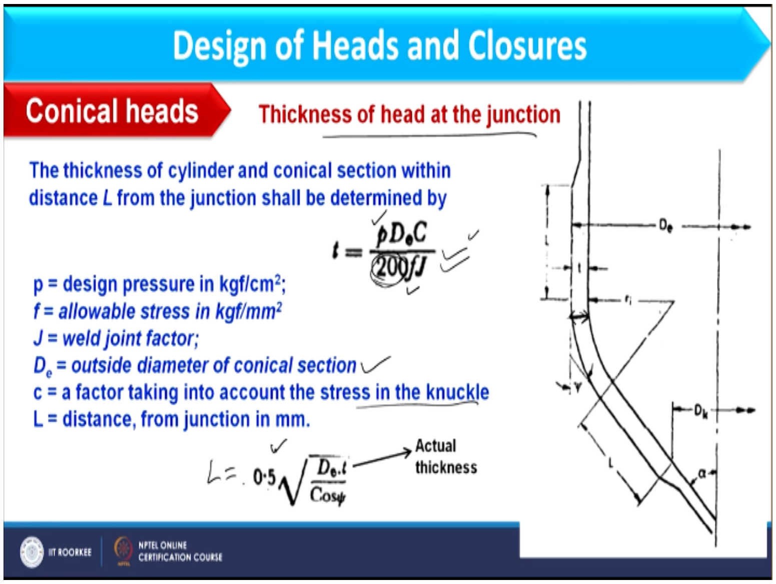

So, as far as design is concerned, first we will start design from the junction, so we will compute thickness of head at the junction. At the junction, you have understood, it means we are computing thickness at this section. So thickness of cylindrical and conical section within length L from the junction shall be determined as T = P D o C/200 f J. This expression we will use and I guess you understand why this 200, because f and P are in different units, P should be in kg force per centimeter square and F should be in kg force per mm square.

So, this is expression is available in quote, where J is the joint efficiency factor, D is the outer diameter of conical section as you can find from this image, and C is the factor taking into account stress in the knuckle. So, according to these knuckles, factor C varies. That we will discuss how it varies and L is the distance from the junction which can be found as 0.5 root over D e * t/Cos Si. So, this expression is used to calculate L where this T is basically the actual thickness of the head at the junction.

And then considering this thickness at the junction, we will compute distance L to calculate thickness L distance away from the junction. I guess you are understanding this.

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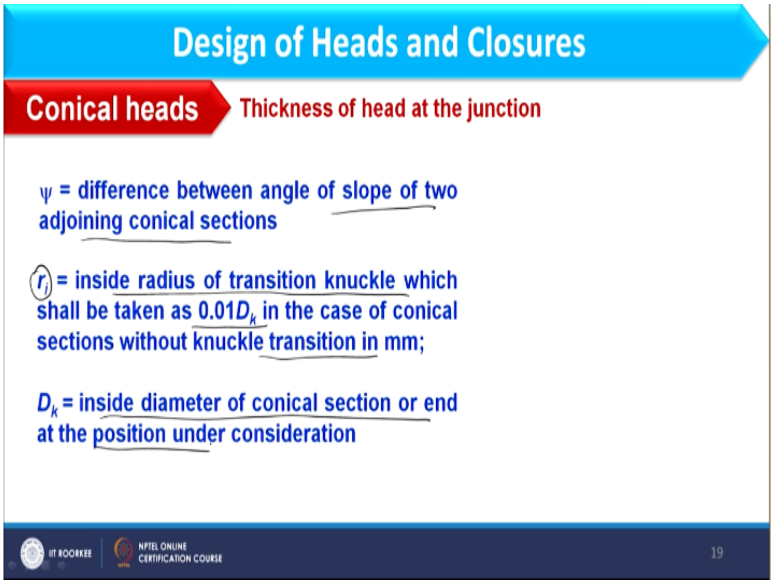

So, here you see, Si I am having, Si is the difference between angle of slope of two adjoining conical sections and I have already discussed why the Si is there. Si and alpha both angles are there, but in some cases these two angles are different. Therefore, we have used different notation for these two. How it looks different, that we will discuss.

Next parameter I am having is R i. R i is basically inside radius of transition knuckle which shall be taken as 0.01 D k. In case of conical section without knuckle transition in mm. So, if you see this R i, R i basically denotes the knuckle transition part and if this is knuckle transition part is not there, then R i will be equal to 0.01 D k, okay. So that value I need to consider while designing.

What is D k. It is the inside diameter of conical section or end at the position under consideration. So, wherever I am finding the thickness, diameter at that particular section will be denoted as D k. For example, if I am finding at the junction, D k will be equal to D i, inner diameter at that particular section.

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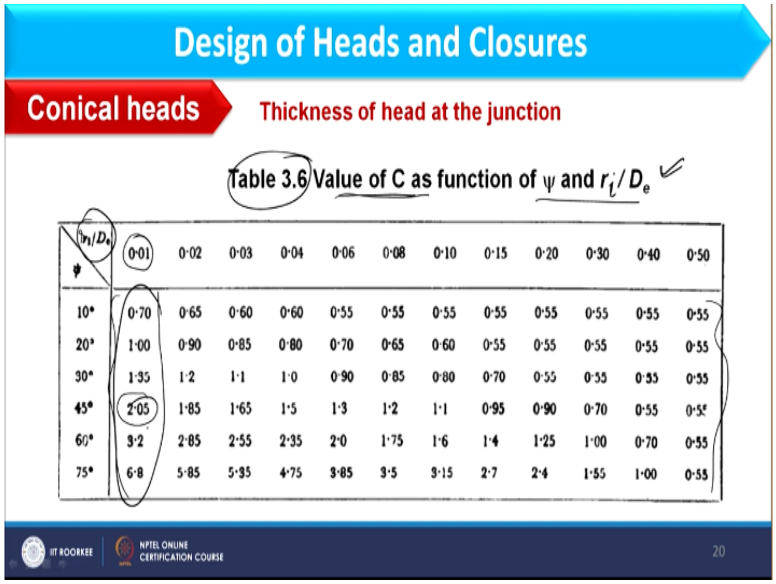

ψ \ r_i/D_e	0·01	0·02	0·03	0·04	0·06	0·08	0·10	0·15	0·20	0·30	0·40	0·50
10°	0·70	0·65	0·60	0·60	0·55	0·55	0·55	0·55	0·55	0·55	0·55	0·55
20°	1·00	0·90	0·85	0·80	0·70	0·65	0·60	0·55	0·55	0·55	0·55	0·55
30°	1·35	1·2	1·1	1·0	0·90	0·85	0·80	0·70	0·55	0·55	0·55	0·55
45°	2·05	1·85	1·65	1·5	1·3	1·2	1·1	0·95	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, in this slide, we will see how to find out value of C as a function of Si and this is not R i, this is R i, R i/D e, okay. This is stable in code IS: 2825, you can find this table as 3.6. So, now if you see this stable, here in the first column I am having different angles of Si and here we have R i/D e, here we have different values of R i/D e and all these values you see are nothing but values of C.

So, if I am not having different values of SI as well as alpha, I can consider Si equal to alpha. If it is different, that difference will be mentioned okay?. Now, we have two conditions that when knuckle part is there and when knuckle part is not there, so when knuckle part is not there, it means R i would be equal to 0.01 D k and D k, if I am calculating thickness at the junction, D k should be D i, okay. If you see this table, here we have R i/D e and here D e, if you remember, that is nothing but the outer diameter and for calculation purpose we can assume D ishould be equal to D o. It means D k should be equal to D o, it means R i/D k equal to 0.01.

So, what is the conclusion? If I am not using the knuckle part, it means C value you have to find through this column only corresponding to different SI value. For example, SI is given as 45 and in this problem it is mentioned that knuckle part is not given, so you can this table as corresponding to 45 and R i/D e 0.01 value available as 2.05, so that 2.05 you can consider value of C. However, if I am having knuckle part, R i/D k will always be greater than 0.01.

So considering the value of R i/D k, you can understand whether knuckle part is there or knuckle part is not there and this point will be more clear when we will solve a few examples based on this. Now we have thickness of conical part away from the junction, as we have discussed away from the junction means L distance away from the junction.

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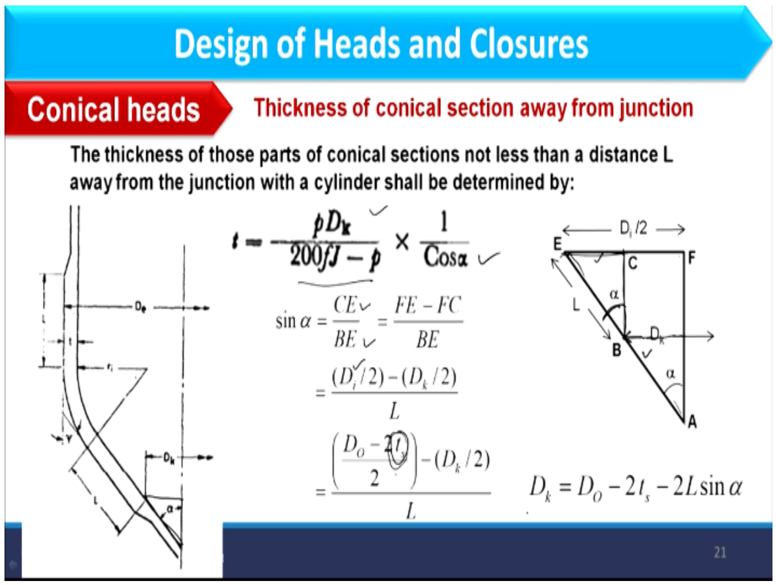

So to calculate thickness of that part, we have this expression as T = PD k/200 f J – P 1/Cos alpha. Here, P is the design pressure, why 200 is there, I hope you have idea this till now, because P and f are different units, J is the joint efficiency factor.

So if you see this expression, what is D k, D k you can see from this diagram that where I am finding out the thickness, inner diameter of that part will be called as D k, okay. So, if you consider this particular section, this section we can use to find out value of D k, okay, as it is shown in this diagram more clearly. So, for example, this is D k and here we have A, B, C and E and F, D I am not taking over here as D k and D I are already included alphabet D, so here we need to find out expression of D k, okay.

Now if you see, this is basically D k and to compute D k, I have to focus on this part, okay. Now, further, corresponding to this, I can draw a line over here and I can focus on this particular section. So, if you consider this section, as well as this section, we can apply equal angle theory here. So, here, sin alpha if I need to calculate, sin alpha would be C E/B E and BE is nothing but length L. So, C E how you can compute, F E-F C/B E, using this geometry you can find out, I think that you can make, it is not very much complicated.

FE is basically D i/2 and FC is D k/2 that you can see from the geometry and this B is nothing but the L. Then further I can replace D iwith this where the TS is the standard thickness of shell because it is available at this particular section where conical section has equal inside diameter to shell. On further resolving this expression, you can find out the final expression for D K, so D K you can find out this way. So, here we have conical section and we have seen design of thickness at the junction and away from the junction.

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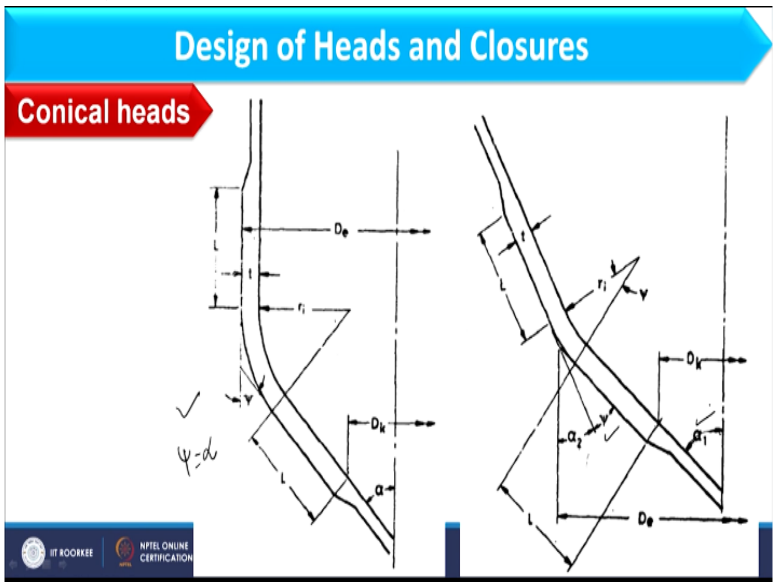

In this slide, you can focus on this particular image, here we have angle alpha and Si, so both Si is equal to alpha in this particular figure. However, if I am focusing on this, here we have this alpha 1, here alpha 2 and Si, so here basically Si as well as this alpha, these angles are different. So, if conical section is placed in this way, we can have different value of SI and alpha. So, this Si and alpha may be same or may not be same, so that depends on how conical section is made okay. So, that was about the conical section.

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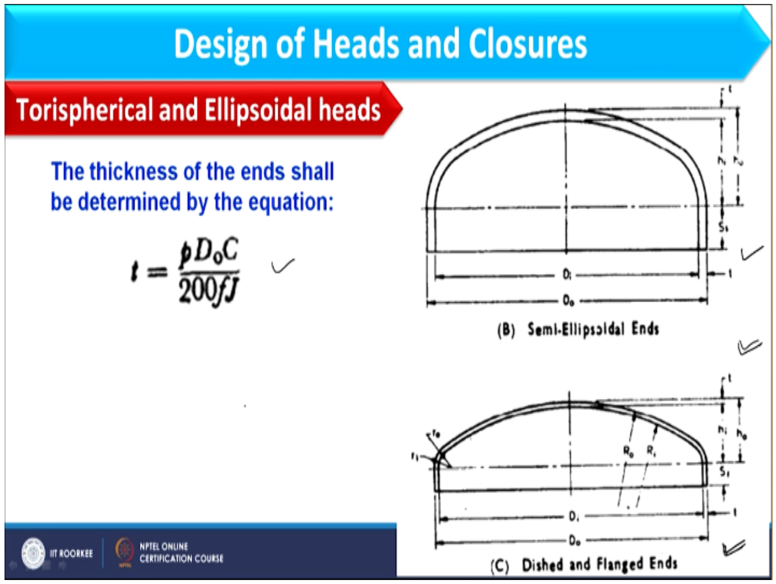

Now we will discuss design of torispherical heads as well as ellipsoidal heads. So, these heads are basically coming under dished or formed heads. So, you see this image, where this figure is of torispherical head and this figure is of ellipsoidal heads, so both heads are basically dished heads, however, in ellipsoidal heads, we have more curved part in comparison to torispherical heads and these two heads are designed using same expression as these are dished heads.

Thickness of dished heads can be determined by following expression which is T = PD o C/200 FJ, here again I am having 200, I guess you understand, I do not need to repeat that again and again. So, here you see, the main point to be considered is how to find C. C is basically the shape factor, and how we can find the factor C, that is the main concern over here. Other parameters how you need to take, that you are already aware. So let us discuss how to find value of C.

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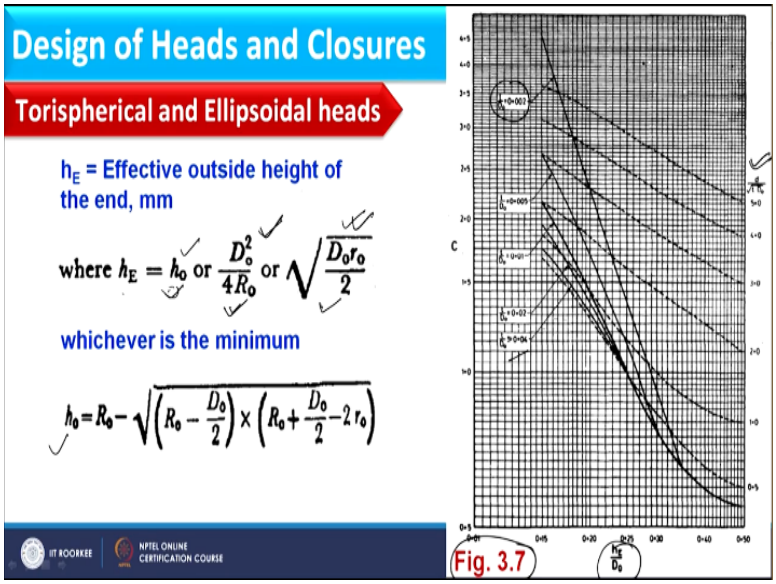

Now, if you consider this particular slide, here I am having this image, if you see this, which is figure 3.7 in IS: 2825, so that figure you can refer, so Y axis of this figure is having factor C whereas X-axis has value of H e/D o. So, once I will calculate H e/D o, I can find value of C and if you observe this graph, here I am having solid lines for T/D o when it is varying from 0.002 to 0.004 and here also I am having broken lines and these lines again vary from 0.5 to 5, okay. On this axis, we have D/root over T x D o. So this image I have to use to compute the value of C.

So, first of all, to use this, we have to find H e/D o, D o is the outer diameter of head or shell, so that we already know, how to find out the value of H e, that I have to speak on. So, H e is basically effective outside height of the end and that can be determined as, here we have H o, D o square/4 R o and root over D o R o/2, so to compute H e, we need to find H o, we need to find this expression and whichever is minimum, that I need to take as H e value, and whichever is minimum among these there, that I need to take as value of H e.

Now, why we are taking minimum among these three as H e, because when I am having minimum H e, H e is basically, if you see the diagram, if you focus on this particular slide, H e is basically this height. H e is basically this H e o that is effective height. So, if I am having more value of H e, it means it has more curved part and it will include higher manufacturing cost. Therefore, if I am having three different values to find out H e, I will select the minimum one.

Now, among these three values, H o you can find out using this expression where R o, D o/2 and small ro, all these values you know about the head, and similarly this value I will find, and I will choose the minimum value among these three as H e. So, we have seen that how H e will be computed.

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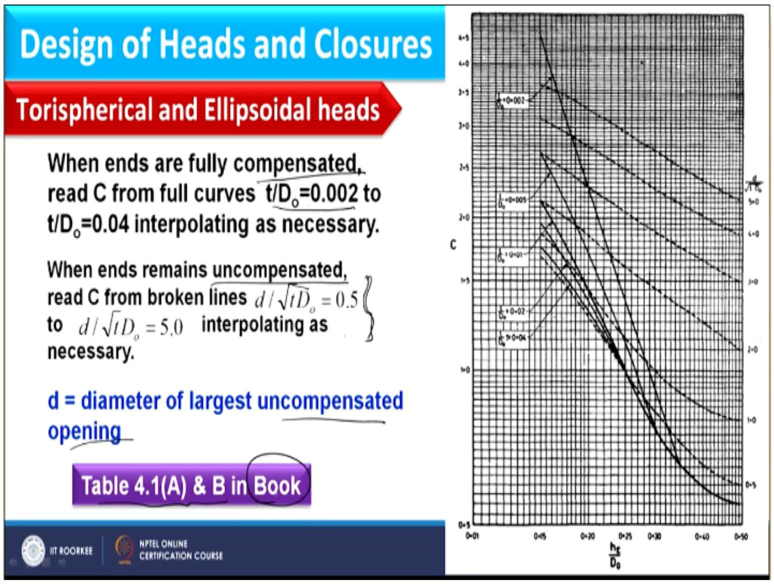

And once H e will be known, in this figure, you can make a line, okay. Let us say H e is 0.2, so corresponding to 0.2 you can make a line and how you need to find out value of C is, when ends are fully compensated, read C from full curves that is T/D o 0.002 to 0.00 that is T/D oequal to 0.002 to T/D o 0.04 and we can make interpolation also.

So, how you need to compute this, if you see the expression, T is equal to PD o C/200 f J. Now, here you need to find C, so how I will further consider is T/D o because if it is fully compensated, we need to see value T/Do, so T/D o I will extract and if you consider this expression, okay, this whole expression will be a constant. Let us say that value is X into C. So, corresponding to H e/D o 0.2, you need to choose value of T/D o and corresponding value of C in such a way so that this expression should be satisfied. So, I hope you are getting how to find out value of C and it will be more clear when we solve a few examples based on that.

There I will elaborate this in more detail. Now, when end remains uncompensated, read C from broken line that is D/root over T * D o = 0.5 to 5, it is varying as you can see from these broken lines. So what is this compensation and uncompensation, that we will cover in lecture 4 and 5 of this week. So, basically when we make any opening, that opening may be compensated or may not be compensated, so based on that, we consider design of heads.

So, till now, you please bear compensation and uncompensation as it is, I will elaborate that when time comes, okay. So, if you consider this statement, here small d is diameter of largest uncompensated opening. For example, in head I am preparing two, three openings. One is having, let us say diameter 0.05 metre and another is having let us say 0.7 metre, so d would be 0.7 in that case. So, considering that d, you need to find out value of C for given H e/D o value. I hope it is clear.

Further, values of C corresponding to H e/D o you can find from table 4.1A as well s B from book and this book is a book from B. C. Bhattacharya, so that book you can use.

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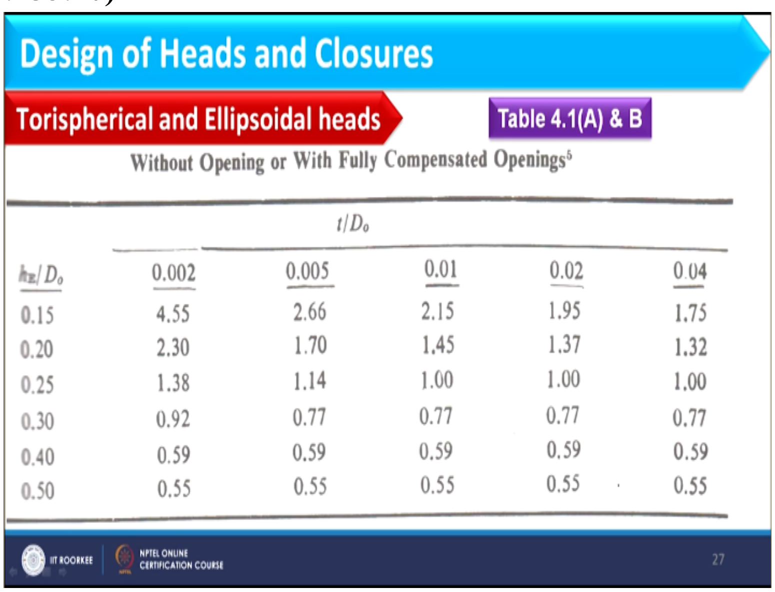

	t/D_o				
h_E/D_o	0.002	0.005	0.01	0.02	0.04
0.15	4.55	2.66	2.15	1.95	1.75
0.20	2.30	1.70	1.45	1.37	1.32
0.25	1.38	1.14	1.00	1.00	1.00
0.30	0.92	0.77	0.77	0.77	0.77
0.40	0.59	0.59	0.59	0.59	0.59
0.50	0.55	0.55	0.55	0.55	0.55

So this is basically table 4A, which is used for without opening or with fully compensated openings and here I am having different values of T/D o which is varying from 0.002 to 0.04 as it is appearing in the graph, and here I am having different value of H e/D o and all these values are values of C, okay.

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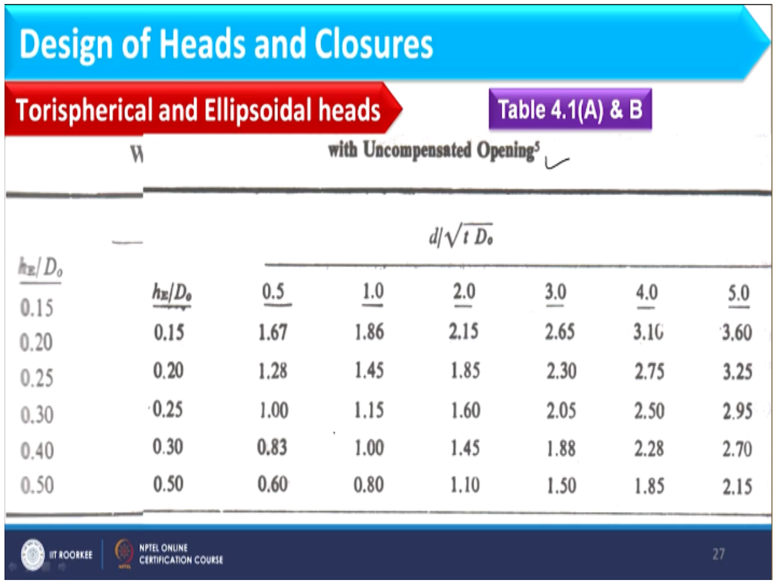

h_E/D_o	$d/\sqrt{t D_o}$ 0.5	1.0	2.0	3.0	4.0	5.0
0.15	1.67	1.86	2.15	2.65	3.10	3.60
0.20	1.28	1.45	1.85	2.30	2.75	3.25
0.25	1.00	1.15	1.60	2.05	2.50	2.95
0.30	0.83	1.00	1.45	1.88	2.28	2.70
0.50	0.60	0.80	1.10	1.50	1.85	2.15

And this table I am having is for uncompensated opening or that is table 4.1B where D/root over T into D o is shown from 0.5 to 5 and corresponding to H e/D o, you can read different values of C from this table. So, in this way, you can use that graph as well as this table to find out value of C for torispherical as well as ellipsoidal heads. So, as I have discussed that torispherical head as well as ellipsoidal head, both heads are designed using same expression, so what is the difference between these two.

Difference will lie when I am having major and minor axis, okay. So, when I am considering ellipsoidal head, it has specific major and minor axis, and accordingly H e/D o value will vary. However, that major and minor axis ratio is not maintained in torispherical head. So, based on H E/D o you can find different value of C for ellipsoidal heads as well as for torispherical head, so in that way you can make different designs for these two heads.

Now, here we will add 6% extra in T for reduction in thickness as toris section. So, when I am preparing the forming section, some material is lost, therefore, we consider additional material while designing that forming section, so if I am considering torispherical head, ellipsoidal head, conical head with knuckle, or flat formed head, wherever I am having that formed section, I will add 6% extra to the minimum thickness. That guideline you need to follow, okay.

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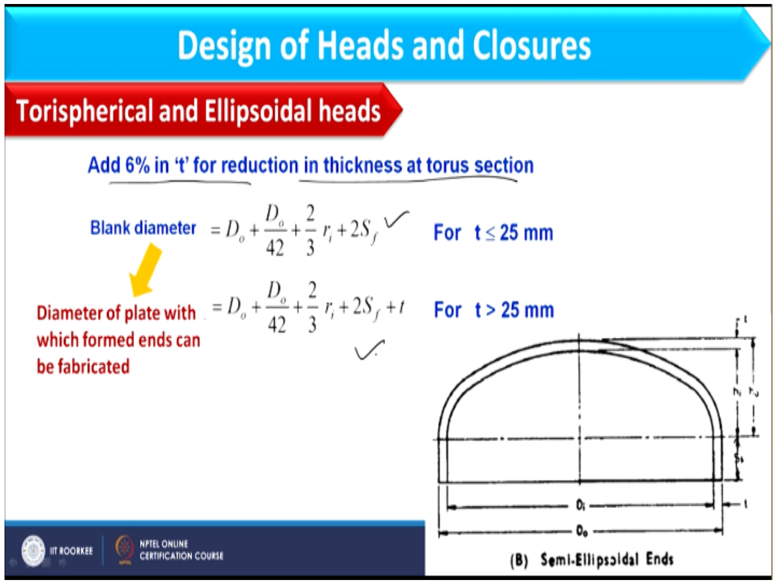

So, once I am having this, we will calculate the blank diameter. What is blank diameter? It is the diameter of plate with which form Ls can be fabricated. So, if I am having this ellipsoidal head, the diameter means the diameter of this whole section, whole plate through which this ellipsoidal head is prepared, so that would be equal to D o + D o/42 + 2/3 R i +2 SF. SF you can understand, SF is basically this straight part, which is beyond the curved section.

So, for T is less than 25 mm, we will use this expression, otherwise we will use this expression, okay. So, based on these, we can find out blank diameter. And here I am stopping lecture 2 of week 2. I will continue design of heads in next lecture where I will illustrate a few examples for designer heads. And that is all for now, thank you.