Equipment Design: Mechanical Aspects

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Lecture 18
Vessel under external pressure

Welcome to the third lecture of week 4 and in this lecture we will discuss vessel under external pressure. So design of such vessels we will discuss here and this topic will be covered in two lectures that is lecture 3 and lecture 4, where in lecture 3 we will discuss about the basics of external pressure and design procedure for such vessels, and in second part that is in lecture 4 we will illustrate few examples related to the topics. So let us start the discussion on vessel under external pressure.

Now what is external pressure. If you consider the internal pressure definition, how we can define that, when it is more than the outside pressure okay. When inside pressure of the vessel is more than outside pressure we call that as internal pressure condition. And in the similar line when outside pressure is more than the inside pressure, we call that as external pressure condition.

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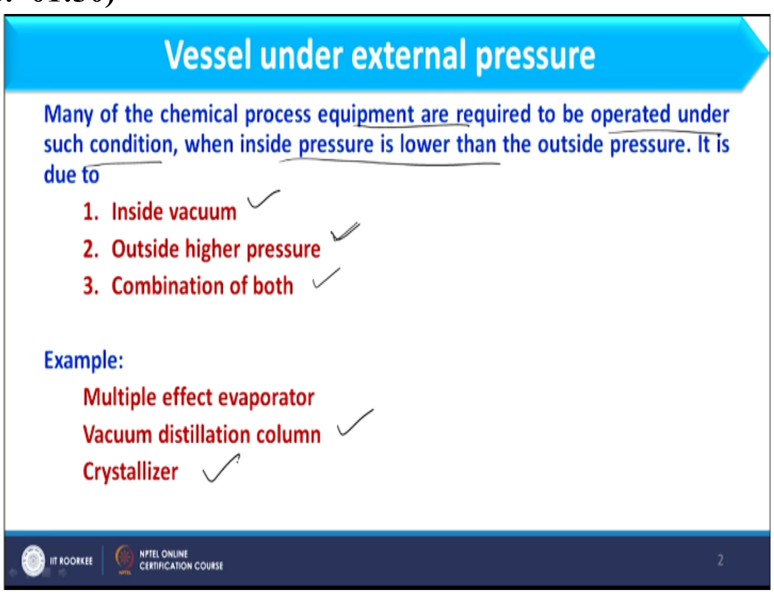

So far as external pressure is concerned, many of the chemical process equipments are required to be operated under such conditions, when inside pressure is lower than the outside pressure.

And this is due to inside, when inside I am having a vacuum obviously outer pressure would be higher than inner pressure and that condition will be called as external pressure.

If outside pressure is higher, for example, if inner pressure is atmospheric pressure and outside pressure is more than atmospheric pressure then again it is called external pressure condition and if the combination of both means internal vacuum and external more than atmospheric pressure. So in all these conditions we consider external pressure and then vessel will be designed in different manner.

Now as far as examples of these are concerned there are definite equipments which are used in such condition. For example, if I am having multiple effect evaporator that is usually operated below atmospheric pressure, and in that system vacuum is created and due to this vacuum its it takes the feed on its own because pressure difference is there okay. So this is So multiple effect evaporator is an example. Another example I am having is vacuum distillation column and then crystallizer. So all these examples comes or operated under the category of external pressure.

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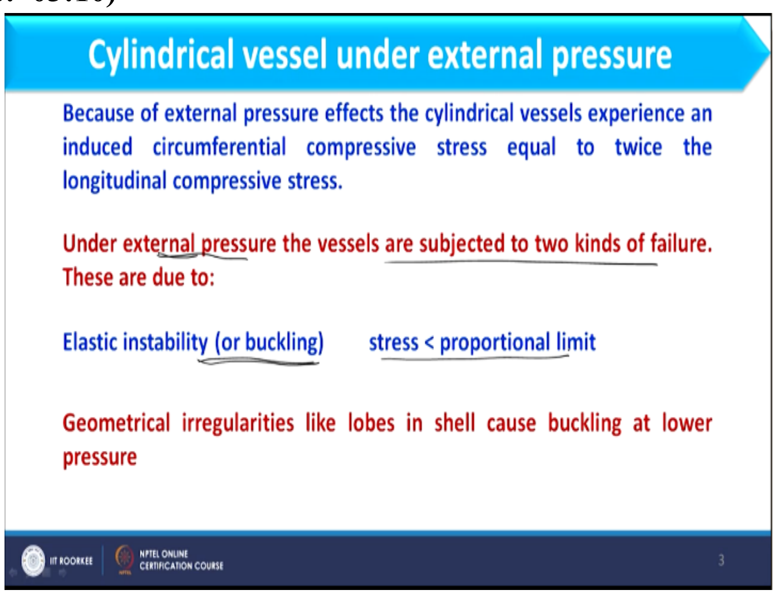

Now what happens when external pressure is applicable. For example if I am having a cylindrical vessel I have Hoop stress as well as longitudinal stress if I am considering thin vessel okay. Now when external pressure will be applicable, it will try the vessel to push inward okay. I hope I am clear. So in that case when internal vacuum is there along the length also, it will try to squeeze and along the circumference also it will try to squeeze.

So in that case it is observed that circumferential compressive stress will be twice than the longitudinal compressive stress because when it is tried to squeeze it, compressive stress will be applicable in that case okay. So that compressive circumferential stress that we can call as compressive Hoop stress, will be twice than the longitudinal stress.

And under external pressure the vessels are subjected to two kinds of failure. First is due to elastic instability or we called it buckling, when stress is less than proportional limit okay. So as far as failure of material is concerned that is at elastic limit or that comes as or that also occurs at plastic limit. So when it is in elastic limit it reforms its shape okay. And when it is in plastic condition or plastic region the failure will be permanent okay.

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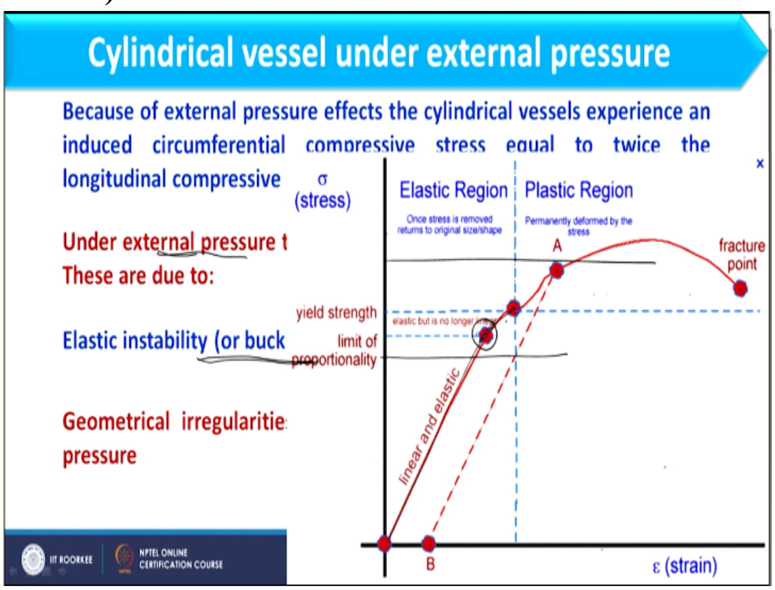

Now if you consider the stress and strain graph, here when it will reach to elastic limit that we up to it will follow the Hooke's law. Basically Hooke's law will be till the proportionality limit and after that we have the elastic failure as we have already discussed in previous lectures. Now why it is occurring, it is occurring due to geometrical irregularities like lobes in a shell cause buckling at lower pressure. What is lobe, when I am having any type of dent or any type of flat section in cylindrical vessel or if any type of irregularity in geometry occur because of that elastic failure occurs.

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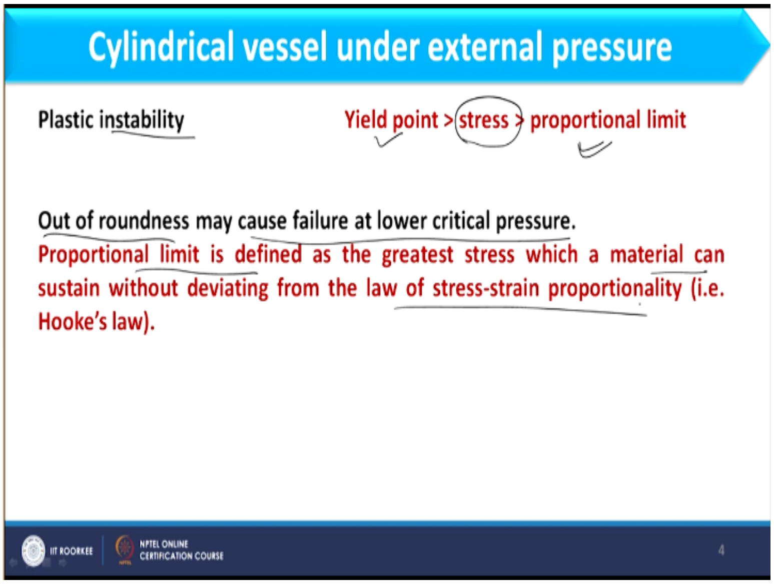

Next I am having plastic instability and the condition is when stress is more than proportional limit and less than yield point. If this condition will be there we have plastic instability. And out of roundness may cause failure at lower critical pressure okay. So what is out of roundness, out of roundness means when geometry is not regular. For example, if I am having cylindrical shell it includes regular or uniform geometry okay.

And for example if I am considering ellipsoidal type of vessel or cylindrical vessel with dent so all these conditions will come under out of roundness and because of out of roundness failure will occur okay.So proportional limit is defined as the greatest stress which a material can sustain without deviating from law of stress and strength proportionality. So basically when the material follows Hooke's law we can call that, it will have the proportional, it is below the proportional limit okay.

But as far as failure is concerned that is basically occurring due to the irregularity in the geometry.

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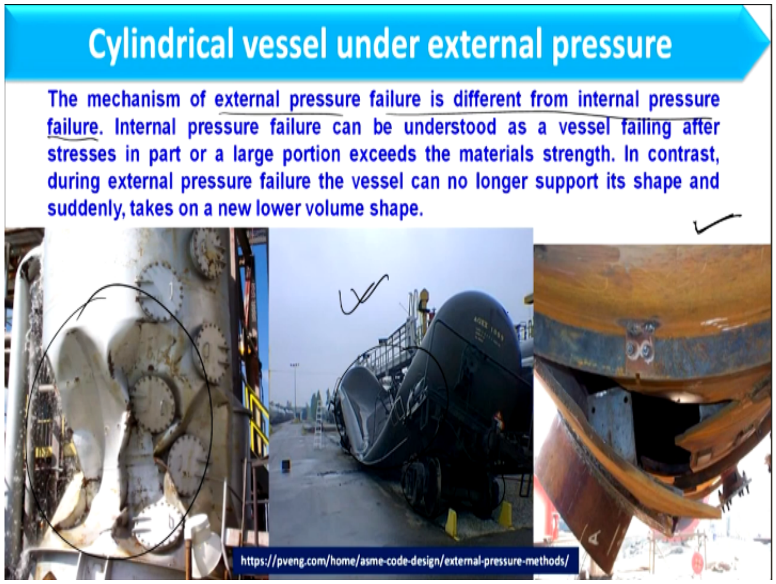

Now we will discuss type of failure occurs when internal pressure or external pressure failure is occurring in a system. So the mechanism of external pressure failure is different from internal pressure failure. What should be the mechanism. When I am considering internal pressure, it means internal pressure would be higher than the outside pressure okay. So in that case when internal pressure failure will occur, it means whatever stresses are generated in the metal part that exceeds the damaging stress of the material.

In that case vessel bursts, it means the pressure is releasing from internal to outer, so it will in form of bursting okay. However, when I am considering external pressure condition, in that case what happens because internal pressure is lower than outside pressure, outside pressure will cause failure because it will try to squeeze it. So in that case we have change in shape, but in internal pressure bursting will occur and in external pressure squeezing will occur as you can see from these diagram.

Here we have internal pressure failure and this diagram we have also discussed previously, and in external pressure condition situation like this occurs okay, when the vessel squeezes. And you can see from this diagram also. Now if you consider this diagram, this is what. If you focus on the wheels of this, it is basically the train trolley. So you must have seen the train trolleys, which carries liquid or compressed gas from one place to another place.

And in this case you must have seen that it is very it appears very strong okay that train trolley. And once failure will occur it will squeeze it will be it will happen like it is made of a paper okay, it will squeeze like this. And this type of failure was basically called as buckling. If you remember in second slide of this lecture we have a word buckling, so buckling is nothing but this where I am where I am having squeezing of the system, squeezing of the vessel.

So this buckling occurs in seconds okay. When we have external failure pressure will occur at instant duration of one second only it squeezes okay. So it is basically a huge structure if you imagine the train trolley and squeezes and it squeezes or reduces its shape in seconds okay. So such type of vessel should be designed very carefully because when failure will occur we do not have time to rescue or we do not have time to recover its shape okay.

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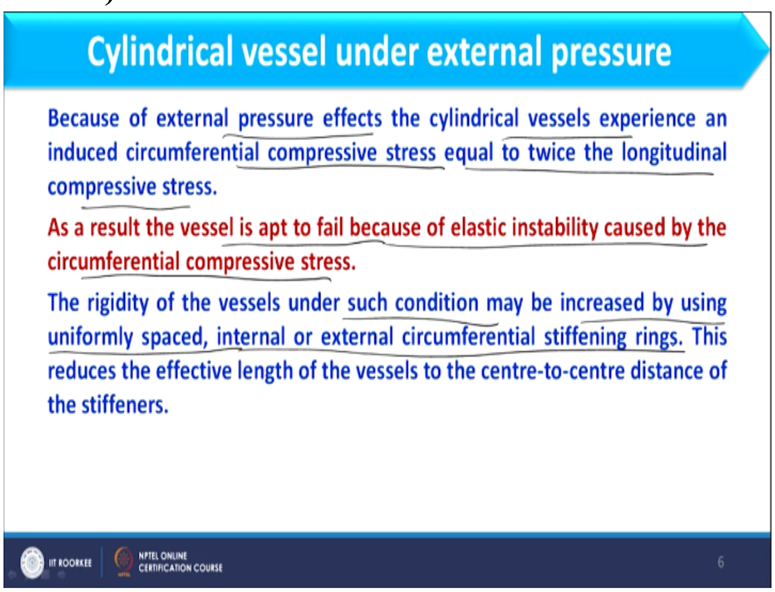

So let us discuss few points about external pressure vessel and the stresses generated in this. So because of external pressure effects the cylindrical vessels experience an induced circumferential compressive stress, which is equal to twice the longitudinal compressive stress that we have already discussed. So in such cases failure will occur due to circumferential compressive stress because that is more so it will fail first. So as a result vessel is apt to fail because of elastic instability caused by circumferential compressive stress.

And the rigidity of the vessel under such condition may be increased by using uniformly spaced internal or external circumferential stiffening rings. Now what is this stiffening rings. It is basically the structural support provided to the cylindrical vessel okay. So because of this structural support failure will not occur. Why failure will not occur that we will discuss.

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Now in this slide we will discuss the images or the photographs related to cylindrical vessel when stiffening rings are circumferential stiffening rings are placed. If you consider this image, here I am having the huge length of the vessel and after certain interval we have these rings. So these rings are nothing but the stiffening rings.

In the similar line you can see this vessel where this structure is basically stiffening ring okay. And if you consider this is basically the stiffening ring separately and which is welded from this side to periphery of the vessel. Now why the failure will not occur when I am using stiffening ring. If I am not using stiffening ring, the whole length will be available for vessel to act or to squeeze okay.

If I am having stiffening ring it reduces the effective length of the vessel okay. Now if you consider this image, if I am not using these stiffening rings the whole length will be available for external pressure to act. If am having these rings it means vessel is having only this much length okay, vessel is having only this much length. It is not having the total length, so effective length of the vessel will reduce and because it is acting on this much section only it will these rings will provide sufficient rigidity and therefore it avoids squeezing the vessel.

So in this way when we are using stiffening rings failure of external pressure vessel will be avoided. So what we have discussed that stiffening ring provides sufficient strength to the structure or to the vessel, and if that ring is placed within the critical limit, it will avoid failure, and if it is placed above the critical limit the failure may occur. So it is better or it is mandatory to define the critical length between the stiffeners.

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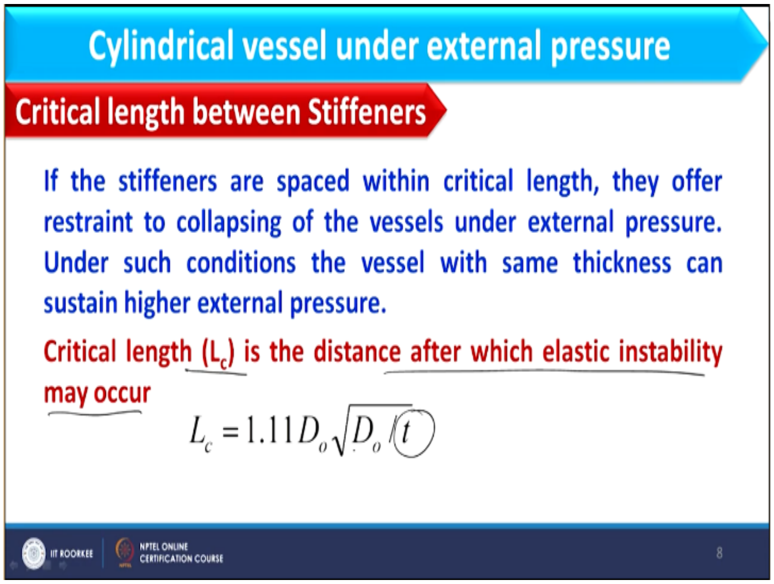

So that critical length, which is denoted as L c is the distance after which elastic instability may occur and which is given by this expression. Here we have L c = 1.11 D not root over D not/t, where t is the thickness vessel and D O is the outer diameter of vessel.

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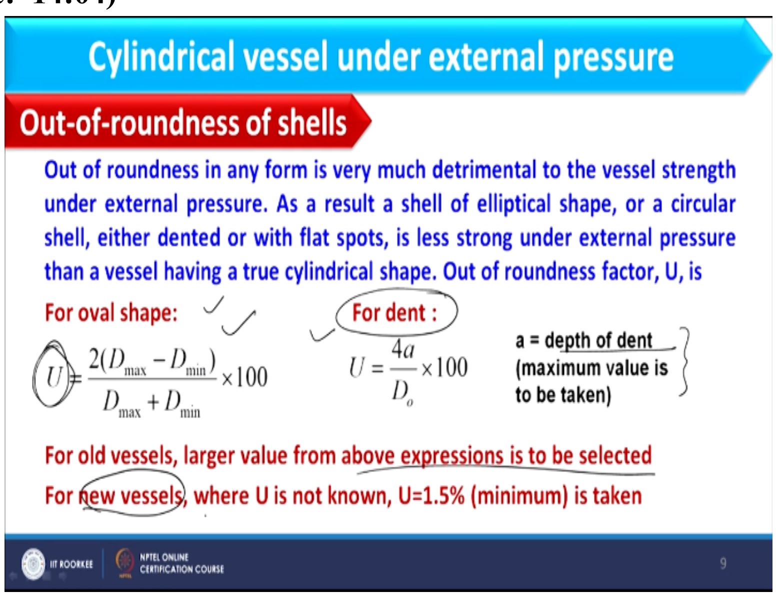

And if you remember the previous slide, there we have out of roundness and we have already defined out of roundness that it is irregularity in the geometry if I am having ellipsoidal vessel or if I am having cylindrical vessel with dent etcetera, we can say that it has out of roundness. So that out of roundness can be quantified as. For oval shape or cylindrical shape it is given as U, actually U denotes the out of roundness, which is equal to 2 (D max – D minimu)m/D max + D minimum into 100.

And if I am having dent, so U can be defined as 4a/D O * 100, where a is the depth of dent that is the maximum value is to be taken. Now if I am having 3/4 dent, a would be the maximum depth of the dent. So for older vessel, larger value from above expression is to be selected. For example, if I am having oval shape along with dent, so we calculate U from both equations and then larger value will be selected for design and that is for older vessel.

For new vessels, where out of roundness is not occurring due to dent okay. In that case value of U should be taken as 1.5%. So this out of roundness will be given in percent. Now we will discuss the design procedure for external pressure vessel, it has basically two conditions. First is elastic failure and second is plastic failure. So let us discuss what is elastic failure.

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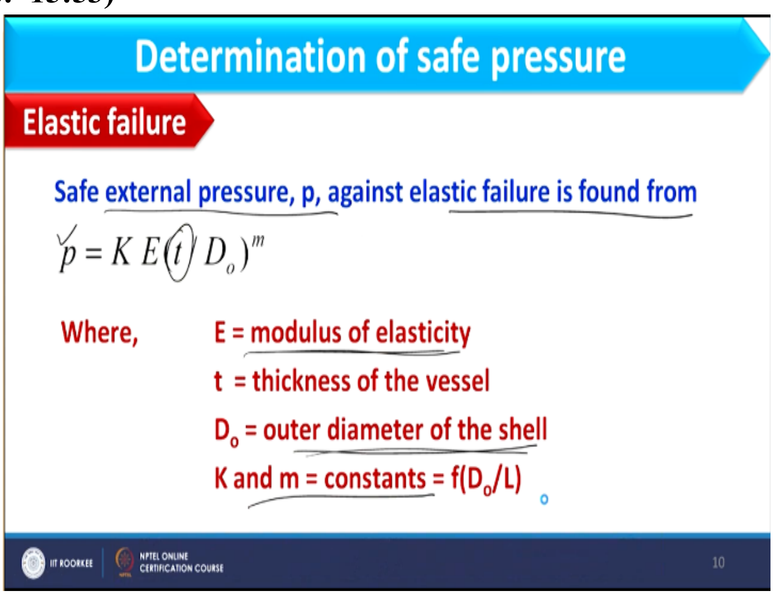

And in this elastic failure safe external pressure p against elastic failure is found from this expression. Now what is safe external pressure, safe external pressure is that pressure which will not allow failure to the system, okay. So whatever pressure I have to consider in design that I will consider as safe pressure, so that failure will not occur at that particular pressure okay. So design pressure in this case, you can consider as safe pressure. So here p is basically design pressure, which is equal to K E(t/D not) power m.

And from here I need to find out t. So p is the design pressure, K and m are constants and D O is outer diameter of shell and E is the modulus of elasticity. And K and m as we have discussed these are constants, which is the function of D not/L and it is given in this table.

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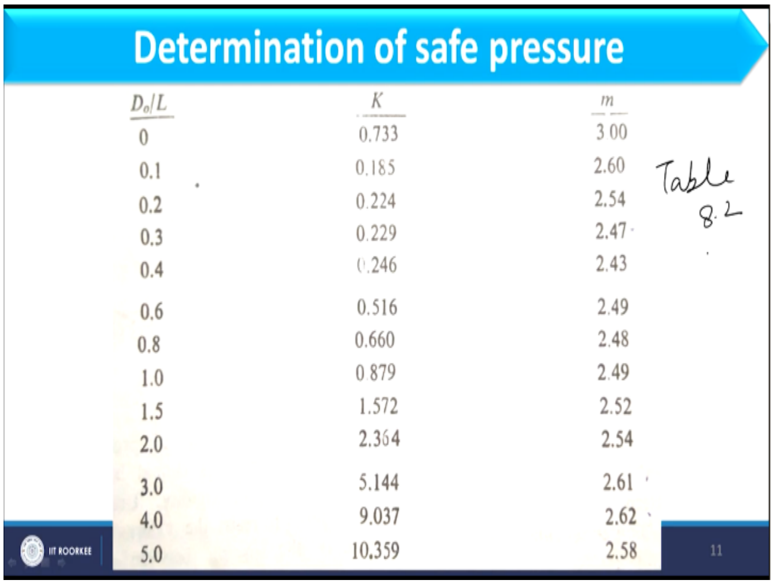

Determination of safe pressure

D_o/L	K	m
0	0.733	3.00
0.1	0.185	2.60
0.2	0.224	2.54
0.3	0.229	2.47
0.4	0.246	2.43
0.6	0.516	2.49
0.8	0.660	2.48
1.0	0.879	2.49
1.5	1.572	2.52
2.0	2.364	2.54
3.0	5.144	2.61
4.0	9.037	2.62
5.0	10.359	2.58

And this is table 8.2 in book given by B. C. Bhattacharya. So here I am having D not/L different values and corresponding K and m values we can see from this table.

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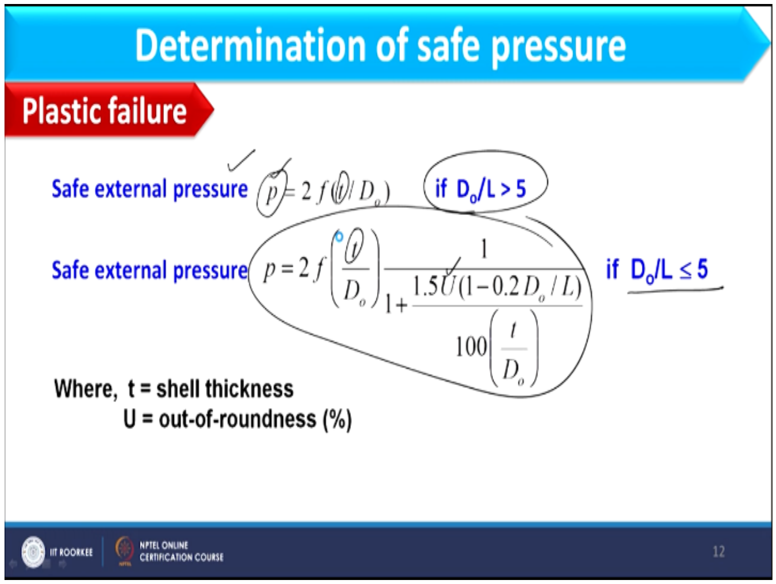

And now will discuss the plastic failure condition, what are the design equations to find out the thickness of vessel under external pressure okay. So here we have the safe external pressure that is p and this p as we have discussed already that whatever design pressure we are considering that will be this p, and which is equal to 2 f (t/D not), when D not/L is greater than 5. However, when D not/L is less than or equal to 5, we can calculate safe external pressure by this expression, okay, where U is basically out of roundness.

And from these expressions we can calculate this t. So what should be the procedure to design the vessel under external pressure is when we are given a design pressure. First we will calculate the thickness considering elastic failure. So previous expression we will consider to calculate the thickness of vessel. Now further that thickness whatever we have calculated through elastic failure that we will consider that we will use in plastic failure expression and we will calculate the pressure.

If pressure is coming greater than whatever we have considered in elastic, it means whatever thickness we have computed that is correct okay. Otherwise what happens we will consider safe pressure directly in plastic failure condition and then we will calculate thickness from that expression. And further I do not need to check that thickness with elastic failure because when thickness can sustain plastic failure it can also sustain elastic failure. So in this way we will design the vessel under external pressure.

Now another condition I am having is what stiffener I should choose okay. As we have discussed that circumferential stiffener will provide strength to the structure or strength to the vessel what should be the stiffening ring okay, what should be the correct stiffening ring okay.

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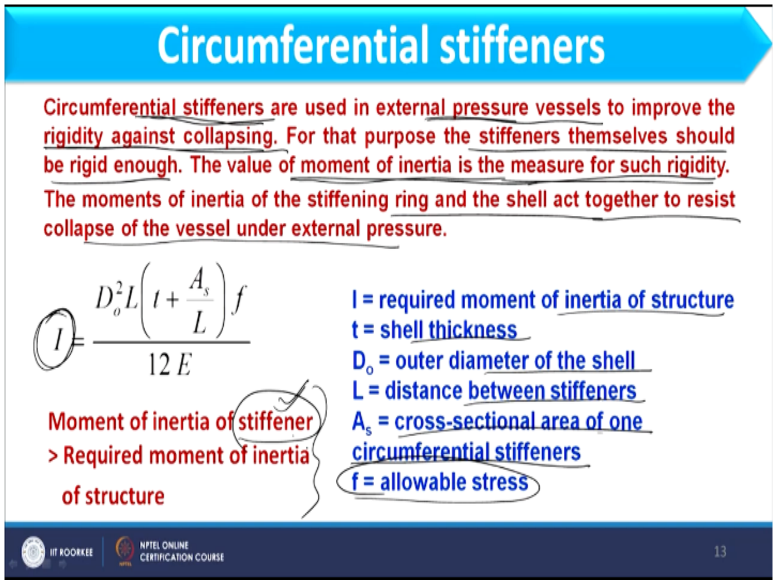

So circumferential stiffeners are used in external pressure vessels as we have discussed already to improve rigidity against collapsing okay. So these stiffeners do not allow collapsing of the vessel because it reduces the effective length of the vessel, but for that case stiffeners themselves should be rigid enough okay. Stiffener should be should not be weak so that when failure will occurs that stiffener also squeezes. Stiffener's role is to provide rigidity.

For that case stiffener should be rigid enough to withstand all external loads. And moment of inertia is a major of such rigidity and moment of inertia is a major of such rigidity, so here we will compute the moment of inertia of the structure. Structure means the vessel along with the stiffener and then that value we will compare with the moment of inertia of the stiffener. If stiffener moment of inertia is higher than that of the structure, it means stiffener is strong enough okay.

Now as far as moment of inertia is concerned, here we will discuss second moment of inertia and we also call this as area moment of inertia, so let us see the expression. So moment of inertia of stiffening ring and the shell act together to resist collapse of the vessel under external pressure, okay. So this is the expression to compute moment of inertia of the structure and it is given by D

O 2 L (t + A S/L)f/12 E, and where I is the required moment of inertia of the structure, t is the shell thickness, D O is the outer diameter of shell, L is length between stiffeners or distance between stiffeners, A S is the cross sectional area of one circumferential stiffeners.

So whatever stiffener I will choose I have to find out the value of cross sectional area for that stiffener and f is the allowable stress of the material. And the condition is moment of inertia of the stiffener, which we have to see from the standard, it should be greater than required movement of the inertia of structure. So if this condition satisfy, we can say that whatever stiffener I have chosen that is strong enough to avoid collapsing.

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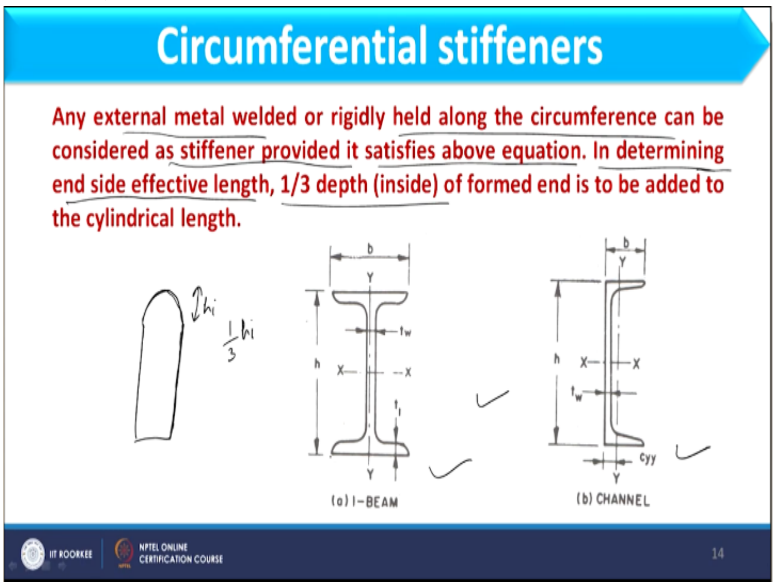

Further any external metal welded or rigidly held along the circumference can be considered as stiffeners, provided it satisfy above equation. So we can have a ring, we can have different type of structure also, for example if I am placing some bar or something like that. So it will also called as a stiffener so we can consider different structures of stiffener whichever is satisfying the previous equation it works nicely with the vessel under external pressure.

So in determining the end side effective length, one-third depth of formed head is to be added to the cylindrical length. What is the meaning of that. For example, if I am having this cylindrical vessel and one side is having form section or formed head okay. So length whatever I have to consider that should be the effective length because stiffener should be rigid enough to withstand the shape of this shell as well as this formed head.

So in that case total height of that form section let us say it is hi, so we will consider one-third into hi as the effective length of the head, which should be added to the length of the shell. And these diagram if you focus, here we have I beam as well as channel and this we have also discussed in column design for support and this I beam as well as this channel these both also work as stiffening ring okay.

And here we have h is the height of these stiffeners and b is the width of these stiffeners as you can see from these diagram. Now here you see yy and xx, what is this yy. If I am placing the stiffener or if I am welding the stiffener from this side to the vessel, the whole yy will be available outer to the vessel. I hope I am clear.

So in that case moment of inertia I have to take along with yy, and for example if it is welded horizontally I have to take xx as a moment of inertia. In the similar line yy I can choose for this channel and xx I can choose for this channel according to its orientation.

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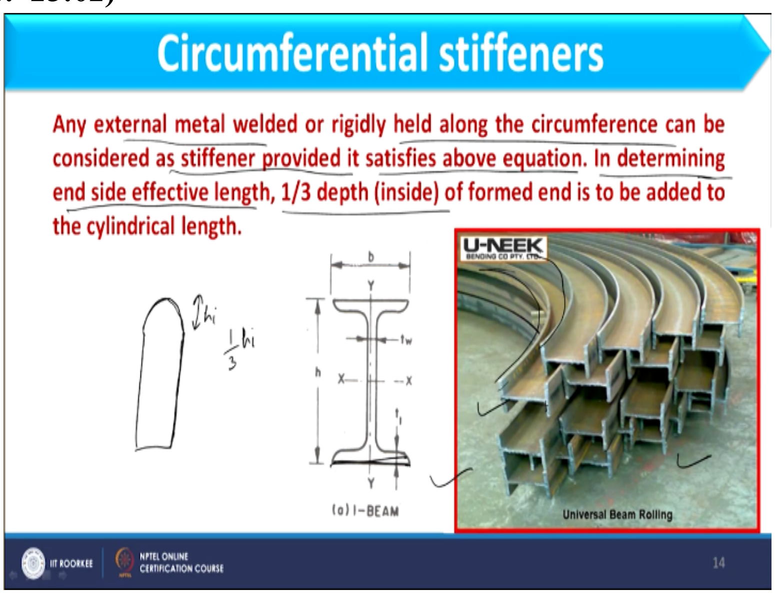

So if you consider I beam its that you can visualize in this image more clearly, this is basically I beam and this section is basically welded to the outer periphery of the vessel okay. So if it is welded, this section is welded it means it is attached in yy section. And moment of inertia we will calculate, we will consider as I yy okay.

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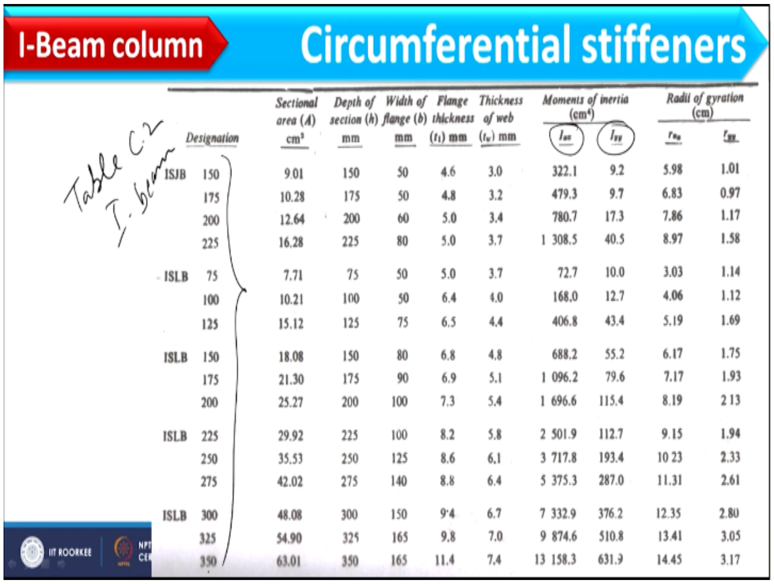

Designation		Sectional area (A) cm^2	Depth of section (h) mm	Width of flange (b) mm	Flange thickness (t_f) mm	Thickness of web (t_w) mm	Moments of inertia (cm^4) I_{xx}	I_{yy}	Radii of gyration (cm) r_{xx}	r_{yy}
ISJB	150	9.01	150	50	4.6	3.0	322.1	9.2	5.98	1.01
	175	10.28	175	50	4.8	3.2	479.3	9.7	6.83	0.97
	200	12.64	200	60	5.0	3.4	780.7	17.3	7.86	1.17
	225	16.28	225	80	5.0	3.7	1 308.5	40.5	8.97	1.58
ISLB	75	7.71	75	50	5.0	3.7	72.7	10.0	3.03	1.14
	100	10.21	100	50	6.4	4.0	168.0	12.7	4.06	1.12
	125	15.12	125	75	6.5	4.4	406.8	43.4	5.19	1.69
ISLB	150	18.08	150	80	6.8	4.8	688.2	55.2	6.17	1.75
	175	21.30	175	90	6.9	5.1	1 096.2	79.6	7.17	1.93
	200	25.27	200	100	7.3	5.4	1 696.6	115.4	8.19	2.13
ISLB	225	29.92	225	100	8.2	5.8	2 501.9	112.7	9.15	1.94
	250	35.53	250	125	8.6	6.1	3 717.8	193.4	10.23	2.33
	275	42.02	275	140	8.8	6.4	5 375.3	287.0	11.31	2.61
ISLB	300	48.08	300	150	9.4	6.7	7 332.9	376.2	12.35	2.80
	325	54.90	325	165	9.8	7.0	9 874.6	510.8	13.41	3.05
	350	63.01	350	165	11.4	7.4	13 158.3	631.9	14.45	3.17

And this is the table, which is basically table C2 for I beam and here we have different sectional area, depth h and b whatever we have seen from the previous images and here we have moment of inertia I xx and I yy, whatever would be the placement according to you can choose the value from these table okay. So these are different designations to be used as stiffening ring. It will be more clear when we will solve a problem on this.

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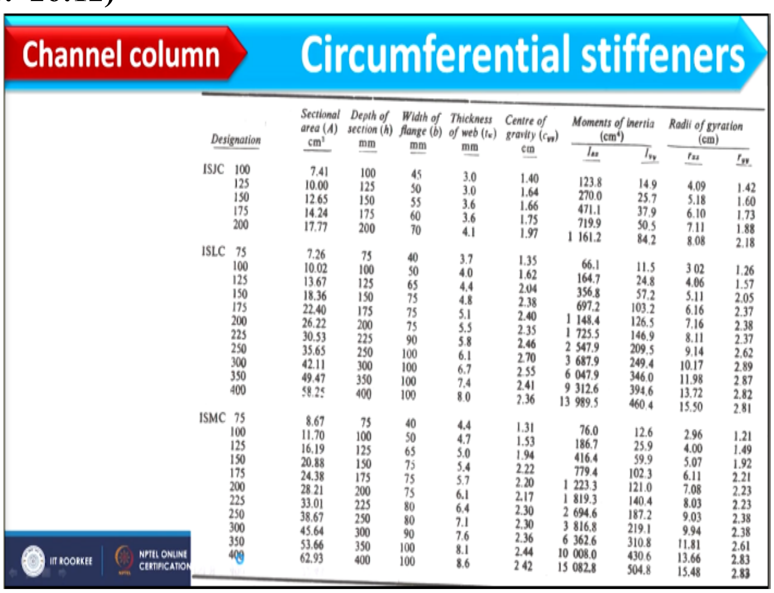

Designation		Sectional area (A) cm^2	Depth of section (h) mm	Width of flange (b) mm	Thickness of web (t_w) mm	Centre of gravity (c_{yy}) cm	Moments of inertia (cm^4) I_{xx}	I_{yy}	Radii of gyration (cm) r_{xx}	r_{yy}
ISJC	100	7.41	100	45	3.0	1.40	123.8	14.9	4.09	1.42
	125	10.00	125	50	3.0	1.64	270.0	25.7	5.18	1.60
	150	12.65	150	55	3.6	1.66	471.1	37.9	6.10	1.73
	175	14.24	175	60	3.6	1.75	719.9	50.5	7.11	1.88
	200	17.77	200	70	4.1	1.97	1 161.2	84.2	8.08	2.18
ISLC	75	7.26	75	40	3.7	1.35	66.1	11.5	3.02	1.26
	100	10.02	100	50	4.0	1.62	164.7	24.8	4.06	1.57
	125	13.67	125	65	4.4	2.04	356.8	57.2	5.11	2.05
	150	18.36	150	75	4.8	2.38	697.2	103.2	6.16	2.37
	175	22.40	175	75	5.1	2.40	1 148.4	126.5	7.16	2.38
	200	26.22	200	75	5.5	2.35	1 725.5	146.9	8.11	2.37
	225	30.53	225	90	5.8	2.46	2 547.9	209.5	9.14	2.62
	250	35.65	250	100	6.1	2.70	3 687.9	249.4	10.17	2.89
	300	42.11	300	100	6.7	2.55	6 047.9	346.0	11.98	2.87
	350	49.47	350	100	7.4	2.41	9 312.6	394.6	13.72	2.82
	400	58.25	400	100	8.0	2.36	13 989.5	460.4	15.50	2.81
ISMC	75	8.67	75	40	4.4	1.31	76.0	12.6	2.96	1.21
	100	11.70	100	50	4.7	1.53	186.7	25.9	4.00	1.49
	125	16.19	125	65	5.0	1.94	416.4	59.9	5.07	1.92
	150	20.88	150	75	5.4	2.22	779.4	102.3	6.11	2.21
	175	24.38	175	75	5.7	2.20	1 223.3	121.0	7.08	2.23
	200	28.21	200	75	6.1	2.17	1 819.3	140.4	8.03	2.23
	225	33.01	225	80	6.4	2.30	2 694.6	187.2	9.03	2.38
	250	38.67	250	80	7.1	2.30	3 816.8	219.1	9.94	2.38
	300	45.64	300	90	7.6	2.36	6 362.6	310.8	11.81	2.61
	350	53.66	350	100	8.1	2.44	10 008.0	430.6	13.66	2.83
	400	62.93	400	100	8.6	2.42	15 082.8	504.8	15.48	2.83

And in the similar line here we have data for channel stiffener and it is basically given in table C3, and table C3 and C2 are available in book given by B. C. Bhattacharya and here I am having different parameters lie sectional h b and here I have I xx and I yy, which I need to extract for computation purpose. So in that way we have to design the vessel under external pressure and we have to choose correct stiffener for the vessel. And that is all for now, thank you.