Equipment Design: Mechanical Aspects
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Lecture 16
Design of Support

Welcome to the first lecture of week 4 and in this lecture we will discuss supports and design of supports. So let us start the discussion. Now what is support to the vessel. Actually, whenever I am designing a pressure vessel I cannot leave the pressure vessel as it is. It requires some structure or some assembly so that it can be connected to the foundation and that assembly is basically called as support.

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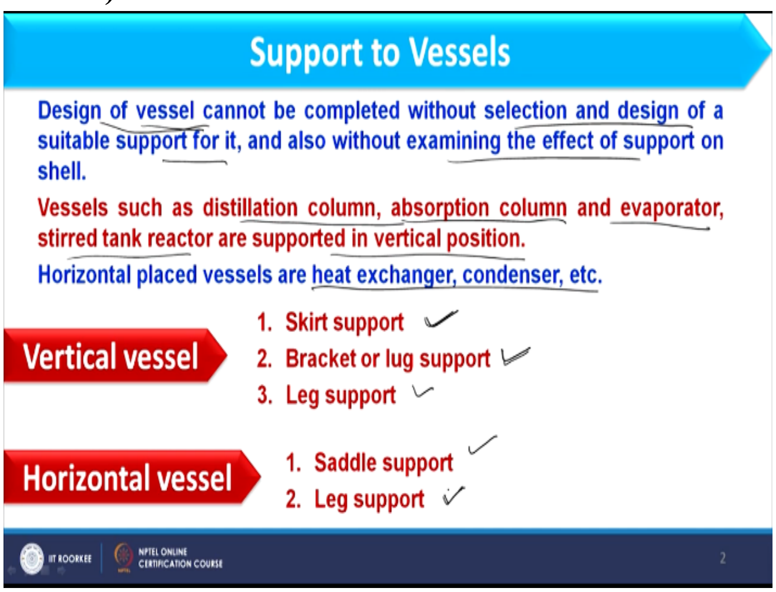

So design of vessel cannot be completed without selection and design of suitable support for it and also without examining the effect of support on the shell. So when I am connecting any support to the shell, the shell will put load on the support and in the similar line support will give reaction towards the shell. So all these factors we have to consider for design of support. Now if you remember the selection of vessel, which we have discussed in the first lecture of this course, these are basically placed vertically or horizontally.

So as far as support is concerned these are different for horizontal vessel as well as for vertical vessel. So vessel such as distillation column, absorption column, evaporator and reactor, all these are placed in vertical position. However, horizontally placed vessels are heat exchangers, condensers. Heat exchangers can also be placed vertically and can also be placed horizontally.

Now, we will see what are the supports used for vertical vessel and for horizontal vessel. So for vertical vessel we usually have three support, first is skirt support, second bracket or lug support and third is leg support. So skirt support is basically used for tall vessels, tall vessels like distillation column, etcetera, which has height more than 20 meter, for that we use skirt support. Bracket or lug support are used for short height vessels and similarly leg supports are also used for short height vessels, okay.

Now for horizontal vessel we use saddle support as well as leg support. So here we have different types of supports. In this particular course we will discuss one support for horizontal and one support for vertical. For vertical we will discuss bracket and lug support and for horizontal we will discuss saddle support. So let us start discussion on bracket or lug support, which is used to support the vertical vessel.

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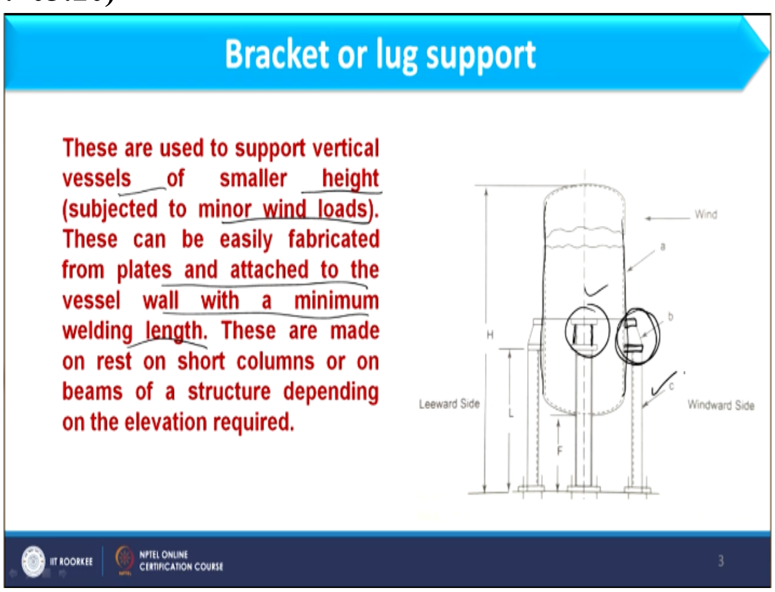

So here we have bracket and lug support. If you consider this is basically the vessel, okay, which is denoted as a over here and this particular assembly, which is denoted as b, this particular assembly is called as bracket or lug, and this c part is basically called as column, on which this bracket sits. So bracket and lug supports are used to support vertical vessel of smaller height. Smaller height means, which is subjected to minor wind loads.

These can be easily fabricated from plates and attached to the vessel wall with a minimum welding length, okay. Now if you focus on this bracket or this bracket it has two plates horizontally placed like this and this and two plates vertically placed and which we call as gusset plates. So these horizontal and vertical plates are welded to the shell and it creates a bracket. So these are made on rest on short column, so this c is basically the column which we have already discussed or on beam of the structure depending on the elevation required.

So in this way we can understand the bracket or lug support and then we will start design, but before start design of bracket or lug support we will see what are the stresses which are acting on these support. So let us start that. The main loads on the bracket supports are dead weight of the vessel, which is its content and wind load. So as far as load is concerned on the support, it support should be strong enough, so that it can bear the dead load of the vessel, load due its content and due to wind, okay.

Now as far as dead load is concerned, what is that, which is basically which will always act. For example, for a pressure vessel the weight of shell will be, weight of heads will be there, weight of attachment for example plates are there and tubes are there inside the vessel, all these, weight of all these assembly will be collectively added to dead load okay. And along with this we will consider another load which we will call as load of content. So load of content will also be bear by support okay. So along with dead load we can have load due to wind.

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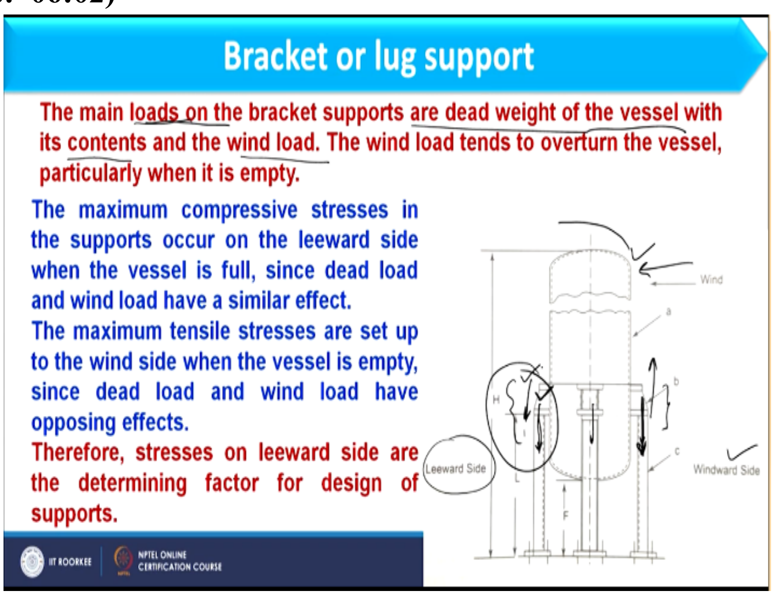

Now if you focus on this particular figure, here this is the vertical vessel where bracket support is attached and wind pressure is coming from this side as it is shown over here. So this is basically windward side. And here we have the leeward side where wind will try to turn. Now as we have discussed that there are two loads, first is due to dead load and second is due to wind load okay. Now once I am considering that dead load in this figure.

All these dead load of the shell will try to put compressive stress to these support and if wind is coming from this direction, it will also try to turn this vessel towards leeward side and put compressive stress to this way okay. So once I am having leeward side it means it has the maximum stress, however, when I am considering wind side or windward side what happens due to load compressive load will occur in a support and because of wind it will try to turn it so wind will create a tensile load over here okay.

So load over here will be opposite to each other and which will be smaller than whatever is created in this way because here both load are acting downward or acting in compressive way. So as far as load is concerned this would be the extreme condition for support to bear and therefore for design purpose also we will consider this condition where load due to wind and load due to dead load or dead weight will be considered together. So let us start design of bracket or lug support.

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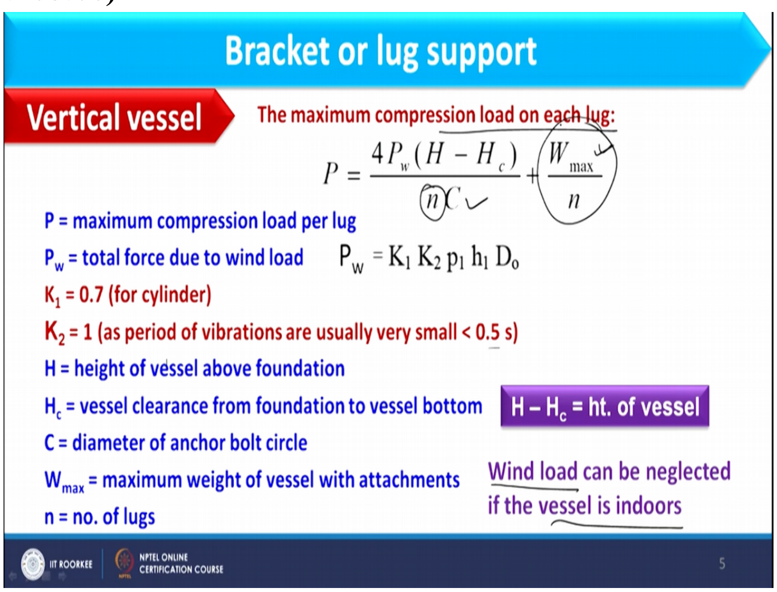

Further if you focus on this vertically placed vessel, this is basically the bracket which has two horizontal plates and two vertical plates as gusset plates so this whole connection will be treated as bracket and maximum compression load on each lug okay. So as we have discussed that compression load will occur due to dead load as well as wind load towards leeward side so that we have considered for design purpose, where both loads will be considered.

So maximum compression on each lug would be P which is equal to 4 P w (H – H c) /n C + W max/n. So let us see these parameters, P is the maximum compression load per lug, P w is the total force due to wind load which is given by this K 1, K 2, p 1, h 1 and D not, where K 1 is 0.7 for cylinder, usually pressure vessels are of cylindrical shape and K 2 we have to take as 1 as period of vibration are usually very small that is less than 0.5 seconds.

So when I consider tall vessels their period of vibration is significantly higher than this, so in that case K 2 value would be taken as 2, but here vessel is of short height and therefore K 2 will never exceed 0.5 seconds and therefore it is taken as 1. H is the height of vessel above the foundation and H c is the vessel clearance from foundation, so basically H – H c will be the height of vessel and C is the diameter of anchor bolt circle, n is the number of lugs.

And W max is the maximum weight of vessel with attachment, it means W max is the maximum dead load, n is the number of loads that we have already discussed. And when vessel is used for indoor purpose we will not consider wind load and then this factor would be neglected. Here you see this is the schematic vessel with bracket support and here W max is there, P is there wherever P will act its arm is also given and H c is basically height from the foundation and H is the total height, L is the height for column okay.

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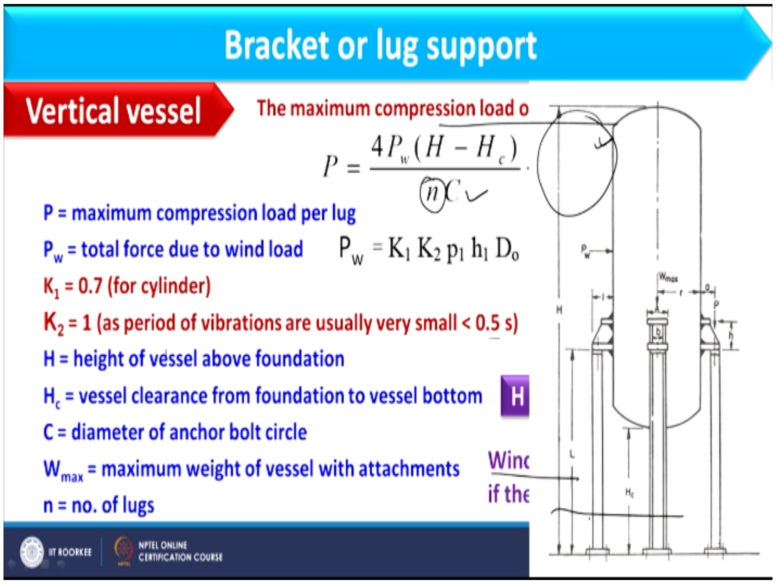

Now if you see we have another parameter l and b and b. So h is the distance between horizontal, l is total width of the horizontal plate, bottom plate and b is basically the distance between gusset plates and a is the length of horizontal plates. And we have seen the total load which is acting on each lug and then we can discuss the stress in shell due to these brackets okay. So that will be given as the axial stress due to reaction of lug.

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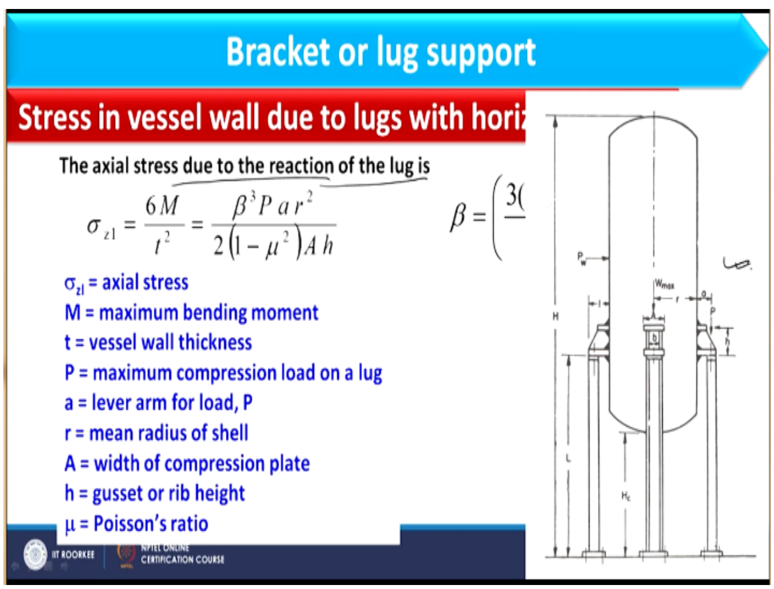

Now first of all you should understand this that once I am having the vessel and below we have the support, this vessel will put compressive load to the support okay. And further support will also react towards the shell because it will try to react towards the shell and because this vessel is acting downward that support will act upward, but direction would be axial only or longitudinal only.

So in that case axial stress due to reaction of the lug is given as sigma zl which is equal to 6M/t 2 and which is equal to beta 3 P a r 2/2 (1 - Mue 2) A * h okay. Beta you can see from this expression, which is equal to 3 (1 – Mue 2)/r 2 * t 2 power 1/4. These are the parameters used in this expression and l whatever would be the parameter that we have already discussed through this schematic.

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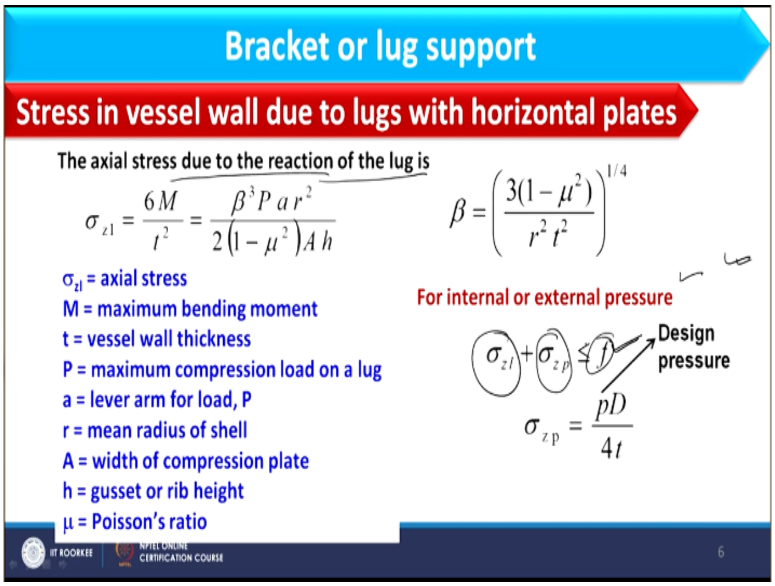

So once I know sigma zl that is the axial stress, so once I know the axial stress I can study the stresses generated due to internal or external pressure. So once I am having these pressures, due to this we have stress in the longitudinal direction and which is given as sigma zp and sigma zl is due to the lug. So the design equation would be sigma zl plus sigma zp would be less than or equal to f. This f is basically allowable stress of support, okay. And zp you can find by this where p is the design expression okay.

Now if you consider this particular equation and if this condition is not satisfied we have to take f as different material for support. And now we will discuss how to find out thickness of horizontal plate as well as gusset plates. So thickness of horizontal plates you can see from this schematic that horizontal plate is this and the plate is fixed on the edges with the load p distributed over about half of the area of the plate.

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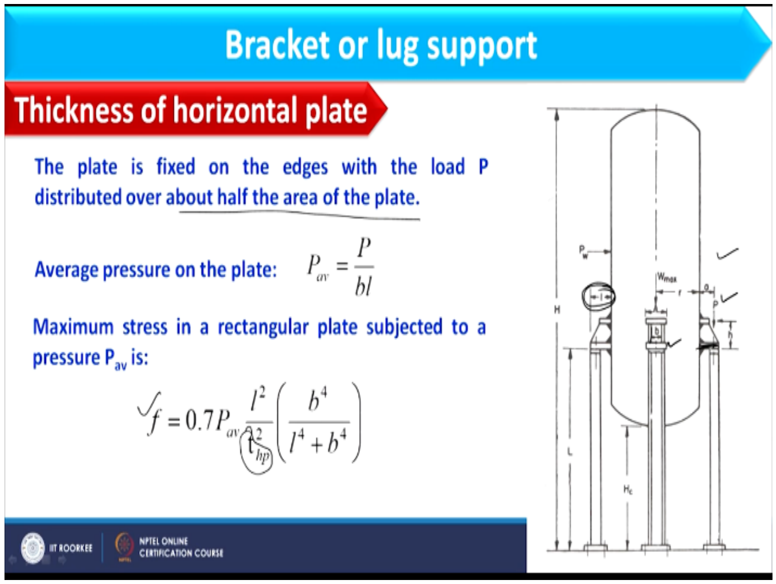

So this p is basically distributed over half of the area of the plate as you can see from this image and then average pressure on the plate would be P/bl. So what is that P/bl, P is the total load and which is acting in almost half of the area and therefore we can consider b which is space between the gusset plate into this l okay. So if I cannot see l over here because l is basically the width of this plate outside. So that is shown in this bracket clearly. So b * l we have taken as the acting area, P av will be equal to P/b * l.

And maximum stress in a rectangular plate subjected to pressure P av is given by this, f would be equal to 0.7, P av * L 2/t 2 hp * b 4/l 4 + b 4. So here t hp is basically thickness of horizontal plate, all other parameters are usually known and f is the allowable stress of horizontal plate material. In this way we calculate the thickness of horizontal plate.

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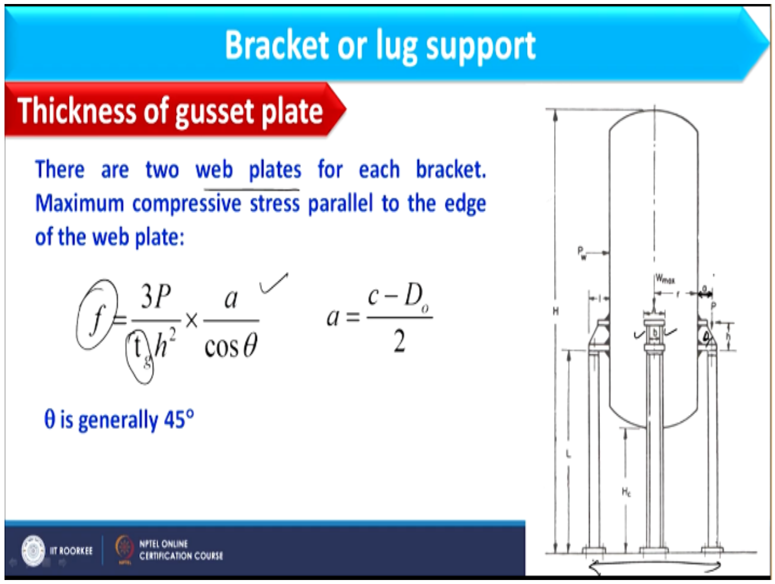

Now we focus on thickness of gusset plates. There are two web or gusset plates for each bracket as it is shown over here. And this is the expression to calculate thickness of gusset plate, where f is equal to 3 P/T g H 2 * a/cos theta. Theta is basically this angle. So t g is gusset plate thickness and f is the allowable stress of gusset plate. And a you can see in this figure, which is this arm. So a is equal to c - D not/2. So c is basically anchor bolt diameter, so that would be this diameter okay.

And this diameter minus D not/2 so that would be given as a. So in this way we can compute thickness of horizontal as well as vertical plate. Now we will discuss design of column on which these brackets rest. So design of column for lug support can be given by this equation.

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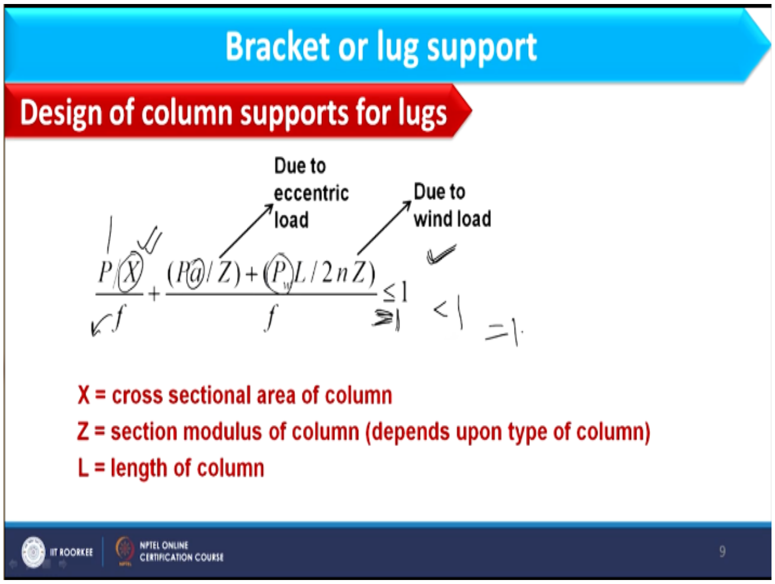

Here P/X/f + (P a/Z + P w L/2 n Z)/f, which is equal to or less than 1 okay. So this P if you consider this P is the total load on each lug that we have discussed earlier. X is the cross sectional area of the column okay, f is the allowable stress of column, and P is whatever we have discussed that is load on each lug, a is the arm that we have seen in the last slide divided by Z, Z is basically the modulus of this structure.

So this P a/Z, this is due to the eccentric load because when P will act it will have the eccentricity also considering a. So eccentric load will be considered by this expression and this expression will be given due to wind load as P w will be there. So what happens this is the design equation where the extreme condition would be when it is equal to 1 okay. So while equating this to 1 we will solve this equation and we will find value of X, here X is the unknown parameter, which is the cross sectional area of column.

So X is the cross sectional area of column, Z is the sectional modulus of column or structure and L is the length of the column. Now what will happen over here, this I have equated to 1 and calculate value of X. So that X value would be minimum possible because if X will have more value than the minimum so this expression would be something like this not equal to 1. I hope you are getting this. So whatever X I am getting from this expression that would be the minimum possible cross sectional area of the column okay.

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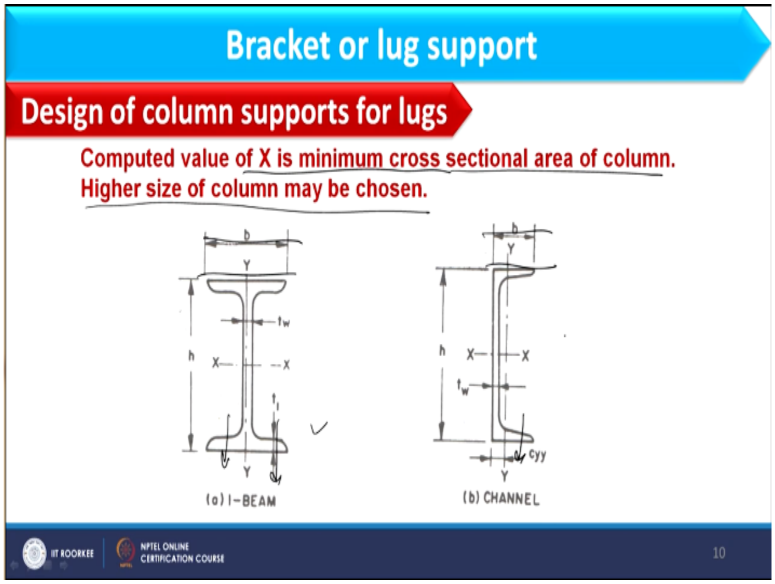

So as it is the minimum possible cross sectional area of the column higher size of column may be chosen okay. So we have calculated minimum cross sectional area. We will refer the standard and see whatever area available above than this that we can choose as a right column for the bracket to rest. So from where I will get that standard. So as far as columns are concerned we have definite shape for this like high beam channel etcetera.

So if you consider this image, here we have this high beam where this is the structure of high beam and here we have the structure of channel okay. The bracket can support over here or can support over here and this section will be connected to the foundation. Now once I am having this structure I have to find the sectional area for these structures and that we can find by this table.

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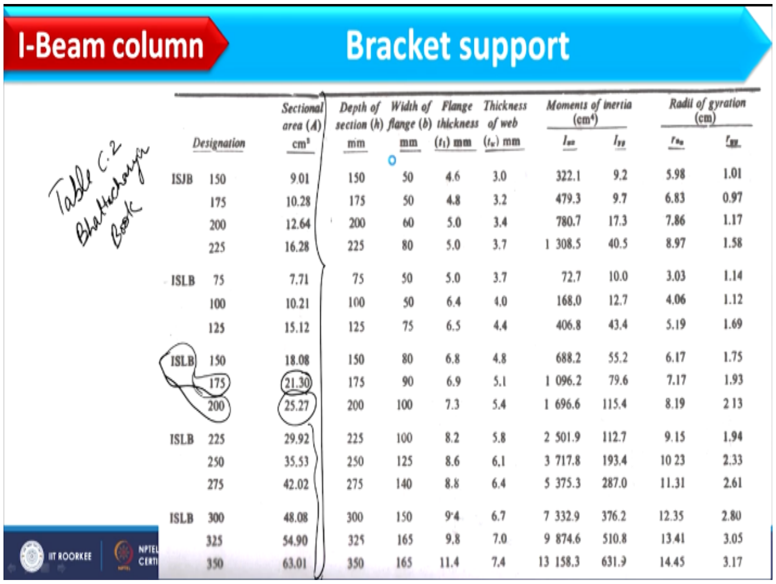

Designation		Sectional area (A) cm²	Depth of section (h) mm	Width of flange (b) mm	Flange thickness (t_f) mm	Thickness of web (t_w) mm	Moments of inertia (cm⁴) I_{xx}	I_{yy}	Radii of gyration (cm) r_{xx}	r_{yy}
ISJB	150	9.01	150	50	4.6	3.0	322.1	9.2	5.98	1.01
	175	10.28	175	50	4.8	3.2	479.3	9.7	6.83	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

Here this table is given for high beam column and this is basically table C2 in Bhattacharya book. So you can refer table C2 in B. C. Bhattacharya book for high beam. Now what happens let us say your minimum cross sectional area is coming as 20 okay and here if you refer here I have given sectional area for the structure. So as 20 cm square is the minimum value I can choose 21, 25 okay.

So in that case you can recommend ISLB 175 is the right column or ISLB 200 as the right column okay. You can choose further value but that would be very large okay. So you can use higher value which is near to the minimum value. However, other parameter I xx, I yy and hb all these value you can see from this standard. So here I xx, I yy and all this value you can see which are also shown in schematic which I have shown in last slide. So this is for high beam.
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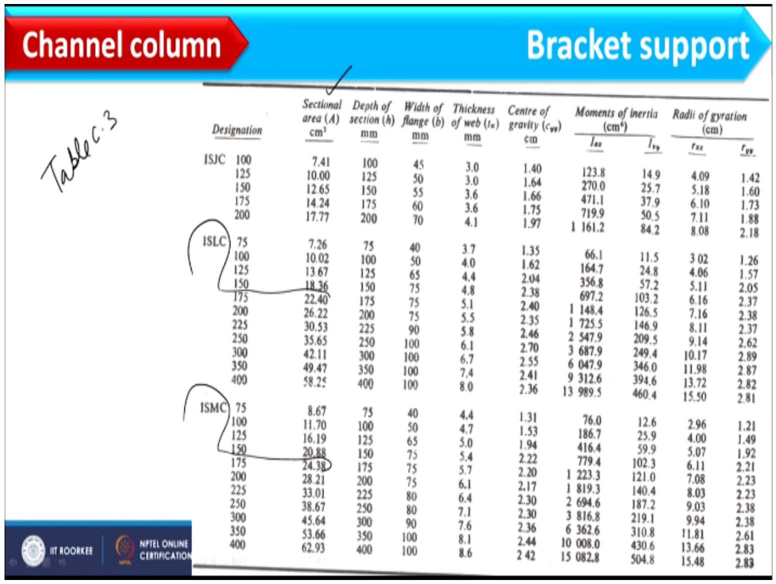

Designation		Sectional area (A) cm²	Depth of section (h) mm	Width of flange (b) mm	Thickness of web (t_w) mm	Centre of gravity (c_{yy}) cm	Moments of inertia (cm⁴) I_{xx}	I_{yy}	Radii of gyration (cm) r_{xx}	r_{yy}
ISJC	100	7.41	100	45	3.0	1.40	123.8	14.9	4.09	1.42
	125	10.00	125	50	3.0	1.64	270.0	25.7	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

Now we have for channel, so here the table C3 is there in the same book and again you can focus on sectional area for 20, you can see here I am having this okay. And here also I can have this okay. So you can refer ISLC 175 or value 200 like that or ISMC 175, 200 like that. So in that way you can choose the right column for bracket or lug support. Now we will see the design of bearing plate. Now what is bearing plate.

For design of support what we have discussed till now is the design of bracket, design of column. Now this column will attach to the foundation through bearing plate okay. One plate is attached to the lower section of the column and then that plate will be attached to the foundation through bolting or anchoring etcetera.

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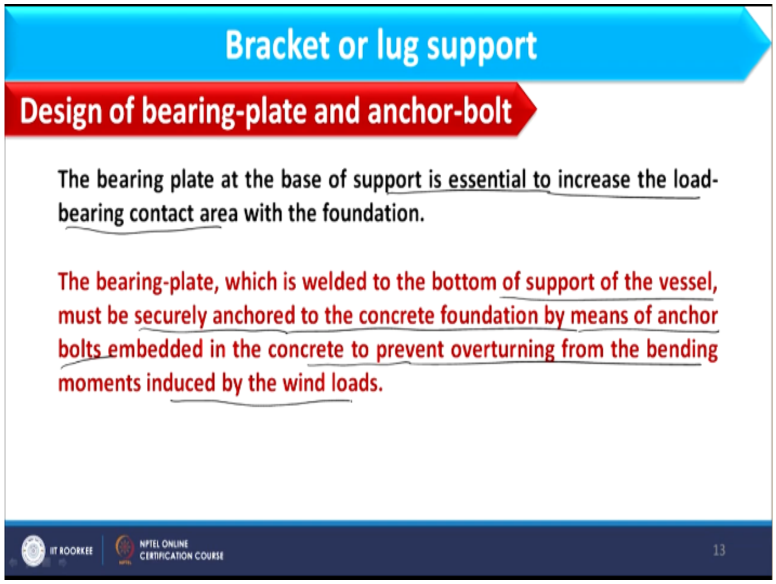

So bearing plate at the base of support is essential to increase the load-bearing contact area with the foundation. The bearing plate which is welded to the bottom of the support of vessel must be secured anchored to the concrete foundation by means of anchor bolt. So what is anchoring, what is anchor bolt that we will discuss. So at present please bear with this. We will discuss that in upcoming slides. And it is embedded to the concrete foundation to prevent overturning from bending movements due to wind loads.

So first we will see design of bearing plate and then we will focus on whether anchoring will be required or not required and what is the condition to check it. So let us start design of bearing plate.

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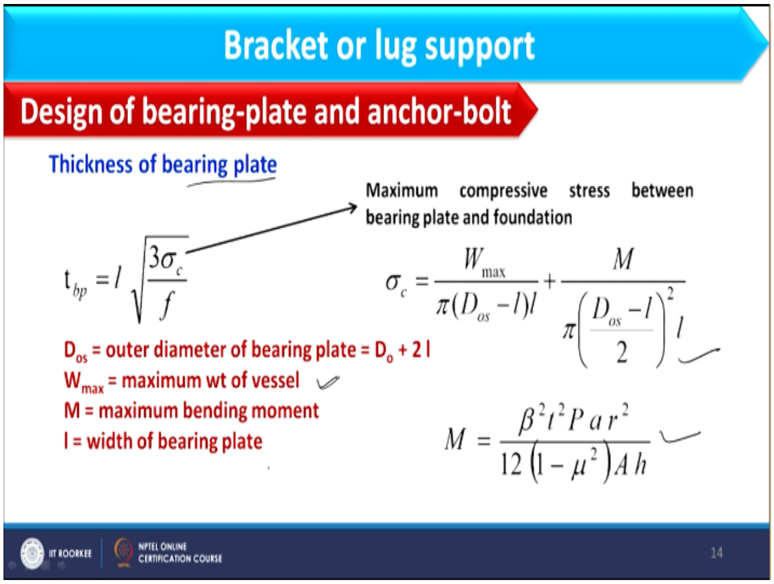

So thickness of bearing plate can be computed by this expression where t bp is equal to l root over 3 sigma c/f and sigma c is maximum compressive stress between bearing plate and foundation, which is given by this expression, where W max is the maximum possible load divided by Pi D OS - l * l + M/this expression okay. So here you see D OS is the outer diameter of bearing plate that is D O outer diameter usually we can consider this as outer diameter of shell plus 2l okay.

W max is the maximum weight of vessel, M is the maximum bending movement which is given by this expression and l is the width of bearing plate. So when we have the column at the lower side of this, we have the bearing plate of width l and then that bearing plate will be attached to the foundation.

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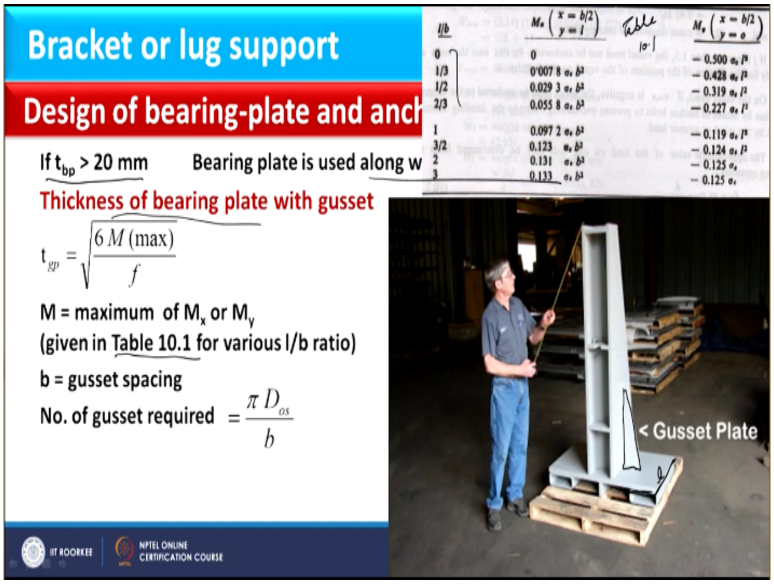

Further if bearing plate thickness is greater than 20 mm, bearing plate is used along with gusset plates okay. So here further we will use the gussets. So if you see this image, here basically this is the support, this is the column, and this is basically the bearing plate where this distance is given as l. So DO you can consider as outer diameter of shell because this will be aligned to shell okay. And if you see in this image, this particular section is called as gusset plates okay.

So if t bp is greater than 20 mm we need to consider the gusset plate and then we will consider thickness of bearing plate with gusset. So t gp will come as 6 M maximum/f. So here you should consider that initially we have calculated t bp which is the bearing plate thickness and if it is greater than 20 mm again we are calculating thickness of bearing plate when gusset is used. So t gp is not the thickness of gusset plate this is the thickness of bearing plate only when I am using the gussets.

So M is the maximum of M X or M Y that is given in table 10.1 that I will show, but this table is given in book B. C. Bhattacharya and b is the gusset spacing. So once I know the gusset spacing I can calculate number of gussets, Pi D OS/b okay and this is table 10.1 okay and here I am having l/b and M X and M Y. So whatever would be the ratio of l/b accordingly you can find out M X or M Y. And here in this expression you need to keep maximum values of these two, which is already mentioned over here.

So in this way you calculate the thickness of bearing plate. Now next point we will consider where anchoring is required or not.

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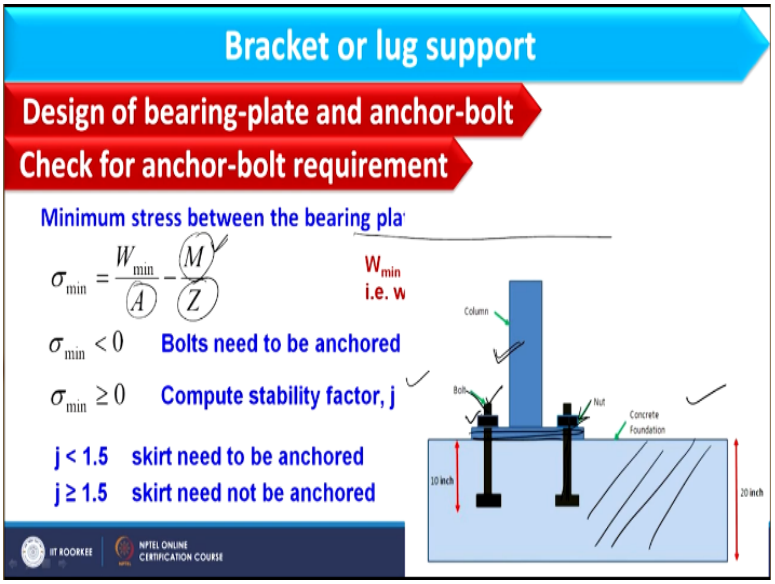

For that purpose minimum stress between bearing plate and concrete foundation should be computed using this expression, where sigma minimum is equal to W minimum/A-M/Z. Now why I am considering the minimum stress because when I am considering stability of the vessel as well as support the support will be most stable when it has the maximum load over this okay. It will not allow this to overturn.

However, when I am having minimum load to this it has more chances to overturn, therefore we are considering sigma minimum over here which is equal to W minimum. Now W minimum is what minimum weight of the vessel. Now how I can calculate minimum weight of the vessel, is weight of the shell and head that at least this much weight will be there. So the weight of shell plus weight of head we can consider as W minimum that is divided by A and – M/Z, this A and Z we can also see in the expression of sigma C okay.

First, the denominator of first term will be A and denominator of second term would be Z, and we have already seen how to find this. So in that case what happens when this weight would be minimum and then this M, M is basically the bending movement. So when this movement would be maximum it has more chance to overturn. So when sigma minimum would be less than equal to 0, bolts needs to be anchored okay.

And if sigma minimum is greater than or equal to 0 whether it is anchored or not that will be decided by stability factor j, which is given by this, where again I am using W minimum and M. So if j less than 1.5 that support need to be anchored. Here skirt is written mistakenly at this place support should come, so when j is less than 1.5 support need to be anchored and if j is greater than or equal to 1.5 support need not be anchored okay.

So let us see what is anchoring. Anchoring is basically when we bolt the material we first let the bolt enter into the concrete foundation and then we place the nut above to this okay. To make you understand the anchoring we will focus on a particular figure and that is this figure. Here if you see here we have this concrete foundation and in which the bolts are first entered okay and then these bolts are placed in the concrete foundation and this is basically the bearing plate and then we will put the nuts okay. So this is bolt and this is nut.

So anchoring means some portion of the bolt is inserted in the concrete foundation and small amount of or small part of that bolt is available at the top for entering bearing plate as well as to tight it through nut okay. So when it is anchored it means it will not allow support to overturn. I hope I am clear. So here we have discussed design of bracket and lug support along with bearing plates. So that is all for now, thank you.