Process Equipment Design
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Lecture –56
Distillation Column: Mechanical Design-1

Hello everyone. This is 12th week of the course Process Equipment Design and here we are in first lecture of this week. If you remember the 11th week as well as 10th week there we have discussed distillation column and in this week also we will cover the same topic that is distillation column. However, if you see 10th and 11th week lectures on distillation column there we have discussed process design about the distillation column.

And in this particular week we are going to cover the distillation column with mechanical design. So, what is basically the mechanical design? If you consider the forces which are working on the equipment, forces like that if we are considering the pressure. So, each distillation column will operate under certain pressure and what is its effect on the equipment. And if I am saying that equipment means if I am having the distillation column.

So, what would be the effect of the pressure on the shell of the distillation column, on the head of the distillation column or on the support of the distillation column. So, in this way what we consider? We consider basically the stress and strain which is generated in the equipment and in other word we consider this as mechanics of the material. When we have different forces and these forces are creating some stress or strain in the system.

And when these forces are creating some forces in the system. So, how that system sustain that pressure or sustain the force? So, how we should design the equipment so that it is able to sustain all these forces that we consider in mechanical design and therefore it is called as mechanics of the material also. So, let us start the mechanical design of distillation column. Now, if you consider the distillation column it is basically tall vessel.

Usually other equipment such as heat exchangers and you can say reactors etcetera all these are not very large in height. So, what we can say these are basically normal pressure vessels and when we consider the distillation column, absorption column or we can say the prilling tower all these are falling in the category of tall vessels. So, as far as mechanical design of distillation column is concerned we are basically going to discuss mechanical design of tall vessels in which distillation column will fall.

In this category you can consider distillation column also, but I am not going to design distillation column itself. So, let us start this. So, let us discuss what is tall vessels? As I have already told you that distillation column is a type of tall vessels, but first of all let us define what is tall vessel?

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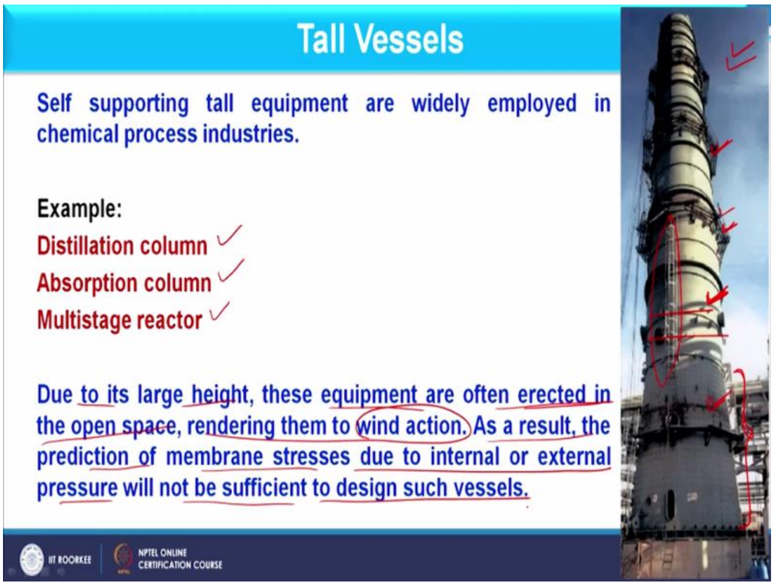

So, as far as this tall vessel is concerned this is basically the tall equipments and these type of vessels or tall equipment are basically self supporting. It means whatever conditions are generated in support of these vessels that is also a part of design because until unless support will not be strong vessel cannot remain stand. So, we have to consider all these factors such as the column itself as well as its support.

So, tall vessel when I am saying it means it is self supporting tall equipment and these are widely used in chemical processes. Such as very common is the distillation column we have absorption column also and multistage reactor. So, if you see here we have the image of tall vessel. So, that is very high in length however diameter of these type of equipment are not so large and when I have told you that it is self supporting it means this support.

So, along with this vessel we should also focus on the support of this vessel. So, if you see this image here we have different components like this section is basically the ladder and if you focus on this section as well as this section this we call as the platform which is available around its outer periphery. So that people can reach there for maintenance purpose etcetera. So, in this way we consider different components in self supporting tall equipment and all these component will be considered while designing of these vessels.

But as far as designing is concerned we will only focus on the mechanical aspect of this. Process aspect of distillation column I have already covered. So, due to its large height these equipment are often erected in the open space. When it is facing the wind action because vessel is available in open space where it is continuously facing the wind forces. So, in that case what will happen erection will take place at the outer surface of the vessel.

So, that also we have to keep in mind that how wind will affect the design of these type of vessel that will be the part of design also. So, once we have the wind action and erection takes place at the outer surface of the vessel as a result the prediction of membrane stresses due to internal or external pressure will not be sufficient to design such vessels. Actually what will happen when we consider these type of equipment where height is very large.

So, in that case we consider that the surface of the equipment or we can say different parts of the equipment, let us say, shell or head etcetera. So, all these part will work as a membrane because if we face the wind these are very small when we consider the wind these sections are very small as compared to wind action. So, in that case all these sections like shell etcetera it will be considered as the membrane.

So, whatever stresses are generated in membrane we consider that also because these will be generated due to pressure. Operating pressure either it is internal pressure or external pressure, but along with that many other factors we should consider and what are the stresses which are generated when different forces will act on that along with the membrane stresses.

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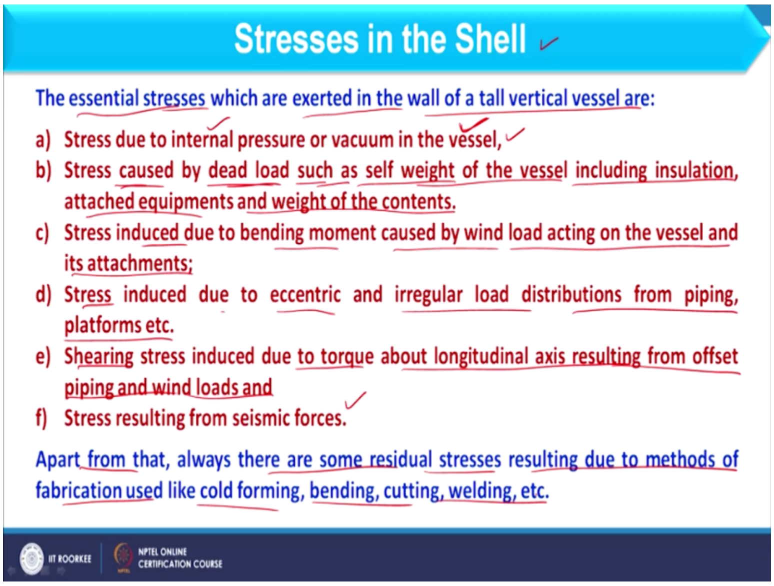

So, let us see that. So, as far as different stresses in shell is concerned we are going to discuss the essential stresses which are exerted in the wall of the tall vessel. So, first of all the stress due to internal pressure or vacuum in the vessel. So, when we consider that internal pressure and when we consider that external pressure is working. Internal pressure and external pressure vessels are defined as wherever we are having large pressure.

If I consider internal pressure it means internal pressure is more in comparison to outer pressure. So, in that case internal pressure will be more than the atmospheric pressure because outer section will have only the atmospheric pressure. In the similar line if I consider external pressure it means external we have atmospheric pressure or more than that maybe some means also, but internal pressure should be the vacuum pressure.

So, in that case more pressure is available at outer surface of the shell and so we consider that as external pressure vessel. But we have discuss that we are considering different parts where stresses are generated like shell and head and support, but here in this particular course we are considering stresses which are generating in shell and along with that in support. First one is the stress due to internal pressure or vacuum in the vessel.

Second is stress caused by the dead load such as self weight of the vessel including insulation attached equipment and weight of the content. So, if I consider the dead load of the equipment it means if I consider the equipment only. Let us say it is having only shell as well as head. So, this shell as well as head will have some load and because of this some stresses will be generated in the shell.

Along with this if we have different equipment. Let us say if I am considering distillation column so inside the distillation column either packing will be there or plates will be there. So, what will be the weight of that plate or packing that we will consider as the dead load. Along with that, each plate or packing will have some fluid also we consider that as a content.

So, weight of that content or weight of that fluid will also be counted because it will also create some stresses in the shell. So, all these we consider in dead loads and along with that we consider the attachment and what is that attachment? If you remember the previous slide there we have seen that ladder is there at the outer periphery, platform is there. So, all these will be counted as attachment.

So, we consider the weight of all these as dead load. Next is stress induced due to bending moment caused by the wind load acting on the vessels and its attachment. When I am having the tall vessel wherever side wind will come it will try to bend the vessel. From one side if wind is coming it will try to bend in this way. So, how it will work like if this is the tall vessel and from this side wind will come.

So, obviously it will try to bend it not that much, but bending will be there. So, in this section we can have tensile stress. However, in this section we consider the compressive stress. So, in this way stress will be generated due to bending moment which is created by the wind action. Further, we can have other stresses also such as stress induced due to eccentric or irregular load distribution from piping platform etcetera.

Actually what will happen when we consider different equipment which are attach with the tall vessel these equipment will produce some stress in the shell. To given an example if I consider the distillation column at the top of distillation column we have condenser. So, condenser will available only in one side of the column not around the periphery. So, in that case there must be some eccentric or irregular load in the shell because that equipment is available only at one side.

In the similar line if I consider ladder it will produce the stress whenever it will be attached. So, usually what we do? We basically place the ladder in circular way over the periphery.

However, that is not possible with the equipment such as condenser etcetera. So, due to these equipment some stresses will be generated and these stresses we count as eccentric or irregular loads.

Further, we have shearing stress induced due to torque about longitudinal axis resulting from offset piping and wind loads. So, what will happen when the wind will move in different direction so it will try to rotate that vessel however vessel is very strongly placed, but when it will not be placed properly some torque will be generated which we will try to rotate the vessel and that also we should consider in design.

So that in such situation shell or equipment should stand properly and then we have the stress resulting from the seismic forces because that is the natural condition when we have the earthquake however during that condition the vessel should remain stand. So, the stresses generated due to seismic forces or seismic condition that also we should include while designing the tall vessels.

So, all these stresses we have to count in designing the tall vessel. However, if you design the normal equipment such as heat exchanger, reactor etcetera there we consider the stresses generated only due to pressure, but not with other factors because these factors are very minimum in that case. However, these factors are prominent when we consider the tall vessel. So, we should count each of these stresses.

However, apart from that there are some residual stresses resulting due to methods of fabrication used like cold forming, bending, cutting, welding etcetera. So, these stresses are very minimum and we can neglect that however the stresses which we have just discussed those stresses are prominent and should be counted.

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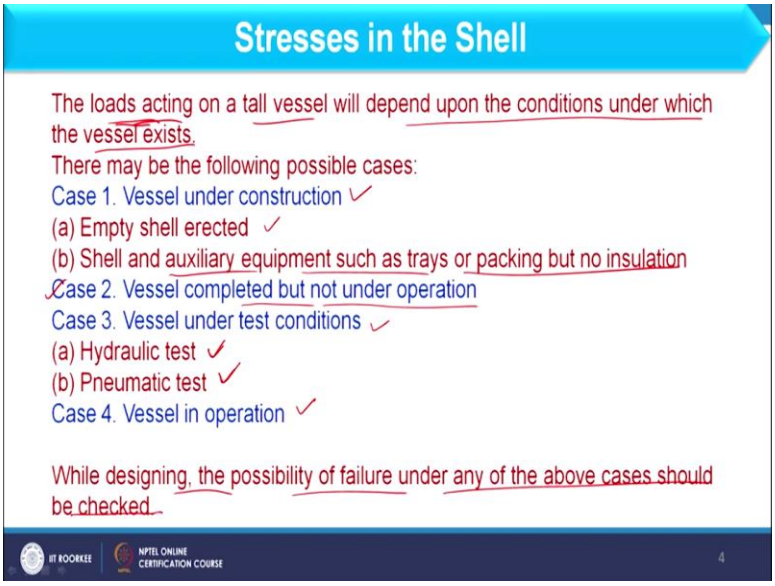

So, we can see that the loads acting on the tall vessel will depend upon the condition under which vessel exists and these conditions we can have with different cases. So, the case 1 is when vessel under construction it means empty shell erected where operation is not going on and no content is there. Shell and auxiliary equipment such as tray or packing, but no insulation.

So, these condition we can consider when vessel are under construction. Second case is vessel completed, but not under operation. Case third is vessel under test condition. So, in that case we have hydraulic test as well as pneumatic test and finally vessel in operation. So, while designing the possibility of failure under any of the above case should be checked. So, in this case we consider different stresses.

And if you focus on those stresses will consider each of this case either it is empty or it is at some operation. So, when it will be some operation pressure will be there and when it will be empty dead load will be there. So, accordingly each of these cases will be counted by stresses we have discussed.

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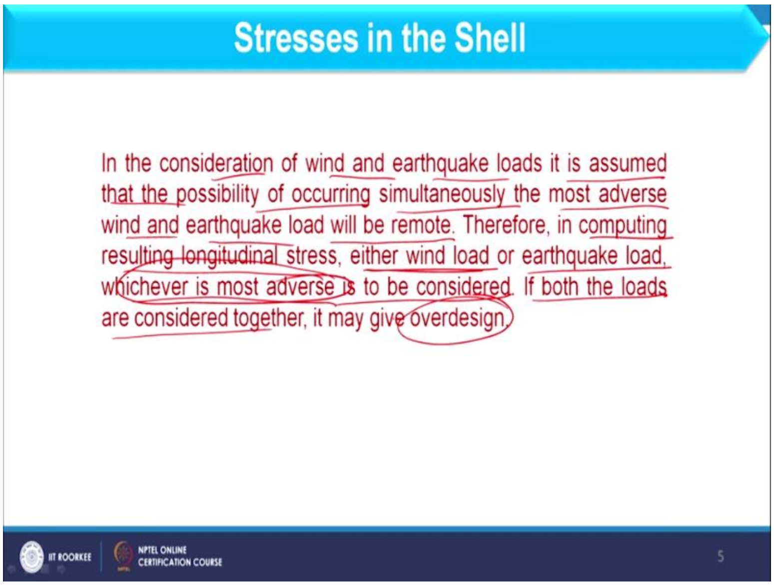

So, further we can see that in the consideration of wind and earthquake loads it is assumed that the possibility of occurring simultaneously the most adverse wind and earthquake load will be remote. And therefore in computing the resulting longitudinal stress either wind load or earthquake load whichever is most adverse is to be considered. So, this point we should consider while designing if both loads we consider we find that it is over design.

So, in that case we should consider the stresses generated due to wind action or due to seismic effect and whichever is larger among this that we should consider in designing. So, I hope you understand what is the meaning of mechanical design? Mechanical design means is when I am having all these stresses how should I choose the thickness of the equipment so that equipment should sustain all these stresses.

So, it means when I am speaking about mechanical design I am speaking about the thickness of the equipment and thickness of the part of the equipment. Let us say here I am considering the shell, I am considering the support. So, it means thickness of these individual section or parts of the equipment we calculate to complete the mechanical design. So, first of all we will see the stresses which are generated in shell due to pressure.

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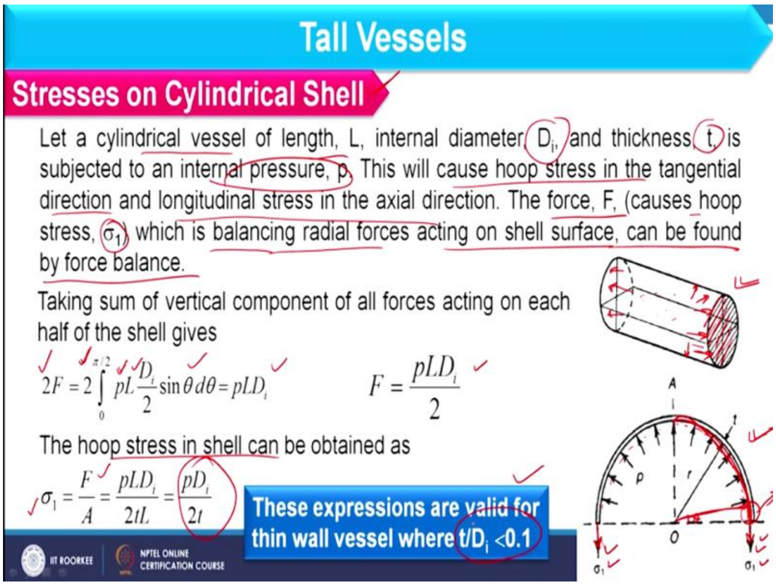

And these we consider as the stresses on the cylindrical shell. So, here we are considering a cylindrical vessel of length L with internal dia D i and the thickness t and it is subjected to pressure p. This will cause hoop stress in tangential direction and longitudinal stress in axial direction. So, if I am having this vessel which is basically the cylindrical in shape and this section is covered.

So, if I am having pressure inside this so what will happen this pressure will be acting in this way at the periphery. It means it will try to expand the periphery of it from inside. So, in that case it will generate the tangential stress which we also called as circumferential stress or the hoop stress and in the same line it will try to push this face also like this. It means it is due to the longitudinal stresses.

So, usually when we consider the cylindrical shell hoop stress as well as longitudinal stress both will be calculated. So, let us see that. The force F causes hoop stress sigma 1 which is balancing radial forces acting on the shell surface can be found by force balance. So, if you see here we have the schematic for the hoop stress where this sigma 1 and sigma 1 which is basically the tangential stress also it will work as a hoop stress.

So, sigma 1 how I can calculate the force we can make the force balance because force generated due to sigma 1 should be balanced by the force generated in this direction. So, let us make the force balance. So, if I consider 2 F means the force which his generated on this phase and on this phase. So, that is basically sigma 1 so that will be twice of the force which is acting on half section of this.

And for this we consider one angle and that angle is basically theta and we should consider this height also. So, that should be if I have this radius as R or D / 2 we consider D / 2 sin theta. So, that will be basically this section and when we consider the area of this section so that would be D / 2 sin theta into L that is along the length. So, we can consider that p and p is basically the pressure and the area should be L D i / 2 sin theta d theta when we integrate from 0 to pi / 2 like in this region.

So, solving this will give p LD i and so the force will be equal to p LD i / 2. So, hoop stress we can calculate like sigma 1 force divide by the area. So, when we resolve this we can find that hoop stress is p D i / 2 t. So, these expressions are valid for thin wall vessel where t / D i should be less than 0.1. So, in this way we consider hoop stress in cylindrical shell. Now we will focus on longitudinal stress on the cylindrical shell.

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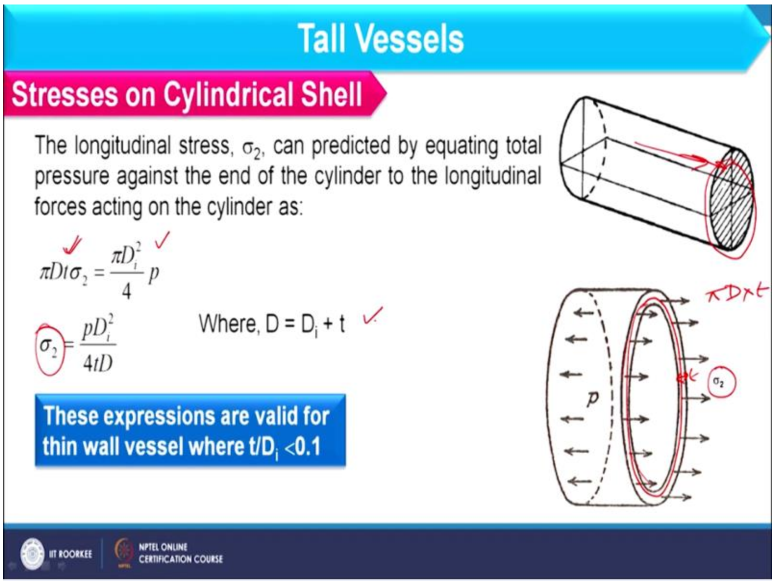

So, if we consider the longitudinal stress it will create sigma 2. So, that will be balanced by the forces which is generated in this shell. So, in that case pi D t into sigma 2. So, wherever this sigma 2 will act if I consider that mean dia so that pi D will be the periphery into t because t is the thickness of this wall. So, that will be the acting area into sigma 2 will be equal to the pressure which is generated over here and it will try to push it.

So, the working area for this pressure in longitudinal direction will be pi Di square / 4 that is the cross sectional area of inside. So sigma 2 we can consider pi Di square / 4 t D. So, in this case D is basically D i + t. So, in this way we can find out the longitudinal stress and hoop stress in cylindrical shell this will be used to design of tall vessel. So, let us focus on the longitudinal stresses which are generated by different factors we have discussed already.

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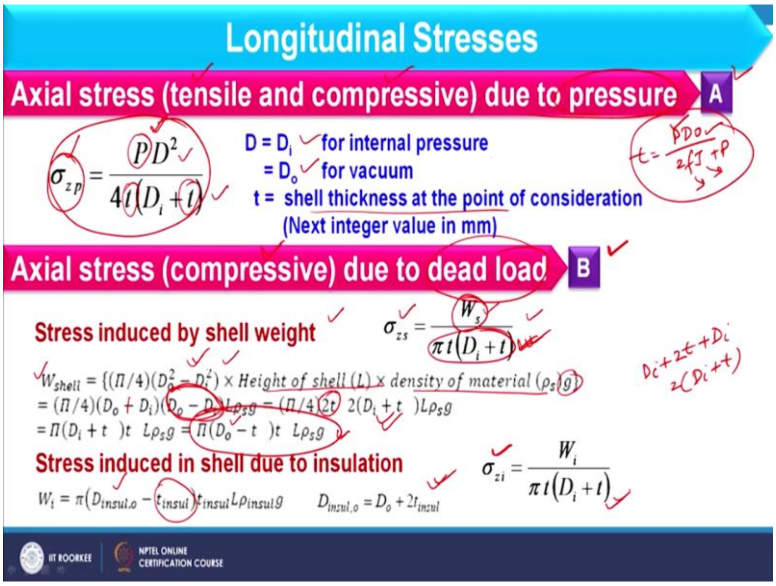

So, first of all we will consider the axial stress that is basically tensile or compressive and that should be due to pressure when it will be internal pressure we can have tensile stress because it will try to expand it and when I am having external pressure it will try to compress it so compressive stress will work there. And that we are counting as A because this is the first factor.

So, if you consider the stress generated due to pressure and hole expression if you see this is basically the longitudinal stresses generated in the shell which we have just discussed in previous slide. So, here P is basically the design pressure D is D i for internal pressure and D 0 for vacuum and in this case t is basically the shell thickness and Di internal diameter + t. So, this t is basically the shell thickness and how you can obtain that considering usual expression of pressure vessel.

Such as t should be equal to PD 0 / 2 fJ + P. So, this P is the design pressure D 0 outer diameter of the shell f is the allowable stress of the material J is the joint efficiency factor. So, considering this you will calculate that t and this t should be used over there to find out the stress which is generated in the shell due to pressure. So, in that way we calculate the longitudinal stress.

Next is the axial stress due to dead load and that we consider as compressive. Why because wherever I am having the dead load it will try to compress the shell so in that case tensile will not work only compressive will be there. So, this is basically parameter B. So, here we should consider stress induced by shell weight and that we can consider like this sigma z s which is equal to W s / pi t D i + t.

So, this W s is basically weight of the shell and if you focus on this what is this? D i + t is the average dia pi D i + t is the average perimeter into t. So, this is basically the area where this W s will work. So, in that way this W s is basically the load which is acting on the shell. So, this will be corresponding to the shell only. So, let us see how we calculate the weight of the shell that is nothing, but the weight of the material.

So, pi / 4 D o square – Di square weight of the shell and density of the material and g. So, we can further elaborate this and here one should be D 0 + D i and second is D 0 – D i because when we expand this. So, L rho s g and when we can solve this if you consider D 0 – Di that should be 2 t. And D 0 + Di should be written as D i + 2 t + D i. So, in that case we can consider 2 D i + t.

So, that is given over here. When we further resolve finally we can have the weight like this pi D 0 – t into t L rho s g. So, that is the weight of shell and similarly we can consider weight of the insulation also the same expression, but instead of outer diameter of the shell we can consider outer diameter with insulation and t insulation should be considered over here. So, that you can consider. So, total stress generated due to this is W i / pi t D i + t.

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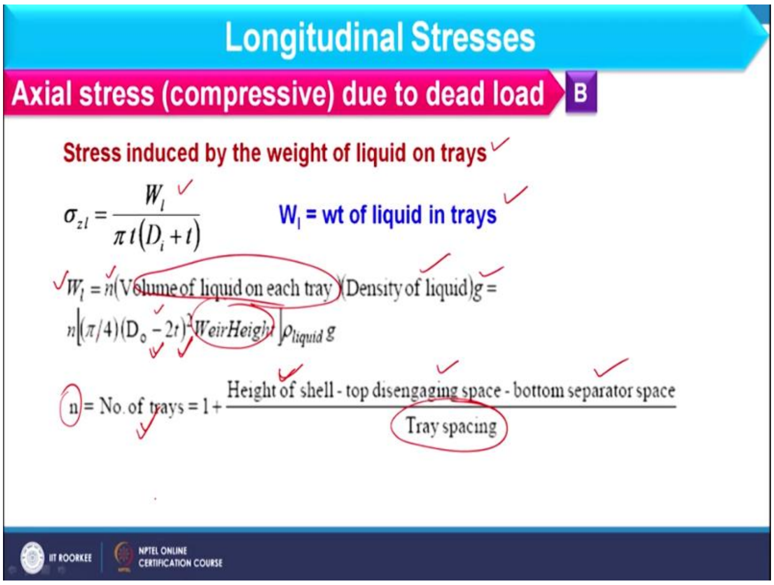

Next, we have stress induced by weight of the liquid on the tray if I am considering the tray column. So, in this case this is the stress W l / pi t D i + t and W l is the weight of liquid over the tray. And how we can calculate W l that should be equal to n volume of the liquid on each tray into density of the liquid into g. Further, n is the number of tray we can see how it will be calculated pi / 4 D 0 square – 2 t square.

So, this is nothing, but D i square into weir height because over the plate wherever the liquid will be there that will be equal to the weir height and accordingly we can consider the hold up over the plate. So, internal diameter square into height will be the weir height and pi / 4 we consider. So, basically what I am considering that hole internal diameter will have the liquid I am not considering here the downcomer section because that will be small in comparison to hole plate.

So, next is how we can find out number of trays. So, that will be 1 plus height of the shell minus top disengaging space minus bottom separator space because there are some extra space which we consider at bottom and top of the column either it is distillation or absorption, but here we are considering for distillation. So, we consider the parameters accordingly and that should be divided by tray spacing. So, it will give the number of trays and so you can find out weight of the liquid over the tray.

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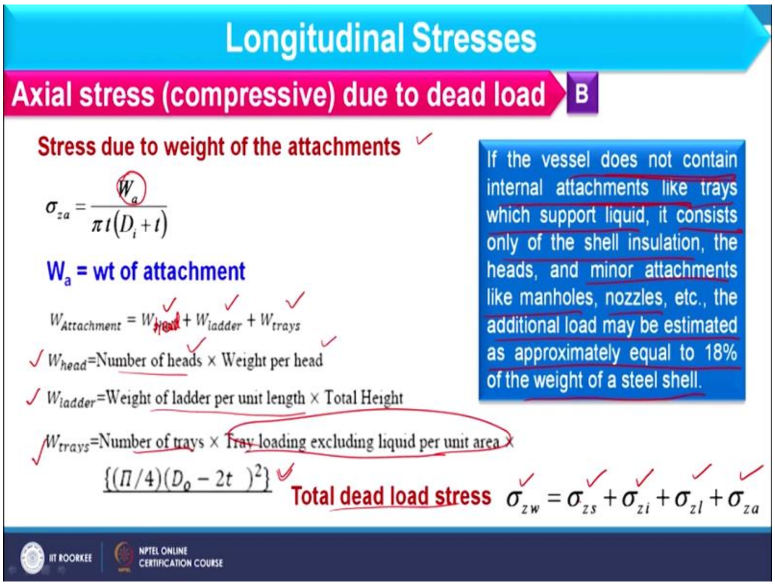

In dead load we have other factors such as stress due to weight of the attachment. So, this is basically total load of the attachment and it includes weight of head. So, this is basically head not the shell. Along with this, we have weight of ladder we can consider weight of trays because these are internal and external accessory which are attach to the equipment. So, weight of head is basically number of heads into weight per head.

So, number of heads will be 2 only, weight of ladder per unit length into total height and in this case this height will include the height of support also because when we place the ladder it should start from the ground. And the weight of tray is number of trays into tray loading excluding liquid per unit area into area of each tray so that is pi / 4 D i square. So, in this way you consider all attachment.

And when we consider overall dead load it should be total dead load stress that is sigma z w it should be due to shell, due to insulation, due to liquid and due to attachment. So, if the vessel does not contain any internal attachments such as tray which support liquid it consists only shell insulation the head and minor attachments like manhole nozzle etcetera. So, in that case the additional load maybe estimated as approximately equal to 18% of the weight of the steel shell.

So, in that way we consider different dead loads and this section we will continue in next lecture also where we will complete the longitudinal stresses generated in the shell. So, that is all for now. Thank you.