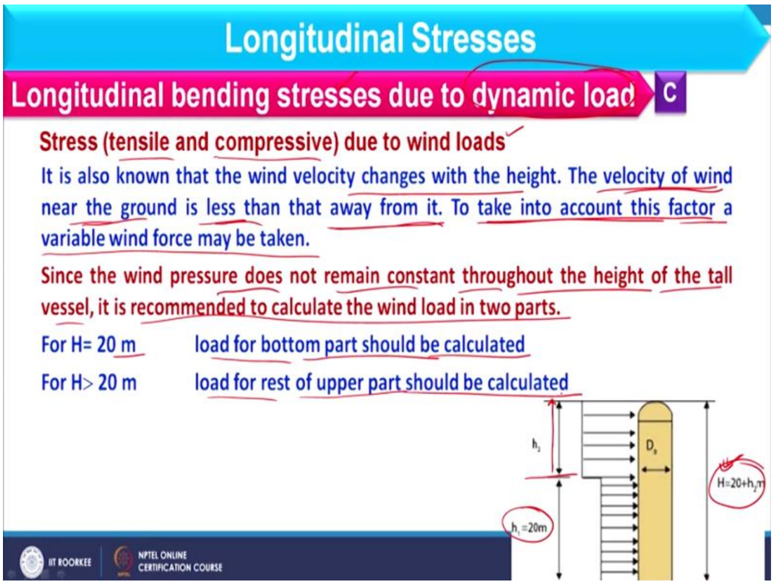
Process Equipment Design
Prof. Shabina Khanam
Department of Chemical Engineering
Indian Institute of Technology – Roorkee

Lecture –57
Distillation Column: Mechanical Design-2

Hello everyone. Welcome to the 2nd lecture of the week 12 of the course Process Equipment Design and here we are discussing the mechanical design of distillation column or the mechanical design of tall vessels. So, in the last lecture we have started this topic where we have considered the longitudinal stresses generated in the shell due to internal pressure and due to dead loads.

So, we are continuing the same stress that is longitudinal stress in shell considering different factors.

(Refer Slide Time: 01:01)



So, let us start this. So, here I am considering longitudinal bending stress due to dynamic load. So, what is dynamic load? Dynamic load means which is continuously changing along the length if that load is changing we consider that as a dynamic load such as wind load as well as seismic load. So, let us focus on the wind load. So, stress due to wind load and that should be tensile and compressive both because when I am having the tall vessel and wind effect will be there obviously it will try to bend this.

So, at this side we can have the tensile stress and at this side we can consider compressive stress. So, both of these stresses will be counted together. So, as far as wind loads are concerned this you should understand that it is changing along the height of the vessel. So, if this is happening the velocity of the wind near the ground is less than that away from it. To take into account this factor a variable wind force maybe taken.

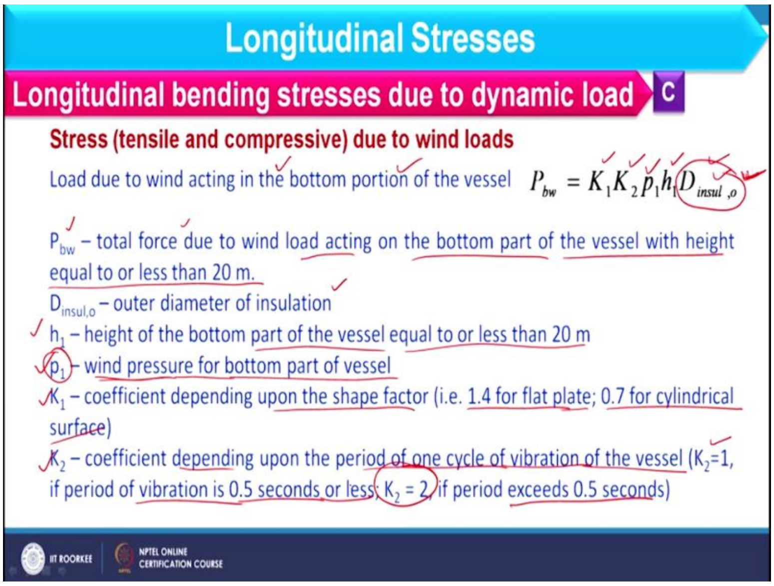
So, that we can understand that at the bottom the wind effect will be less however at the top it will be maximum. So, along the length it is changing. So, we should consider that factor while designing the tall vessel also. So, how we consider that? So, that you can understand from this diagram where bending movement diagram is shown and wind load will be applicable from this side.

So, in this way you can see continuous variation of the bending moment in tall vessel. So, further we can discuss that wind pressure does not remain constant throughout the height of the tall vessel. It is recommended to calculate wind load in two parts. As it is not constant from ground to the top we usually consider this effect in two different parts in the vessel. The first part is when I am having height up to 20 meter.

So, you can see total height of the vessel is 20 + h 2 meter and this height we can count from the bottom not the height of the shell. So, it will include height of the support also. So, we can consider two parts in this vessel. First is up to 20 meter height and second is beyond 20 meter height. When the height is up to 20 meter we consider load for bottom part should be calculated.

So, in that case we consider the bottom part of the vessel and beyond that, that is when height is more than 20 meter load of rest of the upper part can be calculated and this we consider as upper part. So, usually in two parts we calculate the complete wind load and stress generated due to that. So, let us see how to count the wind load.

(Refer Slide Time: 04:45)



So, the load due to wind acting in the bottom portion of the vessel can be given by this expression that is P b w = K 1 K 2 p 1 h 1 and D insulation outer because when the wind will be there it will affect the outer most layer of the vessel. So, at that side usually we have insulation. So, as far as P b w is concerned this is the total force due to wind load acting on bottom part of the vessel with height equal to or less than 20 meter.

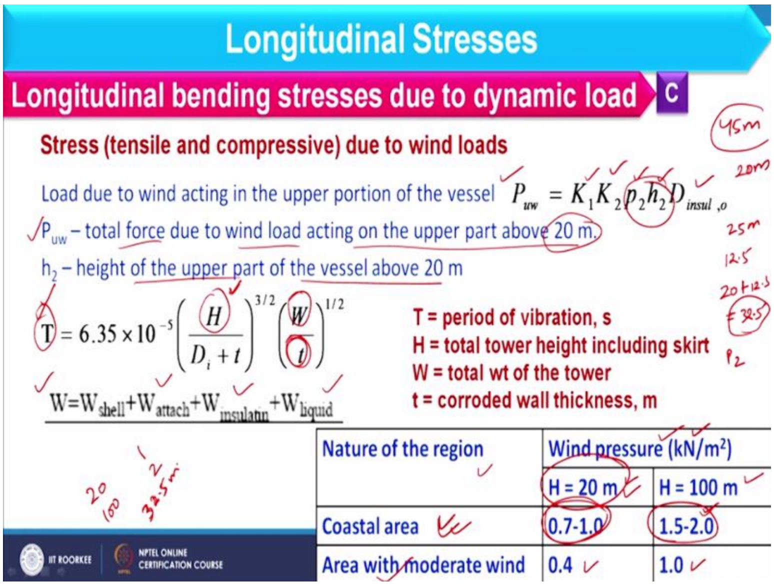
So, that is the total wind load up to 20 meter height. So, that is basically the total force due to wind load up to 20 meter height. D insulation o is the outer diameter of the insulation that we have already discussed h 1 is the height of bottom part of the vessel equal to or less than 20 meter. Let us say if your vessel is less than 20 meter we do not consider upper part in that and then it will not be counted as tall vessel.

So, if the height of the vessel is 20 meter or less than that we consider h 1 as the height of the bottom part and that you should understand this we are counting from the foundation or from the bottom. P 1 is basically wind pressure for bottom part of the vessel. How this p 1 should be counted that we will see and next we have K 1 coefficient it depends on the shape factor like 1.4 for flat plate, 0.7 for cylindrical surface.

So, usually tall vessels have cylindrical surface or cylindrical shell. However, in some case if I am having the flat plate also like rectangular type of vessel in that case K 1 should be counted as 1.4. Next, we have K 2 factor and this coefficient depends on the period of one cycle of vibration of the vessel. So, this we consider as the period of vibration because of wind action vibrations should be there so that we should consider as design coefficient.

And in that case K 2 should be 1 if period of vibration is 0.5 seconds or less than that and if period of vibration exceeds 0.5 second K 2 should be 2. So, accordingly we can have total force which will be increased when we have larger period of vibration and how this period of vibration will be considered that we will see.

(Refer Slide Time: 07:44)



So, in this way we can count the load at bottom part of the vessel and now we will discuss load at upper part of the vessel. So, this can be considered as P u w K 1 K 2 p 2 h 2 D insulation outer. So, expression is same only p 2 h 2 will differ. So P u w is the total force due to wind load acting on upper part and that should be beyond 20 meter, h 2 is the height of the upper part of the vessel above 20 meter.

So, let us say your total height is 45 so h 2 should be 25 now and this expression I am having to find out period of vibration where T is the period of vibration. H is the total height and this includes the height of the support also and this W is the total weight of the vessel and t is the thickness of shell of the vessel. So, as far as total weight is concerned that should be weight of shell plus weight of attachment, weight of insulation and weight of liquid all these weight we have to consider.

So, if period of vibration is more than -0.5 K 2 should be 2 otherwise it should be 1. Now, let us see how to find out wind pressure. So, it will depend on the region they are operating in. Let us say if I am having the coastal area where wind velocity or where wind pressure is more. So, here I am having the wind pressure values, height up to 20 meter we can consider 0.7 to 1 kilo Newton per meter square wind pressure.

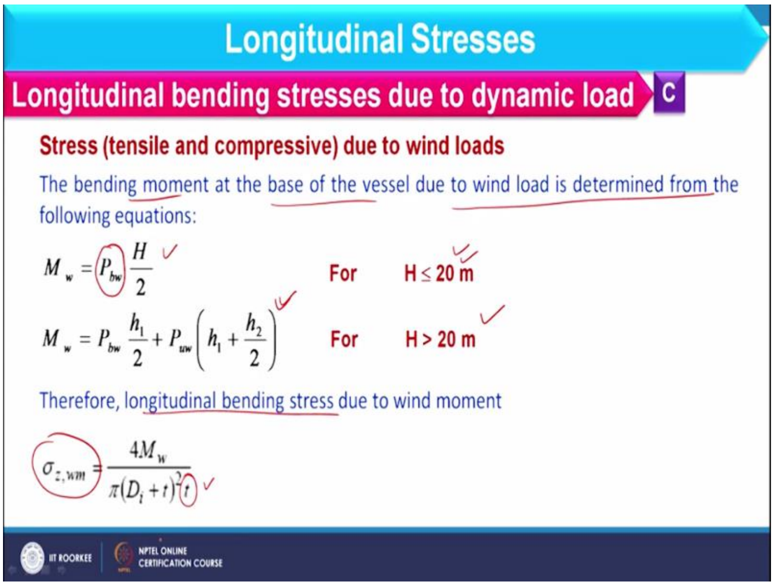
However, when we design it we always design for extreme condition. So, if you are operating in coastal area wind pressure you should consider as 1 only up to height 20 meter. Now beyond that height we can consider wind pressure between 1.5 to 2. So, in that case also you should consider the maximum or the extreme condition and if I am having area with moderate wind then up to 20 meter height, value should be 0.4 and beyond that it should be 1.

Now, how we count this p 2. P 2 is basically the wind pressure at upper part. However, if I consider the upper part in upper part also wind pressure will keep on changing. So, how I should find out the p 2 value because p 1 is very simple up to 20 meter height, value is already given, but how we should take the value for p 2 because it will depend on h 2. So, in that case we should consider p 2 at middle of upper part.

To give an example let us say if height is 45 meter and this should be from the bottom. So, 20 meter height I can already consider over here. Now beyond that it is 25 meter so middle of that should be 12.5. So, total height from the bottom should be 20 + 12.5 so that should be 32.5. So, 32.5 will be the height from the bottom at middle of upper section. So, how I can find the p 2 value that should be through interpolation.

Let us say for 20 meter height if I consider the coastal area value is 1 kilo Newton per meter square up to 100 meter height we can consider wind pressure as 2. So, what should be the wind pressure at 32.5 meter? So, this calculation you can carry out and interpolation will give the p 2 value at middle of upper section. I hope this calculation is clear to you.

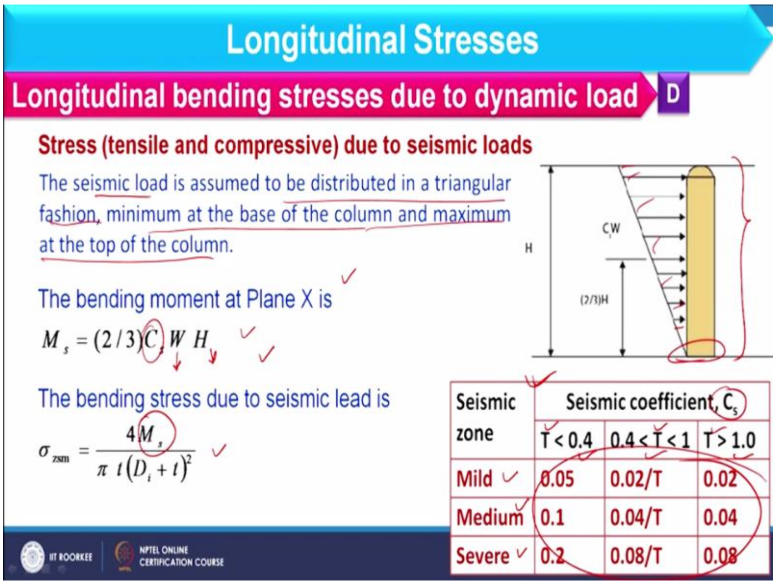
(Refer Slide Time: 12:25)



So, once I am having the wind loads at bottom and upper section of the column we can consider bending stresses. And to consider bending stress we will first focus on bending moment. So, the bending moment at the base of the vessel due to wind load is determined using this equation where H is less than or equal to 20 meter and therefore here we have counted P b w.

In the similar line if H exceeds 20 meter we can consider this expression to find out bending moment and accordingly whatever moment will be we can consider longitudinal bending stress due to this expression where it is denoted as sigma z wm. So, that will be equal to 4 M w / pi D i + t square into t. So, in this way we can count longitudinal bending stress in shell. So, further in dynamic load we will consider another load and that is generated due to seismic load. So, let us discuss that.

(Refer Slide Time: 13:44)

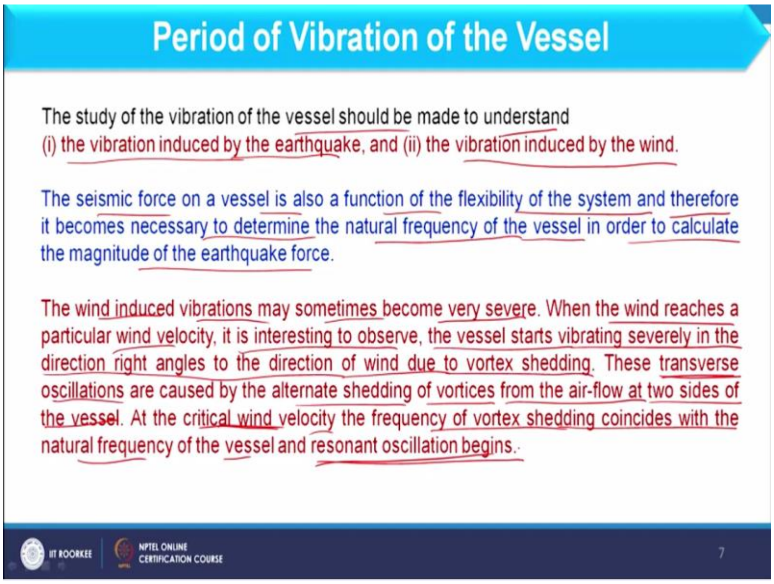


Seismic load is assumed to be distributed in triangular fashion minimum at the base of the column and maximum at the top of the column. So, if we consider the seismic load it means when earthquake will be there it effect will be less at the bottom. However, it will keep on increasing at the top. So, in this way we can consider the seismic load which is moving in triangular manner from bottom to top.

So, bending moment due to this at plane X is given by this expression and that is basically 2 / 3 C s W into H. W is the weight of shell and H is the height of the shell from the bottom and C s is basically seismic coefficient which you can find from this table depending upon the seismic zone either mild, medium or severe. And if you see seismic load depends on this T also and this T is basically period of vibration.

So, in this way we can consider different zones and accordingly you can choose the value of C s. Now, once you have the bending moment due to seismic load you can find out bending stress due to seismic load. So, the same expression as we have discussed with the wind, but here we have M s value not M w. So, in this way we can count the dynamic load in the shell and that is basically cause bending stresses.

(Refer Slide Time: 15:28)

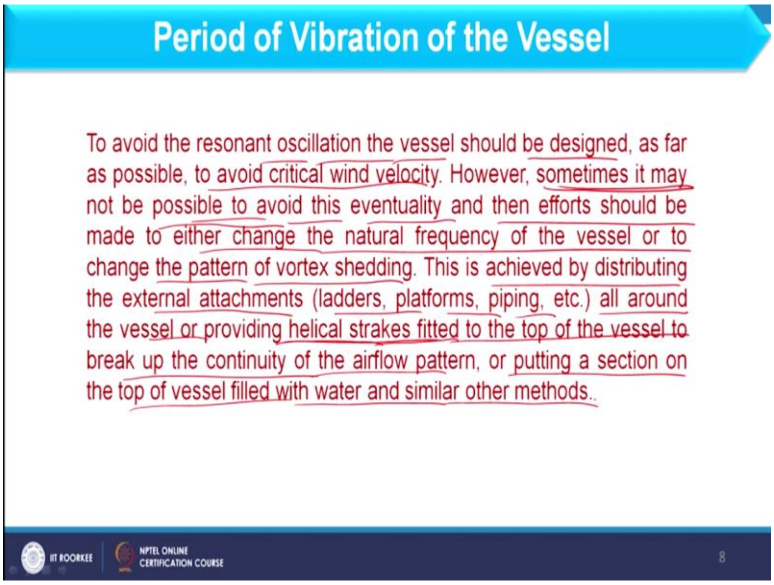


And now we will discuss few points about period of vibration of the vessel. So, usually period of vibration we can consider in two way. First is the vibration induced by the earthquake and second vibration induced by the wind. The seismic force on the vessel is also the function of the flexibility of the system and therefore it become necessary to determine the natural frequency of the vessel in order to calculate the magnitude of earthquake force.

So, in this way you should consider the seismic force on the vessel. Further, wind induced vibrations may sometimes become very severe when the wind reaches the particular wind velocity it is interesting to observe that the vessel starts vibrating severely in the direction right angle to the direction of the water due to vortex shedding. So, what is vortex shedding? When I am having the vessel and wind will come from here and there with high velocity it will basically try to bend along the length.

So, that we consider as the vortex shedding. So, these transverse oscillations are caused by alternate shedding of the vortices from airflow to two sides of the vessel. If vessel will be there it can move from this side or it can move from this side also. So, in this way it will be considered. Further, at the critical wind velocity the frequency of vortex shedding coincides with the natural frequency of the vessel and resonant oscillation begins. So, in this way continuous oscillations will be there when we have large wind velocity.

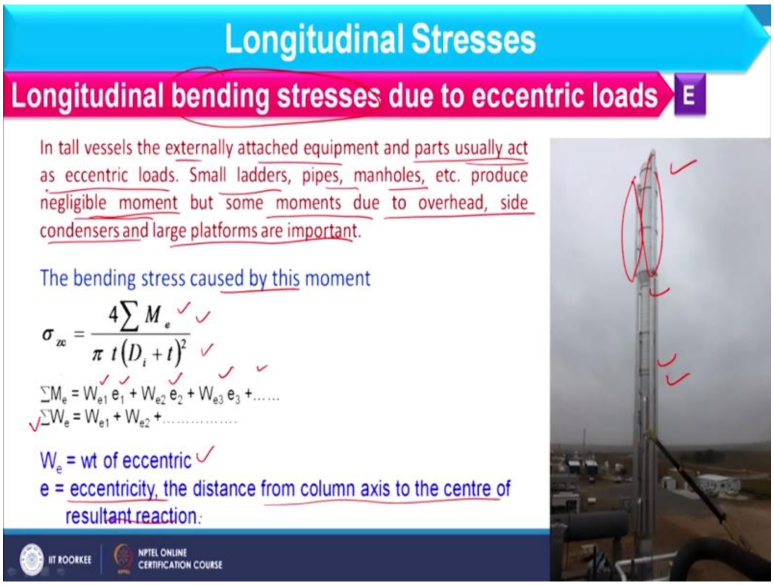
(Refer Slide Time: 17:33)



So, we have to consider period of vibrations accordingly and we have some more points about this that to avoid the resonant oscillation of the vessel because this is not a favorable condition for the vessel. We should design the vessel in such a way so that we can avoid the critical wind velocity. However, sometime it may not be possible to avoid this eventually and then effort should be made to either change the natural frequency of the vessel or to change the pattern of the vortex shedding.

This is achieved by distributing the external attachment that is ladder platform, piping etcetera all around the vessel or providing helical strakes fitted on the top of the vessel to break up the continuity of the air flow pattern or putting a section on the top of the vessel filled with water and similar other method. So, in this way we can avoid the oscillation in the vessel, but period of vibration is very important parameter to consider. So, apart from the dynamic load we can have other load also that is due to eccentric.

(Refer Slide Time: 18:55)



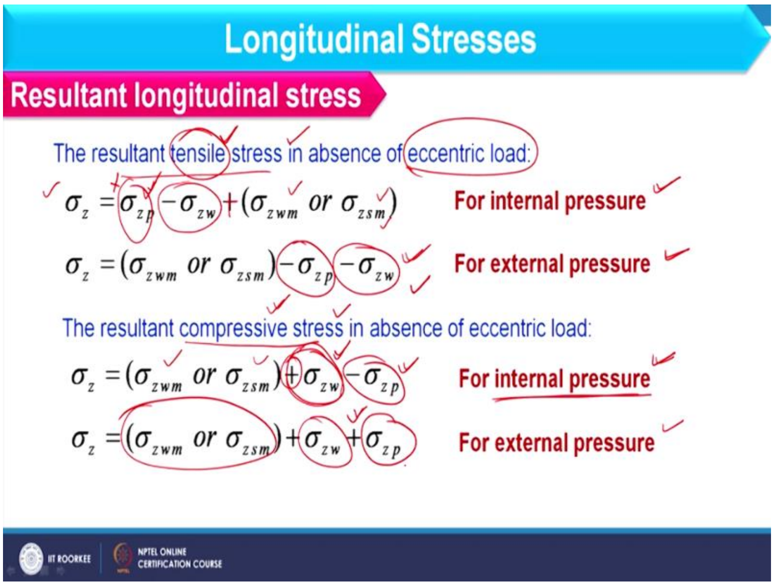
So, we consider that as eccentric load and because of that bending stress is generated in the shell. So, in the tall vessel externally attached equipment and parts usually act as eccentric load, small ladder pipes, manhole etcetera produce negligible moment, but some moment due to overhead, side condenser and large platforms are important. So, usually we neglect this part that is stress generated due to eccentric load.

However, if we have very specific equipment at one side only or we can say the heavy platform at one side only then we should consider this. To give an example if I am having this tall vessel and if you consider here we have different attachments. So, because these attachments are not uniform around the periphery it can have eccentric load. So, bending stress caused by this moment is sigma z e that is equal to 4 summation Me divided by pi t D i + t square where sigma M e is basically weight of equipment and distance from the center to the equipment and similarly we can consider for other equipment also.

And total W e is basically weight of the eccentric and e we consider as eccentricity that is distance from the column axis to the center of the resultant reaction. So, in this way we consider the eccentric load and stress generated due to this. So, as far as different stresses are concerned in longitudinal direction in the shell we have consider stress generated due to internal pressure, due to dead load, due to dynamic load that is wind action as well as seismic load and we also consider that due to eccentric load.

So, now we will consider the resultant longitudinal stress in the longitudinal direction of the shell. So, let us see how to consider this?

(Refer Slide Time: 21:24)



So, first of all I am considering resulting tensile stress and in this I am not accounting eccentric load. So, in this case we have sigma z as the resultant tensile stress and this is the expression and this expression is valid for internal pressure. So, if I am considering tensile stress which is generated in the shell it means it will try to expand. So, if I am having internal pressure in that case what will happen?

Internal pressure will try to expand the shell. In that case tensile stress will be generated in the shell and therefore stress generated due to internal pressure we consider that as sigma z p and that should have the positive value because tensile stress we are counting and this will give the tensile stress in the shell. And next is stress due to dead load that is sigma z w. So, what will happen?

Dead load will always be compressive it will never be tensile. So, if I am considering the tensile stress sigma z w should be negative. I hope it is clear and then we can add sigma z w m a and sigma z s m that is due to wind and due to seismic. So, if you consider the previous slide we have discuss that we consider either of these two because addition of these two will overdesign the system.

So, we will calculate both, but we will consider the maximum among these two and that we consider always as positive because when this will happen at one side of the column we have tensile stress another side we have the compressive stress. So, we consider the extreme condition and so we consider this positive with tensile stress as well as with compressive stress.

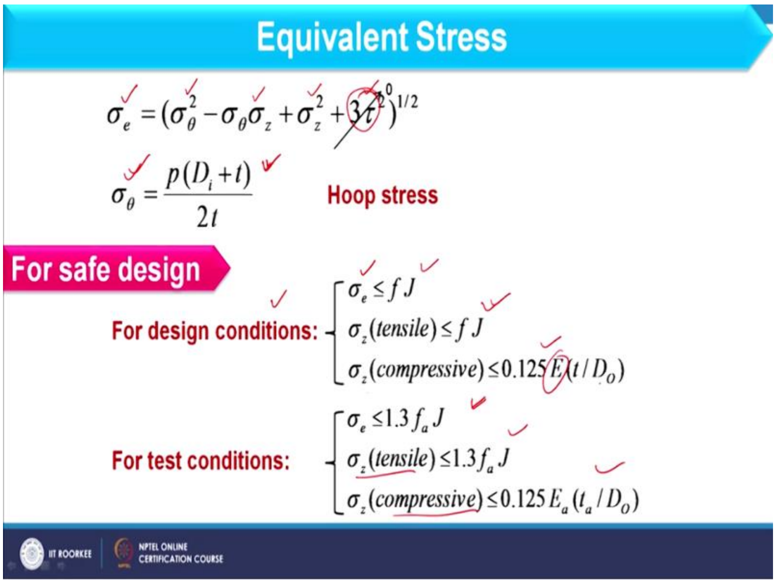
Next, if I am considering external pressure so what will happen? So, if you see when I am considering external pressure it means it will try to push or it will try to compress the shell in that case the stress generated due to pressure will be negative because I am considering tensile, but it will give the compressive stress. So, in that case sigma z p would be negative, sigma z w will always be negative because it will be compressive and I am considering tensile stress.

In this way we can consider resultant tensile stress. In the similar line, I can consider compressive stress resultant. So, when I am having the internal pressure the stress generated due to wind or seismic will always be positive as we have discussed previously, sigma zw is basically stress generated due to dead load. So, it will be compressive and we are considering compressive stress also so this will be positive.

And sigma z p in internal pressure this internal pressure we will try to expand the shell and therefore it will create tensile stress and therefore it will be considered negative when I am considering resultant compressive stress. In the similar line, if I am having external pressure this factor will always be positive, dead load will always be positive and stress generated due to pressure will also be positive because external pressure will give the compressive stress in the shell.

So, in this way you can find out resultant longitudinal stress. Now, we will consider the equivalent stresses in the shell.

(Refer Slide Time: 25:29)



So, as far as equivalent stress is concerned that can be given by this sigma e which will be equal to sigma theta square – sigma theta sigma z + sigma z square + 3 tau square and whole power 0.5. And in this expression we can neglect this term because this tau is basically the torque which is generated due to wind and it will try to rotate the column or rotate the vessel and that is very negligible.

So, we can neglect this. Secondly, this sigma theta is basically the hoop stress and we also have derived the expression related to this previously and we also have derived expression related to this in the last lecture you can refer that. So, for safe design we should consider some design conditions such as sigma e that is equivalent stress should be less than or equal to f J.

Sigma z tensile should be less than or equal to f J sigma z compressive should be less than or equal to 0.125 E t / D 0 and for test condition we can have sigma e which should be less than or equal to 1.3 f a J. Sigma z tensile should be less than or equal to 1.3 f a J and sigma z compressive should be less than or equal to 0.125 E a t a / D 0. So, this E is basically the elasticity of the material.

So, you see in this way we consider different stresses and we can meet the design conditions as well as test conditions and accordingly design of tall vessel can be done. All these stresses which we are counting over here as well as this design condition as well as test condition it will be more clear when we will discuss this with the help of example. So, here I am stopping this lecture that is all for now. Thank you.