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

Lecture 09
Compensation of Opening

Welcome to the fourth lecture of second week of the course equipment design mechanical aspect. In this lecture, we will discuss compensation for openings. So, basically this lecture is divided into 2 parts, lecture 4 and lecture 5. In lecture 4, we will discuss what is compensation, where it is required and what are the expressions to compute the compensation and in next lecture, we will solve a few examples related to this. So, let us start the discussion on compensation for opening.

So, first of all we will discuss what is compensation and what is the necessity of this. So, basically when we are designing any pressure vessel, it requires some openings, okay.

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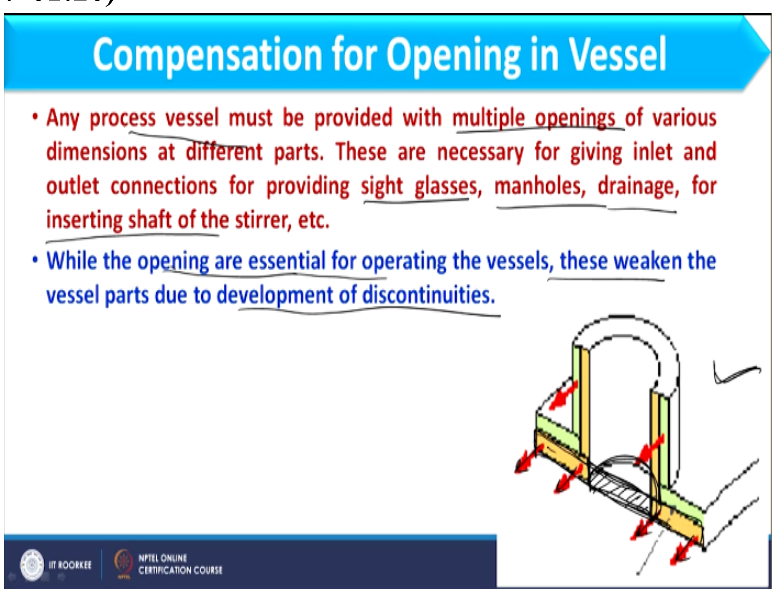

So, that opening, let us say it is used for feed inlet, feed outlet or we may use that for sight glass, so for all this purpose, we need to create some opening in a vessel, so that opening usually circular or that may be rectangular. So, when we have any opening, it means we are cutting a particular section in a regular sheet.

So, once we have that cut, it means that creates discontinuity in whole sheet, okay. So, any process vessel, we are discussing about the process vessel or pressure vessel, must be provided with multiple openings, okay. So, there may be one opening and there may be more than opening. Usually we consider more that one opening because at least I am having inlet and outlet nozzles. So, to insert that nozzles, we need to create the opening in a metal sheet, okay. That may be used for sight glasses, manholes drainage as have discussed already or inserting shaft of the steerer, etc.

So, in this way, we require opening in a regular sheet. Now, what happens when we create opening in a metal sheet. You must experienced that, usually whatever clothes we are wearing, in that clothes , sometimes we have small holes. For example, if this is the cloth, some hole will be created over there and when I put some stress or some force into this, most likely it will start tearing from that hole only. It means what? That hole makes this cloth weak, okay. So, in the similar line, when I am discussing about opening in a metal sheet, these openings make the metal sheet weak in comparison to regular sheet, okay.

So, while openings are essential, we cannot deny the opening because that is required, that is compulsory for operation to be carried out and these weaken the vessel part due to development of discontinuity. So, in regular sheet, when we have the hole, it creates the discontinuity and due to that it becomes weaker. So, lets have more discussion on that, why it becomes weak. So, when I am discussing pressure vessel, what happens, the maximum stress in pressure vessel occurs due to hoop stress. That we have already discussed in thick walled vessel and you can consider that in thin walled vessel also.

So, there you have seen that as hoop stress is maximum, we have equated that to allowable stress if you remember that derivation. So, what happens, hoop stress when I am considering, it is basically circumferential stress, so that stress is basically created by whatever pressure is acting towards the periphery of the vessel. So, as I have told that hoop stress would be maximum, this discontinuity in a metal sheet we will discuss in terms of hoop stress. So, let’s discuss that.

If you consider this particular figure, now what happens, here this I can consider as a regular sheet, okay and whatever hoop stress is working that will work in this direction as shown over here. So, what would be the acting area for that hoop stress. Acting area for that hoop stress is nothing but this rectangle, okay. So, when we have regular sheet, the whole area of this rectangle will work as an acting area. Now, if I am having this discontinuity or if I am having this opening, opening may be circular, that you understand?

Opening will be circular, but as far as hoop stress is concerned, only this much area would be removed, are you getting? So, when hoop stress is concerned, this area would be removed. Now, when we are considering the pressure vessel, pressure vessel is designed to operate a particular stress, a particular we can say working pressure, which creates a stress in periphery or stress in circumference, so that creates a hoop stress.

At the starting of this designing, what we have considered the whole rectangle of the metal sheet is available to us where hoop stress will act, but now because of that opening, what happens, acting area would be reduced, however, whatever pressure is acting that will be remain as it is, so it means it gives more stress in comparison to the initial condition and will more likely to fail until unless we will not consider that in design, okay. So, I hope you have the idea that how the discontinuity matters for pressure vessel designing.

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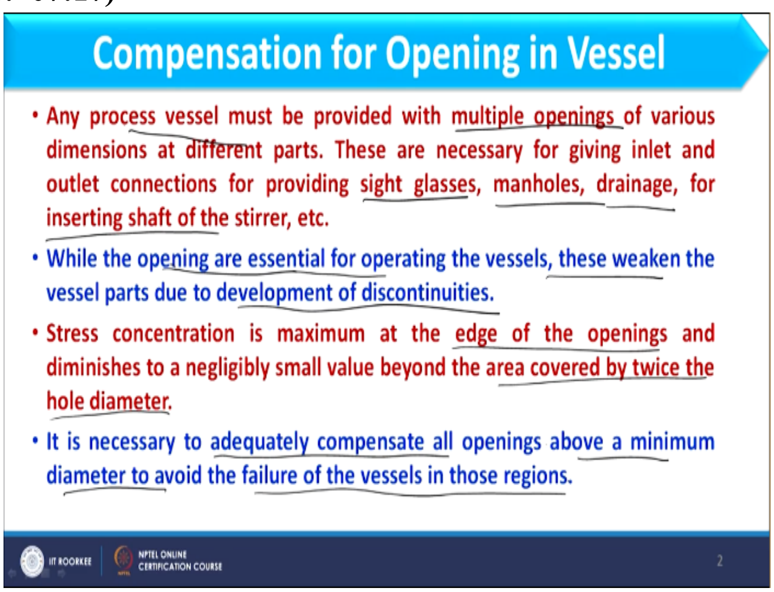

So, stress concentration is maximum at the edge of the opening and diminishes to negligibly small value beyond the area covered by twice the whole diameter, okay. What is the meaning of this? Let's have example of that cloth only, when I am having the hole over here, okay, and when I put certain force into this, what will happen, it will start tearing from this. Why it will start tearing from this, because stress is maximum at the edge of this opening and experience says that this stress diminishes after twice of diameter of the opening.

So, for example, if I am having this much opening, up to this much level, whatever stress is created, that will achieve negligible value. So, usually when we have opening in a metal sheet, we need to consider only twice the diameter of the opening for any rectification, okay. I hope it is clear to you. Therefore, whatever openings I am considering, that we need to compensate and it will require adequate compensation above a minimum diameter to avoid failure of the vessel in those areas. So, it means that openings whatever we have created, that should be compensated or that should be rectified, okay.

Whatever compensation, that we will discuss. Till now, we have only discussed that what is the opening and why it is required, okay. Now, once I have created the opening, because it will give more stress or failure will occur that region, we need to rectify whatever we have created, okay. So, as far as opening is concerned, that you need to compensate, okay.

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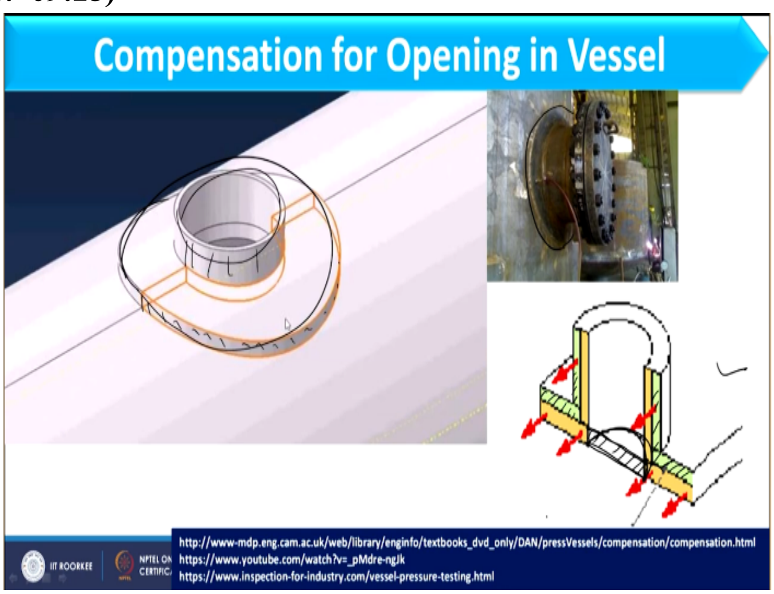

So, if you consider this example, here I am having the hole where I have put this nozzle and this is basically the compensation. So, if you observe this compensation, this is what, this is basically extra material we have placed around the nozzle, okay.

As you can also observe from this image, here we have this opening where nozzle is placed and basically this ring you can consider as compensation. We also call this as reinforcement. So you also see that in this image that this is the section which we have created and this much area we have considered for stress. This is the area where stress will act, okay. So, it means whatever area we have removed, accordingly we need to provide some additional section that has been shown with this green colour.

So, in this way we need to provide some additional material for compensation. So, as far as nozzle is concerned, nozzle is must to place and for that opening is must to create, but that opening should be compensated or reinforced.

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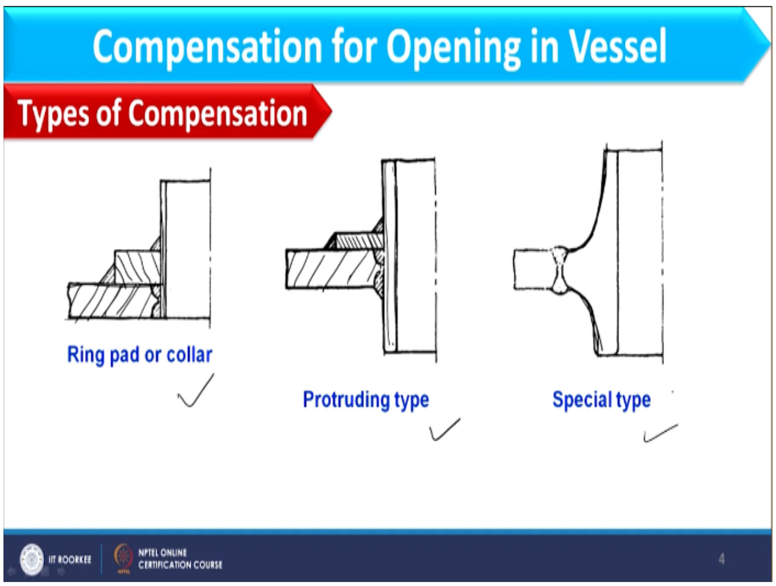

Now, further we will discuss types of compensation. So, first type is ring pad or collar. So, if you consider this image, this is basically the shell part in which I have to create the opening and in this shell part, this nozzle is inserted, okay. So that you need to keep in mind that whenever I am creating any opening that is used to place the nozzle, okay and that nozzle will be placed inside the opening, not outside the opening, okay.

So, actually whatever opening area if I am considering, that opening area would be inside diameter of nozzle, not the diameter of opening. I hope you are understanding that. So, here we have this shell where opening is placed and this section if you are considering, this is basically the ring pad or collar. So, ring we make and that ring is placed around the nozzle for reinforcement of the material.

Second type I am having is protruding type. Now in protruding type what happens, this is basically the shell where opening has been made and nozzle is inserted inside this opening and this nozzle if you are considering, this nozzle is from outside to inside, okay. Some section of this nozzle is outside, some section of this nozzle is inside, and here, this particular section is called as compensation. So, protruding type nozzles are usually used in chemical industry.

For example, if I am designing a distillation column and in a plate at a particular location I want to insert the feed, so nozzle will be protruded, it means some section of the nozzle is outside the distillation and some length of the nozzle would be inside the distillation column to insert the feed at a particular location, so that type of nozzle is protruding type where compensation is required at outer side of the nozzle, and here we have this special type compensation, now what is special over here. Here, if you see, whatever material we are considering that it has a continuous curvature. So that curvature will give proper distribution of stress, okay.

So, this is especially used when I have to make radiograph joint. Radiography we have discussed in weld joint efficiency factor. So, there you must have the idea about the radiography and wherever I need the radiograph compensation, there I provide this special type of compensation. So, these are different types of compensation. Now we will discuss what are the different orientation of nozzles.

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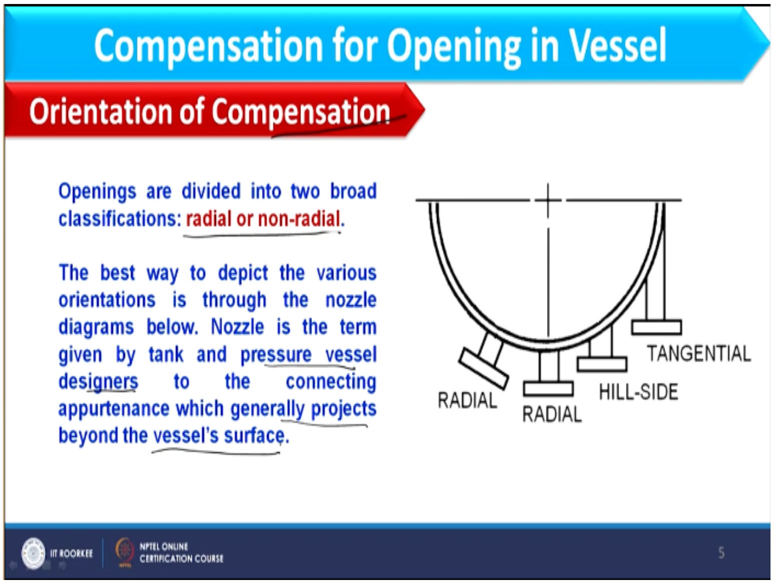

So, basically orientation of nozzle speaks about orientation of compensation because as I have to place the nozzle, accordingly I have to create the compensation, okay. So openings are divided into two broad classifications, radial and nonradial and the best way to predict the various orientation is through the nozzle diameter as shown over here and nozzle is the term given by tank and pressure vessel designers to the connecting pertinence which generally projects beyond the vessel surface.

So when any object we are providing beyond the surface of the pressure vessel or beyond the surface of the component in which I am creating the opening, that is basically called as nozzle. As you can visualize from this diagram, here we have different types of nozzles, this is basically radial type, you see. And nonradial type has 2 types, first is hill-side, second is tangential. Hill-side you can understand, the nozzle is longitudinally placed and tangential side means whatever nozzle I am considering, one section of this would be tangential to the vessel or tangential to the shell, okay.

So, as far as this tangential nozzle is concerned that is used in different equipments, for example, when I am having vapor liquid separator Cyclone, etc, so what happens, in vapor liquid separator, vapor and liquid mixture enters into a separator and because that in separator, we need circular motion so that when it comes to circular motion, liquid will flow around the periphery of the vessel and then through the wall of the vessel, liquid moves down and vapor moves up. So for that type of movement, we need tangential nozzles, okay. So, when I am having tangential nozzles, it means accordingly I have to make the opening.

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As you can see from this image. In this image, we have different orientation of nozzle and these orientations are basically hillside and these nozzles are basically hillside, and if you see, these are basically compensations. So, compensation will be provided according to the nozzle placed, okay. So, these are basically different orientations of nozzles and we can also call this as different orientation of compensation, okay.

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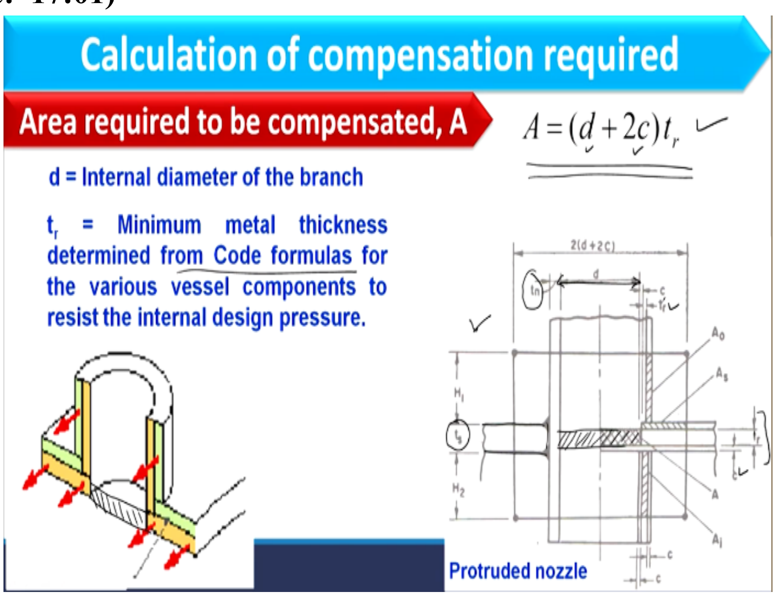

Now we will start calculation for compensation. It means whatever opening we have created, that we have to reinforce. So, how much area I need to provide for reinforcement. Until now you must have the idea that compensation or reinforcement whatever I am providing, that will be in terms of a ring. So, what should be the thickness of that ring pad. So all these calculations we will consider here. So, let's start this.

So, first point is, I have to calculate area required to be compensated, okay. So, if I am creating the opening, how much area I need to compensate, that I have to calculate first. So, it depends on the opening, okay. So, let's understand that with this schematic. So, if you consider this schematic, this is basically the shell where opening is created, this much is the opening, okay. Now, this t s, t s is what, standard thickness of shell, okay. So, whatever opening I will create, that will be created throughout the thickness. It means if t s is the standard thickness, opening thickness will also be equal to t s. It cannot be less than t s, okay.

Now, what happens, how this t s we have computed. If you remember, we have calculated minimum thickness through the expressions, okay and in that minimum thickness, we have added corrosion allowance and that next value of that available in table B1 that we have considered as standard thickness. Now, if you focus on these 3 thicknesses, what is minimum thickness? Minimum thickness is the thickness at which my process or operation will be carried out satisfactorily, okay. Because that we have calculated based on whatever pressure is used during the operation. So, minimum thickness is sufficient to perform the process.

Now, why we have added corrosion, because of continuous operation, wastage of material happens, so to avoid that, we provide some extra material. So corrosion allowance will be used for wasting purpose. Minimum thickness will be used for operation purpose. So, what is standard thickness? Standard thickness why we have considered, because that is the thickness available in the market. I cannot say that I can make the vessel with 6.7 mm or 7.8 mm, no, I have to take the standard thickness available in the marker.

So, what is the main point over here? That whatever minimum thickness I am having, that is sufficient for performance to be carried out and that part only I have to consider for compensation. Corrosion will be used for wasting and t s is the extra material, okay. So, minimum thickness you should consider in compensation and that minimum thickness is, if you can see from this diagram, here we have this t r that is the minimum thickness, c we have considered for corrosion and total t s I have already explained, okay.

Now, as I have discussed that when we create an opening, we insert the nozzle inside this opening and inner diameter of nozzle is considered actually as the opening. I hope you are understanding that, so area required to be compensated is D + 2 c * t r. Now, what is D? D is the inner diameter of opening, that you can understand from this diagram plus 2 c, 2 c why we have taken, to understand the c, we should understand what is t n. T n is the standard thickness of nozzle and that is computed based on same philosophy as we have discussed for shell.

So, here we have t r is the minimum thickness of nozzle, you can consider this as t r dash and we have added corrosion into this and then next standard value available in table B1, we have considered as t n. So, this D is the inner diameter, 2 c is the corrosion, corrosion we have considered at this side as well as at this side also, because that corrosion at both sides of nozzle will be used for material which is going to waste after continuous operation. So, that c further I need to compensate, because that c will not be considered as additional material. C will be used for corrosion, okay. So, this D + 2 c * t r is basically the area which I have to compensate.

So, D is the internal diameter of branch that we have already discussed and t r is the minimum metal thickness determined from code formula that we have discussed in previous lectures, okay. Now, here you can argue that once I have removed opening in circular way, why I have considered area to be compensated as the area of rectangle. If you consider this image, here we have this particular section which I have considered during compensation, okay. So, why it is rectangle, that you can understand through this diagram as well as through this diagram that this much area is basically used where hoop stress will work.

So, therefore that area will be the projected area of force where we are computing the hoop stress and that area would be rectangle, not the circle, therefore, though we have removed the circle from the metal sheet, we will consider rectangular area for area to be compensated, okay. So, here we have discussed whatever area I need to compensate and further, next step will come that whatever material already available for compensation. So, for example, if I am considering for shell or where the opening is made, there we have a standard thickness, okay.

So, that standard thickness will be whatever value next to minimum thickness plus corrosion allowance available in table B1. It means that t s – t r - c. It means that thickness will be available with me as extra material, okay. So, that extra material will already work as compensation. I hope you are getting this. So, if I am considering the opening that extra material will be available in shell as well as that extra material will be available in nozzle because nozzle standard thickness is t n, okay. So, now I have to calculate whatever material is available with us for compensation.

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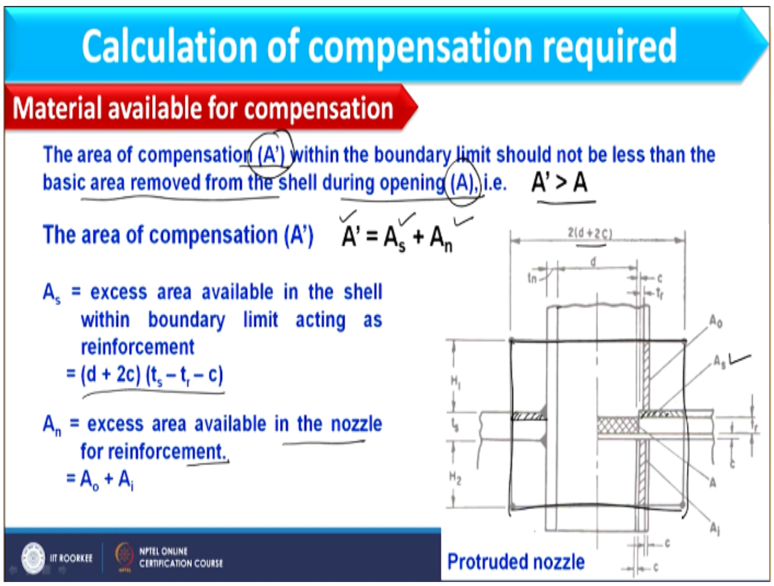

So, material available for compensation is the area of compensation that is A dash within the boundary limit should not be less than the basic area removed from the shell during the opening. It means A is basically the area which needs to compensate and A dash is basically area of additional material available for compensation. So, in no case, A dash should be less than A. Preferable condition would be when A dash would be greater than A.

Whatever area of material available to us for compensation, that should be greater than whatever area I need to compensate, okay. So, now I will calculate area of compensation that is A dash and A dash will be summation of A s + A n. Now, you understand what is A s, A s is basically additional area in shell where I have made the opening, okay. So, that additional area we have considered as you can see from this schematic, the total area at which I have to work is this, okay.

Now, why it is so? Because, if you remember, we have discussed that whatever opening I am creating and stress would be maximum at the edge of this opening and it will diminish after twice diameter of this opening. So, if I am having this opening of D, where I am considering D plus 2 c, so twice of that will be the total area at which I have to focus on. So, A s would be the additional material in shell in that particular area, okay.

So that will be nothing but as it is shown over here, which will be again available here also. So, A s is the excess area available in shell within the boundary limit acting as reinforcement, so that we can compute as D plus D c * t s – t r – c, okay? So, I hope you are understanding this. This is basically he additional material or additional thickness and A n is the excess area available in nozzle for reinforcement and that would be equal to A o plus A i.

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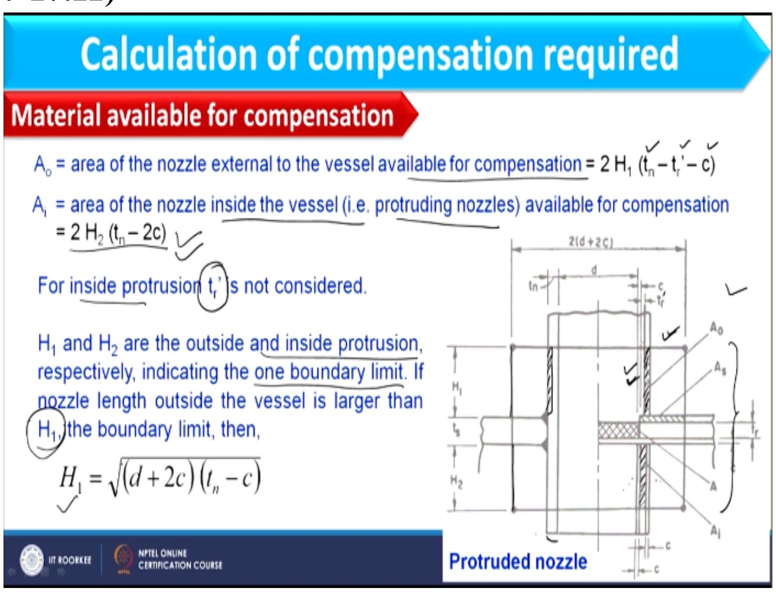

So, if you consider this image, what is A o, A o is basically area of additional material available in nozzle above the vessel surface, okay. So, this is basically the A o. In the similar line, A i is the area of additional material available inside the vessel in the nozzle. So, A o and A i we will calculate and for that purpose, you should understand that as far as total length is concerned, we have considered H 1 as well as H 2.

H 1 is basically decided by the boundary limit above the vessel surface in the nozzle, and in the similar line, H 2 will be decided by the boundary limit available inside the vessel in the nozzle, okay. So that H 1 and H 2 we will compute. So, A o is basically the area of nozzle external to the vessel available for compensation and that we can calculate as 2 H I because area available over here as well as here also, so that would be 2 * H 1 * t n that is standard thickness of nozzle minus t r dash that is the minimum thickness of nozzle minus c. So, this would be the area outside the nozzle and in the similar line, A i is basically area of nozzle inside the vessel that is protruding nozzle available for compensation.

So, here I am having 2 H 2, t n – 2 c. So, you can see that 2 H2 because both side I am considering and t n is the standard thickness of nozzle minus 2 c, why I did minus 2 c, because in this protruding type as this length of nozzle is inside the vessel, both side of this will be in continuous contact with the liquid. Therefore, it will be corroded from both sides together. However, it will not happen in outer length of the nozzle because this section will be in the atmosphere, however this section will only come into contact with the solution or with the fluid, so therefore corrosion will occur at one place only and here in both places.

And further, for inside protrusion, t r dash is not considered if you focus on this particular expression t r dash, we have not considered and what is the reason of that, because at both side of protruding length in the nozzle, same pressure is acting, from this side and from this side also, so pressure difference will not be there, so therefore the thickness will not take place its role. So, t r dash in that case will work as an additional material. Why we have consider t r in outer length because there one side is pressure where operating is carrying out and second side is the atmospheric pressure, so pressure difference is there, which causes failure, which is not happening inside the vessel where protruding nozzle is placed.

So, H1 and H2 are outside and inside protrusion respectively as we have already discussed and which indicates 1 boundary limit. If nozzle length outside the vessel is larger than H1, the boundary limit we can calculate by H1. So, this H1 would be computed by this expression root over (d + 2 c) (t n minus c).

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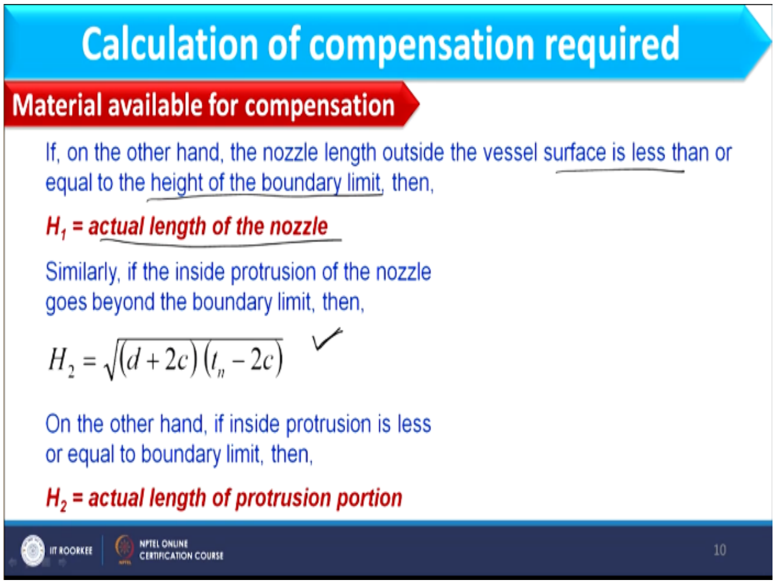

On the other hand, nozzle length outside the vessel surface is less than or equal to height of the boundary limit, then H1 would be the actual length of the nozzle. So, what is the meaning of this? That we will calculate H1 and then we will compare that H1 with the length of nozzle outside.

So, if length of the nozzle is lesser than H1, we will consider H1 as the length of the nozzle. So, in short, you can understand H1 would be minimum of H1 or nozzle length outside the surface. I hope you are understanding that. In the similar line, H2 we will calculate which is protruding length of the nozzle, H2 we can calculate by this expression, and again if protruding length is less than this H2 value, H2 will be replaced with actual length of the protrusion portion. So, in this way, H1 and H2 we can calculate.

Now, we have calculated 2 things, first is area needs to be compensated, that is A and second is A dash which is area of additional material available for compensation. If A dash is greater than or equal to A, it means no other external reinforcement is required. It means thickness of the shell as well as nozzle is having additional material, which can withstand the area which I need to compensate, okay.

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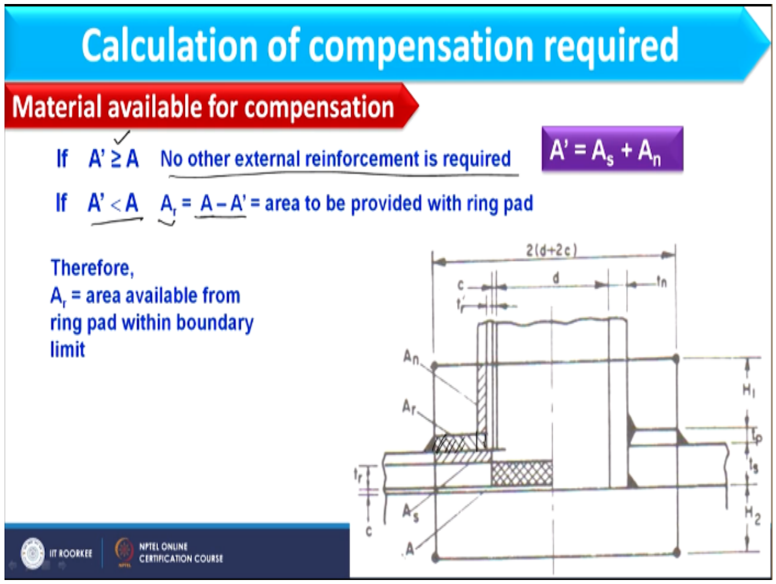

However, if A dash is less than A, then A r we have to calculate and that would be the difference of these two, A minus A dash and that we are providing as ring pad. So, A r is basically area of ring pad which I have to provide as compensation or reinforcement. So, A r is the area available from ring pad with the boundary limit, so you can consider this image, where A r is basically this value, okay. Actually A r should be considered from here, not from here because that compensation will be placed beyond the nozzle surface, okay. So, A r should be calculated from this.

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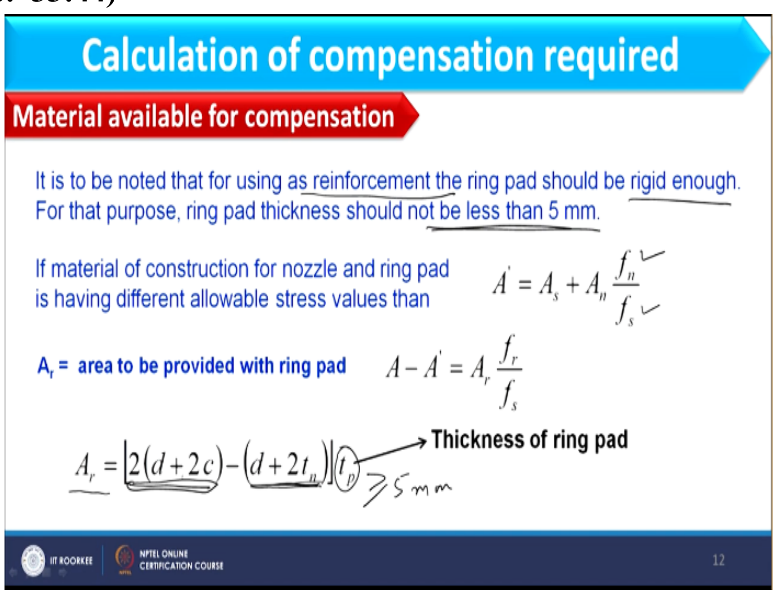

Now, it is to be noted that using as reinforcement that ring pad should be rigid enough. That rigidity I have to ensure and therefore ring pad thickness should not be less than 5 mm. If ring pad thickness is coming less than 5 mm, I have to recommend at least 5 mm. So, if material of construction for nozzle and ring pad is having different allowable stress value, the A dash I will write like this, that is A s, additional material in shell plus A n, additional material in nozzle into f n that is allowable stress of nozzle divided by f s, allowable stress of shell material.

And, in this way, I have to calculate and this is the expression for area of the ring pad where this 2D + 2 c, what is this, this is basically boundary limit around the opening, which is twice the opening, which I need to compensate, minus D + 2 t n that is the inner diameter of nozzle plus 2 t n that is standard thickness of nozzle. So, beyond the outer diameter of nozzle, I have to make the ring. So, therefore A r would be this into t p, t p is the thickness of ring pad and this should be greater than or equal to 5 mm.

So, if allowable stress of ring pad varies, so A minus A dash would be A r, f r that is allowable stress of ring pad divided by allowable stress of shell material. In this way, I will find A r and then that A r will be used over here to calculate thickness of ring way, so in this way we calculate area of ring pad, which I need to provide as compensation.

And here, I am stopping this lecture. I will continue discussion on compensation of opening in next lecture and then we will solve a few examples based on that. And that is all for now, thank you.