Marine Construction and Welding

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Lecture No. # 38

Welding Distortions

We will start with Welding Distortions. Welding distortions means distortions, structural distortions which take place because of welding. Because, till now, we had been seen various methods of welding, and as we said that welding being a thermal process, because of the thermal process, thermal stresses may develop, which which may lead to plastic deformations in the structure. Plastic deformations means, deformations of permanent nature, which are commonly referred to as weld-induced deformation.

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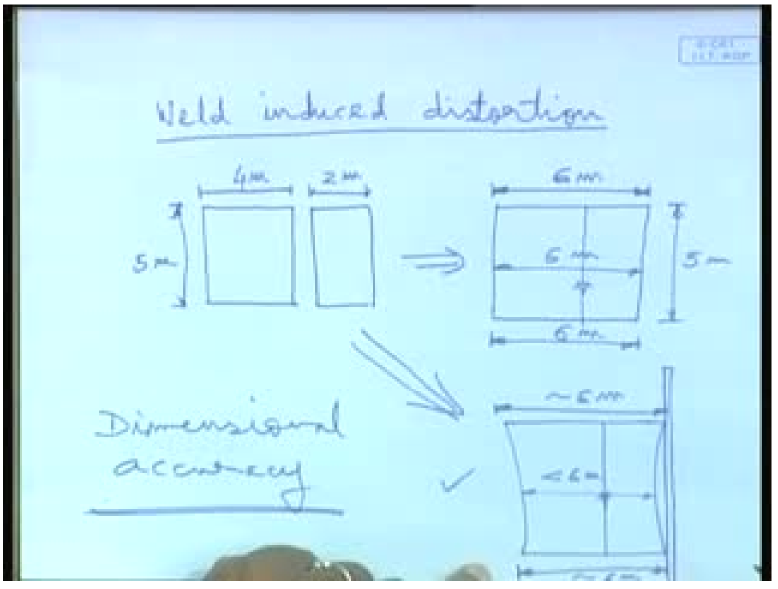

So, any thermal operations done, like we have seen in thermal cutting, oxyacetylene cutting, when we do, also, it may lead to deformations. Similarly, when we do welding also, it would lead to deformations, which can be termed as Weld induced deformations or distortions, Weld-induced distortions; because, you see, the fundamental requirement or the desirable requirement of welding is, as we said that it is a process to join two independent components together; join it, make it one integral, so, it is it is essentially a joining process.

So, what is the end result we look for? We look for a joint achieved, which does not have any defect, right? That is number-1; definitely, that means, it gives you your required, so-called, integration among the two components; means, there were two individual pieces, now they have become as if one. So, number-1 requirement is obviously when you do welding, that it should be a joint-free of any weld related defects. Weld related defects are as such, defects concerning to the fusion zone; there is another requirement to it, that means, when two pieces of plates are being joined, say two pieces are something like this. Let us assume there the two pieces being joined; say this is some length, say 4 meter, this is some length say 2 meters, length or breadth whatever you call it, and this is say 4 meter wide, this is 2 meter wide; so, when you weld it, I would expect a one piece of plate which will have a width of 6 meter, right? That is expected. I mean, that is what we will expect, right? And, this 6 meter means, assuming these plates are perfectly rectangular, so, everywhere it is 6 meter, right? That is what would be expected. And now, welding joint was, say along this line weld was done, but, what in reality we get is not exactly like this; 6 meter we get something like this, this is somewhat little exaggeratedly drawn.

So, there is a possibility that, right at the edge it might be around 6 meter exactly; but here, definitely, it will be less; it will be less than 6 meter. This is what would actually result into, right? So, you can see, again here also it will it might be just near about 6 meter; so, what has happened? We wanted to join these two plates and make one piece of plate which is 6 meter wide and, say length was, I mean this side was say 5 meter, so, we expected a piece of 5 by 6, but it has not become like that. But well, if you go about the quality of the joint, we may find the joint is perfect, so, is the job done perfectly? No, as far as welding is concerned, welding as a process implemented is okay, but the end result because end result you wanted this, that should be the end result; it it has not become like that; some defect has kept in the defect in the dimensions.

So, when we talk about welding defect, it is not not only the defects involved in the welded joint, not only the fusion zone, but also the overall dimension. Because, one of the important aspect is dimensional accuracy; there is something called dimensional accuracy, why? Because this particular, as we have seen, ship building here; as we said in the beginning, it is a kind of a assembly industry, you you are going on, putting on, putting in, several components together; so, as an when I am putting them together and putting process of putting together is by way of welding, if at every stage such dimensional inaccuracy comes in the component, then obviously, the end product also will become dimensionally inaccurate. There are cases where one found that after the ship has been built, it has become shorter by 2 to 3 meters, shorter in length, over a length of, say 200 meter, it become shorter by 2 to 3 meters; it is possible.

That is one way of looking at it. Other way it could be that individual component becoming not coming out to the desired designed dimensions; then, the next component when we are trying to align and weld it may become difficult, right? For example, in this case, it will result like this; that means, the edge is becoming somewhat curved as if it is not straight line. So, suppose I will have to weld some plate here, say this particular plate, in vertical condition is to be welded to some other plate. So, how do I weld it? The gap is too much here, right? So, this gives you a problem, dimensional inaccuracy; so, these are actually results of so-called weld induced distortions.

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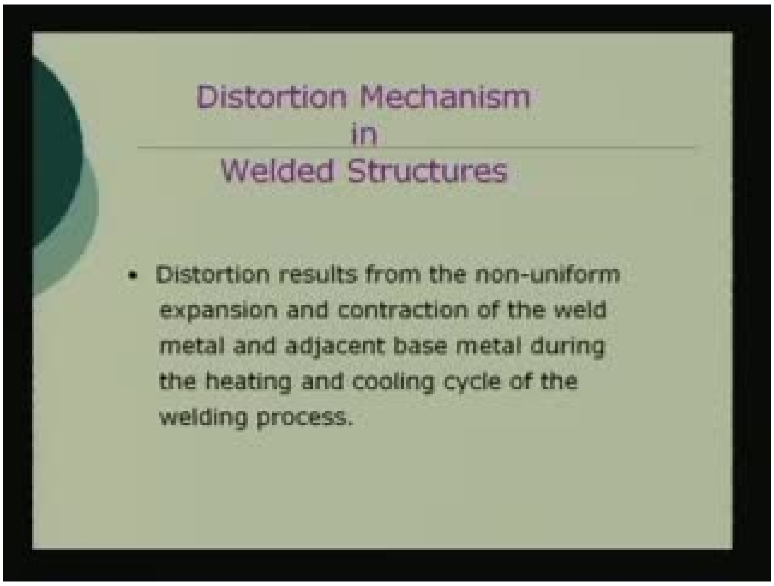

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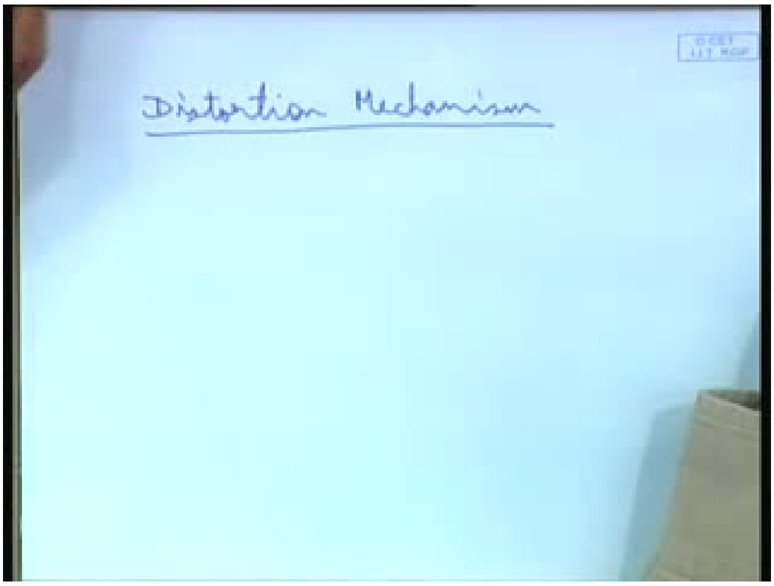

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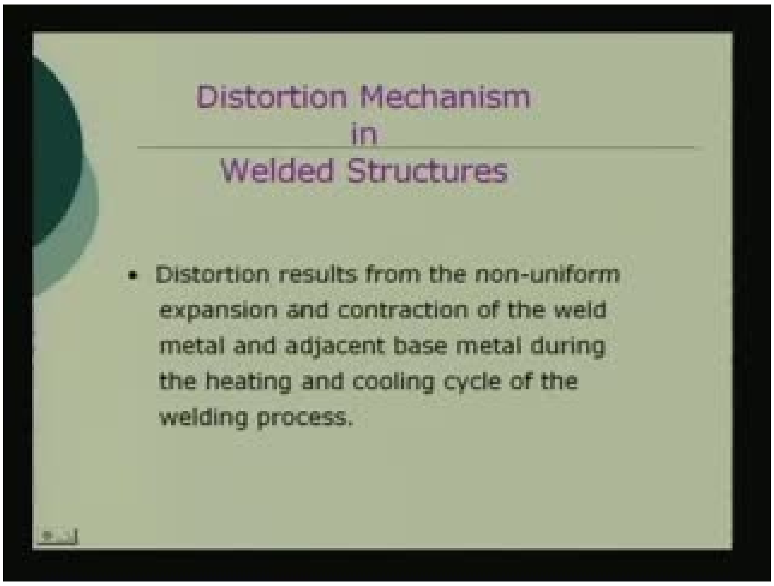

So, if we look in to the distortion mechanism, why, why does it take place? Distortion Mechanism, how it takes place? We have little bit talked about it previously while talking about distortions due to thermal cutting, right? So, it it is essentially, as you can see that here, in brief I have written, the distortion results from the non-uniform expansion and contraction of the weld metal; it is a non-uniform expansion and contraction which is taking place of the weld metal and adjacent base metal during the heating and cooling cycle of the welding process. So, you can see what we are talking about is, it is due to the non-uniform expansion and contraction; that is what is important, non-uniform expansion and contraction of the weld metal, as well as that of the adjacent base metal when during the heating and cooling cycle of the welding process.

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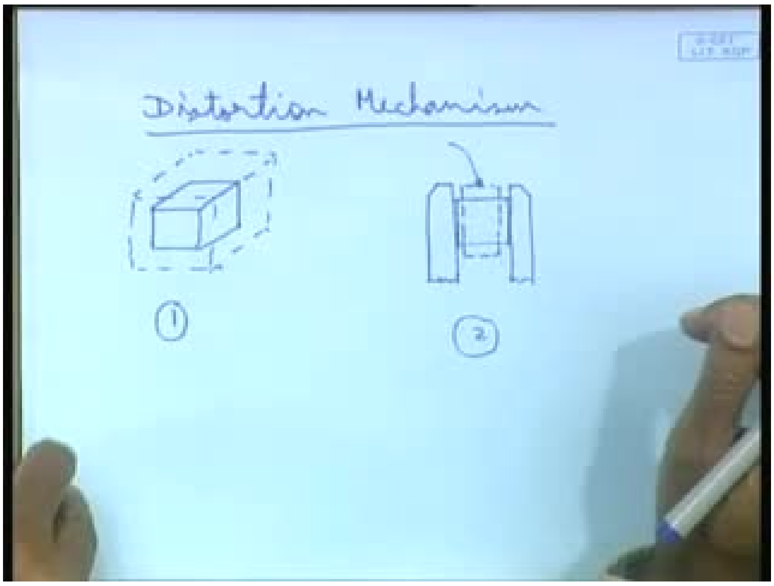

So, it is like this. Supposingly, we take a say a small piece of, say a small piece of steel cube, a cube of steel, right? And, we subject it to uniform heating, uniform heating. So, what will happen? In the hot state, if you can measure it, we will find that the dimension has increased, right? It has become somewhat like this.

This suppose I put it in a furnace, then I have a mechanism of measuring all the dimensions, then I will find its height, its length, its breadth, everything has increased. Now, I will let it cool down; again, I will find that it will come back to its original state, why? Because of the simple reason that it is not undergoing any non-uniform heating or cooling cycle; it is being uniformly heated, again it is being uniformly cooled; so, it being uniformly heated means all the sides it is expanding, right? Because of the simple characteristic it has of, that of so-called thermal expansion. And again, when it is being cooled, it is being uniformly cooled, it is contracting, so, it is coming down to the same shape.

Now, let us assume that it is being, say the same that piece of steel cube, small one is held between two clamps of your wise; what I say, it is being held, it is not being compressed, no force is being applied, enough force such that it does not fall off; that means, enough force in this direction such that it gives sufficient friction to hold on to the place. And now, suppose, again you heat it by some means uniformly, by some means, means you can heat by a, say a gas flame; the same thing, as I said, can be heated by a gas flame, engulfing the entire cube, uniform heating. Here also I am heating it with a gas flame, right?

Now, what I will find that in the hot state? Well, supposingly, I am not measuring what is happening; I am heating it and letting it cool down. Whatever you will find that falls off; it will after it cools down, immediate observation would be, that it is not holding to the place, it will fall off. And now, if I measure, I will find the shape of the thing has become somewhat like this; what I am showing you in the dotted line, obviously little exaggerated, but like this; that means, it has become narrower in this direction and has increase in the other direction.

Why? That means, the dimensions have changed, dimensions have changed. What has happened is that, it could not, when when I was heating it, it could not; that expansion and contraction was not uniform. In the first case, the expansion and contraction was uniform; that means, in old directions it could expand freely again contract freely; but here, it could not expand. So, the stress is developed and eventual result is this.

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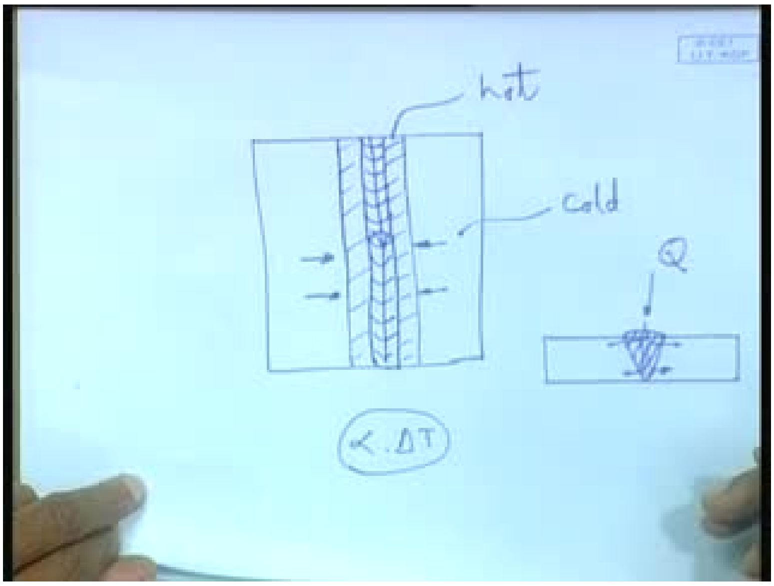

So, this concept equated to the to this will give you why deformation takes place because of welding. Say two plates being welded, means what? A zone along the weld line, say this is my fusion zone; obviously, within the fusion zone, the temperature rose, well above the melting point of the temperature metal, melting point temperature above that. And then, part of the adjacent metal was also subjected to a sufficient amount of so-called temperature rise; such that, it gave rise to the quantity alpha delta t significantly higher, that means, it try to expand; but, the rest part of the plate was cold. This part can be referred to as the hot material; rest part is cold, so that cold material opposes the expansion of this; that is how the expansion takes place, right?

That is how the stresses, eventually the stresses were build up, which leads to contraction of this, contraction of the plate. So, what we can, what we see is non-uniform expansion and contraction which leads to the deformation due to welding, and welding being a process which involves localized heating; that involves localized heating, that means, it is not the entire structure is not being uniformly heated, it is only it is getting heated locally. And also, the heating pattern is also different; different means, heating pattern at the top is when two plates are being welded, so, your weld bead and the fusion zone will look like this; if the welding is being done from top, that means, heat source is coming from the top; you will have more heat coming at the top whereas, less heat coming at the lower half of the plate, because of simple reason heat conduction will be less, right? Thereby, again it will lead to a different kind of deformations, right?

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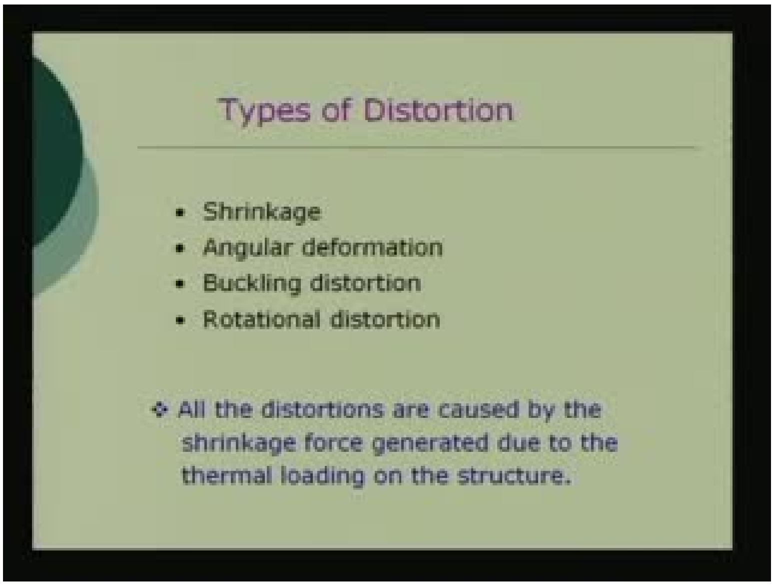

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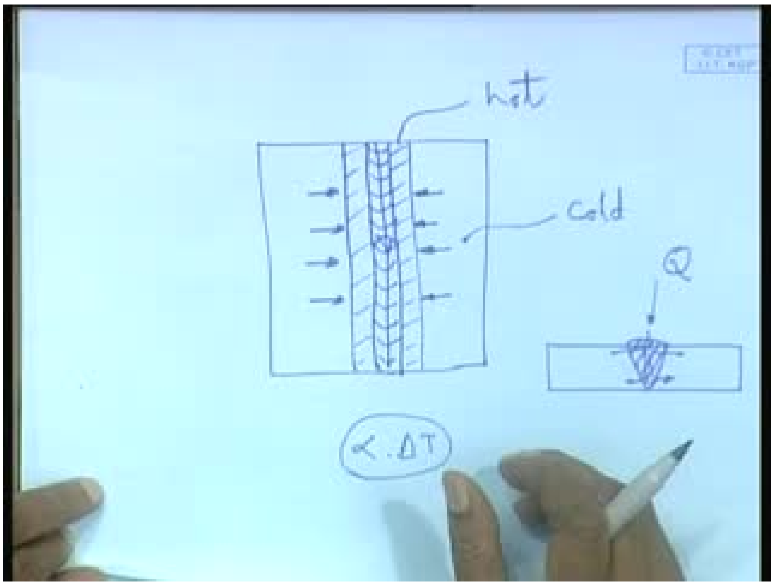

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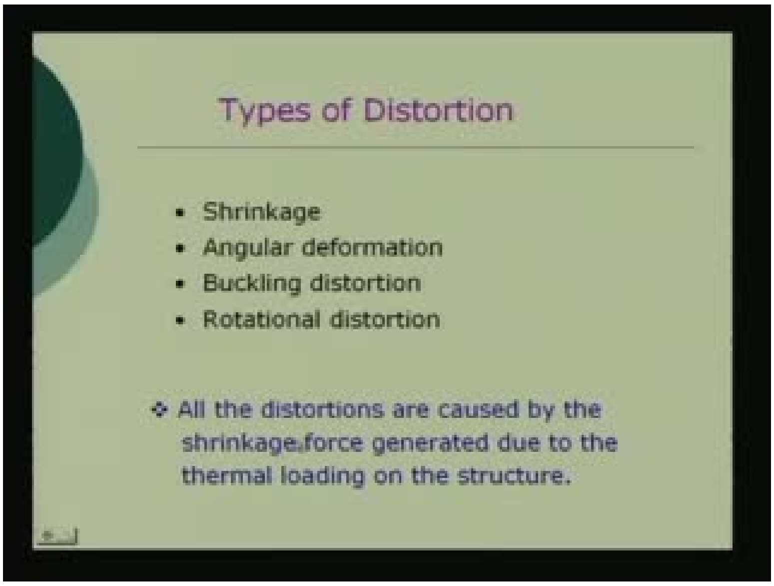

So, we see, because of this, essentially, because of this non-uniform heating and cooling cycle as well as non-uniform expansion and contraction, final thing what is happening is development of shrinkage forces, development of shrinkage forces. That is why it is said that all distortions, these distortions are related to weld induced distortions or thermal distortions.

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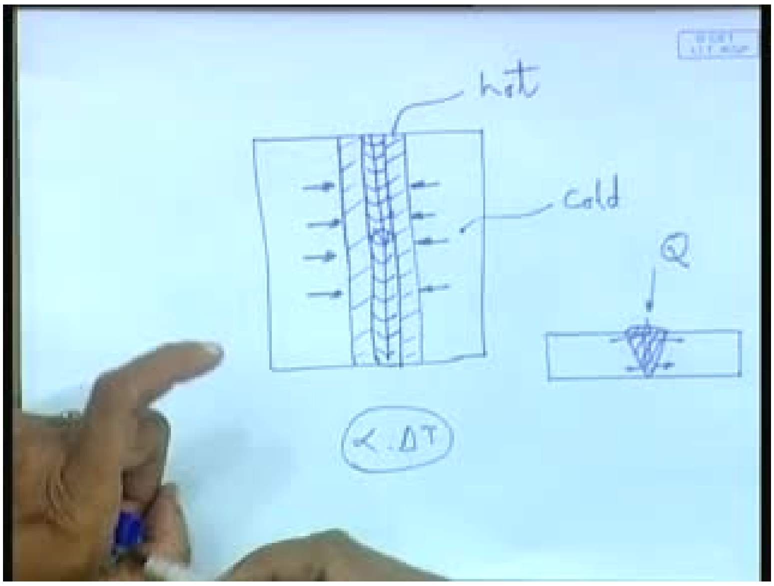

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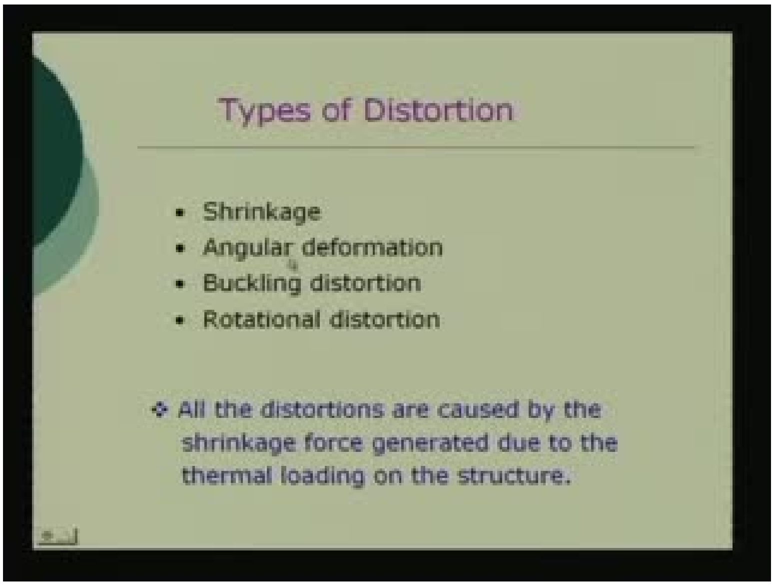

Whether it is weld in this distortion or because of some thermal process like frame cutting of a plate, also also leads to the similar phenomena. So, what happens? They are caused by the shrinkage force generated due to the thermal loading on the structure because of the shrinkage forces. Because of these phenomena, that means, localized heating is taking place, the entire plate is not getting affected because of the heat, part of the plate is getting affected, means, undergoing expansion; rest part of the plate remaining cold, not allowing expansion, and thereby net result is development of shrinkage forces. Now, how these, in which way this shrinkage forces will act on the plate, will lead to basically these four kinds of deformations?

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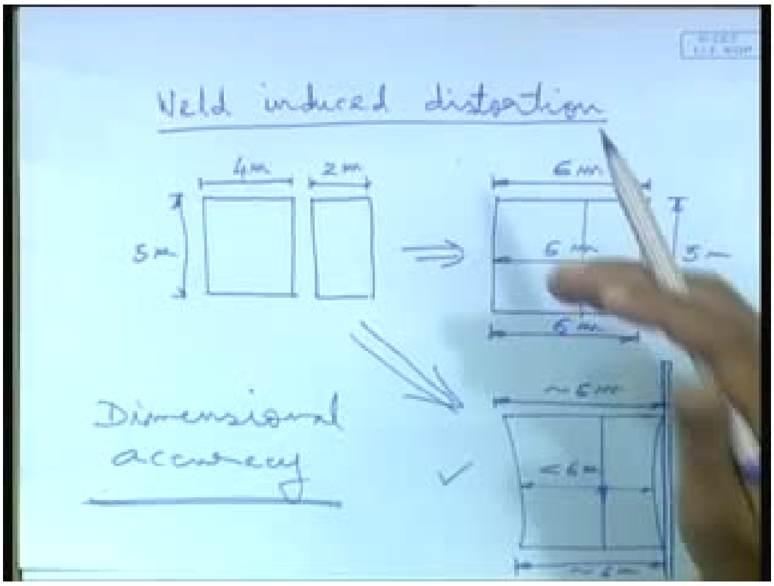

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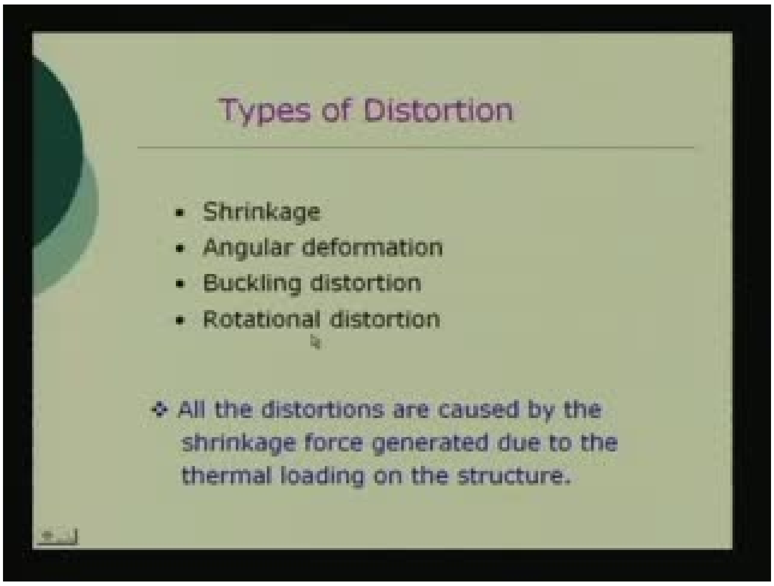

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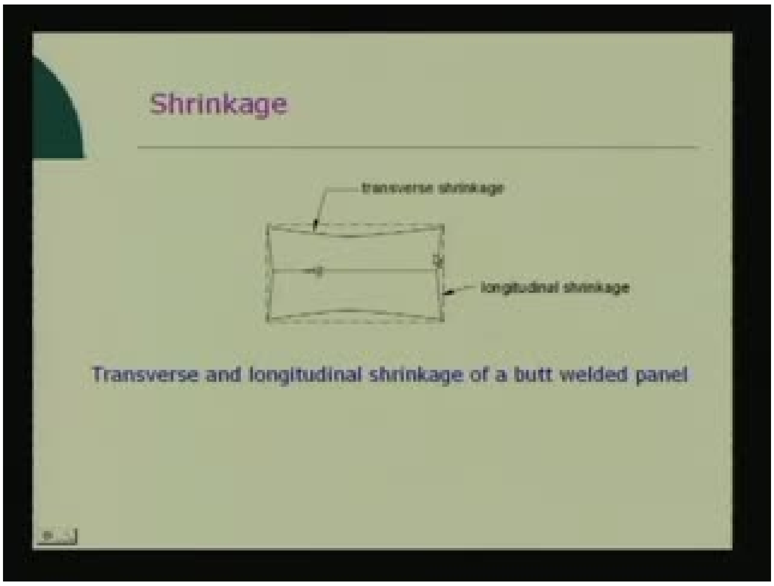

So, whenever welding is done, if there is a deformation, one would expect either in the form of a overall shrinkage, right? Overall shrinkage of the structure which which we have shown here, the overall shrinkage has taken place; of course, here I showed shrinkage only in the transverse direction; it can be also in the longitudinal direction, means, along the weld line, but generally, in the transverse resistance it is more significant. It can be angular deformation, it can be deformation, so-called buckling deformation; structures may buckle. Why buckling deformation? Because, compressive forces, it may lead to buckling of the structure. Then, rotational distortion, we will see, see these a little more in detail. So, this is what is the so-called shrinkage distortions; as you can see, this is the transverse shrinkage, these two pieces of plate we have were welded along, say along the middle line. So, it has shrunk in the transverse direction more, and in this directional, less, in the longitudinal direction.

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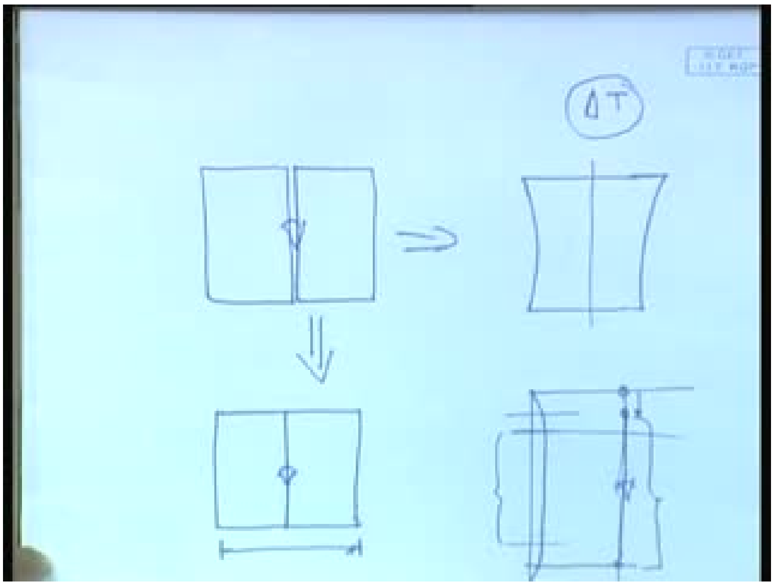

Why it is becoming like this and not a straight line? That means, when these two plates are being welded, we say that the final shape is becoming like this, right? And not, well just straight lines; that means, the overall breadth has become less, but not uniform. What what is happening? It is Essentially, what happens is, say over the length, it will come straight, again it will taper down. This is how the shrinkage takes place; that means, over a certain length, it will be all uniform.

The shrinkage is uniform, but, there is shrinkage is tapering down as if to the original dimensions as well as at the end. This is simply because essentially all the shrinkages, whatever deformations are taking place they are because of the thermal gradient, thermal, I mean, differential in temperature; differential in temperature, whatever temperature differ; temperature rise over and above the ambient temperature, right? So, it depends on the thermal profile, right?

So, what happens is, at the beginning, when the welding is, say, the welding has started from this point; so, before it attains, say, the welding comes, the welding torch comes to this point, the transient nature continues. The transient nature continues, means, after this, a kind of steady state has been attained up to this point, a steady state has been attained; steady state in what sense? That the same thermal profile is being repeated; as such, welding is not a steady state phenomena; it is a transient phenomena, right?

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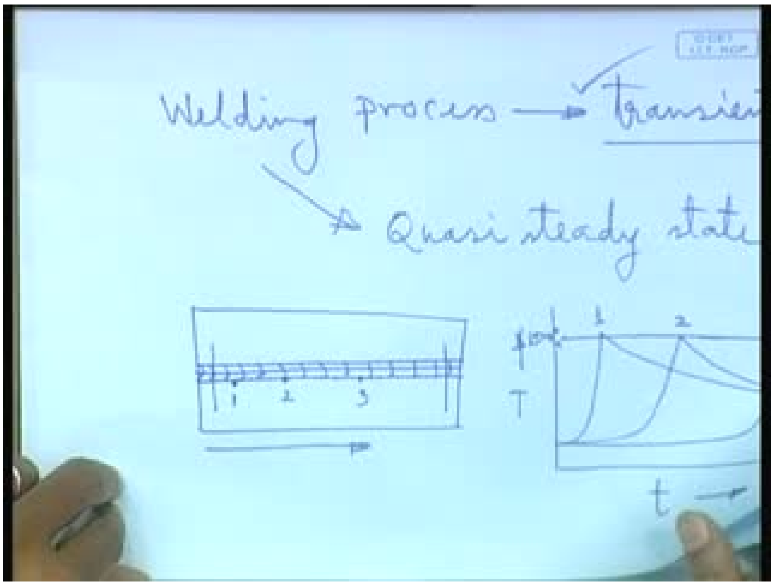

The entire welding process is a transient phenomena; means, you never attain a steady state condition, but, what you attain is a condition which repeats itself. So, that means, a kind of a quasi-steady state; it is not a steady state, but an apparent steady state. Why apparent steady state? Where the same same thermal profile is repeated, same thermal profile is repeated, that is why we see when, say, these two plates are being welded, so we have a uniform weld bead; say this is my weld bead; so, uniform weld bead means what? It means, I have, at all these points, there my fusion boundary, say a temperature level of 1500 degree centigrade was attained; only thing, say my welding is stirring, going in this direction; supposingly, I measure the temperature here 1, 2, 3, how I will see? We will see like this. This is my time, temperature, this is 1, 2, 3, all these temperatures are same.

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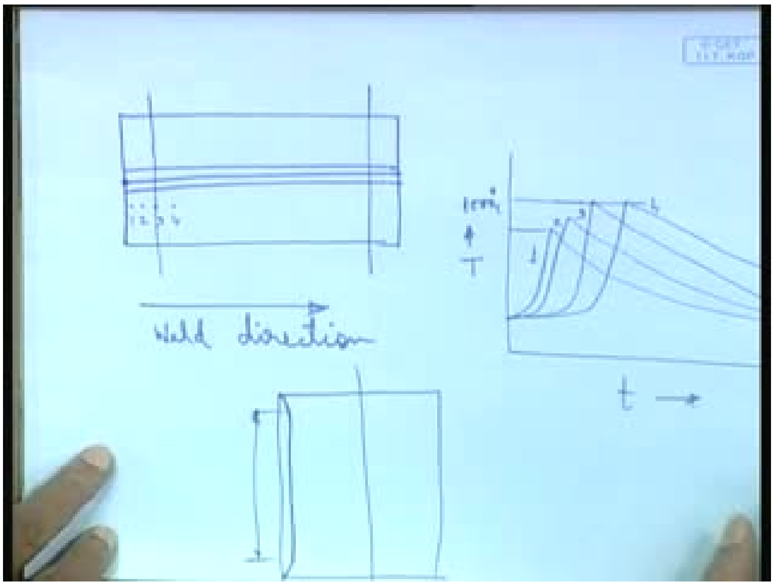

Say, I am taking at the boundary of the fusion zone; that means, it is 1500 degree centigrade, the melting temperature 1500 degree centigrade, right? Only difference is, there is a time lag; because, you can see, they are away from the stirring point, so, at different timings, the this thermal profile is coming, but the same profile is being repeated with a time lag; but individually, any point, it is continuously changing; that means, it is always in a transient state. So, that transient nature is repetating itself; that is what is called quasi-steady state. That is what is called quasi-steady state. So, this makes things, analysis and other things somewhat simpler, because, otherwise transient means, it becomes in the time domain continuously, all the parameters are changing. Anyway, so, what happens? This transient nature at the beginning and nearing the end, it changes; that means, the, what happens is, you have the plate, say the two plates are being welded, right? At the beginning and nearing the ends, this is my weld bead direction.

Suppose, so, if supposingly here, at 2, 3, 4 points, I try to see the thermal profile at these at these points, what I may see is something like this. So, this is the first curve, is for the point 1, second curve is for point 2, it is for point 3, it is for point 4; so, what do you see? That, after it reaches reach that point 3 and then beyond, the whatever is the peak temperature, I am away from the from the fusion zone; not necessarily, it is, say it is 1000 degree centigrade. Say, at this point it is it has attained 1000 degree centigrade; before that, it was less. At point 2, it was say, 600 degree centigrade; at point 3, it was some, say 800, and then, increase 1000, and then it is continuous.

Similarly, as we go at the end again, there will be tapering of the temperature; why that is happening? Because, the plate here, the plate was not there; so, the heat flow pattern was different. Heat could not flow in this direction, because there is no conduction, no plate is there; but, there was convection from the plate edge. Whatever heat loss has taken place through convection, here it is, that means, the conduction, convection the overall heat flow pattern stabilized after the location of point 3, after the location of point 3; that is the better way of putting it; that means, the heat flow conditions stabilizes beyond a certain point. Again, it become unstable while nearing the end; while nearing the end nearing the end means, the end of the weld line, why? Because, again heat flow cannot take place in this, there is no continuity of the plate.

So, that is how the temperature profiles, right, at beginning of the plate, a little zone; again at the end of the plate, a little zone, will be different, the temperature profile will be different. This is temperature profile, temperature profile means, temperature timing straight, right? That will be different; and that being different, your deformations will be different, right? That is why we see, that a part of the plate that, that is that is why we see that the deformations at the beginning is increasing and then, is so-called becoming uniform, stabilizing, again it is decreasing.

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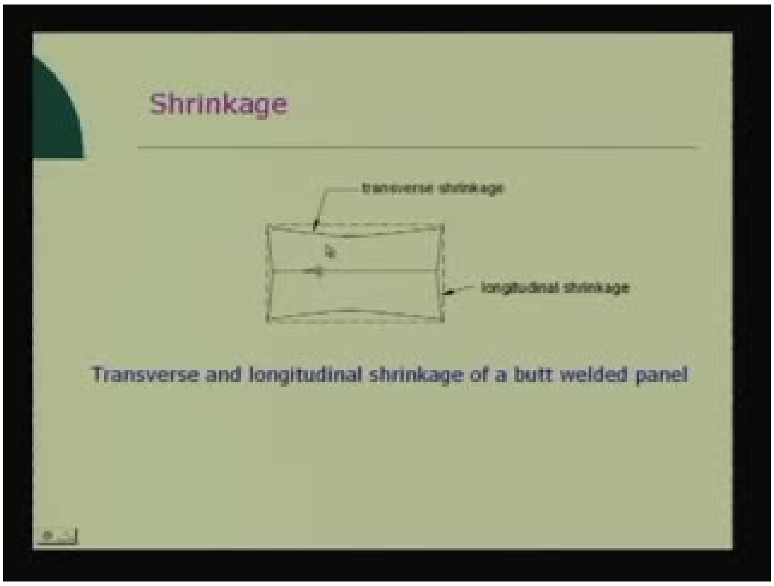

I am putting right at the, as if the original dimension may not be so, it might be a little less depending on the thermal profile and how it happened etcetera. But, at least, this much, that a middle part of the plate will remain uniform, but at the edges, it will not be so, right? So, that is why we see that the deformation patterns, they look like this. And obviously, extend of deformation in the transverse direction is much more, because the heat flow in a direction perpendicular to the welding direction is more, right? So, that is what shrinkage is. So, shrinkage can be of two types; transverse shrinkage and longitudinal shrinkage. Obviously, transverse shrinkage is more compared to longitudinal shrinkage.

Here, what are we talking about? Uniform shrinkage; that means, the entire plate dimension has just shrunk. The plate is totally flat, that means, there is no out of plane deformation. Deform, All the deformations can again be divided in two ways; outer plane deformation, in-plane deformation. So, this is in-plane deformation, it has just shrunk, right?

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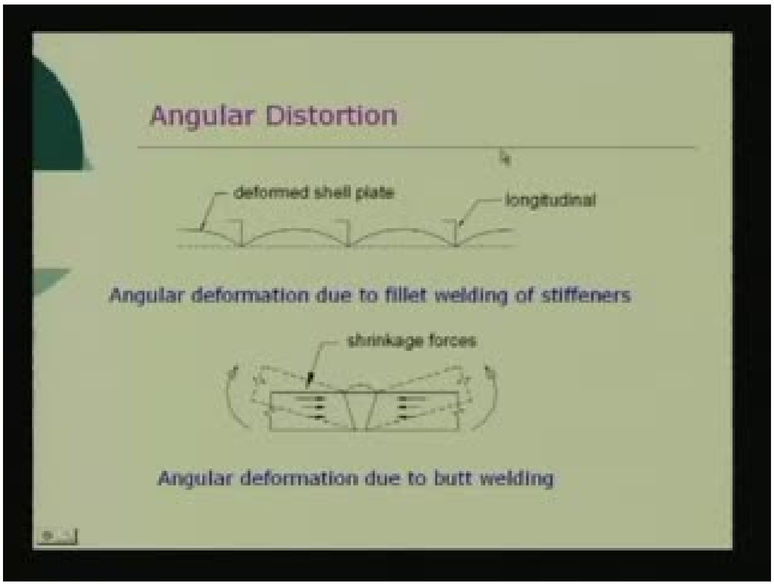

Then comes angular deformation, right? Angular deformation is outer plane deformation; that means, it is going out of the plane of the plate. So, what do we see? Here, two simple diagrams are given; these angular deformation due to fillet welding of the stiffeners, angular deformation due to fillet welding of stiffeners.

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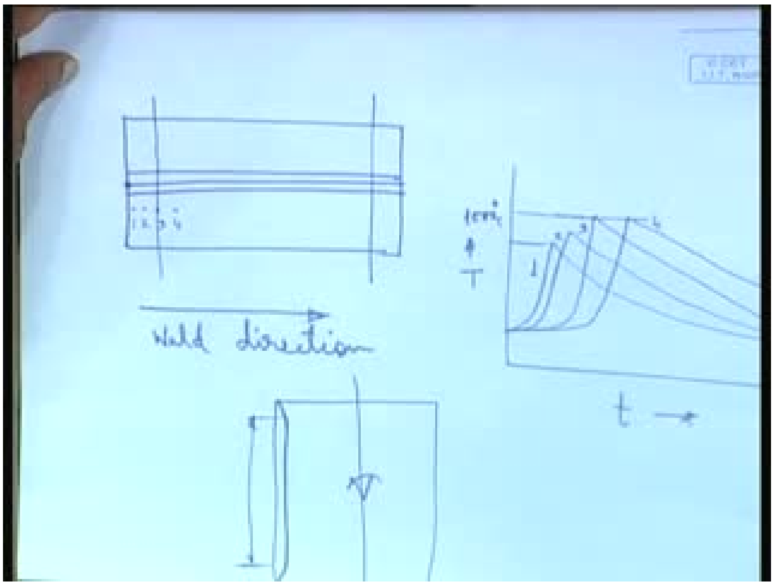

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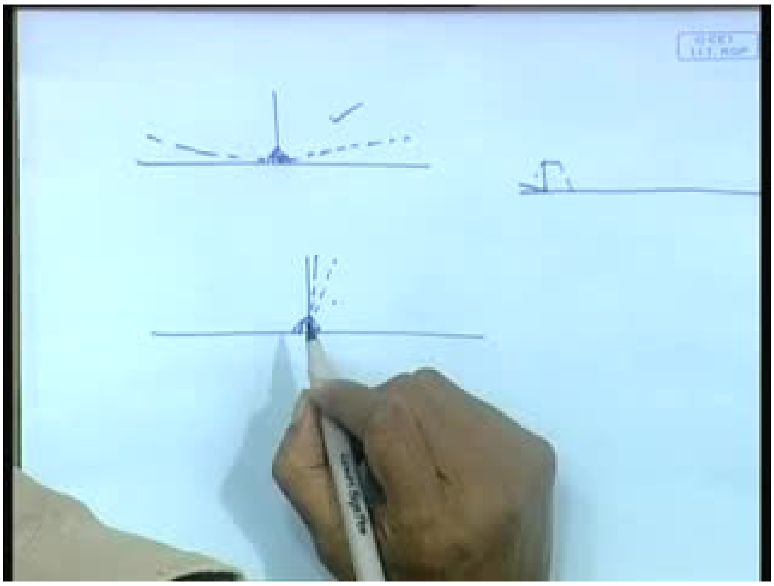

Till now, all these examples what we had been seen, they are all butt-welding, cases of two plates being welded. Now, say the plate is there and some stiffener is welded. So, what will happen? It may lead to, one is, say a plate is there, a vertical stiffener, you weld one side, it may lead to this stiffener getting deflected like this or stiffener is vertical, the plate is deflecting like this, both sides; when this side is welded, this lifts up; when other side is welded, other side lifts up; that is what is angular deformation. Or, in this case, the plate is restrained and the vertical member or the stiffeners is welded. If I weld from one side, it bends, deforms like this; then, I weld the other side, it comes back, but, not to the original position. It remains reflected in the previous position, why? Because, it has become restrained; one side now, has been welded so, it will not, the forces will not be enough to bring back to the original position. Now, what happens is instead of this, this frequently happens. The first one the plate deforms, why? Because of the reason, that when a stiffen panel is fabricated. How do you fabricate? Say, we put a stiffener.

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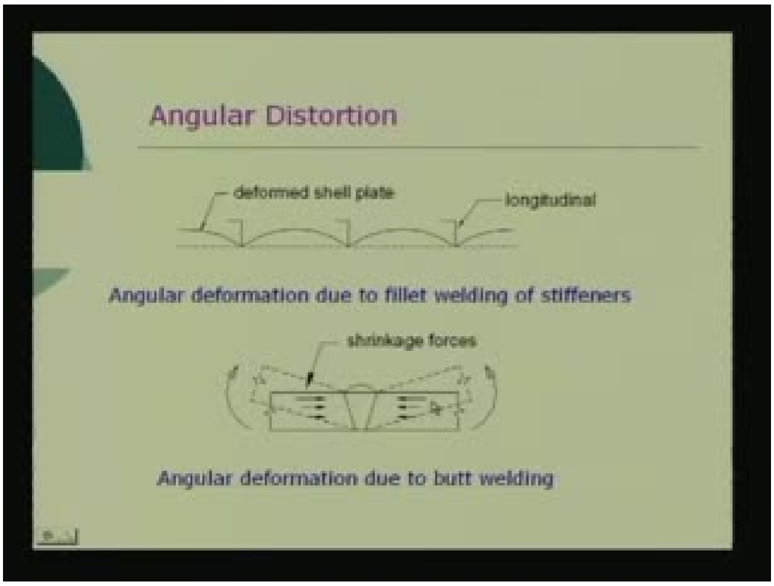

The stiffener is held in a position by means of supports; it is not allowed to move this way that way, stiffener is held in position, but the free edge of the plate is the edge of the plate is free, so, it deforms; that is what is here, it has it it is it is lifting up, deforming, right? Both the edges, they had just as I am welding, the plate is lifting up, right? That is because of the fillet welding and this is because of the in in case of butt welding.

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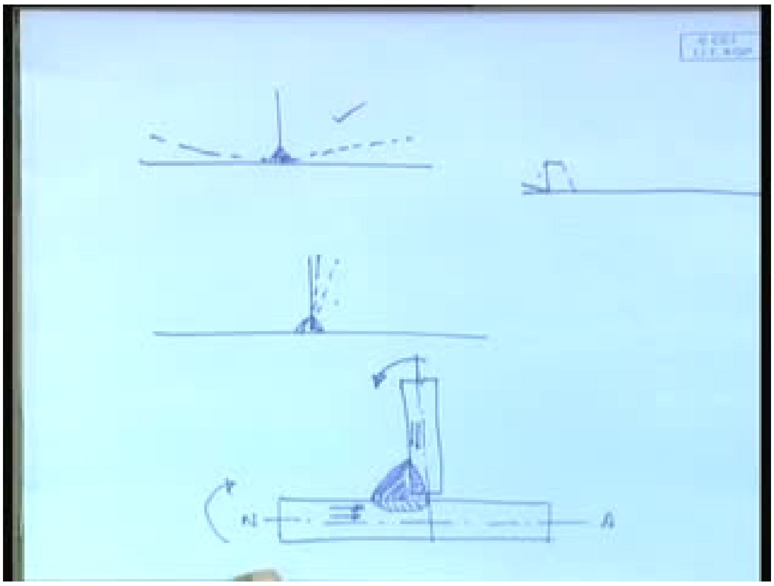

In case of butt welding, that angular deformation due to butt welding, now, as you can see in the picture, this butt welding, the shrinkage force is how the shrinkage forces are working. Since the weld metal is more at the top surface so, more heat is there, so, we have more shrinkage force; because, shrinkage force is directly proportional to the amount of heat which is going in, is directly proportional to the peak temperature it is attaining, right? So, thereby, you have a higher shrinkage forces on the top surface; as you go down, it is lesser, so, that forms a couple that forms a couple which gives you leads to the case of a bending moment and thereby, an angular bending. Same thing happens in case of fillet weld also; fillet weld, what is happening is, suppose, this is your plate the vertical, say a stiffener or whatever is being welded, so the fusion zone would be like this or the weld weld deposit this is be. This will be the weld deposit; this will be the fusion in the parent metal, right? So, what will happen? A contractional force will work here; it will try to shrink, right? Whereas, at the bottom, below the... even here, we have the shrinkages; deformation is even more, say this is my neutral axis, below the neutral axis there is no no force is acting, because the fusion zone will be will be above the half thickness of the material; it will not penetrate much. Because, in fillet welding, it important is, you will have to deposit the necessary material here, in the fillet having the required leg length as you have already mentioned leg length, right? So, there will be contractional forces or the shrinkage forces acting at the top.

So, these shrinkage forces will give rise to a bending moment of the plate, it will bend the plate in the similar reasoning. Shrinkage forces will work in in the vertical plate; plate also, if the vertical plate is restrained, it cannot move so, the bottom plate moves if the bottom plate is restrained and the vertical plate is free to move; it will move is the shrinkage forces is in this direction so, it will have a bending movement this side; so, it bends so, whichever direction, wherever the welding fillet is done, forces shrinkage forces, higher level of shrinkage forces work on the weld deposit, right? So, that is how we see, that how the angular deformations takes place, right?

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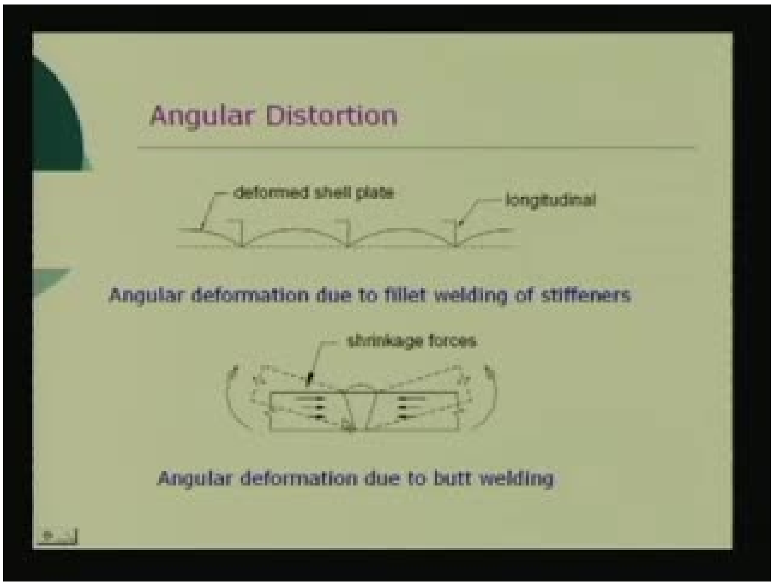

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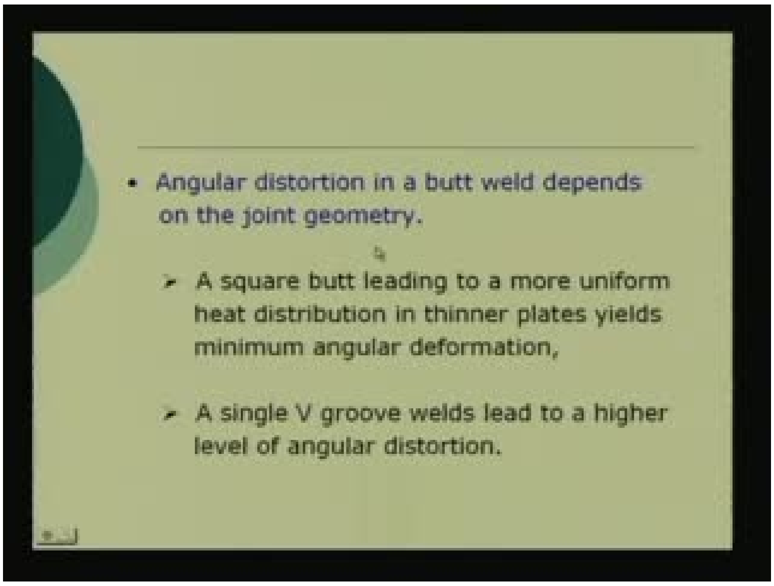

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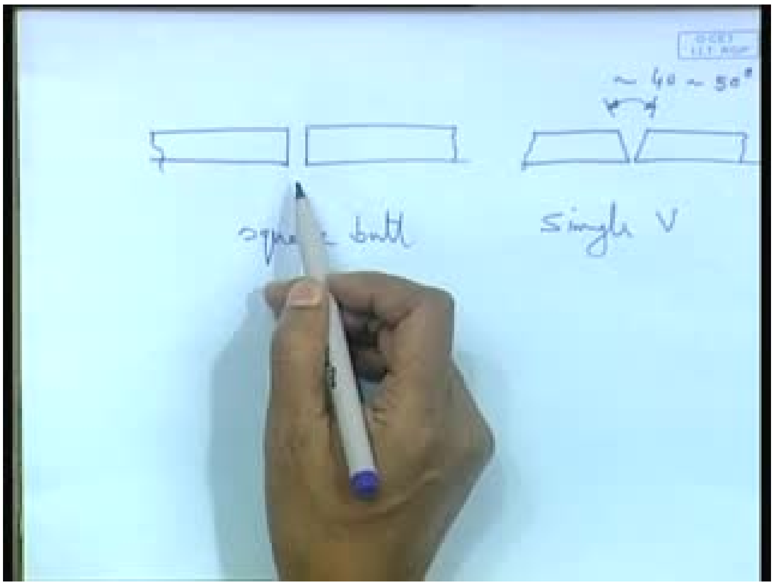

So these are the cases of angular deformation; one in case of a fillet welding, another in case of a butt welding. So, this angular distortion in butt weld depends on the joint geometry; on the joint geometry means as, at times, I have mentioned that this is a case of a square butt, two plates are being welded without any edge preparation; this is refer to as square butt. Whereas, this is single V group, single V edge preparation, single V group edge preparation or single V edge preparation; it is in the form of V, right? It depends what angle you will give and all that; it is generally say, for still 40 to 50 degrees angle; it can be much lesser 20 degree, that is what it is called narrow gap welding; we will not go in that, whatever. Because, narrow gap means, when I am saying 20 degree narrow gap means, it is coming closer to square butt, coming closer to square butt. Why we are going for narrow gap? Essentially, to reduce deformation because, here we see a square butt leading to a more uniform heat distribution in thinner plates yield minimum angular deformation; because, when it is square butt, what happens, your fusion zone is also like this.

So, more or less it is uniform at the top and the bottom, difference is very less; but, when it is a V group difference is quite substantial; as you can see, difference is quite substantial. So, in actually, what happens? In thinner plates, comparatively of the lesser thickness, you go for square butt, right? In thinner plates, whereas, you do edge preparation for thick plates; say around above say 14 millimeter; less than equal to 14 millimeter, not equal to; less than 14 millimeter.

Why this V group is done? Because, otherwise, you will you may not get proper fusion, root fusion; because, the objective is, you will have to have proper weld deposition, proper root fusion, proper bottom reinforcement, proper top reinforcement all these are necessities. So, as the thickness goes on increasing, you will have to, you may have to give an edge preparation such that you can reach the root, necessary root melting takes place, root fusion takes place, right? So, in thinner plates, welding is feasible without any root preparation; that means, without any edge preparation; that means, keeping the edge as square butt. Advantage of the square butt is what as you can see here, schematically that means, the fusion zone is fairly rectangular means, uniform at the top and at the bottom; if that is so, then this shrinkage forces developing also will be fairly uniform or in other words, very less movement will be generated and thereby leading to very less angular deformation.

Whereas, in this case, it is substantially different, the fusion zone; that means, much higher amount of heat is generated at the top whereas, much less at the bottom, so, your shrinkage force distribution also becomes like this. So, thereby, more bending movement takes place; that is why we talked about narrow gap; this single V group, but you keep the gap narrow, 15 to 20 degrees in degrees, such that, that will lead to a fairly uniform heat distribution at the top and at the bottom, anyway, that will not go.

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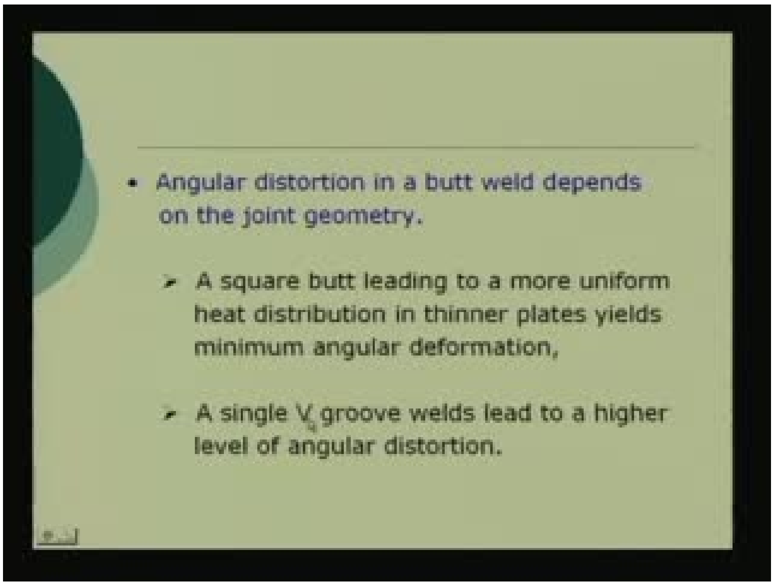

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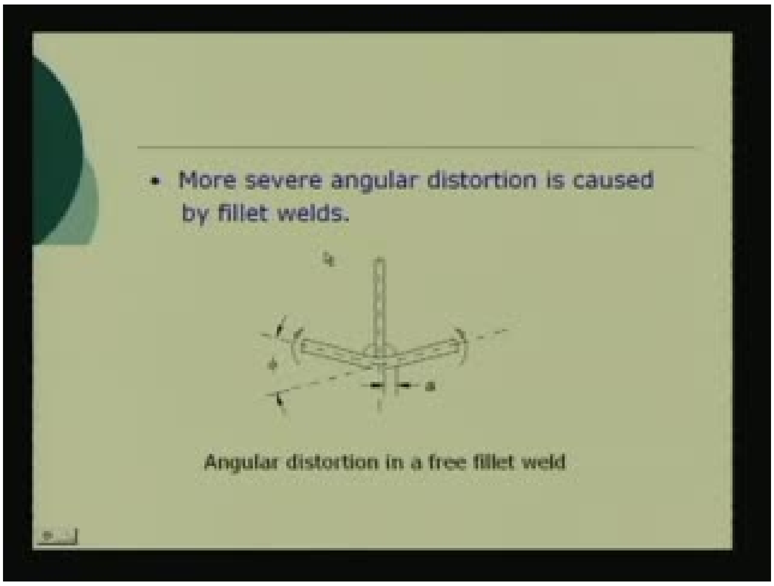

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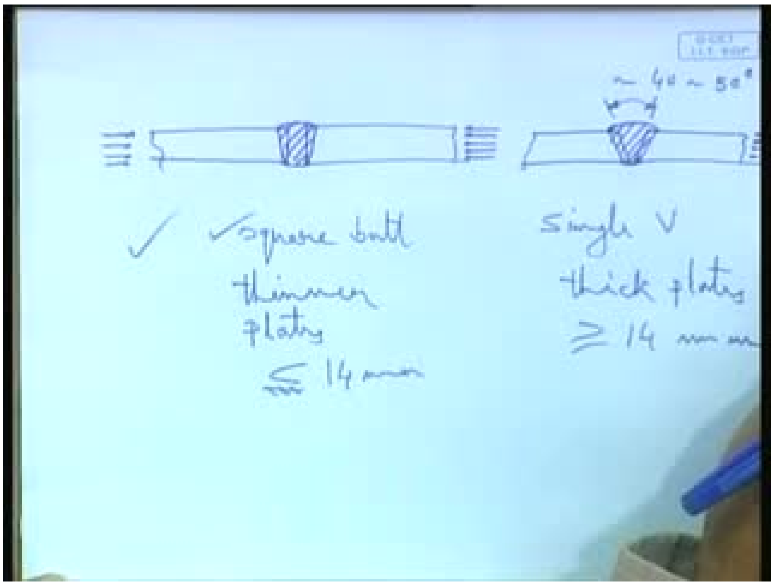

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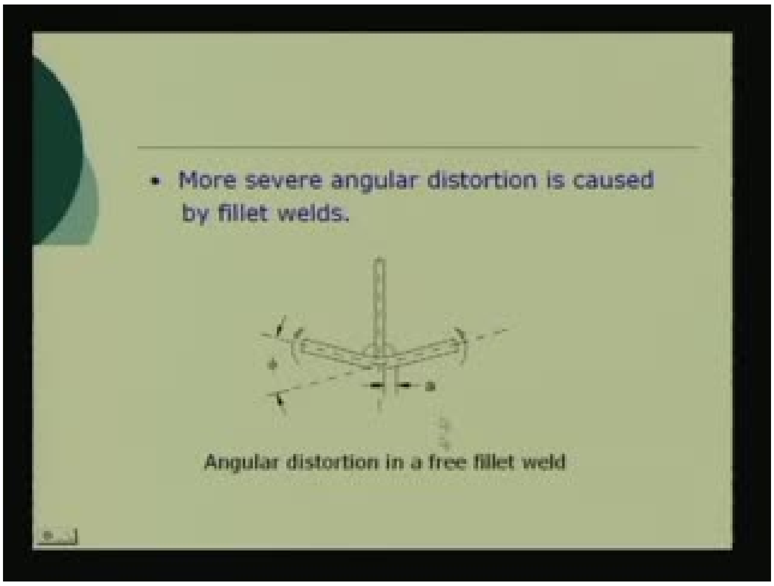

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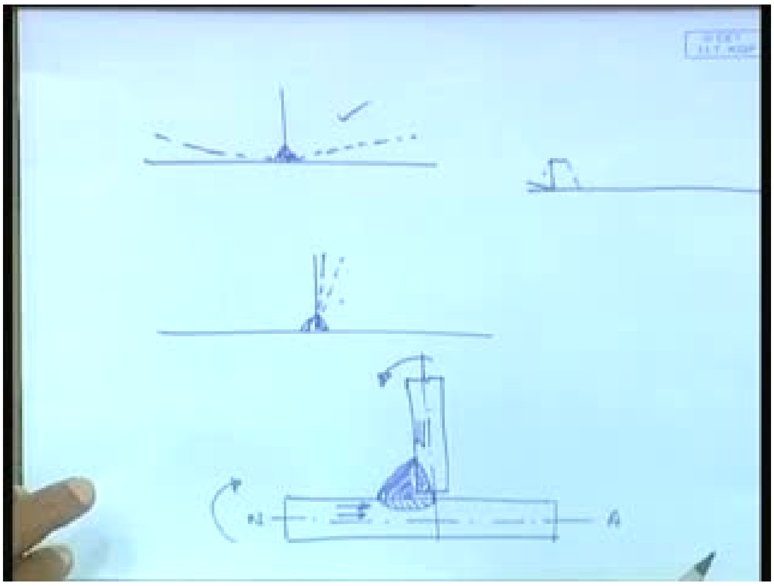

So, a single V groove welds lead to a higher level of angular distortion; as just now, we have talked about. More severe angular distortion is caused by fillet welds; these are because of butt welding. And fillet welding, we have always talked about this, is the more, we see that much more severe distortions take place in case of fillet welding. Because, in fillet welding, as we have seen, the shrinkage forces are, right at the top; there is nothing below. So, the bending movements are much higher, bending movements are much higher.

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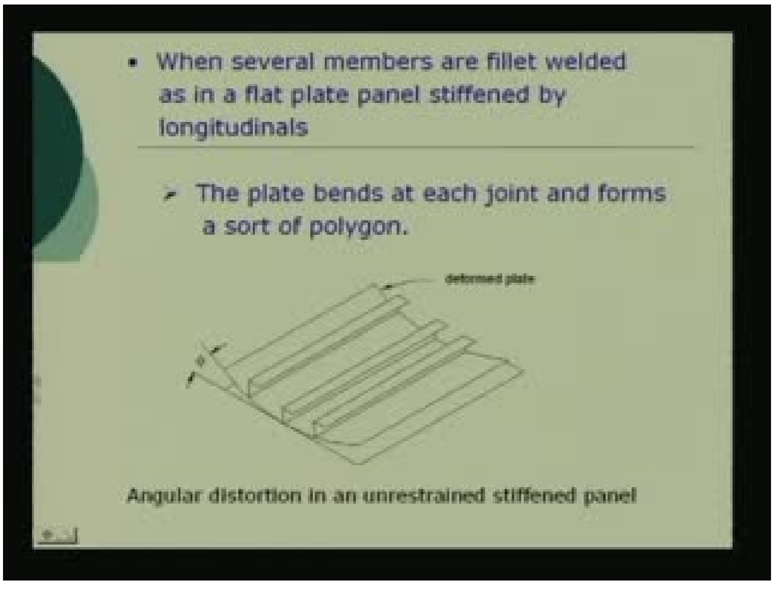

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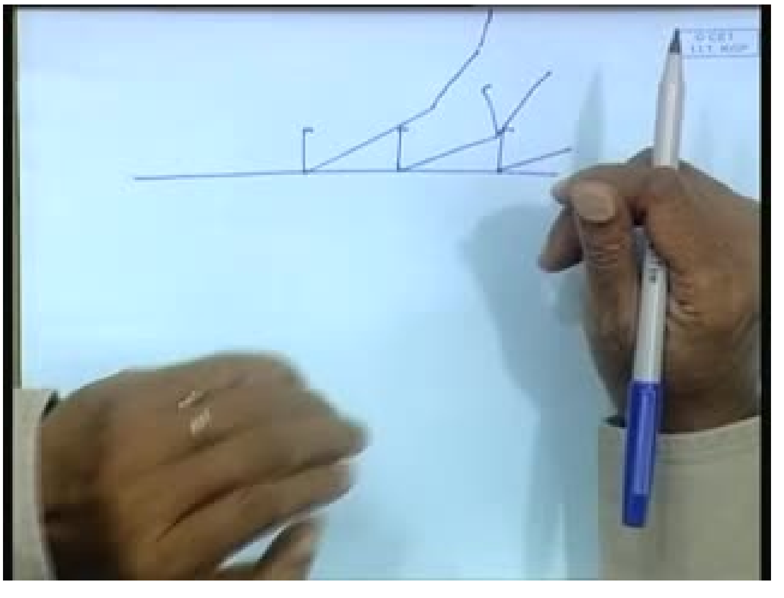

So, in the process, what do we see? When several members are fillet welded, as in case of a flat panel, a flat stiffen panel, we find the plate takes a kind of a cylindrical shape. Here, I have mentioned as a polygon because, as if, wherever you're longitudinal is being welded, it is bending from there. So, when you have a flat plate one say, stiffener is welded, it bends here; when another stiffener is welded, this whole thing bends like this. This is obviously I am drawing with very very exaggerated, right? So, it keeps bending; that is the principle principle of line heating we talked about while bending of plates; same thing, line heating will give control heating.

Here, the deformations are not desirable; they are using the same principle, we bring in deformation in line heating; same principles are working. Only thing in welding things are little more little different as far as distortions are concerned or extent of deformations are concerned. Because here, the temperature attend is much higher, the amount of heat involved is much higher compared to that of the case of line heating. Because, in line heating, we do not go beyond 700 degree centigrade in steel plates in in normal strength steel plates. If we have to work with higher tensile steel plates, we even restricted below 650 degree centigrade; but here, in case of welding, the temperature goes beyond melting temperature all, right?

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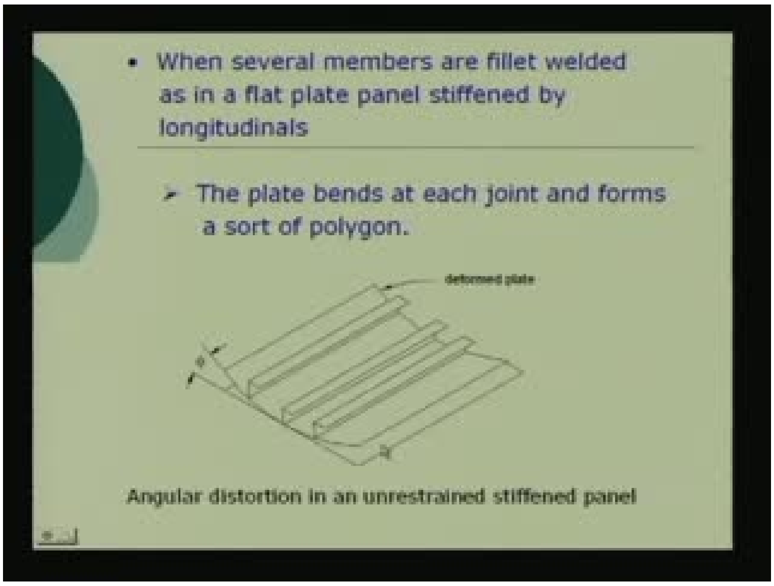

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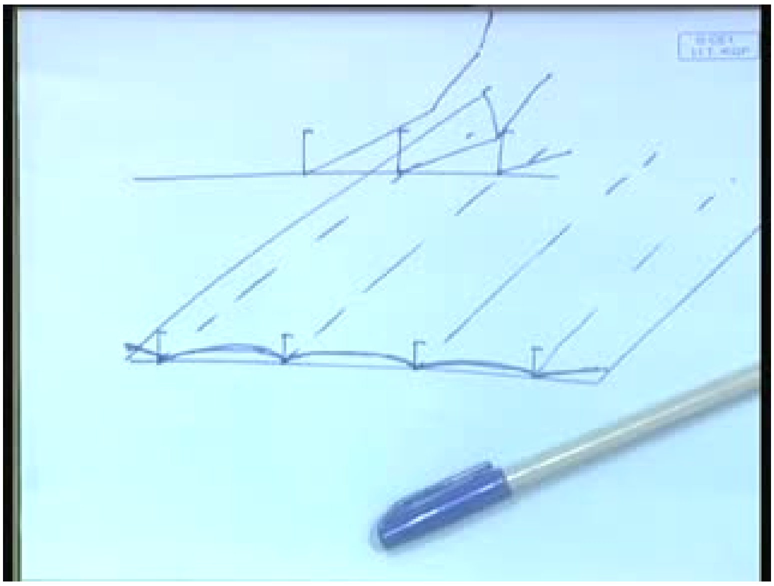

So, I mean, physically, the phenomena are same or similar, but the conditions are little different. In any case so, what do we see that kind of deformations, that means, it is not enough when we say that will have to fabricate a flat stiffen panel which means this; that means, after the fabrication, I am supposed to have a flat panel which stiffness welded welded onto it. So, my design thing was a flat panel with stiffness, but after it is fabricated, we get a curved panel, right? And worst is curved panel means, because this is deformed, the angular deformations have taken place; here also angular deformations have taken place, so, it has become like this; or, the edges are have a angular deformation at this things have buckled, that is also is possible. So, that means, after the welding done, again you have a dimensionally in accurate panel because of the welding deformations like this.

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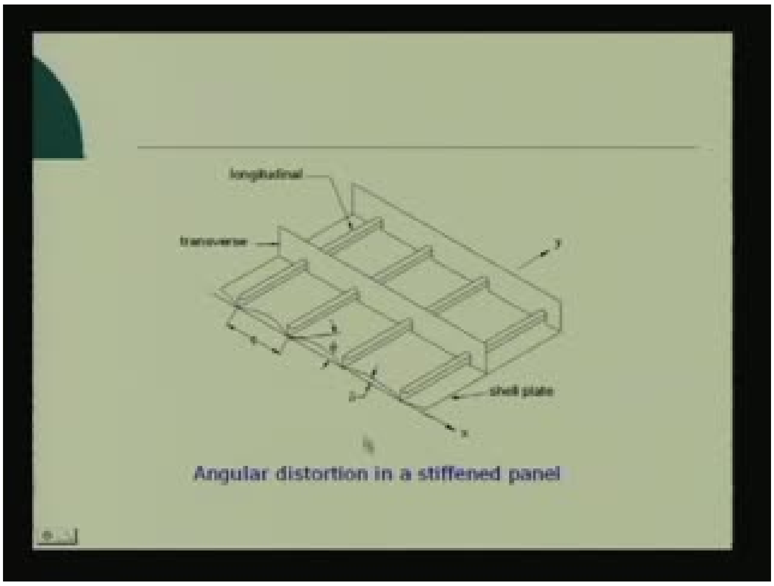

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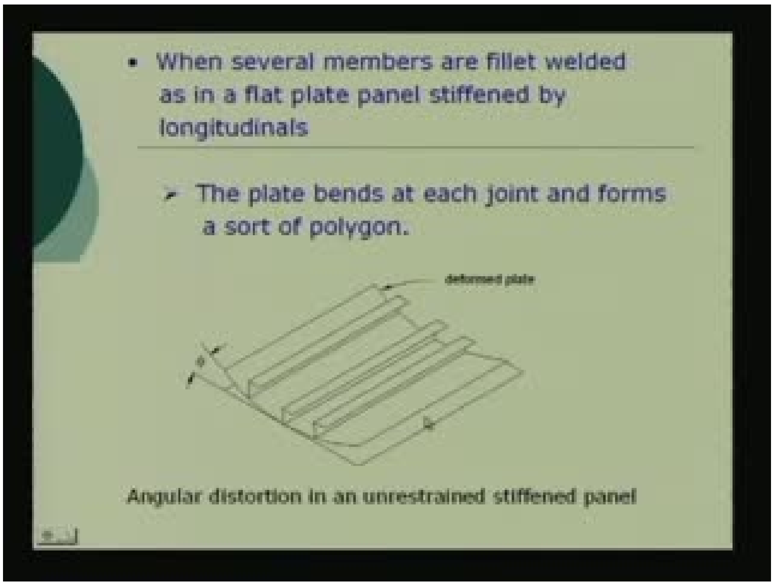

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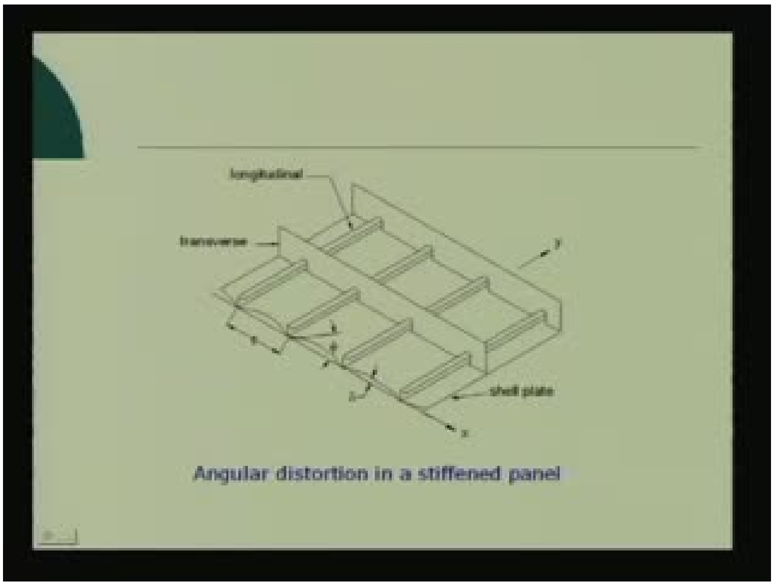

Well, here, I mean, the previous example is a case of a stiffen panel where you have only stiffener in one direction, right? That means, it is free to bend in one direction; it it is restrained along the longitudinals, but can bend along with the longitudinal; so, it gives a cylindrical kind of curvature, the entire ship. Whereas, in this case, we have transverse members also; these are more of a, kind of a, similar to that of stiffened panels which are used in ship building, because, we have longitudinal members, we have transverse members supporting them, right?

So, this is suppose a case of a stiffened panel with longitudinal and transverses say, a part of the deck structures; these are the deck transverse suppose, right? And you have the deck longitudinals; so, there, what will you get? We will get the longitudinal deformation, angular deformation of the edges, but the deformation pattern will change; because here, you have the transverse, that will not allow the edge to deform that much as it is deforming at this edge.

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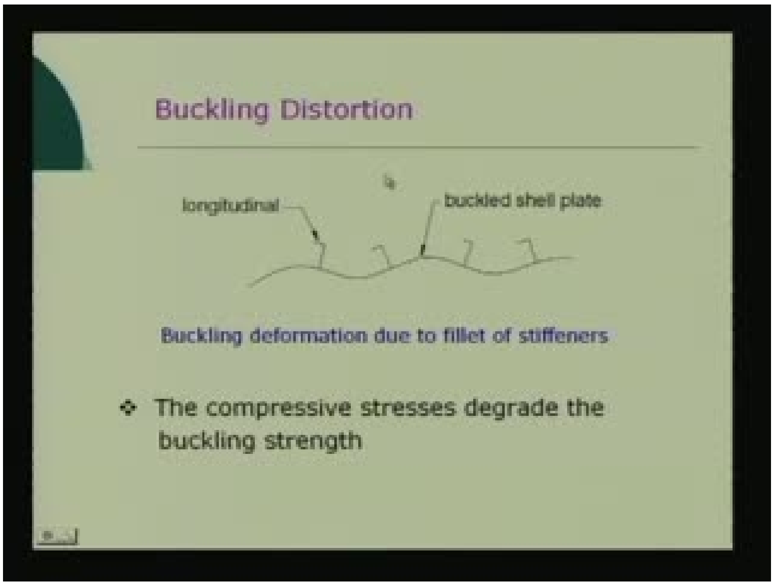

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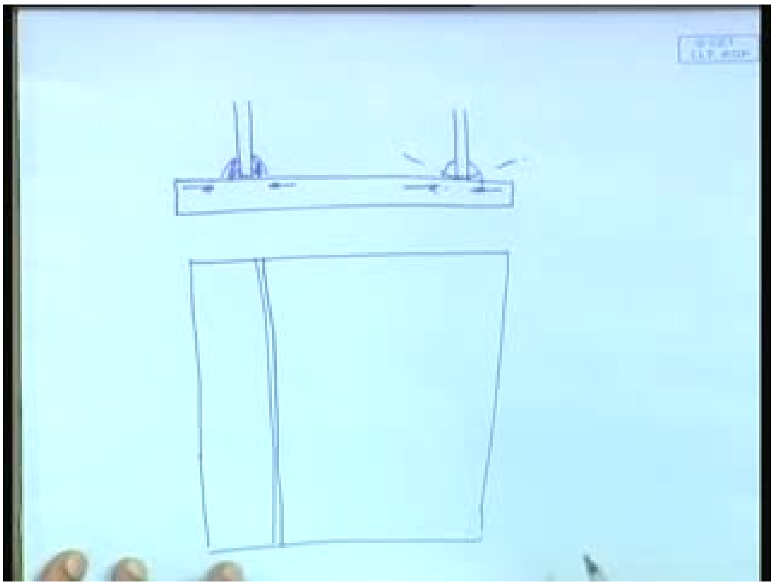

Similarly, at this free edge, this this plate is deforming so much say, by amount of delta, but as you come closer to the transverse it will be less, but in any case, there the case of angular as well as in fact buckling deformation. So, that was the previous one was essentially angular deformation; and also, this medal it could be a case of buckling of the middle plate; and this is a pure buckling deformation, that means, the entire panel has buckled along with the stiffeners. Due to the shrinkage forces, will see that; due to the, again the shrinkage forces. Because, what is happening as you as you saw, if if I once again say let us draw this.

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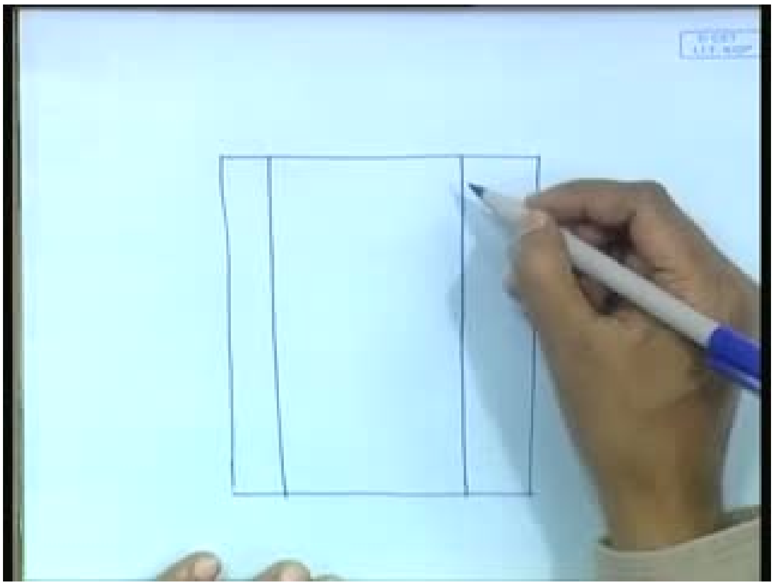

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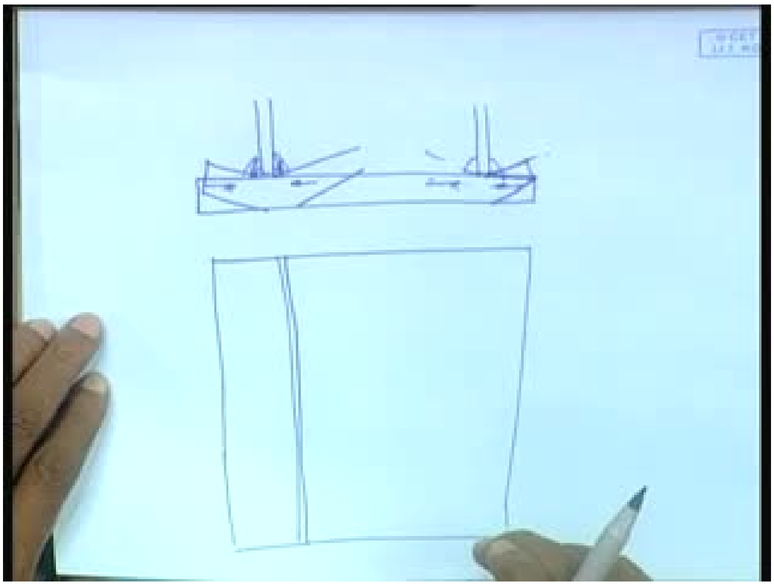

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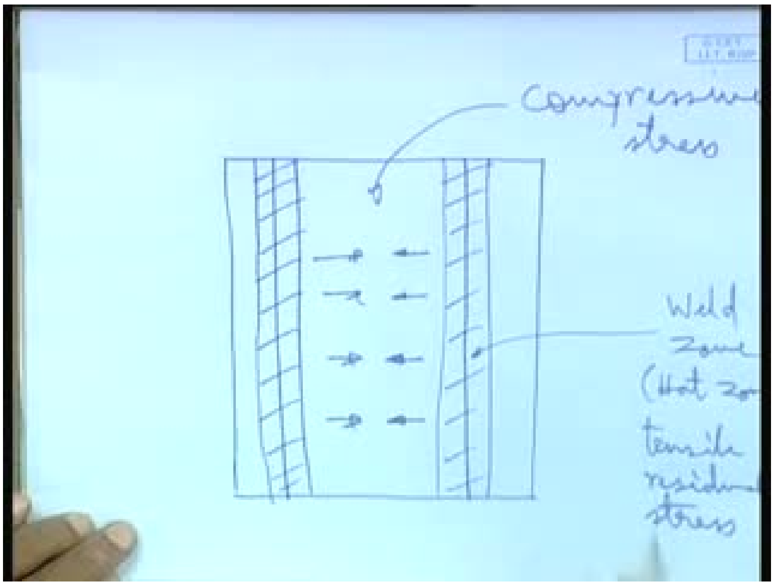

Say, this is my stiffener; fillet welding is being done, right? So, what is happening? The shrinkage forces are working in this direction, right? Here the shrinkage forces are working. So, thereby, you are having the angular deformations. Now, after the weld structure is cool down, in fact the buckling takes place say, this is the - let me draw it little – say, along this line one stiffener has been welded, along this line another stiffener has been welded. Now, after the welding is done, when a continuous panel is being welded, then it is not free to expand or the entire structure is not free to even deform in a angular deformation way. This edge can deform easily, it can take a shape like this, it can take a shape like this, it can deform easily; but the middle, this deforming in this fashion is not very easy, so, what will happen? Residual stress will form, residual stress will form; and what has been observed? After the weld gets, the entire structure cools down near the weld zone, this last line I am drawing. The residual stress is always tensile in nature; near the weld zone, the residual stress is tensile; this is the weld zone or I will say well, by weld zone, I do not mean only the fusion zone, it is the hot zone; means, fusion zone as well as the part of the adjacent material which was subjected to significant temperature rise, right? Significant temperature rise.

Let it be hot zone; the fusion zone along with the adjacent material. So, there you have tensile residual stress, tensile in nature. Rest is balanced by compressive; here, it will be compressive stress. That means, this part is under compression and that leads to buckling. So, buckling is essentially a phenomenon because of the residual stresses developing the tensile in nature and there the compressive in nature and that leading to buckling; so, that way, part of the residual stress is also relived; the structure deforms and it buckles, right?

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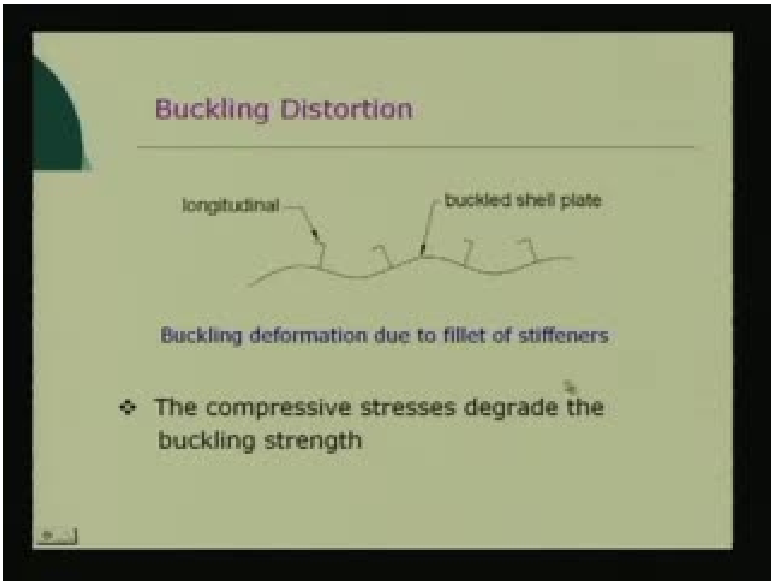

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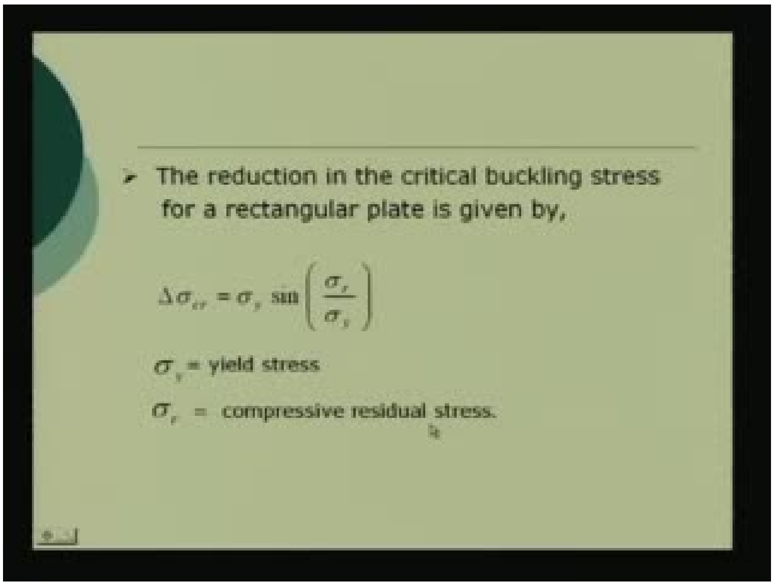

So, that is why you will see a stiffened panel is made. It is more prone to buckling in fact, right? The compressive stresses degrade the buckling strength. What happens, the compressive stress residual stresses, it reduces the buckling stress. It is actually through some such, some sense it goes that the reduction of the critical buckling stress for a rectangular plate is essentially given by this; that delta sigma critical is actually proportional to the ratio of the compressive residual stress to the yield stress, right? And what happens is, this compressive residual stress which forms, it is almost a near, I mean, equal to a more than one third the residual yield stress; they are of very high value. In fact, tensile stress is near about equal to the yield stress. Whereas, the residual stress is near about one third of the yield stress, compressive residual stress. It is distributed over a larger area, so, the magnitude is less and magnitude is approximately one third.

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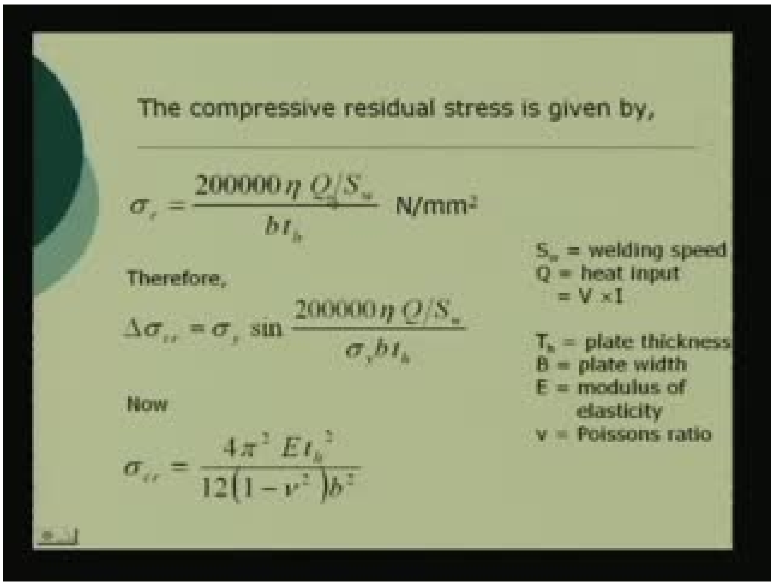

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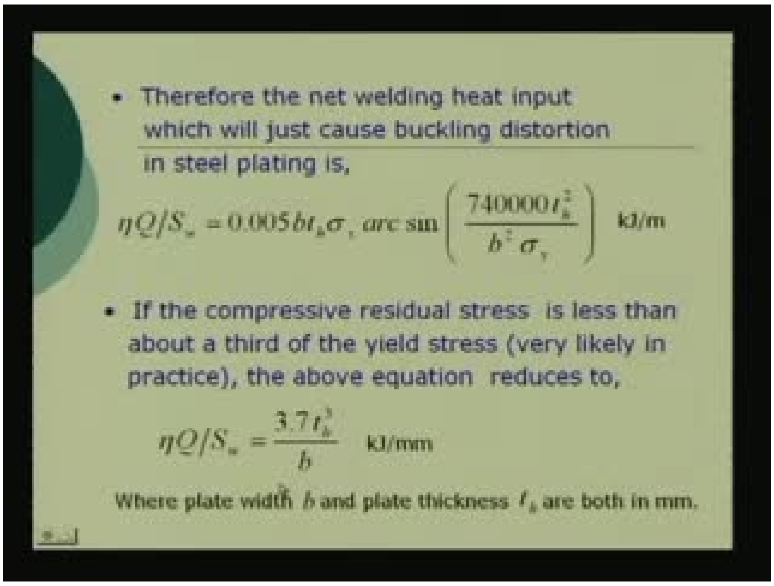

So, what do we see? There are certain direct relations, simple relations with the residual stress, with the heat input; Q is the heat input, right? And the critical buckling is this, say, through Euler formulae is this, so, if we equate these two, we find that the net welding heat input which will just cause buckling distortion is given by this. This is a simple relation because, one way would be to to work out, to work out the entire thermal profile through which you can calculate the stress distribution pattern and thereby, say, when deformation is going to take place; but that is a more complicated process. Whereas, through this, it gives you a simple so-called engineers tool, through which, where the voltage and current and welding speed Q is voltage into current, right? And S w is the welding speed, right?

So, Q by S w is the rate of heat input, rate of heat input; so, depending on the rate of heat input, we can see that what rate of that is related to this. So, this is the amount of, I mean I mean, once we calculate this, that gives me the amount of heat input; which, if given, will lead to, may lead to a buckling distortion. So, accordingly, one can decide what welding speed you will give or what voltage and current you give.

We will look into this little more in the next class.