Strength and Vibration of Marine Structures
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Lecture - 32
Stress Concentration / Structural Discontinuities

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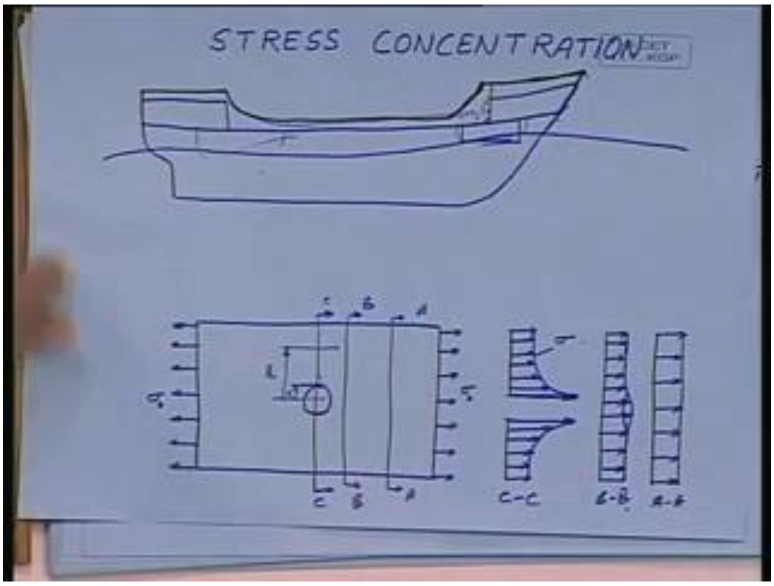

In any structure, we come across this phenomenon when there is an abrupt change in the structural arrangement or what we say when there is a structural discontinuity. Say for example, in our ships we find, let me draw the profile and let us verify. I am drawing the old type of profile; say you have the main deck here and then you usually have a portion.

Sometimes, you may have some increased portion here, also known as the puck. And if you see it from outside, what we do? That we have a bulwark, goes like this. So, this plating which is there goes like this and actually the deck is something like this. So, there is a discontinuity here. Now, if you wanted if the bulwark, we could have finished it here, put a ladler sort of a think here, and then start bulwark and then finish it. But we do not do that and we are trying to leave it. Now, there must be some reason why we are not doing that? Can you tell me what are the reasons?

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Load comes later on. Number one what we do, that this is the part which can be seen outside; it should look pretty. And if you have a discontinuous thing, it does not give a very appealing look, and therefore, if you have some smooth covering like this, it gives a good look. So, look wise it is good, smooth, and then comes the structural part that all this discontinuities are concealed.

Now, the actual thing comes. This vessel when it flexes, there is some sort of an additional stress comes here. So, if we continue in this fashion, then the stresses will come here. And for that, let me try to just take a simple example that you have a plate, let us say a rectangular plate, and we give a small hole here. And if we subject these to say uniform tension, then what type of stress variation will be there?

If you take a section somewhere here, stress variation is like this; you take a section here; this is the hole part; there is no plate. Obviously, when the material is not there, the stress will not be there, but how the stress goes here?

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No. You take a section somewhere here. Section is complete. Sorry, it will be something like that; so, it will be something like this. Now, what makes it to go like that? Here, there is a discontinuity which is coming as a layman we can say that the amount of stress which was supposed to be taken by this part here is not there. And who is going to take it? It is the neighborhood who will have to bear the brand and that is what happens.

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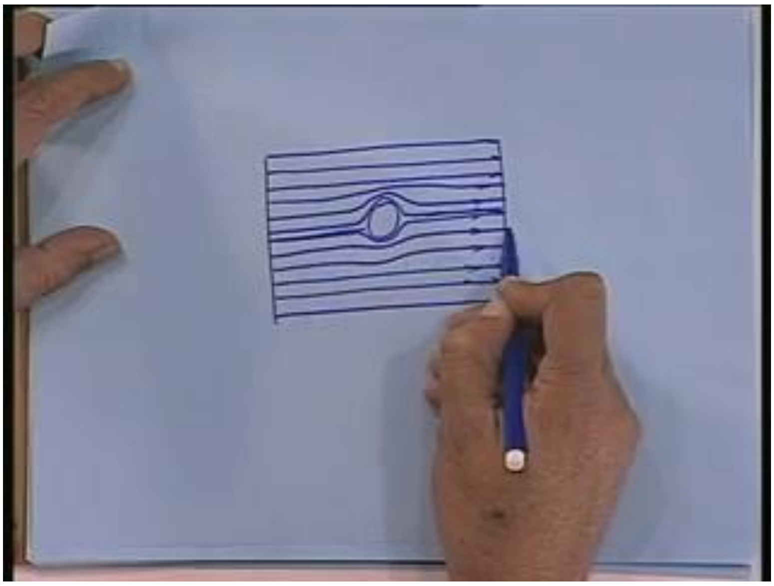

Now, many people try to explain it like this that you consider stress is flowing like a fluid. So, if we are talking about a plate like this, the uniform stress which we are saying is going like this, and then suddenly the material is not there. So, this stress line will go from here to here. But this stress line which was supposed to go straight does not find any material, and therefore, it bends and goes like this; this line goes like that.

What happens to this place? What happens here? This also bends a little. Now, you see what happens. Because this material is not there, all the stress conduits are trying to reach there, but do not find anything. It takes the shortest path and goes like that. And as the concentration starts, it gets deflected a little bit and then it finds that yes it can go like that. So, now, if we just try to plot it, that gives you this variation and you will find that the smaller the hole, larger this will be. I am not going into the mathematics of it, but if you consider this part here, let us say that this is sigma 0 and I want to plot this as sigma across this.

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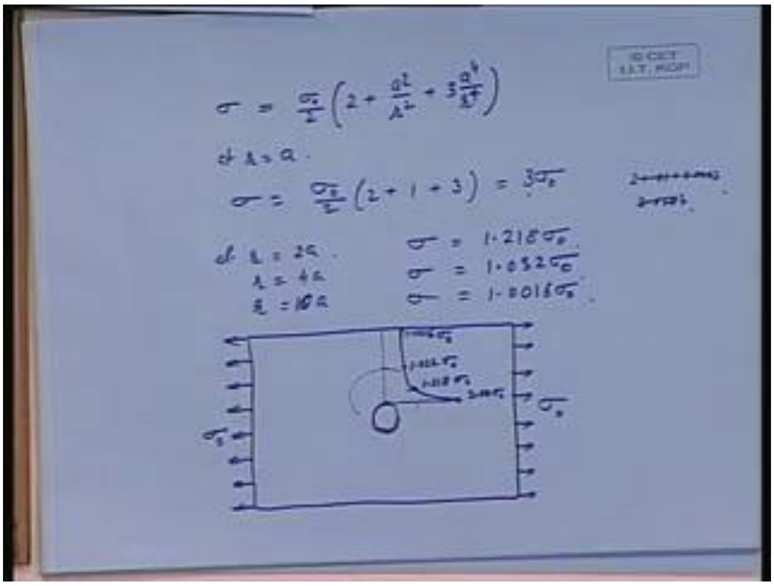

And if I say that this distance from the center is some r and I take that half diameter, you say, then I can write it is derived that sigma is equal to sigma 0 by 2, 2 plus a square by r square. So, this is the stress value which you get. Now, what is this value here? This is the stress value at sigma, sigma at r is equal to a. And if it substitute that value, so, this part has been mathematically derived from theory of elasticity. I am not going into the details how it has been derived and so on and so forth, but knowing this fact that as soon as you make a hole here, the stress which you will get at this place will be of this order. So, the discontinuity is giving me a value like this.

Now, if suppose I like to find out say at r is equal to 2a, what will be the sigma value? Sigma value will be of the order of 1.218 I think. At r is equal to 4a, you say, this will be of the order of 1.032, and r is equal to say 10a 0 0 how much it is? This we should be in a position to calculate 1.0016. So, you see how it changes.

If now I try to plot it, what is the value I have taken 1, 2, 3, 4, 5, 6, 7. This is 3. Now need 2 a2 is 1.2344... So, this this let us say is 0016. This value is 0 32. This value is 1.218; this is 3.

So, see in the vicinity, this is 200 percent more; this is 22 percent more; this is 3 percent more, and of course, this is only 0.16 percent more here just because some material is not available. Some increase will be there because they have to share it; this material is missing, but you see that who shares the maximum is this vicinity. So, the concentration of the stress is around this area.

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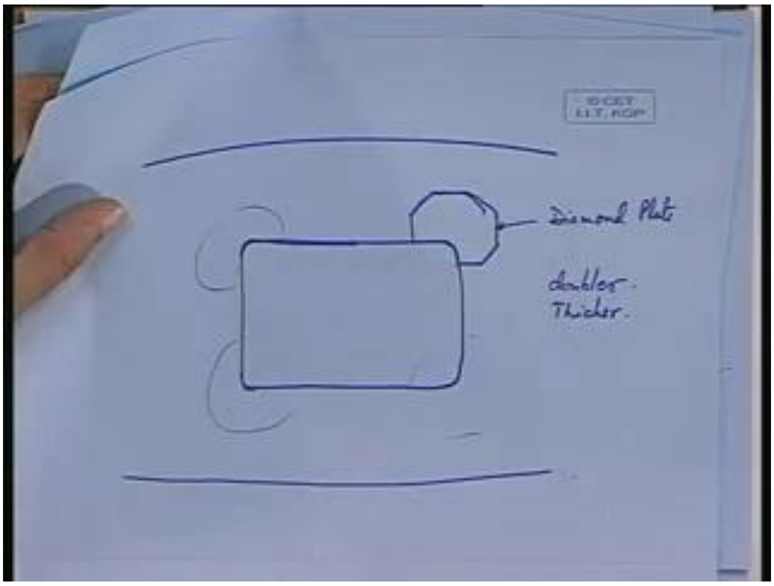

Now, when we come to the ship's part, obviously, when you have a deck we say that you have the deck here and you have a hatch opening. We round it up. We do not leave it just like that; it will be easier for us to cut it straight and then you have the flanges also straight there, but we round it up basically to make it smooth like this. And then even after that, what we find? That the stress value will be of this order; so, stress here will be of that order. And to take care of that in this vicinity, it is not only here, what you can see is that as you go a little away also, the stress percentage is quite high.

So, what we do? We try to increase this part, I think it is something like this, and you have a plate in this side which normally we try to give it in this shape, kind of octagonal diamond shape, we say, diamond plate in two ways; either you have a doubler or you have a thicker plate replacing this thin plate here .

Now, this will try to give you that what should be the thickness of this additional doubler plate. But these days we are not going for the doubler plate just because if you are having two plates welded, there is every likely load that some gap will be there. And there will be a passage for the oxygen to get inside; the water will go there; the moisture will be there and there will be a galvanic action between the two plates there quite likely. And therefore, inside you cannot protect it. So, you just simply remove this part and change it with a thicker plate at this edge. So, all these areas are strengthened to take this additional stress value. The same is the reason when we are trying to do this.

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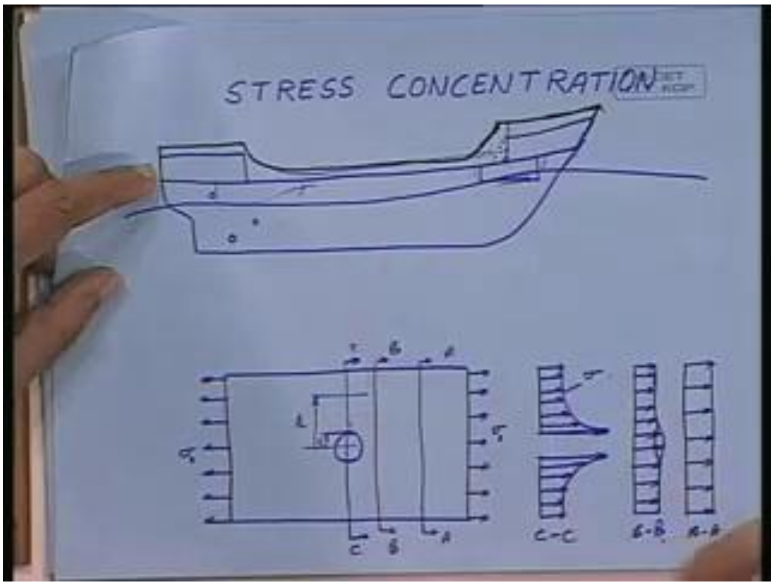

Now, this particular ship will be under bending. So, what will happen? This particular plate will be under stress; tension, compression, whatever it is. And this part of the shear streak we would like to strengthen it. That is the reason why this plate is not given in this fashion because this will also be subjected to that, and therefore we try to give a extended part in a smooth fashion here. So, this is the reason why in these places, we have a plate like that. You see the practical aspect of it and also you try to concentrate something on the aesthetic part of it. And the matching the two, we try to come out with some solution.

Now, there are other things that, here itself let me say that, near the engine room you may have lot many holes; either below the water line for sea intake or slightly above the water line for the discharge. So, these are all circular holes, may be upto 2 inch diameter or 4 inch diameter from where you are sucking in the water and you are also throwing away the water after treatment etcetera. Or it may be just for the cooling purpose for the or there the heat exchange or some such things; you take the sea intake and then throw it out; continuous process.

Now, these holes which we make will be subjected to this stress concentration, and therefore, for the compensation of this, we try to strengthen them by putting a ring sort of a thing. We can say that the pipe which is welded there itself will act as a flange, but again we cannot 100 percent be sure on that side. So, we put the pipe from inside, but from outside also we try to put a ring sort of a thing. So, this part is different.

The same thing, on the deck we have the manholes and we try to put this radius there. And this radius when we try to put that, one can say that more will be the radius, here again from elasticity you will find that this stress which is here will get slightly tapered down. So, if you are having a smaller hole, more concentration will be there. If you have a bigger hole, then the concentration is reduced.

Now, this phenomenon I will try to explain you. You must have read it that during the early 90s, a lot many bulk carries were lost in this sea. I think according to the recorded this thing some about 56 bulk carriers or 56 ships in which majority of them where bulkers, between I think 91 and 93, were lost. And when some sort of investigation was carried out, they found that the average age of the bulkers were something between 12 to 15 years. There were about 20 percent vessels which were beyond 20 years old. But there were about 15 percent vessels which were 6 years and younger, and they were also lost. There was no question of any cyclone somewhere; there was no question of any grounding; the sea was deep. And in a very so called undisturbed condition of the sea, the vessels were simply lost.

Some of the vessels they could get the wrecks; in some of the cases they could get some surviving crew member. In majority of the cases, they could not even trace a single soul of the vessel itself because they went so deep that they did not know where it is.

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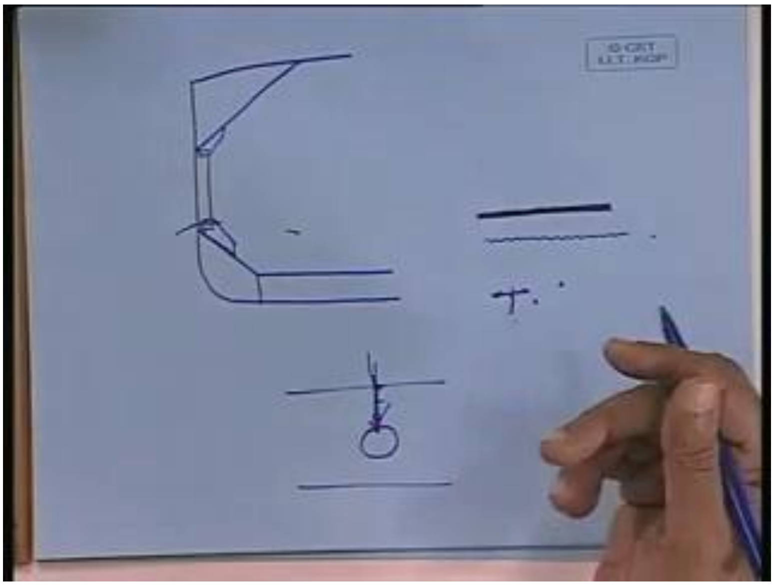

So, whatever wrecks they got and whatever verdict they heard from those surviving crew member, they tried to analyze and came to a conclusion that the bulkers… If we just see the cross section of the bulk carrier, I am drawing the half of it, you have the upper going tank here and you have the bent tank like this here. You are having the frame here which was being connected here; some sort of a bracket down here and some sort of a bracket up here.

Now, the majority of the vessels, they found that the crack started from here and this crack and the bracket which started progressively propagated to the stiffener here, and then finally to the hull and opening it to the sea. And therefore, from this side the water entered and slowly it flooded this part. It is basically a combination of many aspects. They found that why this has not, if it is fatigue here, fatigue could have been here also, but why it always on the bottom knee or knee bracket? Why not in the top bracket?

The thing is that when you are carrying any solid material in a loose condition, this corner cannot be cleaned properly, whereas it does not stick here, but it can stick here into some sort of a joints or knuckles there. The area is dark, and therefore if the inspector or surveyor, whoever goes there, he cannot see it properly and cannot make out whether the thing is properly cleaned, or even for the structural aspect, the welding aspect he cannot find it out.

So, if the cleaning is not done properly, if the same is the case with the painting also and with all those materials which goes and sticks there, either it is husk or it is some chemical or it is some dust particle, whatever you call it, they are prone to absorb moisture and along with the moisture, oxygen. So, they are rich in oxygen moisture and a lot of corrosion takes place. The effect of the corrosion is a smooth surface like this becomes a surface like this.

Now, if you see the surface top, each dent here is nothing, but a pit hole here. And when the thing is subjected to some bending, there is a tension here. And tension means at this part the stress is going to three times the surface stress there. It is a small circular hole on to the surface, and on the surface, whatever is the fiber stress, you can expect that in this side it is three times of that. If that is the stress value, you are likely to have a failure here a hair crack or hair line crack. But the thing is going in a cyclic manner and therefore you are actually not seeing this. And because of the loading, unloading, the material and dust will occupy this part. With the presence of the moisture, some sort of moisture, means air is full of basically Nitrogen; 90, 78 percent Nitrogen.

So, some sort of a metal Nitrites and Nitrates are formed here. These salt crystals try to cover up the crack and it is sealed. So, once the cracks are sealed, it again becomes smooth, intact. And When again the flexing takes place and it goes beyond that cracking stress of the salt, the salt crystal breaks and the metal surface freshly opens to the atmosphere once again; it reacts; first it propagates; the crack propagates; then it reacts. And again it get silt and this process goes on.

So, even if you try to check it, the surveyor will not be in a position to notice this with his naked eye just because of the shear location, the lighting condition, and the phenomenon which is occurring here. These are all the shipping load classification societies consortium has done a combined research and come to a conclusion like this. But a stage comes when this keeps on propagating and once again when it opens, you will find that the surface, if I just try to elaborate it here, say the crack has opened this much. That means, this surface, this cross section is still intact to take the load. After that when again it opens up, then the cross section, remaining cross section is less, but still it is capable of sustaining the load. And after that, when it cracks, you find that this is not in a position to take the further load. The stress goes beyond its capacity and the whole thing cracks, and this from here to here becomes a catastrophic crack.

If you would have known that some crack is there, may be some crack arrester could have been done and repaired it, but if it goes unnoticed in a progressive manner like this, once people say you know a massive heart attack is always associated with previous at least two mild heart attacks. So, you can also say that here also some heart attacks are there. And then finally, a massive breakdown takes place and in such cases it simply goes beyond the hull and water rushes in. So, though the things seem to be very small and very insignificant, but the disaster level is very high here.

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That is why people say that corrosion is to be taken care of and corrosion is given a lot of importance; the material properties and their associated alloying elements, which will prevent all this operation. And that is why the surface preparation, a proper painting, a proper survey after every four years, etcetera, is really a very important part in this case, as for as the health monitoring of the hull is concern. And that is why people say that a good quality paint is to be used because the surface is always under tension and compression, the type of paint protective layer which we have want, must have more or less the same mechanical properties as the surface of this material possesses.

So, if you are taking this, the surface, and on this, you are putting a surface coat here, so the interface must be intact all the time. When you are trying to flux this, either tension or compression, the two must expand or contract together. If suppose the expansion coefficient of this is less than this or the elasticity, then there will be a crack developed here and the corrosion will start from that and pitting will take place. So, though this is a chapter of corrosion here, but still one finds that this theory can be applied on the surface cracks.

That is what I was telling you that I have not gone into the mathematics of it, but this actually happens, and that is why one has to think about that how to arrest these stresses or bring it to a level which can be (()).

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R is any arbitrary value.

Yes. R, R is the location where you are trying to measure the stress; not arbitrary. Now, how do you find that how much of stresses are there? In ships, normally we do not try to measure these, but these days people are trying to measure it, but how, actually you will come to know. If you have already taken the corrective measures like doubler plate and a diamond plate and that region, obviously, the stress level reduces there, but actually how will you try to find out?

Suppose you do not want to do all this mathematical analysis, but you would like to know that what I have talked so far, is there any sense or I am simply saying that it goes up to 3 sigma and you believe it. In fact, one thing can be added to this part here, when you are taking out material from here or let us come to this joint here. How do we take it out? We burn it out basically.

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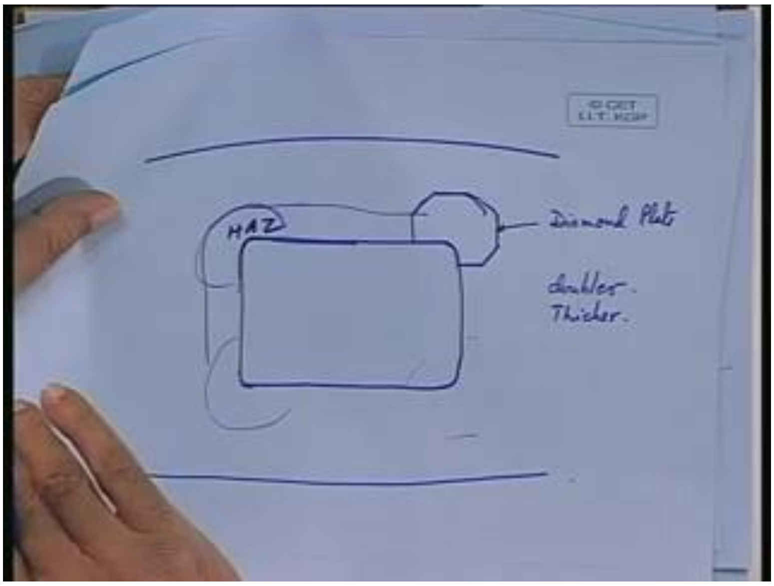

So, with Oxy acetylene gas you try to heat it and then high pressure oxygen you blow it off, and therefore, you get a neat cut here. So, you are heating it to the melting point and then you are removing the material with high pressure here, and then you allow it to cool on its own. So, to remove the material, we are heating and cooling. Are we controlling the rate of heating and rate of cooling? Not exactly. And therefore, in the vicinity of this, the property of the material and the crystalline structure of the mater, of the material, undergoes some changes. Some metallurgical changes take place because of the heating and cooling, and this part is known as heat affected zone HAZ.

After that we try to put some sort of either a doubler, and then some sort of a coaming. So, when you put a doubler here, you are again heating and cooling. And then when you are trying to put the thing, again you are heating and cooling. You are putting a coaming here. Not only that, you will try to weld it from this side; you will try weld it from the underneath also. So, basically, at the same place you are trying to heat at least four times and cool it four times. And I do not know that whether any cooling rate or heating rate thing was properly controlled. Even if it is controlled, what is the effect of it?

So, one has worked over this HAZ multiple times. When you heat, the material expands; when you cool it gets contracted. Depending on the rate of heating and cooling, how much it expands and what rate it contracts, there will be some strains developed here, and associated with the strains, there will be some sort of stresses which will be developed in this zone.

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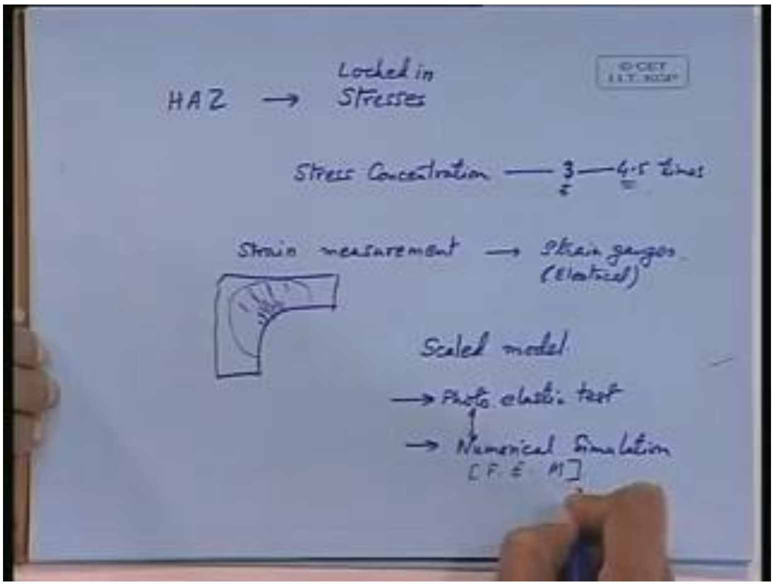

So, heat affected zone is not free from stresses and these stresses, we say locked in stresses. So, these stresses are present and on top of that stress, now we are talking about this stress. So, we do not know the nature of this stress. If suppose we are talking about tension here and already some tensile stress is locked in, there will be additive here.

So, if we are talking about three times this nominal stress here and some stress is already locked in, in fact, it has been found that though theoretically we get a figure of three times the stress, but in practice sometimes you obtain 4,4.5 times the stresses as the ((peak pen)) . So, the stress concentration when we talk about, it is 3 to say 4.5. I would say that this is less, but it is never less than this. This is the lower the limit. It can be anything in between; may be 3.5, nearly 4, and therefore, this cannot be taken very lightly.

So, wherever one has any sort of opening, whether it is for the water intake or water exhaust, air intake, air exhaust, or it is for the hose pipe, anchor chain holes or whatever it is, or chain anchor pocket, everywhere you are having some sort of a opening, a manhole, a lightening hole, a hatch opening whatever it is, so they have to be strengthened. Number one, they have to be smoothened and smoothening is done by giving the, avoiding all shaft corners, giving a rounding up; even after cutting with the gas, one may try to polish it with a grinder and then you strengthen it with the hatch component. And care must be taken that as for as possible a good welding procedure should be used so that in the heat affected zone, the locked in stresses are removed or tried to see that there is very little locked in stresses. This is what is very important here.

Now, when we talked about this, then one would like to verify also. The easiest way of verifying it that wherever you expect that there are stress concentration, try to measure the strain; strain measurement can be done in full scale experiment, which can be easily done by applying some strain gauges. Mostly they are electrical strain gauges and applying those electrical strain gauges, there are different types of strain gauges available; unidirectional or multi directional. One can choose it; apply the strain gauges, and then you can see that how the strains are varying at various locations and one can have an idea.

Another one is a mechanical observation; just the qualitative arrangement where you expect, say for example, when we are talking about this hatch part and this region, you try to put some sort of a paint material, a brittle coating. So, when there is a stress concentration, the brittle material will have a crack. And knowing the amount of crack in a particular zone, one can find out that how much of stress is concentrated here. If you have number of cracks, large number cracks in this zone, then you can say that this stress is concentrated. If some cracks are there, it may be continuous crack also, who knows!

So, then you can say that the stresses are less in this region, more in this region, but this will only give you only a qualitative arrangement; this gives you a quantitative thing. But both are in a practical full scale test, and full scale tests are not easy to conduct because you would not like to take a risk on how this behaves, and therefore, you will always take a precautionary measure.

Third one is that you have some sort of a scaled model and conduct photo elastic test. In this case, the model must be transparent. And when we talk about transparent material, obviously, it is not the parent material; there is a change in the material. So, you have to have a photo elastic material in which you can conduct the photo elastic measurements. You will try to get the material which is isotropic, but it will not have the similar mechanical properties as that of Steel.

So, once again, you will only try to get the nature of the stress concentration and the behavior, how, what type of structure you are taking in, how you expect this stresses will follow. Now, the best way is you try to simulate that numerically. So, you have done this model experiment, tried to have a numerical simulation, and tried to see that what type of stresses you get in your numerical simulation. Find out a correlation between this and this experiment.

So, if there is a one is to one representation here, then you can say that your numerical simulation model will work for any size, any material. And from here you can predict in the actual case that how the stresses will vary; that is the latest. And that is why everywhere you go for a numerical simulation and here the best way so far is the finite element method. So, this is what experimentally one will try to verify and then try to confirm that particular numerical simulation method and numerical method will try to predict that how the stresses will be here under such circumstances.

So, you can do a theoretical study knowing that one can take preventive measure at that design stage itself. Any questions here?

The stress concentration, I wanted to only cover this much, and all these experiments can be conducted because there are various shapes which are available now, to be used in ships, like this circular hole is one, then you may go for some sort of an elliptical hole also.

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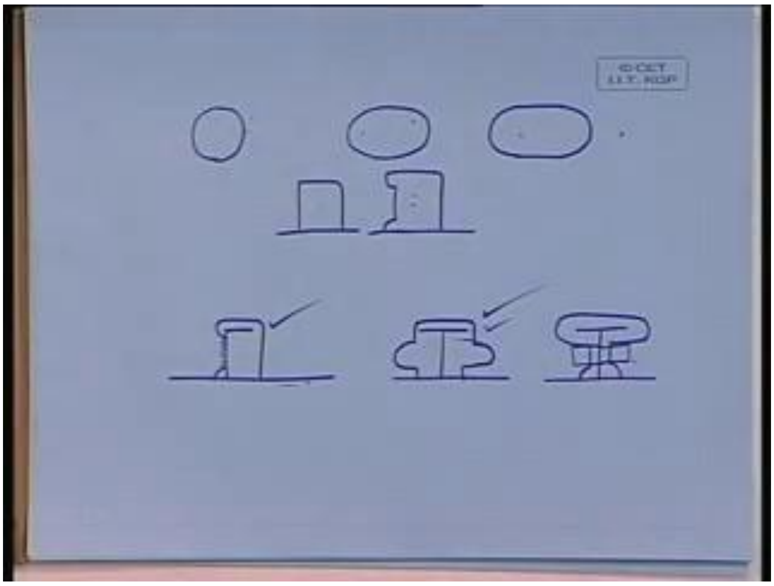

Like in lightening holes, we use exactly it is not this thing what we use is something like this; for this and this you have the mathematical expression. So, from here, one can extend it to this also. Then in the tankers, etcetera, you have a hole like this, a cutout. Basically if we see the bottom plate and you say that you have put a stiffener here, then actually this is not the shape you will get from here. The opening shape is something like this. This is welded here and if they want to make it water tight, then they will put another plate sort of a thing here and try to cover it up and weld completely. Now, this is one shape.

If you are having a t shaped stiffener here, then what type of opening you will have? See angle you can have a, both sides you will be having, no in that case you know what they do? Many a times you like that the liquid should pass through one point to another point. So, wherever it is a water tight flow, you will try to seal it. Where it is not water tight hole, so, instead of lightening hole, you combine the lightening hole with this cut out and one can go for a hole like that; a very peculiar hole. Now, this part basically if you try to see is nothing, but this part, and this girder and this is the part which is nothing, but this part.

If it is not like this, then one can go for this type of one opening and then they will have a collar plate welded here. But this type of an opening will create a problem. You see what happens, you take the bottom, you weld this. And then you will take the flow and try to put it on top of it. So, this part should be all clear and therefore this goes well, whereas this part will create a problem. You have to yes you have to take one by one and then put it in position, and then try to weld it; that becomes a difficult part. You cannot put it directly; you have to slide it.

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You have to slide it along the length. So, that is why they have gone for this. If you open Lloyd's register of shipping's structural book, you will find this opening. You will find this opening here. Now, you see what is the complicated shape here. These are practically required and theoretical result is available only for these two; a circular hole, an elliptical hole, even for a rectangular hole with circular ends which we use as manholes, is not available. But one can extend this to this and try to use it. What about this part which is a simple type of a stiffener? Either you can have this for a angle iron or you can have a slightly smaller one for a bulk plate.

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Coefficients and change the units: See when a particular person is trying to use the formula, it should be easy to use also, and therefore, they found that what these two scientist cum engineers have suggested is actually easy to use. Let us pass on to now composite construction.

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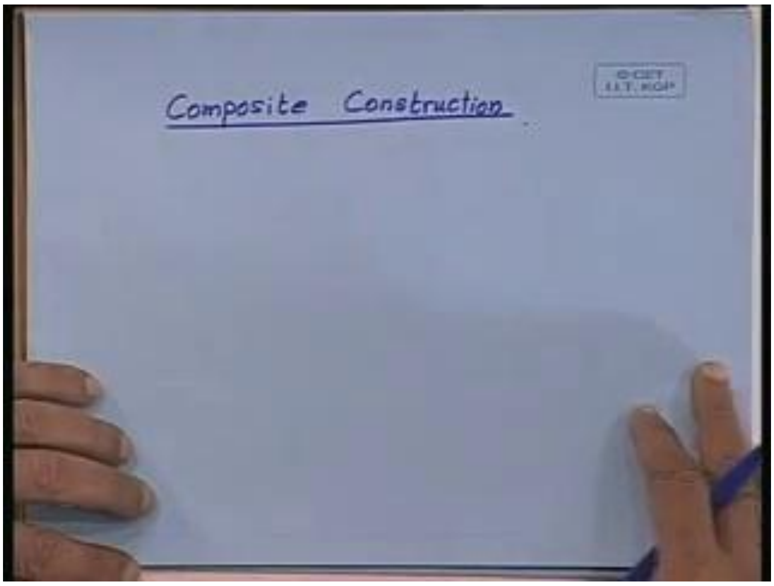

See, this term and ship building started long back when passenger crafts or the passenger ships where very much in use. Air traffic was very expensive and I suppose transatlantic air traffic was not there at all. At that time, people used to move around the globe on ships only. The fact was known that the centre of gravity of the ship plays an important role in the stability of the vessel and the reputation of a passenger ship used to fall if the vessel used to severely roll and pitch, and that was only likely when the centre of gravity is going high up.

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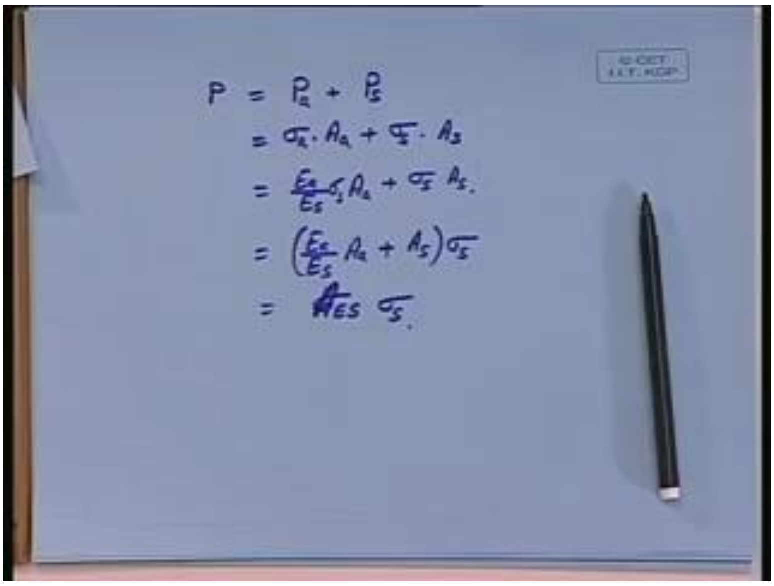

Two things if it is too high up. So, I can say the total force is equal to P Aluminum plus P Steel. What is P Aluminum?

No. Sigma in Aluminum into area of Aluminum and sigma in Steel area in Steel.

What is sigma Aluminum? Now, let me substitute from here. Sigma s let me take out. So, now, whatever is here, this is equal to what? I say this is some sort of a sigma equivalent of Steel which is equal to P now. Sorry not sigma equal area equivalent Steel. Now, what is this area equivalent Steel? Area equivalent Steel is area of Steel plus area of Aluminum converted to Steel with this ratio.

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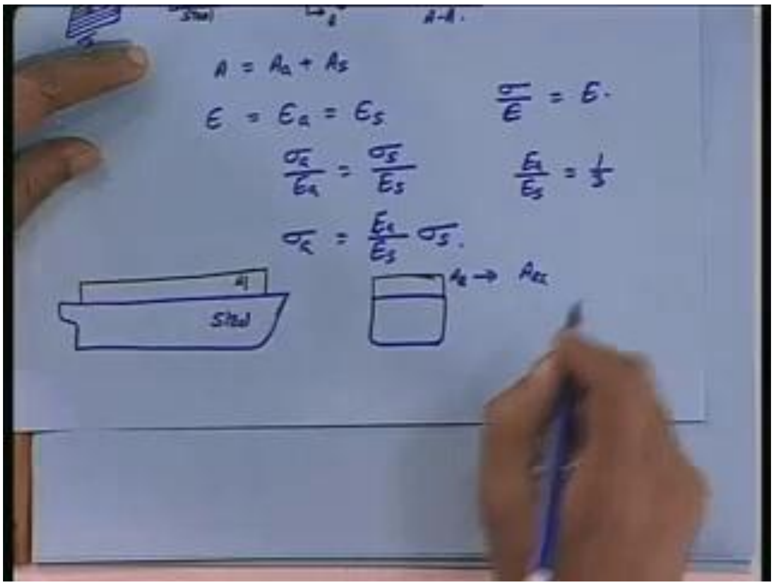

So, now, this gives me a clue that in the bending case, whatever Aluminum part is here, you convert this Aluminum area to equivalent Steel area.

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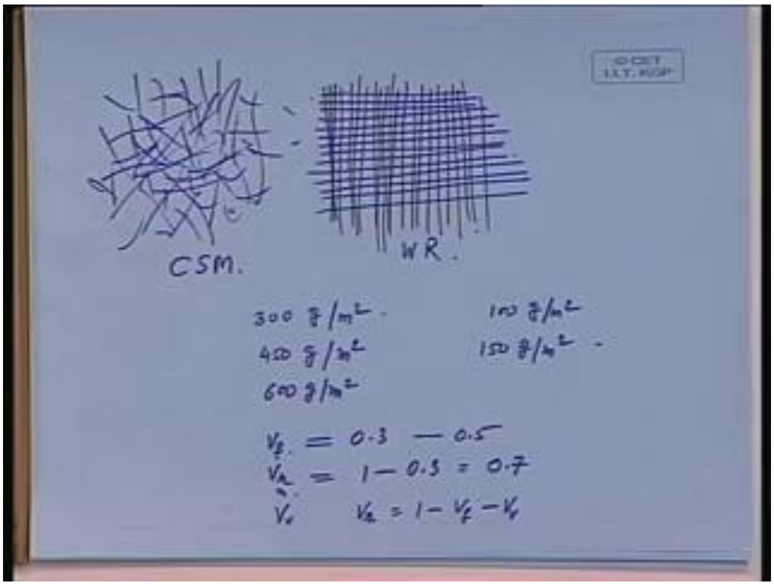

This is woven roven. So, these materials are available in specification we say that 300 grams per meter square or 450 grams per meter square. These are standard values available in the market. One can also get say I suppose 100 grams per meter square, 150 grams per meter square. So, you can get these materials in roles. If you take one meter square, it will be so many grams. So, how much of glass content is there in that?

Now, when you try to make a sheet, you have seen the helmets; they have this glass fibers in it. So, when you make a sheet, you take a particular volume of that and in that volume how much of glass fibers are there, that tells us that what is the volume fraction of this.

Usually, we will find that the volume fraction of glass that is the fiber we say, noted like this, is of the order of say 0.3 and it can be go up to maximum 0.5, and volume fraction of resin, either resin or metrics they say, is sometimes we say that volume fraction of vacuum. When you try to mould the thing, some bubbles are there; it occupies the volume it is embedded inside, but it does not provide any weight or it does not provide any strength. So, if something is there, then we can say that volume fraction of resin is equal to 1 minus Vf minus volume fraction of vacuum. Usually the construction method should be such that volume fraction of the vacuum should be equal to 0. We will do one thing. We will continue this in the next class. A little, I will not talk much about it; I will simply try to tell you about the materials.