Strength and Vibration of Marine Structures
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Lecture - 33
Composite Construction

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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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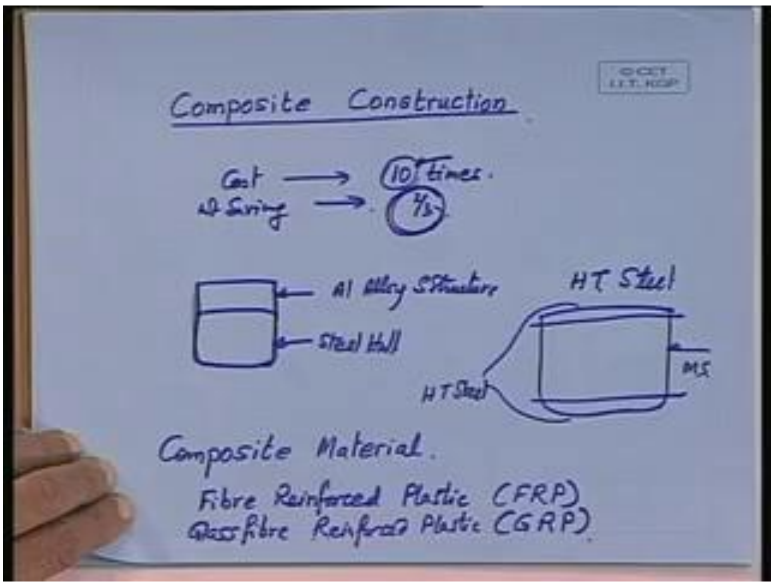

See, this term and ship building started long back when passenger crafts and the passenger ships where very much in use. Air traffic was very expensive and I suppose transatlantic air traffic was not there at all. At that time, people used to move around the globe on ships only. The fact was known that the center 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 center of gravity is going high up.

Two things: If it is too high up, then it will role heavily and pitch heavily; if it is too low, then it will have a very slow time period and it will lead to high acceleration. So, both ways it was not suitable for the passengers. They were not sea fearers. The crew gets used. The crew and officers, after certain time period, they will get used to this because this is their bread and butter and they have to better understand how to live with the sea conditions with those motions. But a passenger would like to pay and travel. So, if 1 particle of vessel is not comfortable, he will try to wait for other vessel and take the ticket in that. He will avoid a particular vessel and try to prefer another one and the business will be shifted from one to another.

So, g played, the centroid played, a very important role. As far as the economy of passenger ships are concerned, are likely of or affinity towards a particular passenger ship. Number 2 - the rules and regulations were there and if one would like to give a passenger accommodation under the main deck, which also people never liked. We have to see through the port also. But if you are having an accommodation above the main deck, then you can go to the prominent and see around and so on and so forth. So, the tendency was that to provide accommodation about the main deck at the cost of losing the g, gn. And therefore, this concept of composite construction, those days, cropped up that why not use a lighter material over the deck construction; use a material, the usual mild Steel for the up to the deck construction part and above the deck you try to use some sort of a light material.

Obviously, lighter than that used to be wood, but again something went against wood is it is highly inflammable. So, you require fire resistance, you require this resistance, water resistance, etcetera, etcetera. So, people used to prefer Steel only, but Steel has this disadvantage. And then I do not know who was the first to suggest it, but they found that Aluminium alloy can be used as the above deck material for accommodation, which is much lighter though expensive, but much lighter, and it had other plus points that the corrosion property in the sea atmosphere is much better compared to Steel hull. And therefore, it was tried out that yes you can give the comfort to the passenger, but not at the cost of loss of gm, but at the loss of initial investment; you may have to invest more.

So, ultimately, with the material properties known, they found that the cost at that time may go to ten times, but the weight saving was two-third. That means if you have w ton of Steel to make this super structure or the above deck accommodation, you require w by 3 quantity, w by 3 tons of Aluminium alloy to provide the same accommodation with the equivalent strength, but at ten times the cost. But this saving was very good because you are attracting the people and a little bit of this cost was offset by that because of the occupancy level increased. And because of the good corrosion properties, the maintenance cost is reduced and that also compensated this of the maintenance cost. So, the first composite material was Steel, Steel hull and Aluminium alloy super structure. This is how the history started.

Then, in late 70s, when there was a fuel crisis and closer of the channel there, ships used to go around the African continent, and therefore, they found that economically it is not viable to have small size vessels; rather go for tankers and the bulkers which are at least say 80000 Ton that weight or more. So, the size increased and when the size increased, obviously, the all the dimensions will go in the same proportion, more or less. So, the depth increased, and the section modulus and the bending moment also increased, but ultimately, the stress at the outer most fibers which increased to a level with the mild Steel cannot take unless you provide additional scantlings there, and which made it non profitable and they went for high tensile Steel.

And then these big tankers were built with top and bottom structure HT Steel and remaining mild Steel. So, here one can say that this much is high tensile Steel, this is high tensile Steel, and the inner core material is all mild Steel. So, this is also using two different types of Steels with two different mechanical properties. So, this was the second type of composite material. So, this is also composite; this is also composite as for as ship building is concerned. But if we talk about structural engineering, then before that people have used composite material like you have the Steel girders on a bridge with wooden sleepers at the deck. You had these beams and columns made of Steel and motor or the concrete. So, Steel as the fibers and concrete as the metrics. So, you can say that this is a composite material of a higher quality that you have a reinforced material there. So, this composite material was in use for civil engineering material and for ships also once started. And today, when we talk about composite construction, we basically mean by the composite material. Here, it is in true sense, the composite construction. But today we are using composite material and the most popular composite material is the fiber reinforced plastics.

Fiber can be of various types: You can have metal fiber; you can have nonmetal fiber; you can have organic fiber and so on and so forth. Somehow, for ships we use glass fibers. So, a special type of fiber which is nothing, but glass fiber, reinforced plastic we use and we say GRP. Glass fiber reinforced plastic – GRP; fiber reinforced plastic - FRP. So, when we say FRP, it can be any fiber. You can even say the concrete slabs, concrete beam, concrete column, they are also FRP; not FRP, they are fiber reinforced concrete - FRC. So, now we have these 3 materials available as composite material. Now, let us take a very simple condition.

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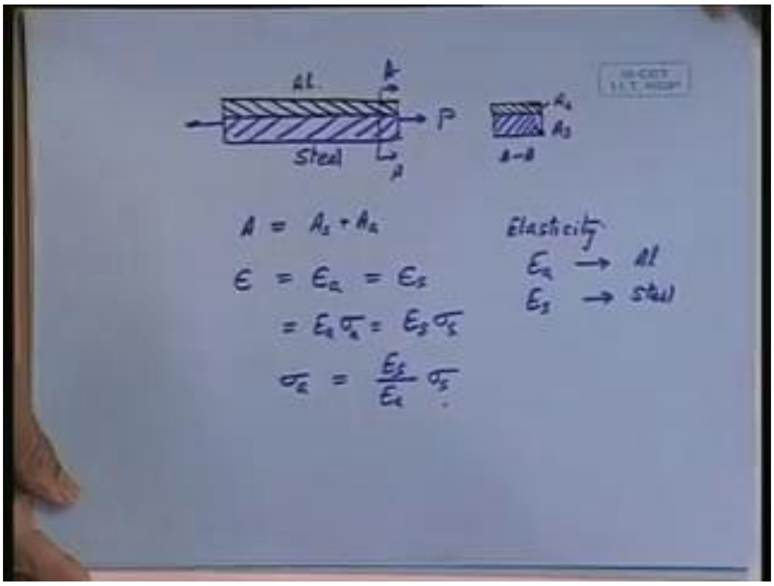

let us say that we have a piece of material in which we take one layer as Steel. I am not saying that whether it is mild Steel or high tensile Steel or whatever Steel, just Steel. And you take another layer on top of it which we say Aluminium. You make a test piece and our assumption is the deck inter phase is perfect; they are grouped, and then you apply some load here.

Let us say, when we take the cross section here, this is the Steel part cross section A and this is the Aluminium part. So, let us say that this area is A Aluminium and this area is A Steel, and the first equation I get total area A, total area is A Steel plus A Aluminium. Now, I said that the inter phase is perfect. And when I apply a tension, then the elongation in this material will be some epsilon and this is same for Aluminium and Steel; there is no interlayer slippage. So, whatever is the expansion of the total combined material, the same expansion the Aluminium part will undergo and also the Steel part will go. We also assume that the material, whether it is Aluminium or Steel, follows Hooke's law; that means, stress is directly proportional to the strain.

So, we assume that the elasticity coefficients, you have E a for Aluminium and E s for Steel, and therefore, we can say that this can be written as E a and material stress here. So, epsilon A can be written as elastic constant of Aluminium multiplied by the stress in Aluminium which is equal to …(Refer Slide Time: 17:04). So, we can say that sigma a is equal to... So, the stress in the Aluminium part can be related to stress in the Steel part by this factor. Now, the elastic constants for Aluminium and Steel, we are saying constants, material properties, they are fairly constant and therefore, this ratio will also be a constant. Correct? And this stress can be written in terms of the stress value here.

Student: Ea is the longest. Ea is the longest; it is epsilon.

Epsilon, not e. Epsilon is this stream.

Student: ((Refer Time: 18:23))

E epsilon is equal to sigma; E epsilon is equal to sigma, sorry. E epsilon stress by strain sigma y; this is E epsilon is equal to sigma. So, sigma is equal to?

Student: Sigma is equal to e epsilon into e into epsilon

No, no; just a minute. You have stress by strength, sigma by e is equal to constant, and therefore, e is equal to moment.

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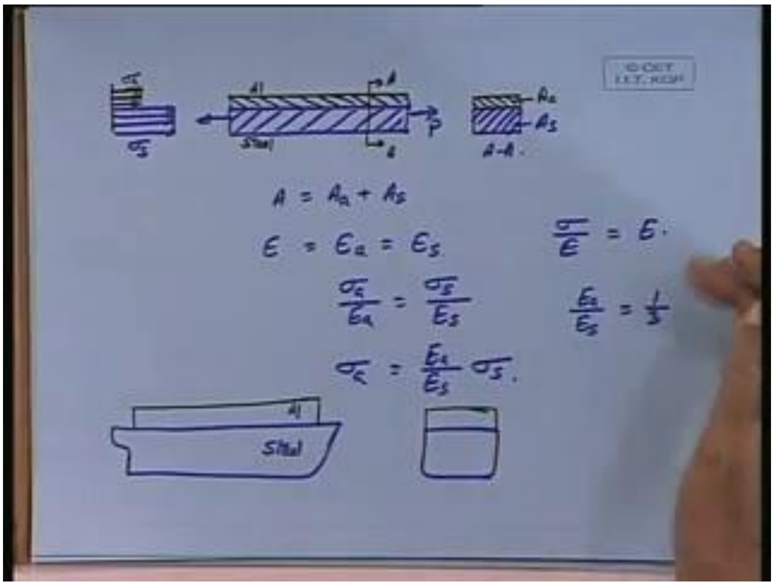

Let me rewrite it; let me rewrite it.

Student: Sigma by e.

Everything you do it without writing, then let me rewrite the whole thing. I think it will be clear. Okay. So, this is equal to sigma by E. So, this I write here as … ((Refer Time: 20:47)).

Student: Sigma upon E

I suppose now it is okay.

Student: Yes sir

And therefore, sigma A is equal to… ((Refer Time: 20:57)).

Now, this ratio, numerically what is the value? I do not know exactly, but I suppose this will be of the order of one-third. So, when the same expansion is given, whatever stress is generated in the Aluminium, sorry in the Steel, in the Aluminium part almost one-third of that level will be generated. Obviously, in the Aluminium part, the stress carrying capacity will be less, the permissible stress level will be less, and therefore, you required slightly thicker plate there.

So, if you try to draw the stress strain diagram here, you will find that if this is the stress here, the corresponding stress here will be, this is one-third of this more or less because this is on this ratio; so this is your sigma A and this is your sigma s.

So, now, when we talk about the section having this material here, then the basic part is we make use of this property.

Student: ((Refer Time: 22:45))

This factor?

Student: will that be a fraction one-third?

This is more or less it works out to be depending on what is the value you have here. Let me see if any value is given here; then we can work it out.

Student: E s?

Es is 200 some Newton; Newton, futon, etcetera 30 into 10 to the power 6 psi. Let me see if the values are given here. We simply say these are the order of 3; E s by E a is equal to 3.

Student: ((Refer Time: 23:55))

1 by 3, that would have been one-third, one-third of this.

Here, see just the ratio is given. The actual value is not given. A Steel is 13 to 10 to the power 6 psi. So, this will be 10 to the power 7 psi; that is all.

So, we can say that we will also write down here A by E s is equal to 1 by 3. Whatever units you use, it will work out to be 1 by 3, and that is why I am saying that this will be the stress level. So, what happens as soon as you put Aluminium? The stress in the material comes down to one-third because of this ratio.

So, that will try to give you the saving in the material, but as because the material is expensive and to withstand this one-third of the stress, you require may be slightly thicker plate, not the same plate thickness as Steel. You require slightly thicker plate. So, the weight, actually you save. You save the weight, but the cost increases because the material is expensive.

Now if we have taken this part and I say that I am having Aluminium accommodation here. I am talking about a passenger ship. So, this is Aluminium and this is Steel. It is undergoing bending. So, how do you get the stress here and here? So, first of all you try to draw the midship section, put the Aluminium part here, and then now, this stress is coming out to be one-third, in this ratio. So, what I can say that ((Refer Time: 26:46)).

Let us try to see here, what are the forces coming. So, if I say that the contribution here is p 1 and this contribution is a or P P Aluminium and P Steel let us say.

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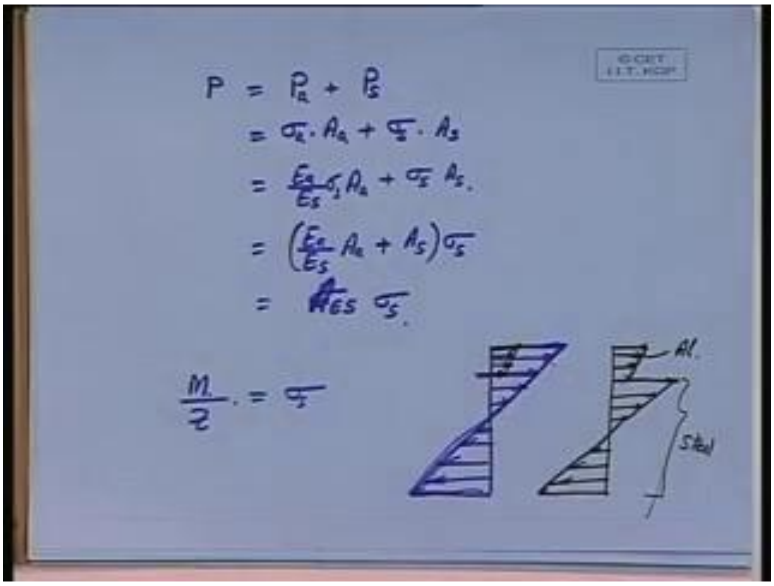

So, I can say the total force is equal to P Aluminium plus P Steel. What is P Aluminium? No. sigma n Aluminium into area of Aluminium and sigma n Steel, area in Steel. Steel what is sigma Aluminium? Now, let me substitute from here. Sigma s let me take out. So, now, whatever is here, this is equal to what? I say this is some sort of a sigma equivalent of Steel which is equal to P now; right, sorry not sigma equal area equivalent Steel. Now, what is this area equivalent Steel? Area equivalent Steel is area of Steel plus area of Aluminium converted to Steel.

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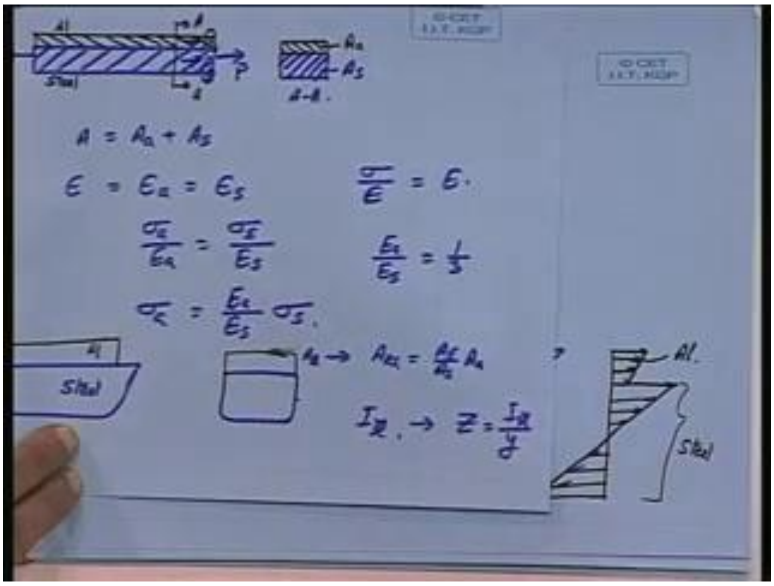

So, now, with this ratio, so now this gives me a clue that in the bending case, whatever Aluminium part is here, you convert this Aluminium area to equivalent Steel area which is equal to this part. So, each area you convert it in this fashion. And now, this is your Steel part. After converting the areas, now you find out what is I midship.

You know the bending moment; you know the I midship; you know the distances. And therefore, this will give you the section modulus I by y, and therefore, M by z will give you the sigma which is in Steel. So, this you will check up again in the Steel this thing.

If it is within the elastic limit, fine, and then you convert back this Aluminium area from this equivalent area here, or if you are interested in finding out the stresses, I will first find out the stress in the equivalent Steel part. But if my structure is Aluminium, after a particular height, then this will be only one-third of that. So, this is, this I will take one-third. If it were Steel, then this was the stress; if it is Aluminium, this is the stress.

So, actually, now if I really want to draw a correct stress diagram, my stress diagram will be something like this. This is the Steel part; this is the Aluminium part. So, in this region, this is the stress value; in this region, this is the stress value.

Student: ((Refer Time: 32:30))

Steel, Steel.

Student: Steel. So, directly the stress value which you will get

This is Steel. This is Steel.

No we are getting this Steel. Now, this level upward is Aluminium. So, you simply make it one-third, apply this coefficient here, and that modified version I have drawn here. So, this is for the Steel part; this is for the Aluminium. This is the equivalent Steel stress in this particular Aluminium part.

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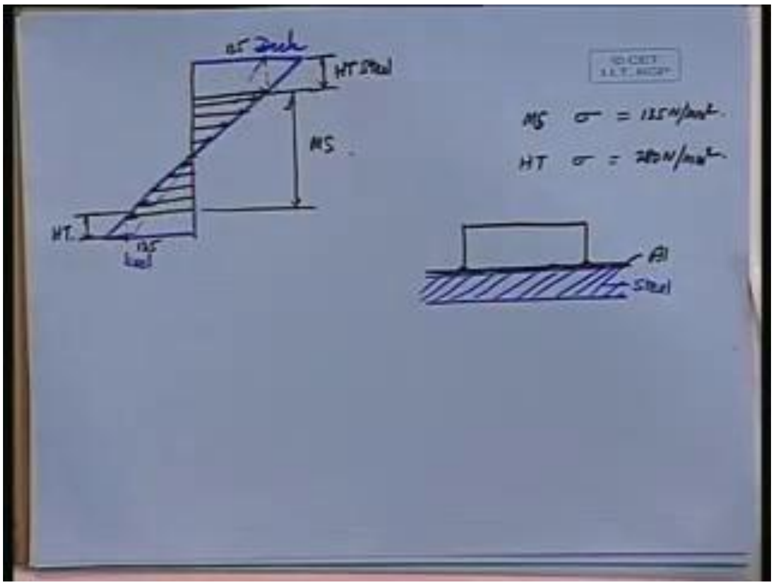

Now, after knowing this, now let us take up this part. This is much simpler, in the sense, that high tensile Steel and the mild Steel will have the same elastic modulus; only thing that their safe working stress limit will be different. So, you draw the …

Extreme fiber, this is a keel and this is a deck. Now, you find that the mild Steel has got only this much of capacity. Say, in mild Steel, the limit is given; mild Steel the limit is given; sigma is equal to say 135 Newton per millimeter square. I am just taking some figure and you are taking some sort of a high tensile Steel where the sigma limit is how much? 235.

Student: 200

No, no. It is much more than that; it can be say 280. Now, I am not getting 280 here, I am not getting 280 here, and I am not getting less than 135; it is crossing this limit.

Now, here the cost from here to here may not be like Aluminium ten times, but definitely is expensive; it may be more than 2 times. I do not know about the costing, but I suppose it is of the order of 3 times. So, this is being of zero stress value and I have been provided by 135 Newtons per millimeter square as the working stress. So, I take a 135 here; I also take 135 here and then you draw back. So, you find that 135 is up to here. So, up to this and below this, the stress is less than equal to 135, and therefore, this zone is suitable for mild Steel; beyond this, it goes beyond the limit of this and I am forced to use high tensile Steel. So, I put here high tensile Steel.

So, what I am trying to do? It is only the extreme fibers or extreme objects I try to construct from the high tensile and the major hull part I am still making with the mild Steel. So, my cost of construction is not increasing. At the same time, I am not allowing that you limit this to 135. If you try to limit this to 135, then what will happen? You have to go with this type of a stress curve which will enormously increase the thickness of the structure. So, now I am not increasing the thickness of the structure, but at the same time with the combination of mild Steel and high tensile Steel, I am in a position to make an optimum design. I am saving on the cost; at the same time I am saving on the weight also.

Student: ((Refer Time: 37:40))

No. This is not a very big problem. This is not a big problem.

The problem is here. Aluminium welding is the problem, but now Aluminium welding has also become easier; in the sense that, nowadays you are having a clad, Aluminium clad Steel available.

Student: ((Refer Time: 38:11))

No. One layer is made of Aluminium. It is available in defense vessels. They are using it. What happens? That normally suppose you are having a 10 millimeter plate, so out of 10 millimeter, 9 millimeter will be Steel. So, this part is Steel and a thin layer here, this is Aluminium. You make the ship; put this layer on the deck. Underneath, you weld it as usual as a Steel, but the top layer is Aluminium. So, now, when you are erecting an Aluminium structure here, you can always have Aluminium to Aluminium welding which technique is now available.

Earlier there was no Aluminium welding available. So, 1 had to do riveting. So, if you riveting, it does not make any difference whether you rivet the Steel with Aluminium or Aluminium with Steel. Only thing is that, having two different materials, there will be a galvanic corrosion there. So, there one has to take a proper care by putting some sort of a jute soaked in red oxide of flood or some such thing and then you rivet it, or you put some sort of a composite, rubber composite and then try to rivet the thing. So, it is water tight and all the same time you are having it, and then you give the deck sheathing etcetera, which is also some rubber composite material. But now, because of this problem one is getting rid of this and if you really want to reduce the weight of the structure, one of the defense vessel I saw was even the main part of the bulkhead was made of Aluminium there. So, they used a clad Steel ring structure which was connected as a frame and then from the other side Aluminium bulkhead was welded to it.

Student: Is there any changes in the inter phase between Aluminium and Steel.

Not change, they have been made with a special technique known as the bombarding.

Student: (( ))

No. It is a clad thing. It is basically with the blasting they have to make it. They blast the two part in such a fashion that they get stuck to each other.

Student: ((Refer Time: 40:47))

Fused into it with the help of a blast; that is the cladding process. And because of that process, the cost is more. In fact, earlier this clad stainless Steel used to be used in a nozzle; the inside of the nozzle because you are having a gun metal propeller working in a mild Steel. Then with the gun metal propeller, the corrosion and erosion, both will take place because the clearance is only 3 millimeter. So, in the region of the propeller tip one used to use a stain Steel part.

Student: Is that bounding strength will depend on how much fusion intensity is there?

That is done. We do not have to bother about it. It is all classed item. The item is approved for ship building. It is a ship building quality material.

Student: ((Refer Time: 41:44))

Definitely, otherwise how will you weld it?

So, now because this technique is available, the construction has become very simpler and therefore, people are going in a big away of Aluminium super structure. And I said that not only Aluminium super structure, even the internal bulkheads in a defense vessel where you cut down the weight to increase the ammunition. So, all these techniques are available. So, we have done this Aluminium part; we have done the high tensile Steel part.

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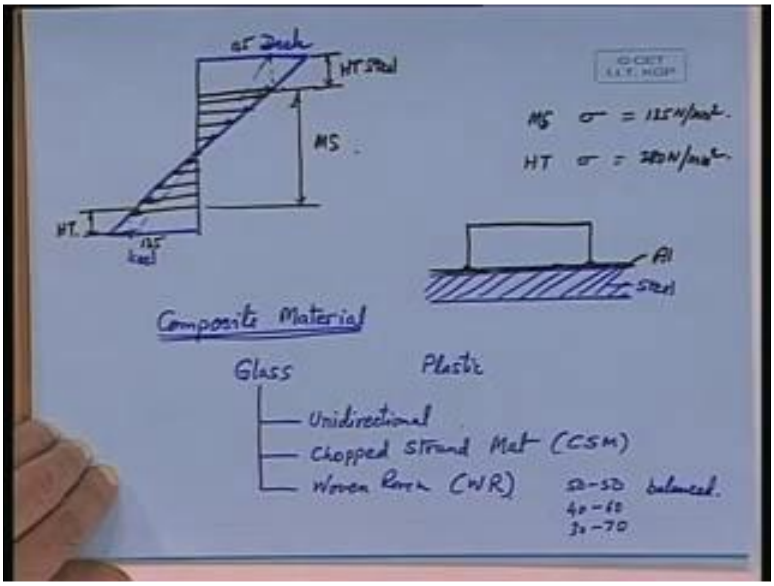

And the last material is the composite material itself. Once again, I will not go into the mechanics of all these. It is available; now text books are available and in our department a big number of people are working on composite material for ship use, marine purpose. Including me; myself, myself, I mean Professor Mukopadyaya and we have got half a dozen of research scholars are now working in the topic and more than half a dozen have already finished the PhD.

So, there is a strong group of structural engineers working in this institute under this material and mainly the work is going on in Aeronautical engineering, Naval architecture Mechanical and to some extent in Civil engineering. I do not know whether Mathematics people are doing anything on this material or not. There was a time when a strong group on elasticity, and stress and elasticity used to be there in Mathematics department, but I do not know at the current time whether that group exists or not.

Now, this composite material which we are talking about is a nonmetal. We are talking about GRP which is being used mainly for ship building. As the name says that the reinforcement which is filament basically is the glass material and the metrics is plastic, the tensile strength of this material is very good and this has got a very good burning property, and we have fused the two together to get material a property which suits you.

So, the basic advantage of composite material is that the mechanical properties of the material can be engineered by the engineer by choosing the proper mixture of the two and the proportion the layer. So, the glass is available. One is we say that unidirectional. You simply have 10 glass pieces which are drawn in one direction and you can lay them in one direction just like that in each fiber. But you cannot keep it always straight bricks. And many a times, when we want an isotropic property, we would like that the property of the material, even this, we would like to have same strength in any direction; so isotropic property. To obtain that, we chopped the glass pieces into small small strands and then orient them at random and they occupy a random this thing. And when you pack them in that condition, it behaves like a cloth. In fact, all these materials are available in roles.

So, you get a mat out of it in which the glass strands are oriented at random and we say it is a chopped strand mat. We have seen those coir mattresses. You can just take a small layer of it. You can say that chopped strand mat also comes in the similar fashion. Then the strands can be woven. Because they are drawn in longitudinal direction, so you can take them in two directions and they can be woven like this, and it is woven like a cloth. So, you can have different textures having different types of strands, different number of strands, and different thicknesses in different orientations. So, we have woven roven. This is known as CSM chopped strand mat and woven roven is known as WR.

Now, when we have taking woven roven material, then we can use one type of a arrangement of the glass fibers in one direction and a different one in the different direction; like you have khadi cloth you know in one side, you have the silk strand on the other side; you have cotton strands and it gives you a different finish.

Student: Basically a trading of the tires.

Not trading of the tires. No. There it is one single direction. You are not taking the cloth. I am talking of one single layer. So, it is just woven like cloth here. If it is woven in this fashion, then we call it a cloth, but if it is not this way like Asian cloth Bora, you can see the material in our department, then it is basically woven roven. So, the cloth finish material is used for the finishing touch - the last layer, and the other one for the strength material. And if they are all of same part, two directions, then we say it is a balanced woven roven and if in one side more strands are there compared to the other side, then we say that what is the percentage of weaving there. So, usually you have 50-50 that is balanced, but you can also have 40-60, 30-70 and so on. Now, by wearing this, you can get more property in one direction compare to the other direction.

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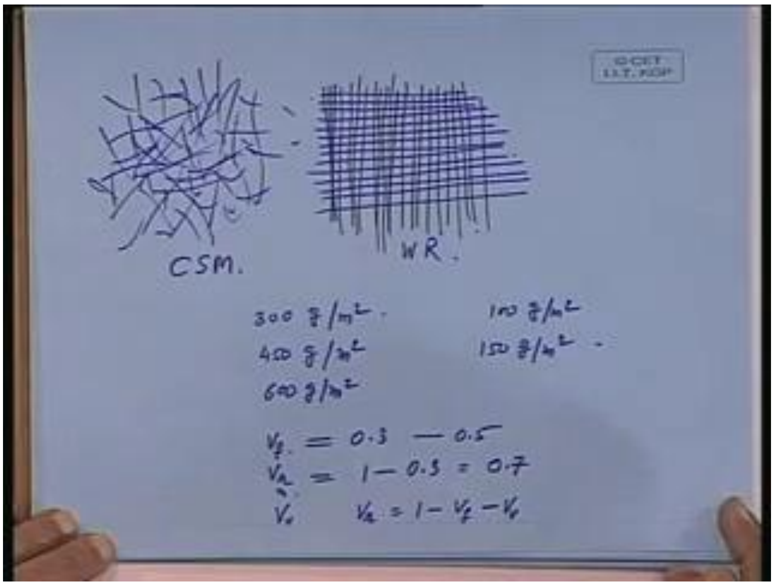

Now, you have the chopped strand mat and difficult for me to draw it like this. Anyway, let me draw it like this. This is you coming to show me in 5 minutes. How it is 5 minutes come, so fast. I do not know. This is woven roven. So, these materials are available in specification. We say that 300 grams 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 1 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 these 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.

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Take it.

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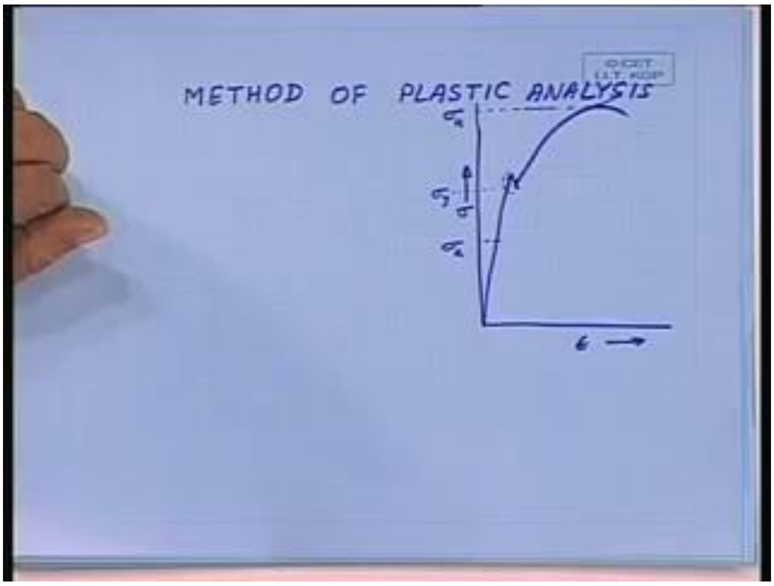

Usefully we try to analyze our structures based on a stress strain diagram like this or stress displacement diagram, and this is a typical curve. Nature of the curve is typical for Steel in which we say that the, as you start applying the load, the stress starts from zero and more or less it goes linearly, up to a point known as the yield point stress. Then there is a small jerk here and then again it goes in non-linear way up, and then it follows a downward trend, basically the ((Refer Time: 54:46)).

This is a typical nature of Steel. In other material you will not find this, this part, and for Steel we say this is the lower yield point and this is the sorry this is the upper yield point and this is the lower yield point. And where it is supposed to reach the maximum is known as ultimate strength.

In fact, beyond that the curve goes in this direction, but just before breaking, the cross section reduces and we compare the strain on the basis of the original area, whereas the area here starts shrinking. And therefore, the stress should increase, but because we are taking original area, it comes down

Most of our structure which we which we design, we try to get a stress value which is in the linear part so that when you load it and then try to unload it, it follows the same path, and that is what we say that the material follows Hooke's law - stress is proportional to the strain which was given by Hooke.

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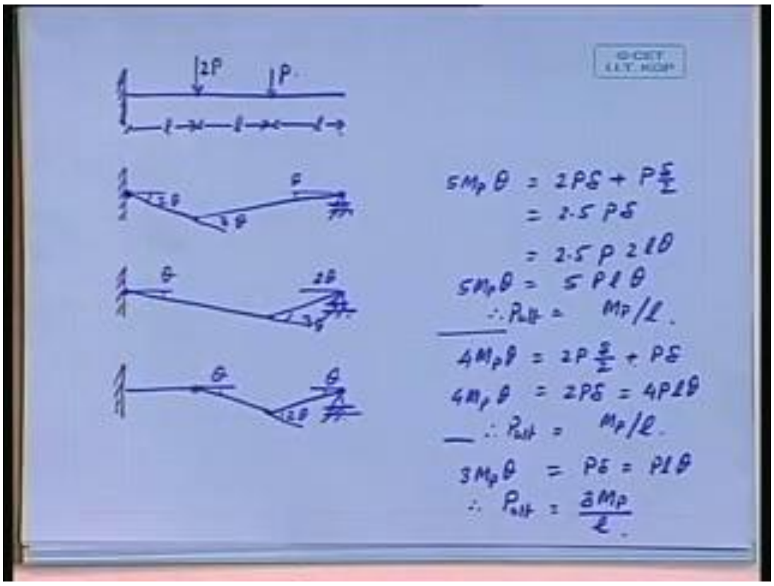

Only this load is moving, but the work done by this hinge and this hinge is 3 MP Theta. One MP here, 2 theta here, and this load is moving down; so it is P into delta and which is equal to Pl theta. Therefore, ((Refer Time: 56:31))

So, now you see this has got MP by l, this has got MP by l, and this mechanism has got 3 MP by l. So, the last mechanism is out of question. It can be either this mechanism or this mechanism because both have got the same ultimate load, and it is only the imperfection in the structure or slight imbalance in the load, you say it is 2 P or this is P or there is a small difference in the time of loading, the quantity; it can take either of this mechanism for failure.

So, this is how the beam problems are solved and finding out what is the MP from section modulus, one can try to design. And based on this, one finds that as we can see from the rectangular section that your shape factor is 1.5. In fact, you are getting some 50 percent additional strength there. For other sections also, the t section which I have given you, you will find that some 15 percent or 30 percent, you will get extra there. So, depending on the shape, you get an enhancement. And if you base your design on the basis of this elastic theory, though we have assumed that it is fully elastic and fully plastic, that means, in the plastic region we have assumed that once it comes to the yield point stress it stays there, whereas in true picture even if you modify it, it is linearly elastic and linearly plastic.

It is basically non-linearly plastic, but even if you consider it to be linearly plastic, then also though you are underestimating, but still you are having some additional strength there. And this way if you try to design some structures, then you are really trying to save some load, some material, and make a lighter vessel.

So, this is what I wanted to cover here.