# Basic Construction Materials
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## Lecture-08
## Materials Engineering Concepts-Part 5
## Mechanical properties (cont'd.)

Hi, I am Radhakrishna Pillai from IIT Madras. Today in this course on basic construction materials, we are having this module on materials engineering concepts. Today we will be continuing discussing mechanical and also the non-mechanical properties.

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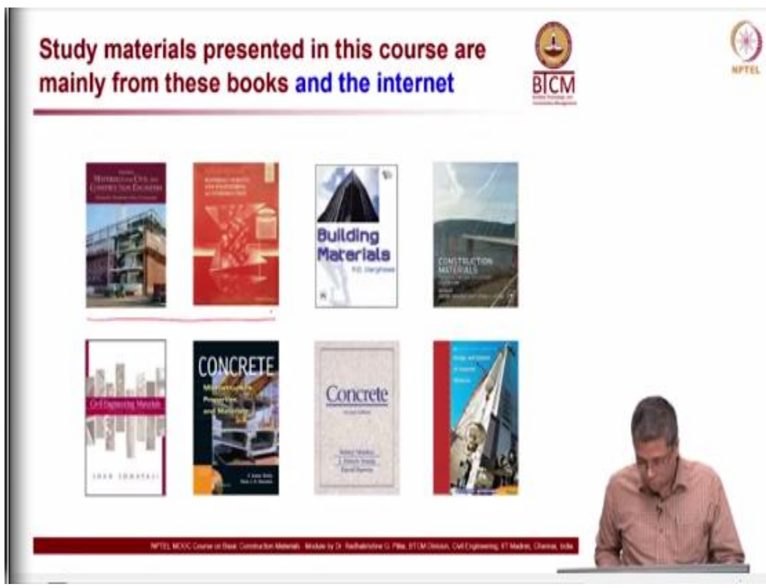


So, these are some other books, and today's materials are mainly coming from these 2 books and of course, a lot of photographs from the internet are also being included for demonstration purposes.

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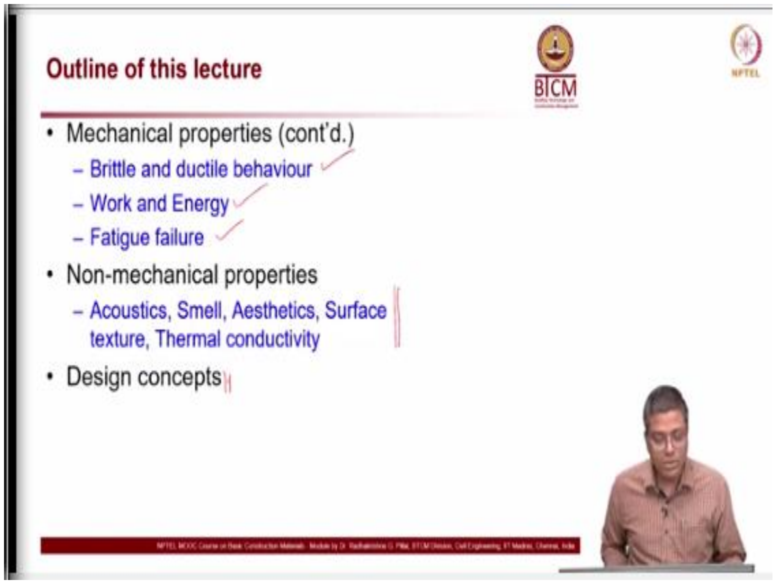


So, today we will cover mechanical properties mainly looking at brittle behavior, ductile behavior, and also looking at work and energy, fatigue failure mechanisms. Then towards the end, we will briefly talk about various non mechanical properties, because that is also becoming more and more important while selecting material for construction. Finally, we will just have a brief discussion on overall design concepts for selecting various materials.

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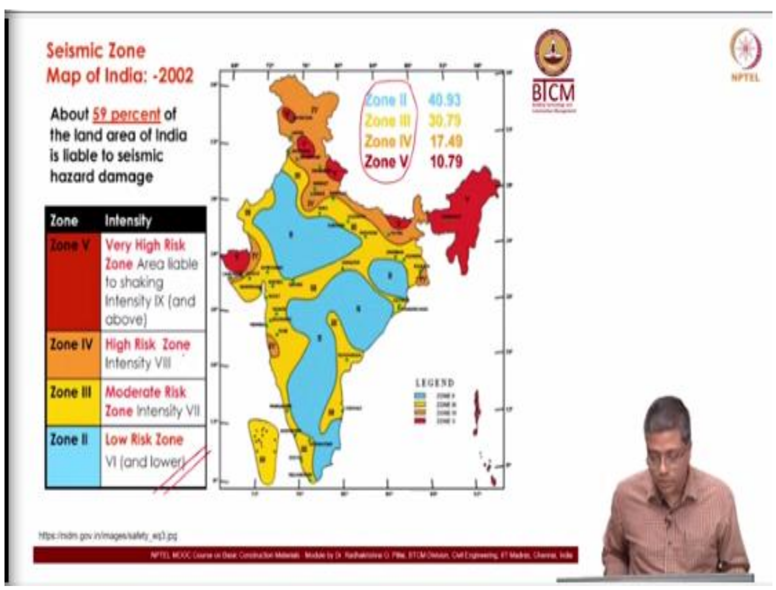


Now let us look at this map, seismic map of India, where we have India is divided into 4 zones, each having different risk level. So, looking at the zone 2 which is blue color, you can see that it is of lower risk zone. Then zone 3 which is moderate risk zone- yellow colour, zone 4 is high risk zone and zone 5 with red colour is very high risk zone. So, in India we have all these the various geographic locations which have different hazard level for considering seismic activity.

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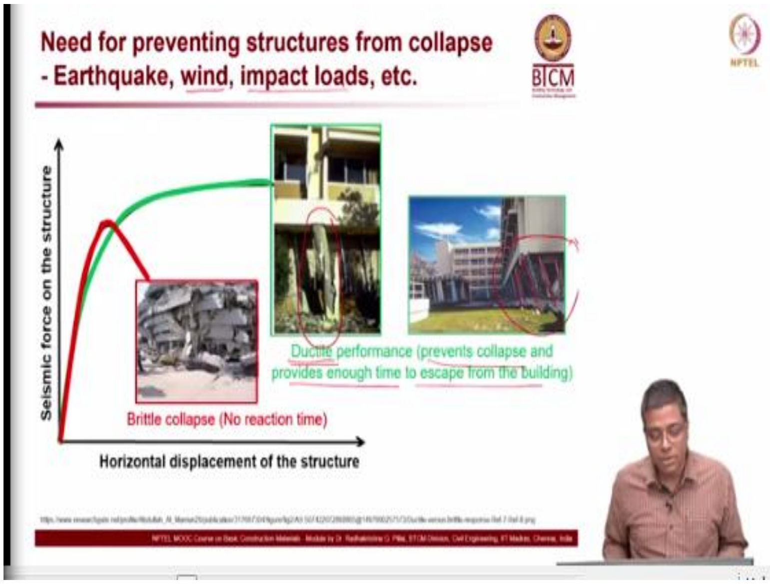


So, that means we also have to design our structures to resist such loads. So, here you can see an example on the left side the photograph in the red box that is actually a multi-storey building, which is collapsed due to an earthquake. People in that building did not get any reaction time to come out of the building. So, a lot of damage both for the building and also for human lives.

Now the behavior of that building is represented by this red curve which is showing very brittle behavior or in other words, the width of that graph, if you see the red graph, it is not very wide. and also the area under the graph relatively small or less. Now look at the green case, which is a ductile structure, you can see that this column over here at the lower floor of this building, it is actually swayed or tilted but not collapsed.

So, people in that building actually can come out after the earthquake and it is also very clear from this photograph, it is of the same building. You can very clearly see that the columns are inclined here or in other words they are tilted or swayed but they have not collapsed. So, this is what we want, we want our structure to be ductile to absorb the energy but not reach the collapse level.

In other words, lot of energy is required to collapse the structure, so that is our objective. We need to make our structure ductile to prevent the collapse and provide enough time to escape from the building. So, how do we achieve this?, that is the main thing which we are talking right now, and what type of materials we should use to achieve this kind of behavior?

This is not only for earthquake loads, but also for wind and impact loads where we need ductile materials, so that we can save lives and also structure. I mean even the structure, we can probably retrofit that, if it fits only deformed and not collapsed, there are possibilities for that.

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This is another type of structure, a road structure where you can see on the left side you have a lot of cracks, crack structure, and wide cracks. The wide crack is mainly because of the concrete which is used, the plain concrete which is actually brittle in nature. So, it will crack, but it will not bend or deform as we expect from a reinforced concrete system.

On the right side, I do not know if it is a reinforced concrete or a fiber reinforced concrete, but some kind of ductile system is being used. This photograph is from the internet. So, this ductile behavior, because of that, the road on the right side is not going to crack like you see on the left side. Or in other words even if it is going to crack you might see lot of smaller cracks but not very large and wide cracks.

That is mainly because the stresses developed are getting distributed because of the presence of either the steel reinforcement or the fibres, etc. So, the more ductile the material is, you can actually control the amount of the crack width or crack resistant will be relatively better.

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Now here are the 2 examples of metals, when you talk about brittle and ductile behavior. On the left side, focus on this red box, you can see that the shape of the bottom portion and the top portion. It is kind of exactly if you want to put those pieces back together, you can actually glue them together.

I mean there is no deformation which had happened at those broken fracture surfaces. In other words, the material did not flow much at the breaking point, before it fractured. That means it is relatively a brittle failure. Whereas on the right side, you can see the material has flow, it is flowing here, as you pulled it gets narrower or necking is happening.

So, that kind of flow is happening because the material is more ductile in nature. So, we want this kind of ductile material, so that we get enough warning before the structure collapses. So, if you see on the left side more clearly, you see the crack on this cast iron pipe. There is a crack going as you can see that at the pipes cross section. If I take a cross section on the left side, it is still going to be circular.

Whereas on the right side, the steel pipe which is deformed, if I take a cross section here, it is probably going to be something like this. So, it has opened up and deformed, whereas on the left side, cast iron which is very brittle material, it just cracked.

There is no deformation to the shape of the material, so that is the key difference between a brittle material and the ductile material. The ductile material deforms before it fractures, whereas the brittle material does not deform, it just breaks into 2 pieces. That is the key difference between ductile and brittle materials.

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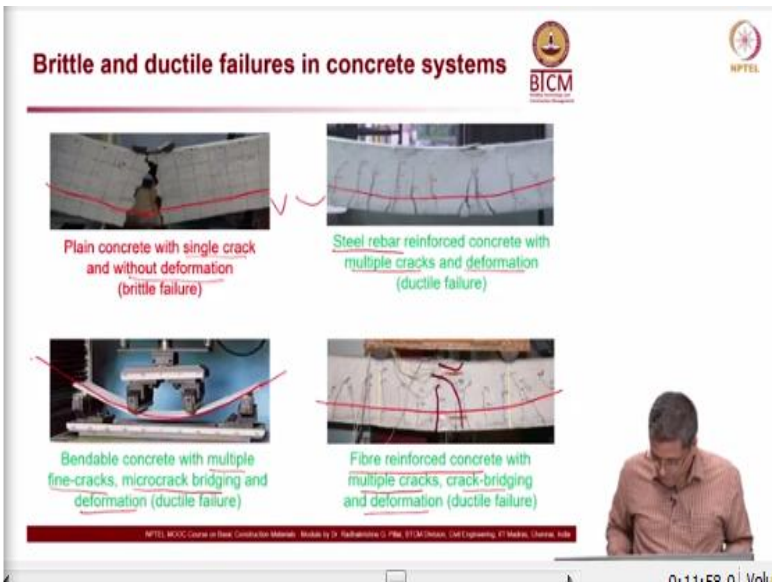


Now here it is about concrete, you can see on the first picture, it is a plain concrete with single crack and no deformation, very clearly brittle behavior, as I showed in this picture here on the left side. For example these pieces here, they are not bend or anything, they just cracked exactly, as you see the cracking and the remaining portions are still plain surfaces.

Now, look on the right side top figure where steel reinforcement is there, and the concrete has multiple cracks. All these four images are from a flexure test or the bending test. So, you take a beam and then try to bend it, and then we see how it is behaving under the transverse load. Here you can see there is a deformation. So in other words, this beam, it was originally straight and now had a small curvature there.

Now on the plain concrete system on the left side, you have a straight line here and another straight line here. So, it is more or less a V shape, whereas on the top right side, this is more or less a curvature shape. The bottom right is a fibre reinforced concrete, where it has multiple cracks and crack bridging, because the fibres will help to close the crack or bridge the crack. It will not allow the crack to propagate that easily, it will absorb some energy and then it will prevent the crack from propagating and also there is a deformation.

You can see the shape, it is this kind of a curvature, it is not a V shaped like in the top left. Here you have a bendable concrete with multiple very fine cracks, which sometimes are not even possible to see with your naked eyes. These micro cracks gets bridged because of the presence of very fine fibre material in such concrete. This is still not there in the market a lot, but probably in the research lab.

So, people are trying to demonstrate that it is possible to make very flexible concrete, if you introduce very fine fibres into the concrete. You can see deformation here also in bottom left, you can see the shape is not at all straight of the concrete panel member. So, the idea here is, we can make concrete which is ductile in nature by introducing steel rebars or fibres, or even microfibers. It all depends on how the steel and concrete work as a system.

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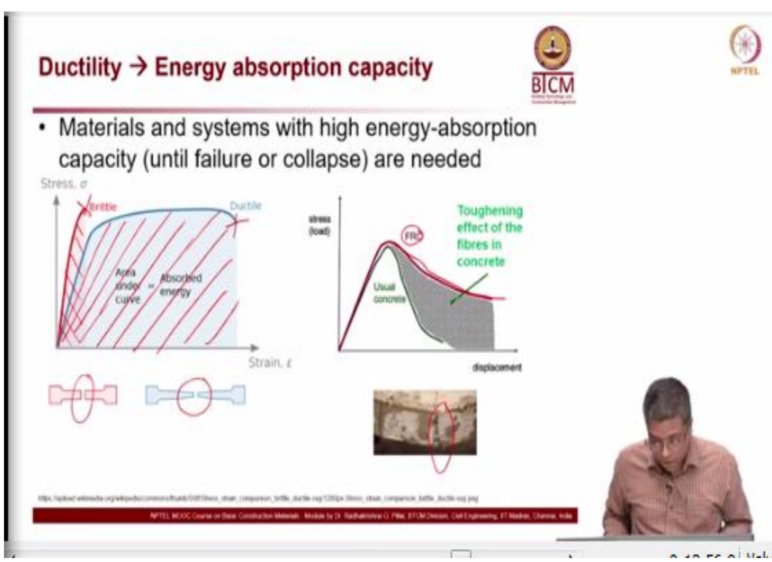

Now what is the whole idea when we introduce this steel into the concrete etc.? It is mainly to enable the absorption of more energy before it can fail. So, here on the brittle, the red curve on the left side, you can see the area under the brittle curve and you have another larger area under the ductile curve. Definitely, the one under the ductile curve is much more.

So, that means the ductile material is able to absorb more energy before it fails or before it fractures, fracture happens here and here in these 2 cases. So, here also you can see that brittle material has no deformation and in ductile material, very clearly it gets elongated and necking is happening, and then eventually it fails. Now, in case of concrete, you can see that usual concrete has this green curve which is at the bottom here.

Whereas the FRC stands for fibre reinforced concrete, it follows a little different curve, that with a larger area under the curve. So, this shaded region the black hatch, which you see is the additional energy which the fibre reinforced concrete is able to absorb. And you can see here there are one photograph showing the fibres inside the concrete which gets stretched and is able to absorb more energy before the concrete system fractures or fails. So, the toughness of the concrete is higher, it needs more energy to break it.

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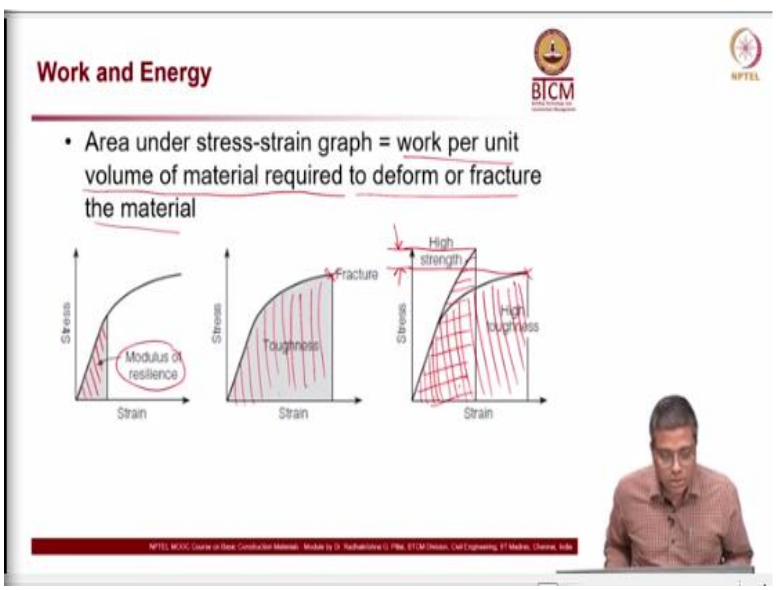


Now area under the stress strain graph - what is that indicating? It is essentially the work per unit volume of material required to deform or fracture the material. Now in the first sketch here, you can see modulus of resilience that is essentially looking at the area under the curve until the yield point or in the elastic region of the graph.

When we consider the plastic region that is where we really look at the toughness. Because we also talk about plastic movement or plastic deformation of the material and until fracture you take and that area under the curve we call it as toughness of the material. Now there are 2 concepts to look at while designing the system. Strength and toughness, because strength is definitely a widely used parameter for designing anything when we look at collapse condition.

If you want to extend that collapse, because the collapse is essentially as a function of the energy absorbed. In the case we discussed about that quick resistance designs, you have to have systems with high toughness or it should not break into 2 pieces until a lot of energy is absorbed. So, that is the case where we look for high toughness but not necessarily a high strength material.

So, here in the second case, where it has high toughness, the strength is less. So, this is the delta we are talking here, this is difference between the 2 materials. So, even though a material will have lower strength, it can still withstand some more forces because it has larger toughness. So, the energy required to break the material maybe more in case of low strength material.

So, in this case you see low strength but high toughness. The area under this curve is more as compared to the area under the first curve. So, we look at all these aspects when we design structures to resist an earthquake or wind or impact load etc. Toughness is very important parameter in addition to the strength.