Basic Construction Materials
Prof. Radhakrishna G. Pillai
Department of Civil Engineering
Indian Institute of Technology-Madras

Lecture-06
Materials Engineering Concepts-Part 3
Mechanical properties (cont'd)

Hi, I am Radhakrishna Pillai, today we will talk about mechanical properties, some properties which we could not cover in the previous lecture.

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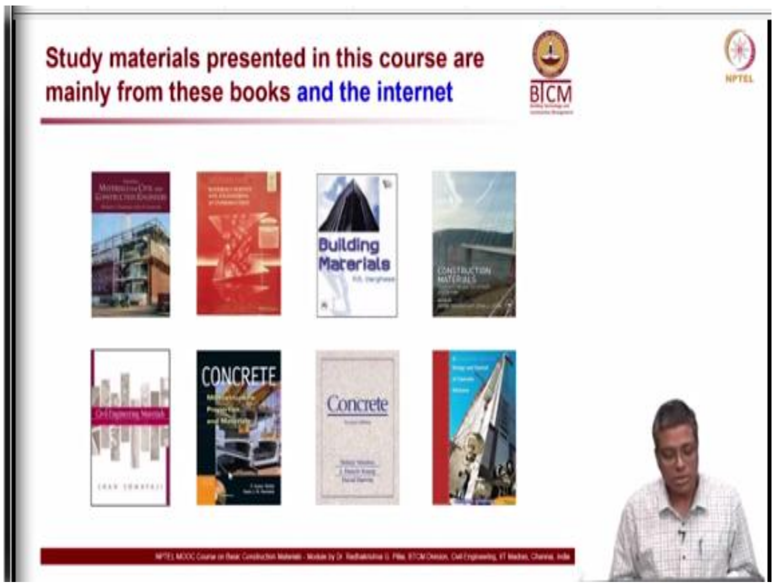

So, these are some of the books which I use. And most of the material for today's lecture, it is mainly coming from the book, the first book shown here by Mamlouk and Zaniewski.

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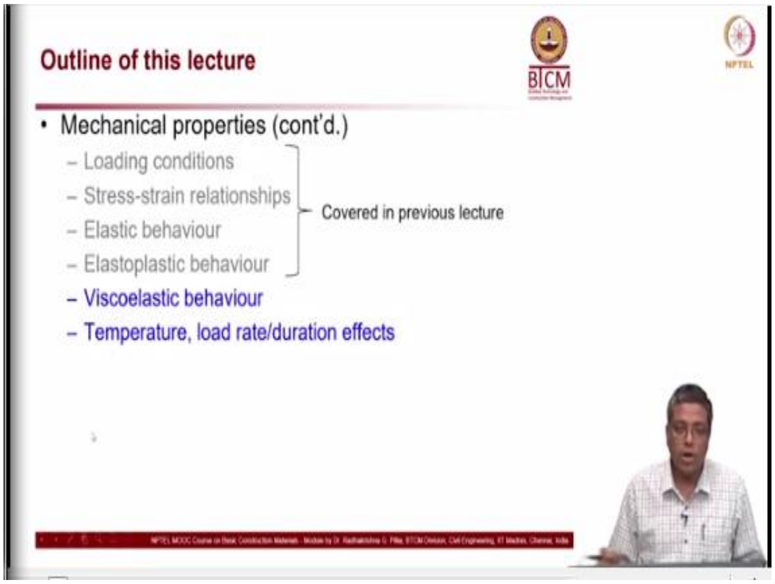

Now, we covered loading conditions, stress strain relationships, elastic behaviour and elastoplastic behaviour in the previous lecture. Today we are going to focus on viscoelastic behaviour and also looking at how temperature, load rate and the duration of the load affects the behaviour of various materials.

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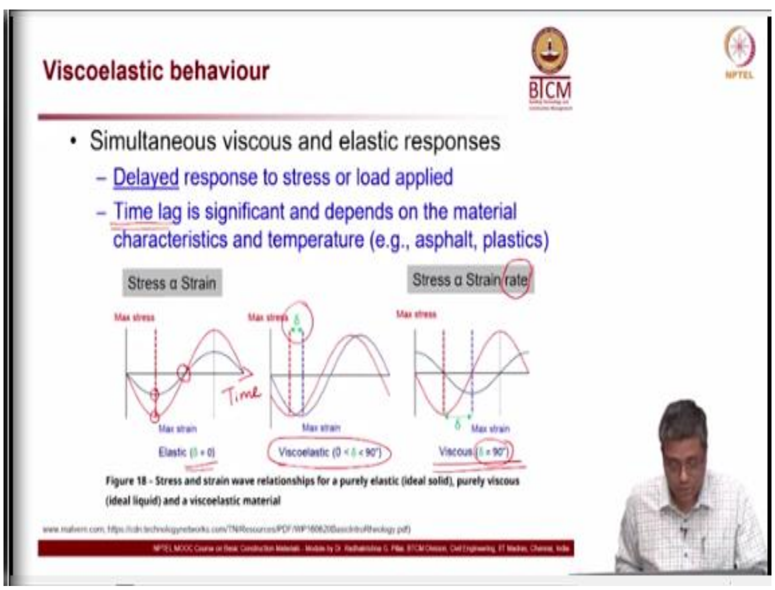

So, what is viscoelastic behaviour? So, this is essentially a simultaneous viscous and elastic responses when materials behave in that way. And there is a delayed response to the stress or load applied. What it means is - Let us say you look at the 3 graphs at the bottom, the first one is on elastic behaviour, the second one is on viscoelastic behaviour and the third one is on pure viscous behaviour.

Now, in the first one which is on elastic behaviour, stress is proportional to strain and you can look at that graph where you have the red curve, which is the stress curve and this is as a function of time. Now, the blue or the dark colored or the black curve is on the strain, which is the stress graph and which is the strain graph as a function of time.

Now, you can see here that the maximum stress is occurring or maximum strain is occurring at the same time when the maximum stress is occurring, or in other words, here also you can see it is happening at the same time. So, there is no lag between the stress and its effect on the material, which is strain. So, there the time lag is insignificant or almost zero in case of elastic behaviour or there is no phase difference.

If you are looking at the viscous behaviour, which is on the right side, this one, there is a phase difference of about 90 degrees. And what that means is there is again significant time lag and also the stress is proportional to the strain rate and not just the strain, there is net additional word strain rate or rate is very important there. So, in the first case, elastic behaviour, the stress is proportional to the strain and in the viscous behaviour stress is proportional to the strain rate.

In most of our examples, we will talk about shear stress and shear strain, anyway we will come to that later. And this time lag, it actually depends on the material characteristics and temperature. Now if you look at the viscoelastic behaviour, there is also definitely a time lag, but that is in between the pure elastic case and the pure viscous case. So, you have a time lag or phase difference that is this indicated by delta there.

So, that is a typical behaviour of a viscoelastic behaviour. That means, the strain is, if you look carefully, the strain is followed by the stress applied. Or there is a lag to the reaction or stress which is applied or stress if you look at as action and strain as reaction, then you can think of in that way.

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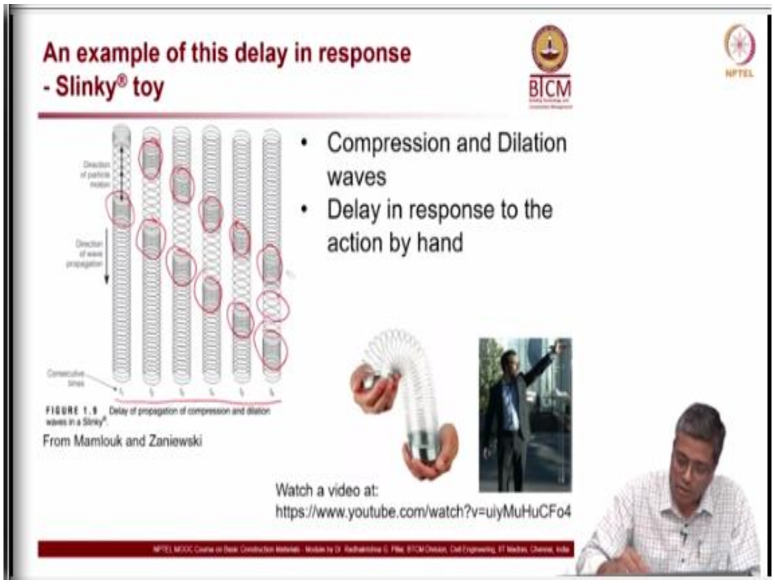

Now here is an example to show this viscoelastic behaviour, this lag you can see here, let us look at this sketch here you have different time instance. So, at time t 1, this compressed region of that spring, so this is a slinky toy which you might have seen. So, when you play with this toy, as your hand moves down, it is not necessary that all the points along the spring is also moving downward.

You might notice that when your hand is moving downwards, some portion of the spring is actually moving upward. Because it is still just about to react to the previous action of your hand which is moving upward, so you can imagine that scenario. So, here you can see from t 1 to t 6, this compressed region of the spring is actually moving or it is moving downward, whereas, the particles can move up and down. And then here also you can see some compression waves are there and here is the dilation waves.

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So, these are the dilation waves or they are those regions experiencing some expansion. Anyway, the point is that the action of your hand, if your hand is moving forward, it is not necessary that all the points in this spring is actually moving forward, some point might be moving backward. So, there is this delay in the response to the action by hand. Now this delay is also, this is a very simple example to show you how or what this viscoelastic behaviour and what that time lag which I mentioned in the previous slide means?

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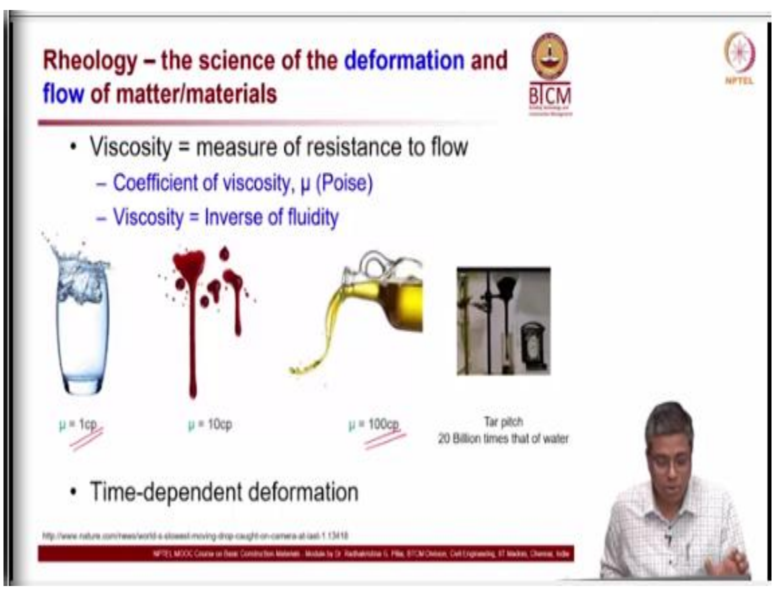

Now, when you go to real materials which we use, first thing to look at is what is this viscosity and then how it affects the rheological behaviour? So, now what is rheological behaviour? It is the science or rheology is the science of the deformation and flow of matter or materials. Now, what is viscosity? It is measure of the resistance to flow. Look at the examples here, first you have water then blood, then you have oil and then on the right end you have tar or asphalt or bitumen (all similar material).

Now, viscosity is the measure of resistance to flow. That means, if you think about water and oil, which are probably more familiar to you. You can think water is less viscous than oil, even if it is hot water, it is less viscous than oil. So, you can look at the numbers here, this is the viscosity for water, 1 centipoise, whereas for oil it is about 100 centipoise.

Now, another thing is, this is again a time dependent phenomenon, time dependent deformation is what we are looking at. It is now again the load applied and the reaction by the material, there is a time lag, there is a possibility of time lag.

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Now, here I am going to show you 2 examples, which are probably the longest laboratory experiments which have been conducted, especially in this area. So, you can see the first experiment was started in 1927, in the University of Queensland in Brisbane and 80 plus years have passed, now 90 plus years and now you have only 8 drops formed.

In their experiment, what they did is, they put in a bitumen material or tar and then allowed it to form the drop and fall by itself, without applying any load. So, it is all under gravity load. Now, how long it takes for each drop to form? about 7 to 13 years. Now what happened is in 2000, there was one drop and they missed the drop, the camera could not capture it.

Another experiment of similar nature is happening in Trinity College, Dublin. Again it started in 1944. It is an experiment on pitch in this case, and high viscosity and low flow is what they are studying. And actually the last fall was captured in camera and you can see the video on this website which I have given at the bottom left corner. You can go to that link and watch this video on this experiment.

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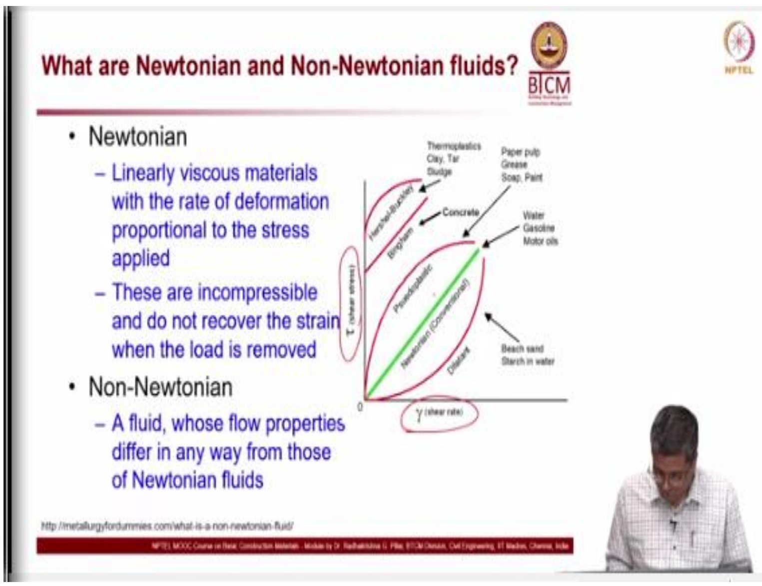

And, 2 more concepts here. There are 2 types of fluids when we talk about their shear rate and stress. One is a Newtonian fluid and the other one is Non-Newtonian fluid. So, what is Newtonian fluid? Look at the graph here, you have shear rate on the abscissa and shear stress on the ordinate. Now here, the Newtonian fluid is the one which is following the green line. That is, the shear stress is proportional to the shear rate or strain rate like we discussed earlier. So, there is this proportionality constant and that is a Newtonian fluid. One example is water.

Now, these are linearly viscous materials with the rate of deformation proportional to the stress which is applied. These are incompressible materials and they do not recover the shape once it is deformed, even after the load is removed, because we are talking about plastic deformation and not elastic deformation. This is plastic deformation.

Now, non Newtonian fluids are fluid which has the property which do not match with the Newtonian. So, that means anything other than the green curve over here, we can call them as non Newtonian fluids.

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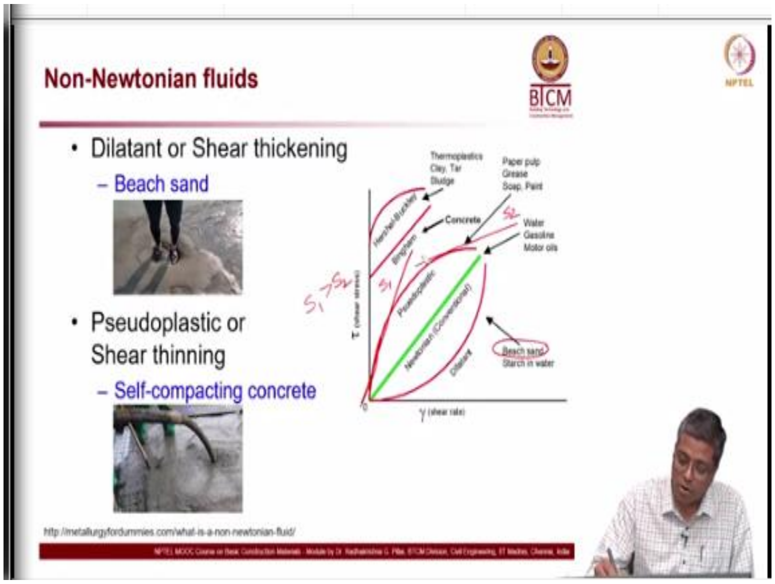

Go to the next slide. So, here you can see there is one curve which is given below the green curve and that is a dilatant, or we can call it shear thickening material. An example is beach sand. Now, look at the first photograph, where you can see that person is standing on either a beach sand or muddy water. And what you will notice in such cases - you can think of when you went to the beach or something similar last time.

When you stand there and as the water moves away from below your foot, what will happen is, you will start feeling that the sand has become more and more stiff as water is moving away. So, that is basically this kind of behaviour over here.

So, what I am saying is, if I take a slope of the curve here, in the beginning when there are a lot more water below your foot, this is the slope. But as you apply pressure, more water is removed from below the foot and then you will see that the soil or sand becomes more and more stiff. So, if I take this as slope 1 and this slope 2, slope 1 is smaller than slope 2 or the slope keeps increasing. That is what is dilatant behaviour or shear thickening behaviour.

Now let us look at shear thinning behaviour or pseudoplastic behaviour, these are all the materials above the green line. One example of this is self compacting concrete. As you can see on the photograph below, that is actually concrete being pumped or pumpable concrete or the concrete which is self-compacting. Usually when we compact concrete we use needle vibrators or some kind of tool to pack the concrete, here in this case, you do not need those kind of tools and it is a very good technology. You will hear about this later in this course.

But this material or this concrete, you do not need any external force or vibration to compact the concrete. It will flow by itself. How this is achieved is by changing the viscosity or flow properties of the concrete. And what is the behaviour here - I mean for concrete, we use something called bingham model which is shown here, you can see this.

And this height here is what we call as yield stress, for concrete. And where this point, there is a deviation there, that is why we call yield stress. So, let us not worry about that for a moment, we will look at this curve which is pseudoplastic curve. Now here just like I mentioned in the previous case of dilatants, look at how the slope is changing here and here. The slope, imagine this is S 1 and then here the slope is S 2.

Now in this case S 1 is greater than S 2 or in other words as the more and more load is applied the stress is, slope is decreasing. So, this is what we call as pseudoplastic net behaviour.

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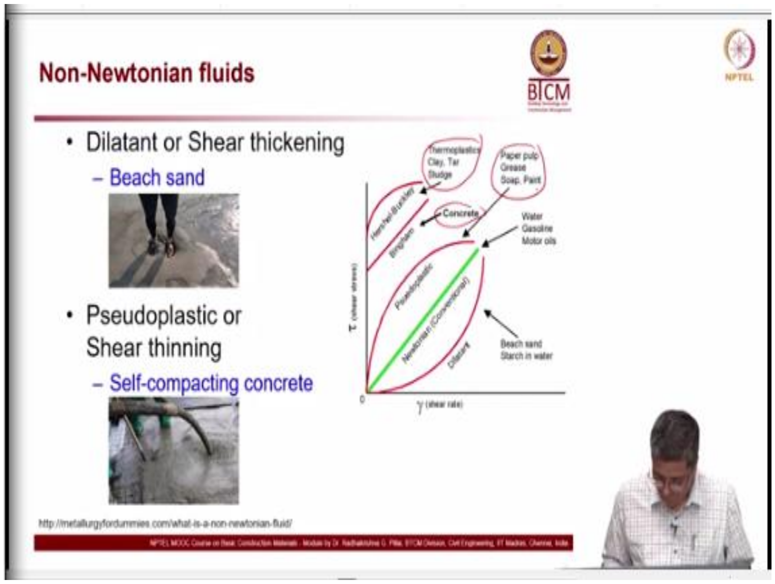

And in another case when the slope was increasing, we call it dilatant behaviour. So, for application purposes, the self compacting concrete is very good because you do not need much energy. You need energy, like the amount of energy required to mix or place the concrete is less. Once it is starts moving, it will flow by itself maybe very slow but it will flow and then fill all the small pores, small spaces, hooks and corners in the form work etc, it will fill up very nicely.

Let us say upcoming, the use of this material is day by day increasing, so you will hear this more later. So, 2 types of materials we looked at. And then some more examples of this pseudoplastic materials are thermoplastics, clay, tar, sludge, definitely concrete, paper, pulp, grease, soap, all this. So, the point is, once the material starts moving, then it becomes easier to move it further.

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Now, viscous behaviour - which is permanent deformation due to short term loads. When we say material is viscous, we are thinking about short term loads. Now here, short term load means the time of application of load is very very small. Now here in case of traffic, let us imagine you have a truck or a car moving along a road. Here you have every wheel of that vehicle is going to move on the road at very high speed.

So, if you take a point on the road, let us say you take one point over here on this road, the time for which that wheel load is applied is very, very small, fraction of a second. It moves so fast, right, so that is what is the short term load which I mean. And then multiple traffic loads are also there, that means depending on number of vehicles which are there, you will have more and more traffic load, the number wise.

And what happens because of this, the material starts flowing or the asphalt starts flowing laterally, because of this load application. You can see here that there is a deformation also, so there is a deformation like this. And then there are also moments which happened in this direction, Now what do we call that? We call that rutting. So, this happens right along the wheel path of the road.

So, you can see here, this is the path, the wheel path and that is where you will see a depression like this one. So, we call it rutting and this is happening because the material is moving or it is flowing. It is not flowing like water, but it is flowing in a very, very slow rate as every car passes through the road or every vehicle passes through the road. Now higher temperature can reduce the viscosity, that means when during summer the flow rate or the speed of the flow will increase as compared to winter.

And also, you can see probably like because the flow is more easy or the material becomes less viscous, it might even bleed and flow upward on the road surface. So, this is an example where a person is pushing his finger close. You might have seen in some places during summer that the asphalt or the bitumen starts flowing upward and then it gets all above the aggregates on the road surface, so that is example here.

And very familiar to you, oil example here, when you heat it up, it is going to flow easily. When it is cold, it is going to I mean even you might have seen frozen in the oil in the bottle in the winter season it will get frozen. So, definitely viscosity is a function of the temperature.

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Now, another behaviour which is important here is creep. Here also we are talking about permanent deformation, but this is mainly due to the long term sustained load not short term load like in the case which we just discussed in the previous slide, which is viscous behaviour. Here, permanent deformation and load long term sustained load. Now where does this typically happen? In materials where you will see ionic, covalent and such bonds and also amorphous materials.

Now, examples are concrete, you have wood and metals. Now in the concrete how this happens is because of this long term sustained load, there could be microcracks which form inside the concrete. Now, it is not like large crack which you see outside but we are talking about microcrack which forms inside the concrete. Here is an example of a bridge which showed creep deformation which took several years to show, not in 1 day or 2 days, not immediately after the construction.

After long time because of the load, the heavy weight of the concrete itself, it started deflecting downward. You can see creep deflection, it is written here. So, this is one very good example demonstrating that concrete can actually creep, and here we talk about flexural creep.

Now another example is wooden sleepers below the railway tracks, you can see here the wood. Imagine you have a particular thickness and if that wooden piece is used without any pre-compression or pre-loading. Then, maybe after the rail tracks are placed, after the train starts moving, you will see more deformation or the wood gets compressed by let us say the thickness of delta x (Δx). Now in a case 2, if I preload the wood, then what will happen is the delta x (Δx) can be reduced.

So, when I say delta x (Δx), it is the deformation after the rail track is placed and during the service. Now, so people actually what they do is, they precompress the wooden timber before they place it below the rail track. So, because of that, the compression which is happening after the rail track is placed is going to be minimal. So, preloading or prestressing of wood is very, very useful to reduce the creep deformation after the installation. So, maximum possible compression you do it before the installation, so that after installation it is less.

Another case is metals, where creep happens when the ambient temperature or the temperature of the metal itself is more than about 30% of its melting point. If it is less than that, then the creep deformation is not very significant. Now another example is about pipelines, you can see here, I will show, look at the picture here. But the same picture I am going to show in the next slide, so it will be more clear there.

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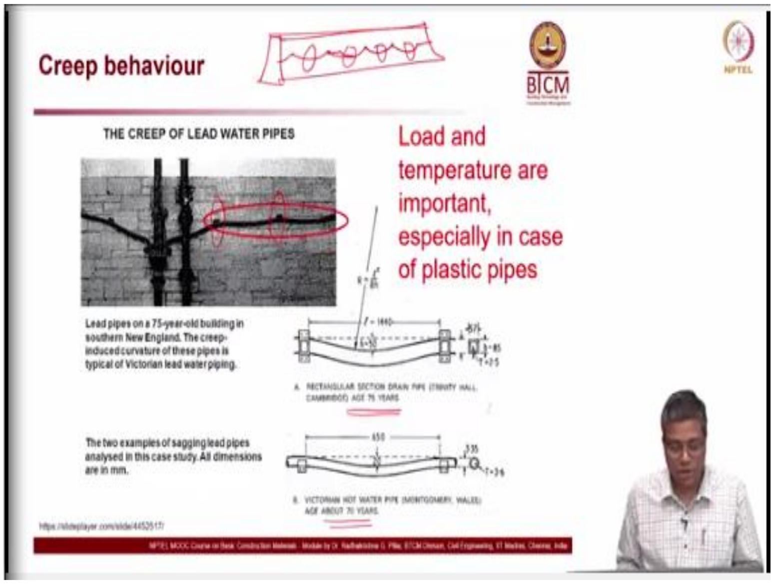

You can see here inside, that red region, you can see the pipe is deformed. Originally it was a straight line between the clamps. This is the clamp 1, and is the clamp 2. So, originally it was placed as a straight line and then as time passes, the weight of the pipe or the fluid which goes through that, was continuously acting downward, and because of that it started sagging. For the sagging, we are going to call it as creep behaviour, because it is a permanent deformation.

It is not just elastic deformation, it is permanent deformation and also, this sagging is happening over a period of time, several decades. Look at here, the first case here it is 75 years, second case here we are talking about 70 years. So this becomes very, very important factor. The creep behaviour is very important when you talk about any structural element, or any material for that matter, if your structure is designed for several decades.

If whatever you are building is meant to last only for few years or just couple of decades, maybe creep is not important, but it depends on the structure. I am not going to say that it is not important, it depends on the structure and the size and shape of the structure, so various factors. Because the cumulative deformation is what is, that we look at. So its very very important to consider. But unfortunately, some places we do not consider and then we see a lot of problems like this and it also affects the aesthetics.

One example where you can see this creep behaviour very, very easily is, when you go on the road, look at the deviators or the barrier between the lanes on our highways and roads. I am talking about those black and white painted barriers. You will see electrical conduits placed on that, fixed onto the side of that. Have you seen anywhere where it is straight line, it is very difficult. Because all of them, you will see that from clamp to clamp it will have a sag. So clamp to clamp, I am going to draw it here. So, I am talking about these kinds of systems on the road. So, you will see an electrical conduit going like this, like this, it will go.

So, this is what I am talking about, this sag is because of the creep. And what is the material use for the pipe? The electrical conduits are either made of some sort of plastic, they are not metals all the time. And now they are all exposed to sunlight and considering our climatic conditions, the temperature is very high and probably that is making the conduit material very soft. And when it is soft, it starts sagging a lot and then it undergoes creep deformations. So next time when you are on the road, you can look for this. It will be interesting.