Basic construction materials
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Lecture 31
Cement and Concrete 4 - Part 1

Hello everybody, so far in this chapter on cement and concrete, we have looked at the qualities and properties of the ingredients. Then we took a look at some of the processes involved in actually putting together the concrete in practice. Today we are going to talk about concrete properties.

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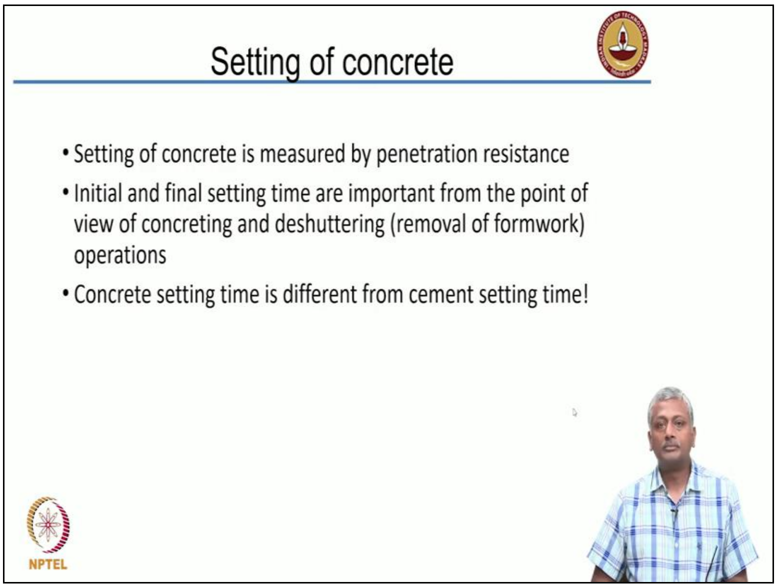

We talked earlier about the fact that cement hydrates by reacting with water and slowly leads to the setting and hardening of the cement itself. Now please remember that concrete is a conglomerate that is made with cement, water, and aggregate. So what happens is how the concrete sets are not the same as the way the cement sets. Please remember that in cement, we talked about using this test called the Vicat test to determine the setting time of the cement.

Of course, concrete also sets because the cement is hydrating and gaining strength, but the setting time of the concrete may not be the same as the setting time of the cement. So we need to measure the setting time of the concrete typically measured by a process called penetration resistance. Now, this generally involves taking the concrete, which is fresh; we sieve it through a 4.75 mm sieve so that we remove the coarse aggregate.

We collect the mortar, and this mortar is collected in a cylindrical container, typically about 6 inches or 150 millimeters in diameter. Then we have these needles attached to an apparatus that can measure the resistance or pressure that the needles give when they are being penetrated into the concrete. So as the concrete gets harder and harder, the needles will give more and more penetration resistance, recorded as the setting time of the concrete.

So there is an initial setting and final setting like in the case of cement. From the point of the practicality issue, the initial set time is obviously important because it tells us the amount of time we have to complete all the processes related to concreting that involves placement, consolidation, finishing, etc. So, all those things need to be completed while the concrete is still pliable.

Once it goes past its initial set, the concrete cannot be moved around freely without causing some distress in the concrete. Moreover, the final set is important to the point of view of having attained a final form for the concrete, and that means that we cannot alter the shape anymore beyond that point without failing the concrete. So and that is also important because we can know when to start removing the redundant formwork, which supports the concrete from underneath.

However, which is on the sides, which are defining the shape of the concrete mould itself. Again, to emphasize once more, concrete setting time be quite different from cement setting time. This is again an issue because the concrete setting is also determined by the cement paste to aggregate ratio; it is also determined by the presence of these mineral and chemical admixtures that we add to the concrete.

When we look at cement setting time, we do not add any of those ingredients. We test cement setting time as it is, whereas, for concrete, we test it as the concrete mixture has been prepared with all the additives. So, we need to ensure that we have some idea about how long it takes for concrete to set. Usually, when we do not have admixtures, the initial setting time of concrete will typically be between two to three hours.

Normally when we do not have any admixtures, the presence of admixtures like water reduces; for instance, our setting time may go up to four to five hours. However, we need to ensure that it does not extend too much, or in other words, we do not get what is called set retardation. Moreover, in some sites, it is prevalent that sometimes when we overdose, these chemicals or chemical additives are added to improve the early age properties of the concrete.

We may experience set retardation, which can ultimately cause the concrete to not set for several days on end. And this is a common scenario at many job sites where they add additional admixtures to ensure they are getting the required properties. However, this discussion is a subject of a different course, probably a higher-level course in concrete technology.

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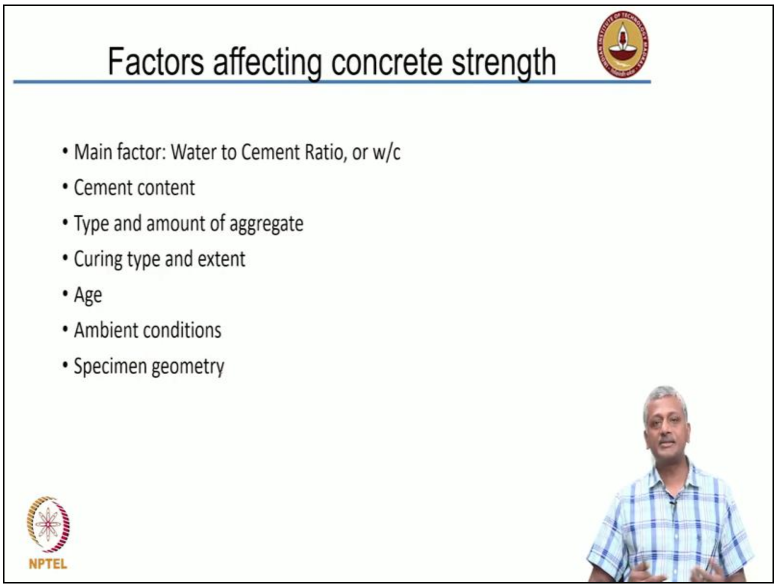

So once the concrete sets and hardens, it starts gaining strength. Concrete starts gaining strength rapidly at first, and then the rate of strength gain slows down. Usually, as in concrete design, we are familiar with concrete strength at 28 days. We generally talk about 28-day strength. So in most cases, we will see that concrete is specified in terms of a grade we specify.

So grades of concrete are, let us say, M30, M40 etcetera; this means that a concrete cube of 150 mm side 150 millimeters side cube which is cured underwater at 28 days gives a strength of 30 Newtons per millimeter square that is what is meant by M3. Of course, there are a lot more statistics involved in this definition. I will not go through that now; essentially, the number indicating the grade tells us the 28-day strength.

The concrete hardens rapidly at first, so in most modern concretes, we will see that we already would have attained 70% of 28-day strength by seven days. Generally, that is the point when we usually stop curing is usually stopped by seven days because our concrete has attained about 70% of its strength. 28-day strength is not the ultimate strength of the concrete.

Concrete, if it continues to have a moist environment around it means that water from concrete does not dry out to the surroundings. Then, the cement in the concrete will continue to hydrate and contribute to strength. So concrete may continue to gain strength beyond 28 days, sometimes beyond a year, but the incremental strength gain will be limited beyond 28 days unless we use special cement-like fly ash-based Portland Pozzolanic cement.

In those cases, there will be significant gain beyond 28 days also. Now what affects the strength the main factor is the water-cement ratio. The ratio of the mass of water to the mass of cement in the mix is the primary factor that governs the strength. The other factors may be cement content to some extent; if we put more and more cement, we get some increment in the strength, even keeping the water-cement ratio constant.

If we increase the cement content, we will get some increment in the strength to an extent, but beyond that, we will start seeing that it drops. The type and amount of aggregate depending upon the type of aggregate we use, limestone granite, anthracite, quartzite, and so forth, and how much of this aggregate we have in our aggregate to cement system ratio **can also determine the strength**.

The curing and the extent of curing are we doing water curing are we doing compound based curing are we covering with a wet hessian cloth and how long are we going to be curing for 1 day, 3 days, 7 days, 14 days and that will also determine the ultimate strength that our concrete attains. The age of the concrete obviously as I said at 28 days we are getting potentially the main strength of the concrete.

Even that is not 100, it is about 90% of the overall strength that concrete can attain, but we consider that enough for design purposes because that is a good check for us to see whether the concrete quality is correct or not. As I said 7 days we already achieved about 70%. By 3 days typically, we will be achieving around 30 to 40% of 28 days that may change depending upon the type of cement and so on.

Some cements are rapidly hydrating; they gain strength early; like we talked about, rapid hardening cement in those cases, we will get much higher levels of strength at the early ages and then a slowdown in the strength development at the later ages. The ambient conditions can also dictate the strength. For example, if we have a very drying environment, it will remove the water from the concrete, and that will lead to a low rate of hydration, which may lower the extent of strength.

So we need to keep our environment moist. If the temperature is high, it will speed up the reactions in the initial stages. But then, if the temperature is high throughout, it may again cause some issues with the hydration and lead to a lowering of the strength. So, all those factors need to be governed carefully. Interestingly strength is also dependent on the specimen geometry; in some countries, we test cubes; as I said, 150 mm cubes are tested in India for the strength of the concrete.

But if we go to some European countries or even the US they use cylindrical specimens; cylindrical specimens have a length to diameter ratio of 2 the height or length of the cylinder is twice the diameter, and that usually results in a strength value that is lower than what we get from the cubes we will talk about that in just a minute.

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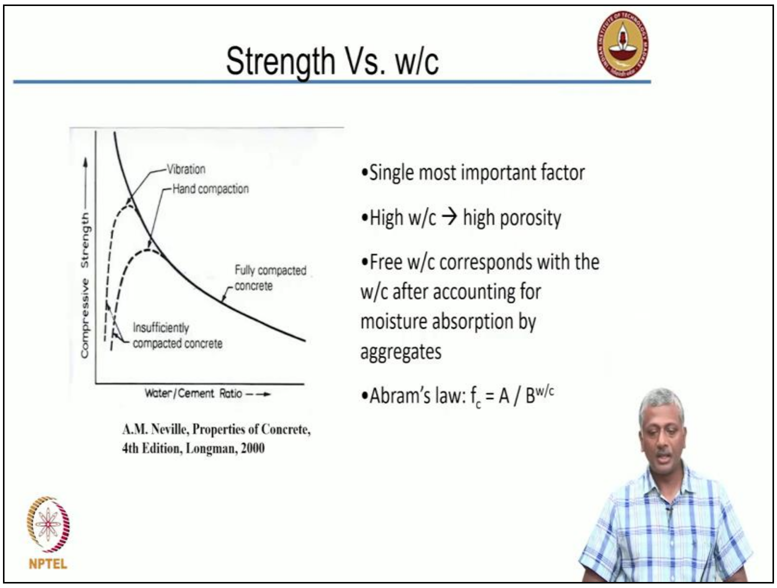

The main factor that affects the strength is the water to cement ratio, and this is a very famous relationship produced by one of the scientists named Abram or Abram's law that is what it is called. So Abram's law states that strength is a function of the water cement ratio in some power function. Nevertheless, this need not be the correct form of the equation our strength is inversely proportional to the water-cement ratio, that is all.

It can have a linear relationship; it can have this power type relationship and so on and so forth, but that is not important. The vital part of understanding is as the water-cement ratio increases the strength reduces. There is a limit to how much we can increase the strength by reducing the water-cement ratio. If we reduce the water cement ratio to some extent, our strength will keep on going up.

However, then it all depends on how well we can compact our concrete. Concrete that has less water will be tough to compact. So there will be a limit of hand compaction and the limit of vibration-based compaction beyond which we cannot further reduce our water cement ratio. So it is impractical to think of concretes which have a very, very low water-cement ratio.

Now, what is that very low? Unfortunately, the definition of that very low has changed over the years today. It is possible to produce concrete with very minimal compaction, which is almost flowing in such cases also, concrete can be produced by water-cement ratios of as low as 0.15 that is the power of the chemical additives. If we do not have chemical additives, we cannot produce concrete of less than 0.4, and water-cement ratio because it will be almost impossible to compact.

Anyway, so all that depends on how much compaction we give; why is high water a problem? As discussed before, in the initial system, we have water, and cement volume is occupied by water and cement. As the cement hydrates, the hydration products fill up the volume. However, if we have more water to begin with, we have more porosity the more the porosity, the lower the strength.

So generally, we always talk about strength versus free water-cement ratio. What is the free water to cement ratio? The water that is remaining after accounting for the water that the coarse and fine aggregate has absorbed. We talked about water absorption of aggregate as a vital characteristic to determine and what role it plays in controlling the mixed characteristics on dry days or rainy days; we talked about that previously.

So here, free water-cement ratios whatever is remaining after accounting for that absorption. So please remember that strength is inversely proportional to the water cement ratio. We do not have to bother about any law like this; we can fit anything we want to see. Today statistical data fitting makes things capable of fitting any relationship through any set of data, but that does not mean anything; we need to understand the physical significance.

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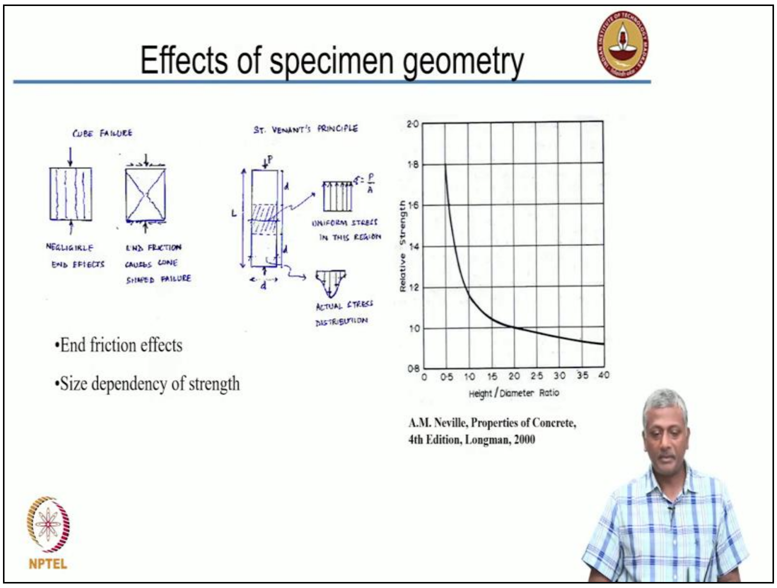

Now I was saying earlier that strength may be dependent on the specimen geometry. In some cases, when we test cubes versus cylinders, we may get very different results. Now, why is this the case in our mechanics of materials? We would have learned or will be learning a concept called **Saint-Venant's Principle**. So, the principle states; that the end conditions which are there during the test will affect the specimen up to a distance equal to the least lateral dimension.

So what I am saying what are the end conditions in the strength test? We have our cube or cylinder sitting between the loading platens, and the loading platens are going to compress the cube or cylinder. Now the platens are made typically out of metal, and the concrete and the metal interface may have some friction. Because of this, when we compress something, the natural tendency for the material is to bulge outwards.

There is a Poisson effect, so bulging of the specimen will happen outwards. So what will the friction on the top do? It will try to prevent this bulging. So in fact, the friction between the platen and the specimen causes an increase in the compressive strength of the concrete. In other words, instead of plane compression, we now get a biaxial sort of stress state which leads to an increase in the strength of the concrete.

So that is what is seen here in a cube; the loading platen is giving compressive load, but because of the end friction, which keeps the cube from bulging out, we are causing some biaxial state of stress. As a result, we get a failure that is defined by this hourglass type shape. We would get a failure plane like that so, if there were no friction if the end effects were negligible.

If there were no friction, we would get a true failure pattern, and it should have been like this; we should have had vertical cracks through our specimen. **If there is no friction, we will get vertical cracking because the compression causes an exceeding of the lateral tensile capacity**. Please remember that for any material to fail and fail in compression is very difficult. What typically happens is that most materials that are compressed bulge out and exceed their lateral deformation capacity and tension.

Moreover, that is why we get cracks that are parallel to the load here. We get cracks that are parallel to the load. Of course, when we have friction, we start getting cracks that get inclined because of the friction effect. Why is this any different in a cylinder? As I said, the cylinder has an l/d of 2. So the end effects are felt only up to a distance of d from the ends, which means we still have a very small infinitesimal zone in the center of the cylinder where the end effects of friction are not playing any role at all.

That means we have pure compression at the central part of the cylinder. So if we take a cylinder and break it, we will see that we get a failure which is more or less like this. We get almost vertical cracks in the center, and then there are some inclined cracks like that, which is the failure pattern of a cylinder. So cylinder strength, is typically about 20 to 25% lesser than a cube.

However, one interesting thing that we need to consider when a cube is cast we put the concrete from the top, and all but one face of the cube is perfectly smooth because they are against the mould. So typically, when a cube is cast, we turn it by 90 degrees and then do the strength test so that we do not have to prepare the ends. In a cylinder, we cannot do that. So we take the cylinder, pour the concrete, and cast the cylinder and the same direction only we are doing the test.

So a cylinder is a more appropriate representation of a member like a concrete column which is a vertical member where concrete is poured in that direction, and the loading is also in the same direction. In the case of a cube, it is not the same. So because of that, when we do your reinforced concrete design concepts, we learn that the cylinder strength is taken to assess the compressive capacity of a column.

So please remember that the cylinder strength is the concrete's true compressive strength; the cube strength is usually 20 to 25 more than cylinder strength. The same concept can be understood by looking at what happens when we change the height to diameter ratio of a cylinder. As I said, our standard height to diameter ratio is 2, and that is where we get the true strength. What happens when we increase the height to diameter ratio? Usually, we start reducing the strength.

Not very significant, but yes, we can reduce it to about 10%. What happens when we reduce the height to diameter ratio? We get to a stage where we are almost so at the height to diameter ratio of one. We are at the cube level. Even beyond that, we are causing a significant increase in our relative strength. As we keep on reducing the height to diameter ratio, our relative strength is going up because of this aspect of St. Venant’s principle.

The end friction effects will be felt throughout the specimen when our l/d ratio decreases beyond two. So please remember this is the reason why strength is not considered to be a material property because it depends on so many tests related factors.

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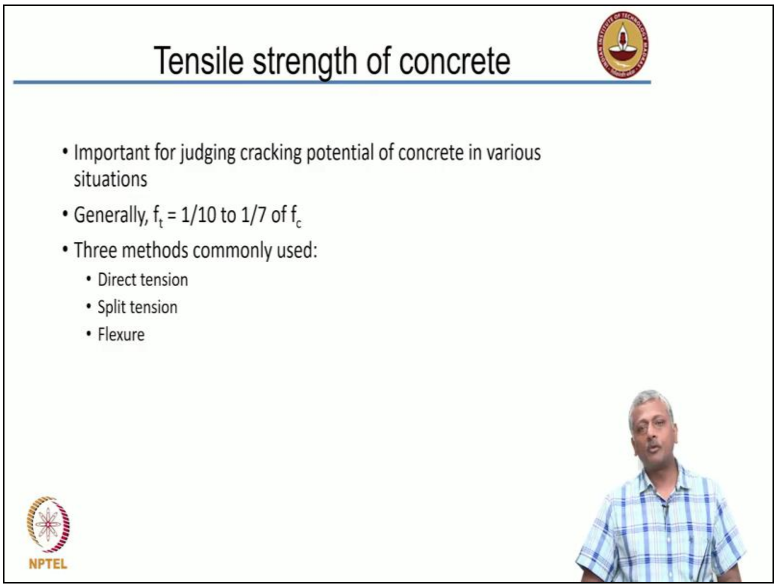

What about tensile strength? We always talk about compressive strength because that is what concrete is good at. But still, for some applications, we need to measure the tensile strength of the concrete. How do we measure tensile strength? We have to prepare a concrete and then pull it apart and measure the load at which the failure occurs. The problem with this, which we call direct tension, is that it is tough to hold the concrete.

Before that, usually in most engineering applications, even if tensile strength has been proposed as a criterion in the specification, in most cases, people do not seem to bother by testing the tensile strength. They assume some relationship, and that relationship generally pegs the tensile strength anywhere between 1/10th to 1/7th of the compressive strength.

However, there are different methods by which we can measure tension. Tensile strength is important in some applications like pavements and other applications where cracking can happen. Tensile strength is important for judging the cracking potential of concrete. Concrete will crack only because its tensile capacity is getting exceeded, not because it is getting compressed. Please remember that the cardinal relationship or cardinal truth about any material like concrete brick or stone is that it does not fail because of compression; it fails more because of tension capacity being exceeded.

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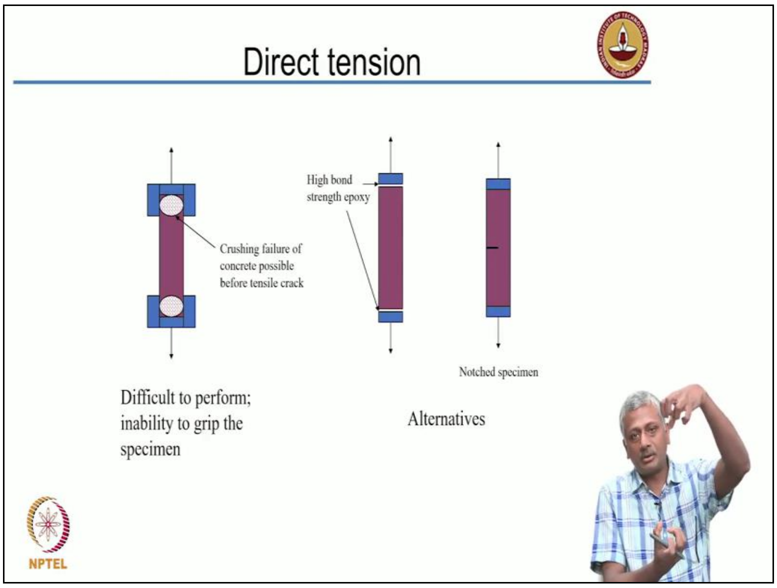

So what is direct tension? As I said, direct tension means we are simply holding the concrete and pulling it apart? However, if the concrete specimen is large, the amount of pressure that we need to put to hold it together at the ends may sometimes cause the crushing of the concrete at the ends. Our concrete at the ends may crush because we are putting too much pressure to hold the specimen.

Because of that, people try to adopt other means; instead of holding it, we glue it to the platens at the end using a high bond strength epoxy. But sometimes, that is a problem because it becomes more of a test of the epoxy strength rather than the concrete strength. The other thing is that we can put a notch in the center of the concrete cylinder. A notch is a defect that we are already putting in.

So when we are actually crack pulling it apart, the failure will exactly occur at the notch. So we are pre-defining the location of failure. However, the acceptable test method is the direct tensile test because that gives us a clear response. Unfortunately, it is very difficult to perform because of which we go for indirect methods.

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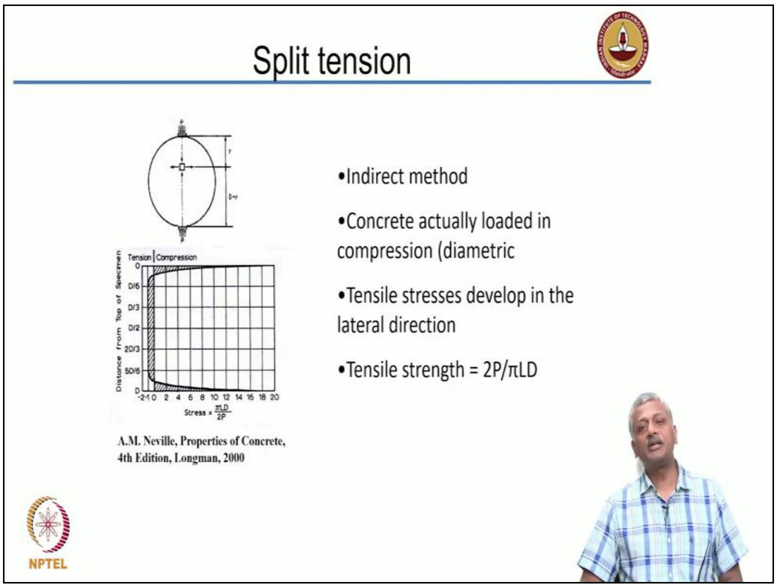

What are the indirect methods? One is called the split tension test. Why is it an indirect test because? We are not applying a tensile load here; we are applying a compressive load. So we take a cylinder of the concrete, and we subject it to a line load, a diametrically opposite line load, and that is what we see the section of that is shown here. We are compressing our concrete diametrically through diametrically opposite points. So this is a compressive load that we are applying on the top and bottom across the diameter of the cylinder.

Let's take the element in the center of this concrete along the diameter. We will see that as we get away from the edges, as we get closer to the central part of the concrete, the lateral tensile effects are much greater than the compressive effects. Because when we are crushing in this direction, it will start splitting in that direction, or tensile load will be in that direction.

So if we take the stress distribution across the diameter, we will see that the top where the load is being applied is in compression. However, a large portion of the cylinder is actually under tension along the diameter. So what happens is that the tensile capacity gets exceeded in that lateral direction, and the concrete splits. So, in other words, concrete splits into two halves, which is why it is called a split cylinder test method.

Moreover, it is called indirect because we are applying compression and not tension. So here, we can calculate the tensile strength quite simply with this equation two times the load applied divided by pi times length times diameter of the cylinder. So that is what is called an indirect tensile strength.

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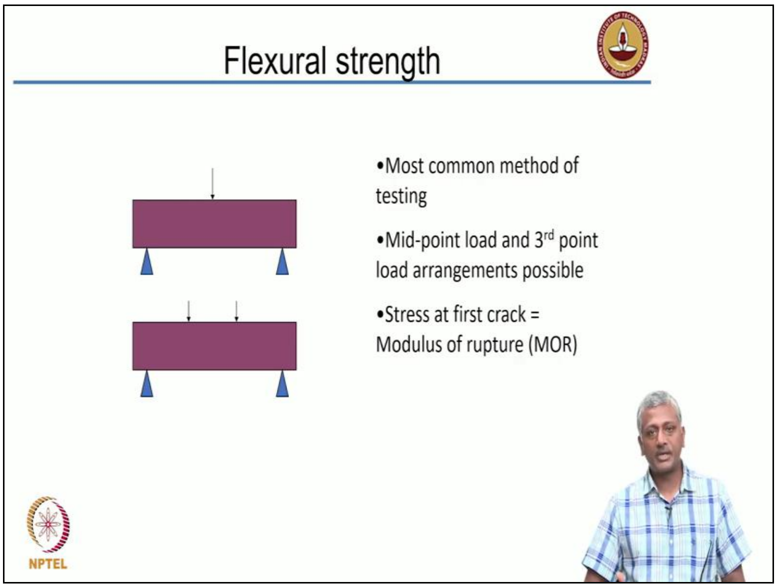

The other way of testing the strength indirectly is flexure or bending. In most cases, the tension becomes our problem and contradicts bending like in a beam; for instance, when we bend the beam, the bottom fiber of the concrete is under tension, which is where it causes cracking. That is what exactly we do in this case of flexural strength determination. We have this beam which is simply supported.

Moreover, we either apply a central load that means midpoint load, or we apply what is called a third point load. Why is it called third point load because the distance of the load from the corners is exactly one-third of the span. This distance is exactly one-third of the span, so the distance between the loads is also one-third of the span. The interesting part here is that when we do this third point load test, we get a large zone between the loads where shear is zero.

We do not get any shear between the two-third point loads; we do not get any shear; we get pure bending. And that is the reason why usually we prefer this third point loading arrangement; we would have all done shear force and bending moment diagrams in a mechanical materials course; we will know that for this arrangement, we have shear and the shear changes sign exactly under the load in the zone under the load the shear will change sign.

But in the case of equal loads equidistant from the supports, we will have a zone in the center where there is no shear; there is only pure bending. So here, what we do is as soon as the first crack appears, we measure the load, and the stress is then calculated from the load as the moment multiplied by C divided by I where C is the distance from the neutral axis. The neutral axis, in this case, lies in the center.

So C is nothing but d/2, and I is the moment of inertia. So this is a simple arrangement for determining tensile strength indirectly because we measure the strength in bending.