Admixtures And Special Concretes

Prof. Manu Santhanam

Indian Institute of Technology Madras

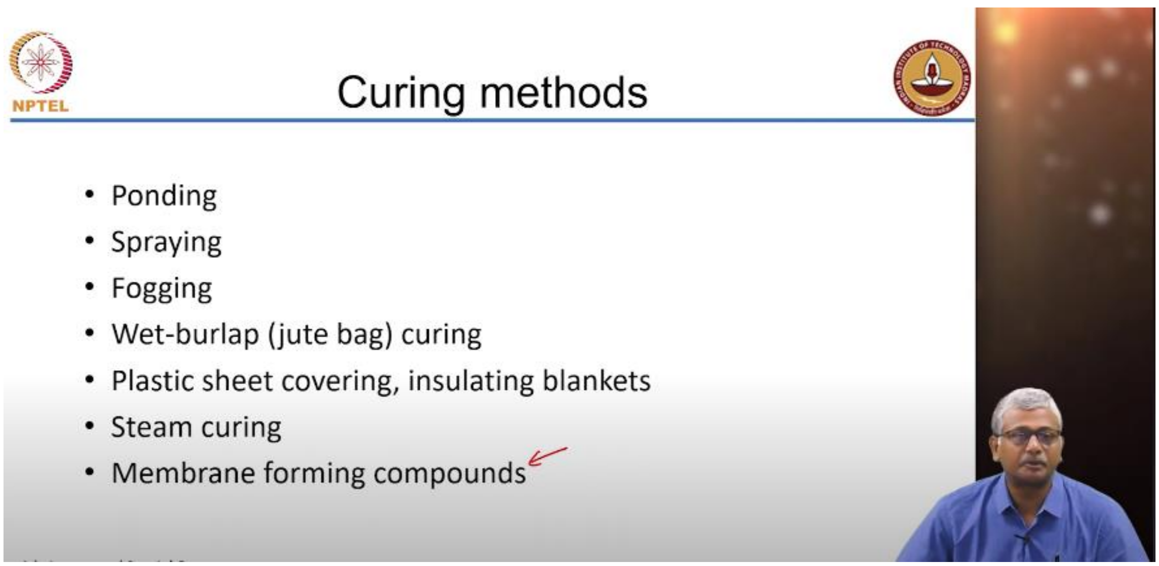
Department of Civil Engineering

Lecture 5

Overview of Concrete Performance: Curing & Hardened Concrete

Methods of curing:

(Refer to slide time: 0:27)



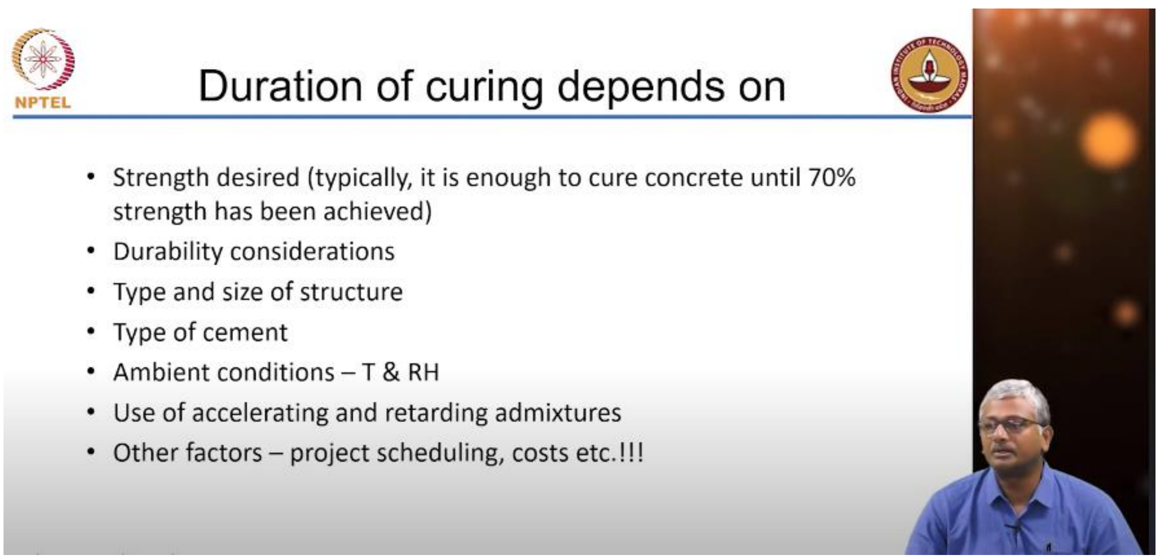
There are different ways in which we can cure concrete,

- Ponding
- Spraying
- Fogging (these are all practice in the field)
- There is also wet burlap curing that is often followed for vertical surfaces where it is difficult to really pond the moisture.
- Plastic sheet covering and insulating blankets are taken care of in regions where we have issues of low temperatures in ambient conditions because of which there is difficulty in actually setting and hardening of the concrete. So insulating blankets

basically help in maintaining the temperature in the concrete. Plastic sheets are essential for highly flowable concrete which is susceptible to plastic shrinkage cracking. Now this is something we will talk about later when we discuss high strength or self-compacting concrete. There is a high potential for plastic shrinkage cracking for exposed surfaces of high strength or self-compacting concrete. In such cases it is beneficial to ensure that there is no evaporation from the top surface so plastic sheets are good.

- Steam curing obviously is used when we want a very high rate of strength development in the early stages and we also do steam curing quite a bit in precast yards where we need to have an increase in the productivity of the production of the concrete.
- Membrane forming compounds is a subject that we will talk about in detail later on when we discuss the specific chemicals that are used as membrane forming compounds.

(Refer to slide time: 1:52)



We know that we have to cure concrete for attaining a specific level of strength. Now how much do we cure it? The idea of curing again I think I had emphasized this previously also is primarily to actually engage in concrete that is durable. Rather than strength, curing has to impart durability to the concrete and that is where we really need to ensure that at least some level of strength has been ascertained in the concrete before we can stop curing. Typically 70% is the usual thought process. Now what happens with 70% is that you have this for modern cements: the concrete strength at 70% is typically attained by about 7 days and you will rarely see that in sites curing beyond 7 days is actually practiced.

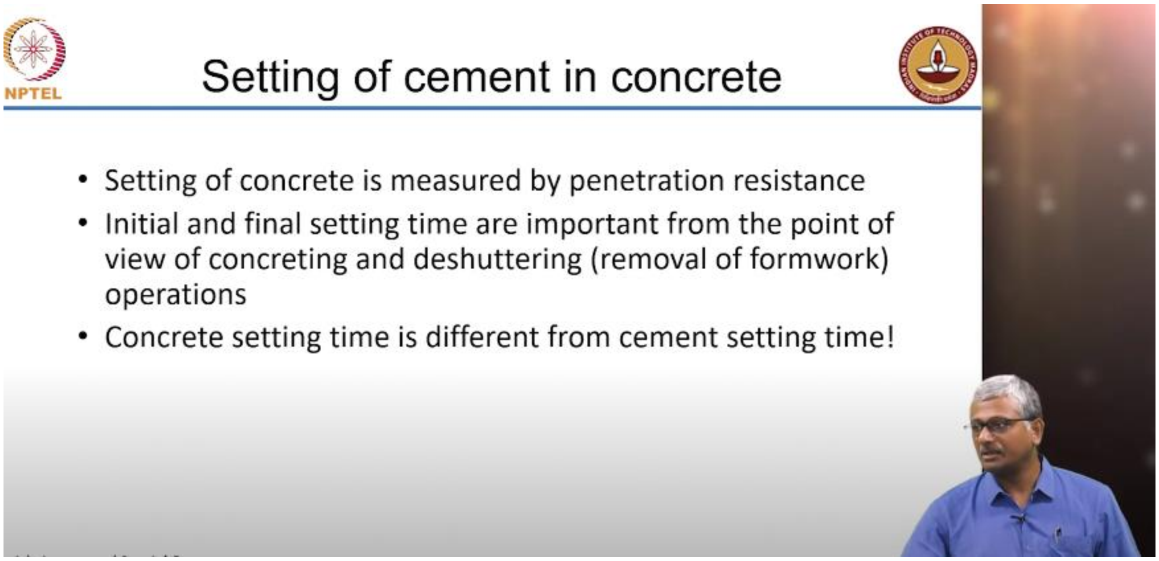
You have certain circumstances in which concrete needs to be cured for much longer and this can happen when you have concrete which has a very low water to cement ratio where internal desiccation or self-desiccation can be quite a realistic problem in the beginning. So other aspects that you really need to worry about with respect to curing, the considerations for durability not just attainment of strength but also durability is important. The type and size of the structure. Usually for structures that are very large the effect of lack of curing is not as critical as for structural elements which are very small. For instance if you compare a beam to a dam the effect of not curing on the beam is much greater than the effect of not curing on the dam but that does not mean you do not cure larger structures it is just that you cure them for a lesser duration. The type of cement obviously will dictate the rate at which your strength is being obtained. If you have a high early strength cement then obviously you do not need to cure for too long.

Ambient conditions in terms of temperature and humidity govern the rate of strength development so obviously they have an effect on the overall curing process and use of accelerating and retarding admixtures again because of the way that they affect the setting process. Sometimes it is factors other than these which can dictate the length of curing, project scheduling, costs, people do not want to waste their time spraying water on concrete. So it depends on who is at the site whether curing is actually done or not, how long is curing done again depends on the whims and fancies of the people who are operating on site and very often we see that curing is not really done for even 3 days sometimes even 1 day so you really have a problem with respect to curing if you do not plan it well in advance and if the project conditions demand such non-technical reasons sometimes do not do this process. Unfortunately that is the truth and that is what gets done in sites and that really affects to a large extent the durability. It may not affect the strength that much if you look at data for strength development in the laboratory where cubes have been cast and possibly even stored in air dry atmosphere you may still get about 80 to 90% of the strength without any problems but when you really test the properties of the cover concrete the durability is going to be significantly affected. Why because curing is obviously necessary to ensure that cement hydration gets completed or rather at least progresses to the maximum potential.

What happens when hydration increases? Why is durability improved when hydration increases? What is the primary reason? What does durability depend on? Durability depends on the interconnectivity of the porosity. So with more hydration you are going to break that interconnectivity and when you have less interconnectivity you have less permeability so obviously you have better durability.

Setting of cement in concrete:

(Refer to slide time: 6:22)



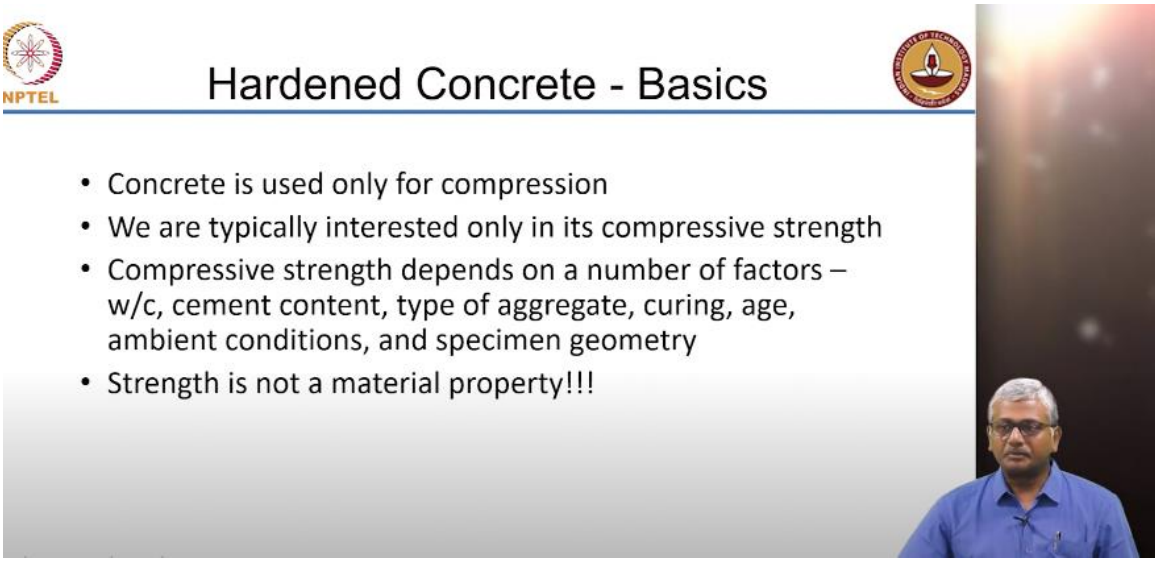
Now cement setting time is measured in the lab using your Vicat apparatus but the concrete setting time is not exactly the same as setting time of cement. Cement in concrete obviously undergoes hydration reactions because of which it leads to setting but the presence of aggregates and the environmental conditions wherever concrete is actually cast also have an effect on the setting process. So you need to actually develop methodologies by which you can predict or at least measure the setting of cement and concrete on site. This is important, obviously from the point of view of concreting operations you need to ensure that you are finishing your surface of the concrete much before the initial set happens because after that you really are not able to mold the concrete in the specific shape. Secondly you want to know the final set because beyond that point concrete dimensions are not going to change significantly so you can start removing the shutters which are on the sides for instance. So you have an obvious necessity for understanding the setting time of concrete from the perspective of planning your concrete operations.

So please remember concrete setting time is different from cement setting time. Why do I say this? Why should concrete be set at a different time than the cement? You are saying chemically the silica and the aggregates may affect the setting. How do you measure the setting time of cement? How do you make the cement or cement paste to determine the setting time? It is made with a certain water to cement ratio, you make it at your consistency level. In concrete your water to cement ratio could be anything else also depending on the strength of the concrete that you require. In concrete more often than not you will have chemical admixtures present. So all these will definitely affect your setting time. Cement testing is supposed to be done at a controlled temperature and relative humidity. On site concrete can be subjected to any kind of temperature humidity combination. So there is no way that cement setting time can exactly predict what the concrete setting time is going to be. It all depends on the concrete mix that is used and because of that you need to start measuring the concrete setting time which can be done quite easily with the help of a penetration resistance device.

So you take fresh concrete that is supplied to the field, sieve it through a 4.75 mm sieve, extract the mortar component out and just have these penetration needles that are actually inserted into the concrete at different time intervals to see the resistance to penetration of the concrete. So as concrete sets the resistance to penetration obviously increases that is what you do in Vicat apparatus also. You are basically using a needle to penetrate the concrete and you have an arbitrary check point where you define that this much resistance to penetration is enough to call it initial set or final set.

Hardened Concrete:

(Refer to slide time: 9:27)



So now just let us briefly look at hardened concrete. It is not going to be a very detailed discussion because it is quite simple to understand the basic properties of hardened concrete. The first and foremost characteristic is that concrete is excellent in compression but poor in tension. So we are really interested only in the compressive strength of the concrete. For all practical purposes for reinforced concrete members which are subjected to any kind of tension we believe that concrete in the tensile zone is weak in tension.

But how do we design reinforced concrete members like beams? There is no contribution to the tensile resistance by the concrete. We give all the contribution to the steel. So in essence concrete may as well be cracked in the tensile region. Now obviously if concrete is getting cracked then we have to worry about crack widths depending on the environmental service. We have to ensure that we select enough steel to ensure that the concrete cracking does not open up too much.

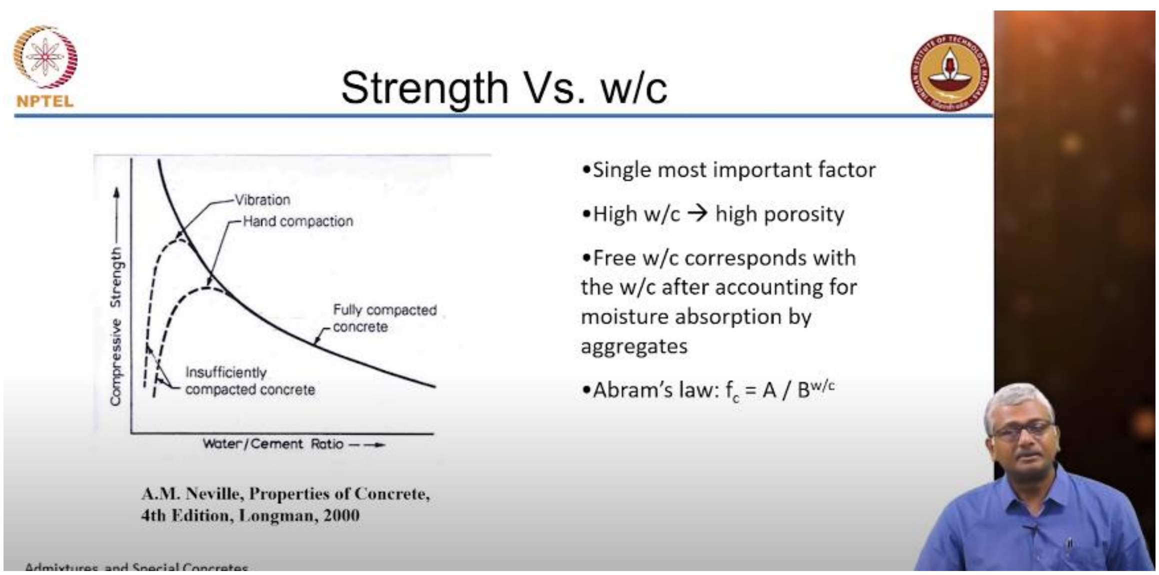
Now there are several different factors that affect compressive strength. It is not just the water to cement ratio although our fundamental principle of concrete design is based on the fact that strength is dependent on water to cement ratio. There are several other factors, cement content, type of aggregate, curing, age, ambient conditions and incidentally even the specimen geometry can dictate the compressive strength. That is why we say that strength is not a material property. Then what kind of a property is it? We want to test the concrete as a material and we say compressive strength is a performance parameter that we often call for in construction projects.

So what happens, why do not we say strength is a material property? What is a material property? Can you give me an example of a property of a material? Modulus of elasticity or young's modulus.

But strength is not, why do I say that? If you test the strength, if you do a tensile and compressive strength of concrete, will you get the same modulus of elasticity? Yes, concrete has to have the same modulus irrespective of the kind of test that you do on it. That is why we call it a material property. Strength on the other hand as I said it depends on so many factors including specimen geometry. So if you test a cube or a cylinder you get different strengths.

Strength Vs w/c

(Refer to slide time: 13:27)



So if you test a cube or a cylinder you get different strengths, why? Before that of course strength is also dependent a lot on the extent of compaction you can give to the concrete and of course that is determined by the extent of water to cement ratio that you have in your system. Depending on what kind of compaction you give either mechanical compaction by vibration or hand compaction you can get a different extent to which you can lower the water to cement ratio. So technically the lower the water to cement ratio the higher the strength but there is a limit to it because you cannot compact your specimen beyond a particular point. If the concrete has a water to cement ratio less than about 0.4 you will not be able to compact by hand. So at that limit your strength will start going down because the degree of compaction will not be enough to completely avoid all the porosity in the system or voids in the system. But with machine compaction with vibration now we have roller compaction, vibratory rollers all kinds of things are present so you can actually take the theoretical lower limit of water to cement ratio down significantly.

Abrams law named after the scientist says that as the water to cement ratio increases the strength decreases. He proposed a power relationship but it need not be always true of the concrete that you are testing you can also have a linearly decreasing relationship. You can have a quadratically decreasing relationship; it doesn't really matter. This is some sort of an arbitrary relationship that is defined; you do not have to keep fitting curves between strength and water cement ratio using this Abrams law.

$$\text{Abram's law: } f_c = A / B^{w/c}$$

Now this water cement ratio is often called free water to cement ratio which is the extent of water available in your concrete after you account for all the absorption by the aggregates.

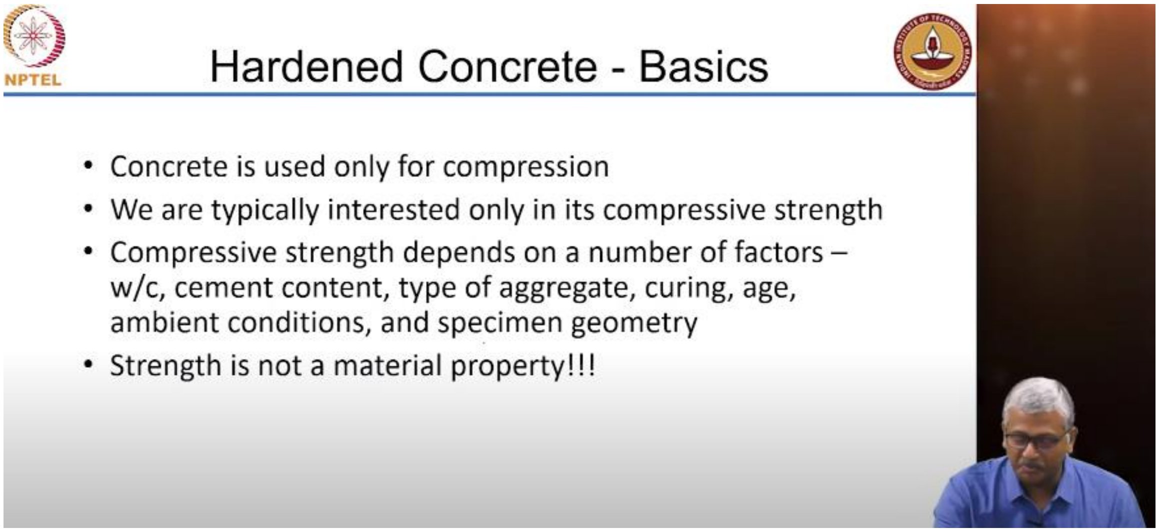
How much is the water absorption of natural aggregate typically? Like granite or limestone aggregate what would be the extent of water absorption you think? 1% or less around 0.5 to 1% is more typical, even less than that for coarse aggregate. For fine aggregate you may have up to 1% if you have river sand.

If you have crushed sand if you make sand by crushing coarse aggregate is the water absorption would be higher or lower? It will generally be higher because when you crush you produce a lot more fines in the system and because of the silt size particles the extent of water uptake by the sand can be significantly high.

If you go to Mumbai for instance your water absorption can be as high as 6 to 7% which makes concrete very difficult to actually properly design unless you are doing water content measurements from time to time. So it depends obviously on the extent of moisture absorption which is dependent on the type of aggregate that you are using.

Specimen geometry:

(Refer to slide time: 17:22)



You test a cube and you test a cylinder you get different strengths. Why?

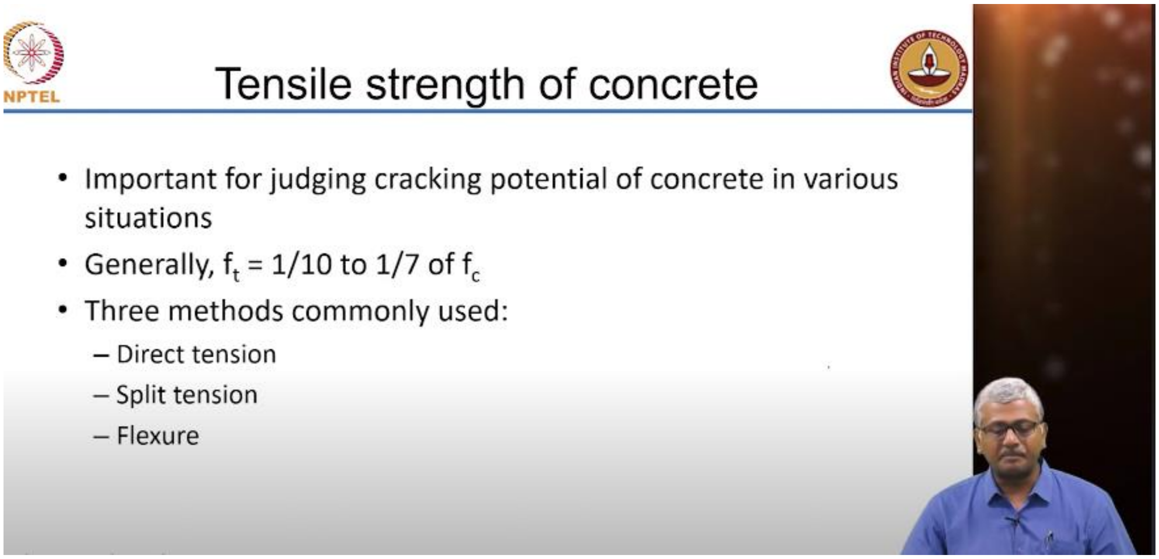
Slenderness is only a problem if your length to diameter ratio increases significantly. What did you learn in structural engineering? At what L by D is slenderness a real problem? L by D should not be more than slenderness 12. Typically its 2 i.e. 150 mm diameter and 300 mm height or 100 by 200 mm.

Why does the cylinder then produce less strength than concrete? You have a confinement effect of the end platens. You have the platens between which your specimen is getting loaded. If the specimen height or length of the specimen is not too much more than the width, then the confinement effect is felt throughout the length of the specimen and that confines the specimen from bulging outwards and cracking.

So how does concrete fail when you compress? It bulges outwards and cracks. Rather than crushing it bulges outwards and cracks and that bulges outwards because of the tensile capacity in the lateral direction getting exceeded. So when you have confinement because of the frictional effect of the platens it restrains that bulging outwards and because of which you end up with higher strength in the cube because L by D effective L by D in a cube is 1, cylinder is 2. Because of that you do not get any pure compression in the cube.

Tensile Strength of concrete:

(Refer to slide time: 19:18)



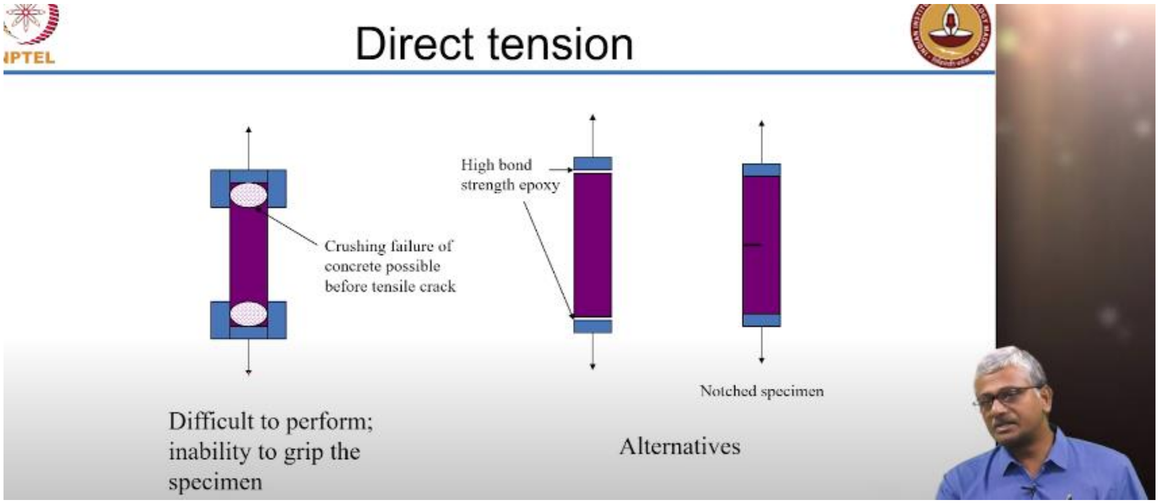
It is only in some cases that we actually go and test the tensile strength. For instance when we have concrete pavements the flexural strength is often a performance parameter required to judge the performance of pavements. Rather than compressive strength pavements, concrete pavements rely on the value of concrete flexural strength. So it is important obviously to judge how the concrete is going to behave in flexure and sometimes even the cracking potential needs to be judged. For instance when you have a case of thermal expansion or contraction in the concrete that is obviously going to lead to tensile stresses in the concrete. You want to know at what tensile stresses concrete failures are likely to occur. As generally as a thumb rule the tensile strength is around $1/10^{th}$ compressive strength. When you test it in flexure it is probably about $1/7^{th}$.

So let us say you have a 30 MPa concrete in compression, the tensile strength will be or flexural strength will be around 4 MPa. If you do a split tension test when you use a cylinder to test the split tension you will get even lower strength than that typically around 3 MPa. To measure strength we have 3 methods.

- Direct tension
- Split tension
- Flexure

Direct Tension:

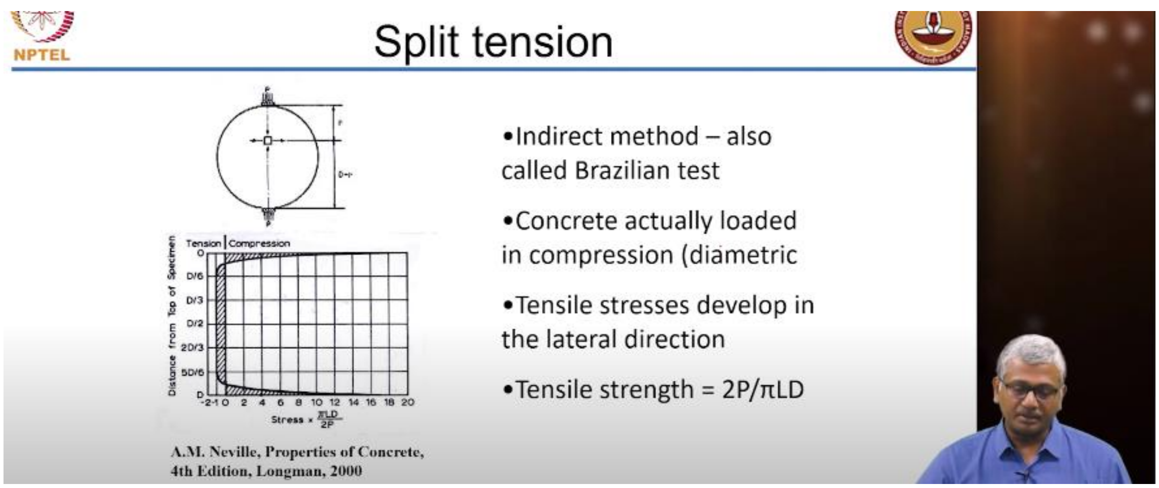
(Refer to slide time: 20:58)



Direct tension is not that easy to perform because concrete specimens have to be at least three times the size of the aggregate. If you are using 20 mm aggregate you should use at least a 60 to 75 mm size specimen. Such a specimen if you try to grip at the ends that may lead to a failure of the concrete by crushing at the ends rather than the tensile failure of the concrete itself. So you may want to sometimes use a high bond strength epoxy at the ends to pull off the concrete but if your epoxy is not strong the failure will happen at the epoxy and you will not really have any failure in the concrete. The other thing is to have a notch but then again you are not testing a true tensile strength of the concrete you are actually testing its crack propagation ability. It is not exactly tensile strength, you have other factors at play there also, the sharpness of the notch and so on and so forth.

Split Tension:

(Refer to slide time: 21:51)

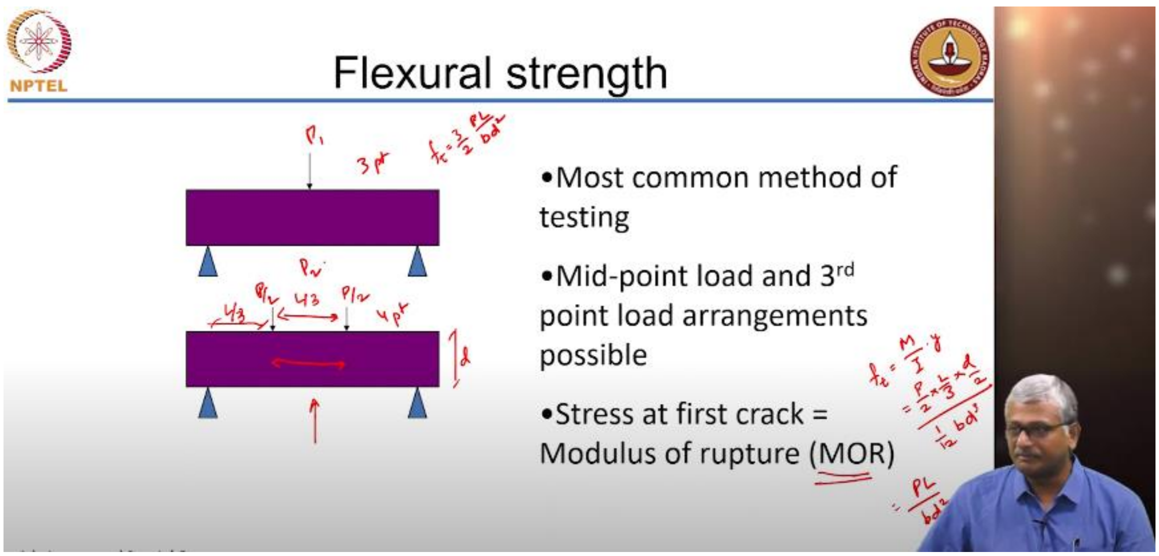


Split tension is a very neat way to test tensile resistance of concrete. It is an indirect tension test because we are not really applying a tensile load, we are only applying a compressive load diametrically to the cylinder and when we do a load application, the zone which is in most part of the cylinder is subjected to actually a constant tensile stress and because of the kind of geometry we adopt and the line load that we give we can actually test the tensile strength fairly easily using this equation.

$$\text{Tensile strength} = 2P/\pi LD$$

Flexural Strength:

(Refer to slide time: 26:04)



Flexural strength of course is done in two different modes typically a midpoint loading or a third point loading mode. Sometimes it is called a 3 point or a 4 point test depending on where you are and what type of connotation they use for the different tests

What is the advantage of choosing the third point loading? You have a zone in the center where there is no shear; it is perfectly pure bending. You are actually getting a true flexural response of the concrete. So when the first crack appears you call it the modulus of rupture, (MOR). The flexural strength of the first crack is termed as modulus of rupture. How do you calculate the flexural strength? What is the beam bending formula?

$$\mathbf{M / I = \sigma / y = E / R\ i}$$

So here, $M = PL/6$, $Y = d/2$, $I = 1/12(b/d^3)$

$$\sigma = PL/bd^2 \text{ ....For 3 point loading}$$

$$\sigma = 1.5PL/bd^2 \text{ ....For mid-point loading}$$

So does this mean that the strength in the two tests is different or the modulus of rupture is different? It cannot be, so where are we going wrong?

This is P_1 and this is P_2. You are getting the crack at different loads. So depending on which way you do the test you will get different loads and when you do the calculation you will get approximately a similar value for the modulus of rupture. There may be some differences because of the presence of some shear because only at exactly at the center here you do not have any shear. So if your crack is exactly at the center then you have an infinitesimally small zone of pure bending otherwise you will have the effect of shear also.