PRESTRESSED CONCRETE STRUCTURES

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Module – 01: Introduction, Prestressing Systems and Material Properties

Lecture – 05: Concrete (Part - 1)

Welcome back to Prestressed Concrete Structures. Today, we shall be covering the fifth lecture of the first module on Introduction, Prestressing Systems and Material Properties.

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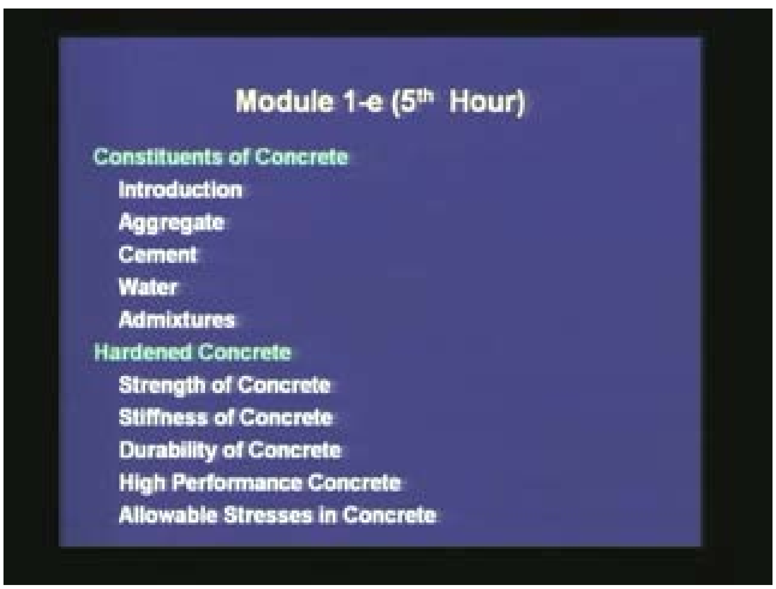

In this lecture, we shall first cover the constituents of concrete: aggregate, cement, water, and admixtures. Then, we shall cover the properties of hardened concrete: strength of concrete, stiffness of concrete, durability of concrete, high performance concrete and the allowable stresses in concrete.

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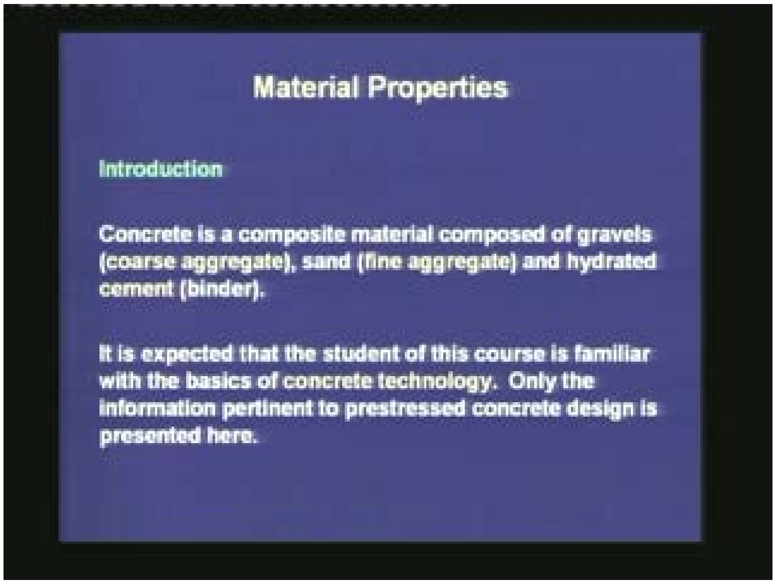

Concrete is a composite material composed of gravels which are the coarse aggregates, sand which is the fine aggregates and hydrated cement which is the binder. It is expected that the student of this course is familiar with the basics of concrete technology. Only the information pertinent to prestressed concrete design is presented here. All of you should have undergone a course in concrete technology, which has been used in reinforced concrete design. Hence, the discussions of today will be more of a review in nature, rather than going into the details.

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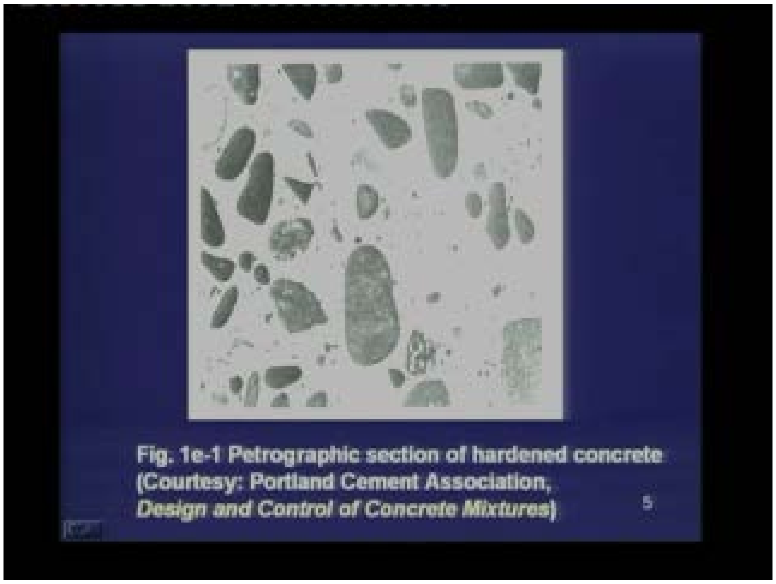

This is a petrographic section of hardened concrete. You can see that the concrete itself is a composite material, consisting of these large coarse aggregates. The space between the coarse aggregates is filled up by the fine aggregates and the hydrated cement paste. Although the concrete is a heterogeneous material, it is treated as a statistically homogeneous material for the purpose of design.

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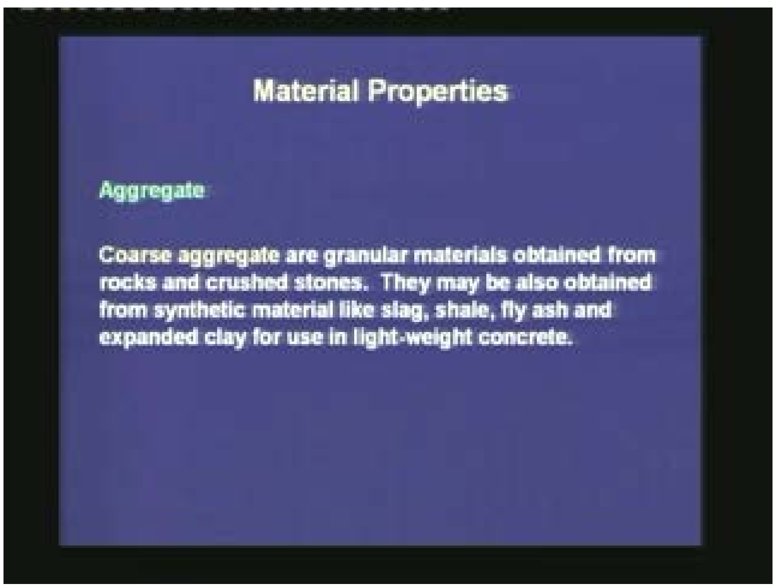

Now, the first constituent, the coarse aggregates are granular materials obtained from rocks and crushed stones. They may also be obtained from synthetic materials like slag, shale, fly ash and expanded clay for use in lightweight concrete.

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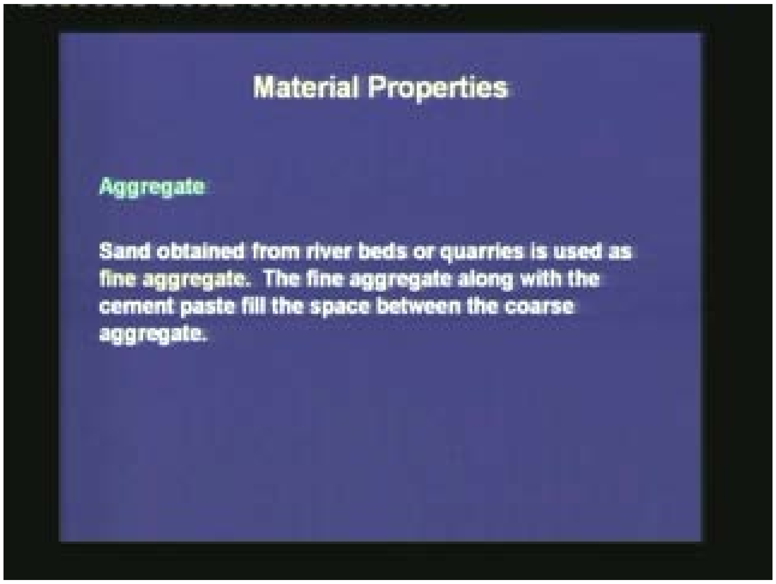

The coarse aggregate is the basic constituent of the concrete, because it covers the maximum volume within the concrete. The next constituent is the fine aggregate. The sand obtained from riverbeds or quarries is used as ‘fine aggregate’. The fine aggregate along with the cement paste fill the space between the coarse aggregates.

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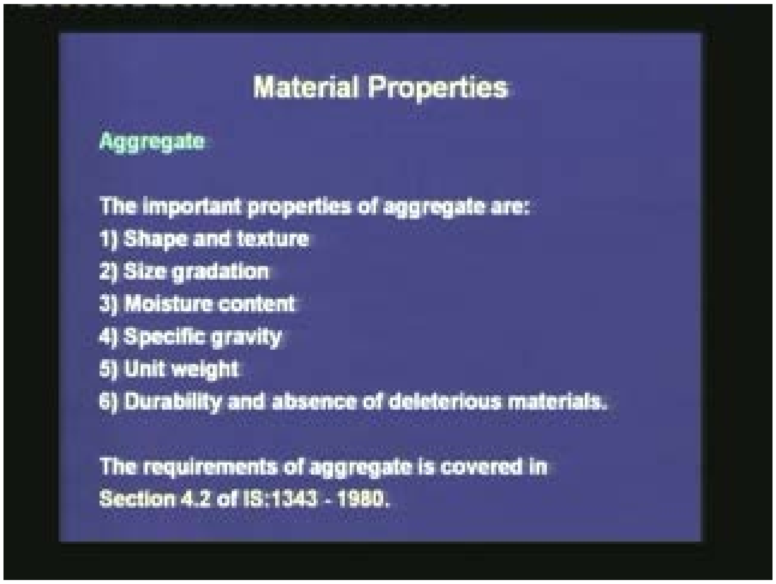

The important properties of aggregates are the shape and texture, size gradation, moisture content, specific gravity, unit weight, durability and absence of deleterious materials. Most of these properties are covered in detail in a course on concrete technology. There are some requirements of aggregate in Section 4.2 of the code IS: 1343.

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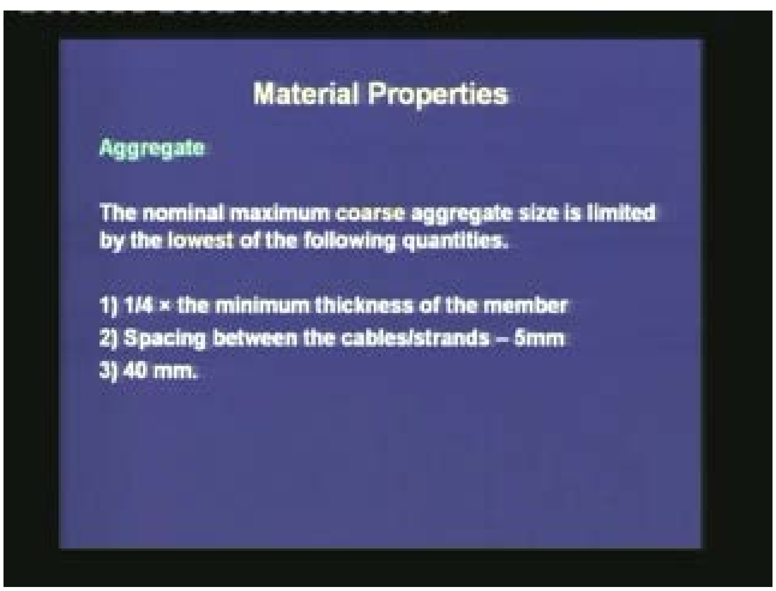

The code allows us to use aggregates within a nominal maximum size. The nominal maximum coarse aggregate size is limited by the lowest of the following quantities. First, it is a quarter of the minimum thickness of the member; second, the spacing between the cables or strands minus 5 mm, and third 40 mm. The purpose of restricting the maximum aggregate size is that, the concrete should be able to flow properly within the member during the casting. If the concrete is not able to flow properly, then it creates honeycombs, and as you remember that the prestressed concrete is subjected to stresses even before the service loads act on it. If there is honeycomb and if the quality of concrete is not good, then the prestressed member will not be able to sustain the prestress itself.

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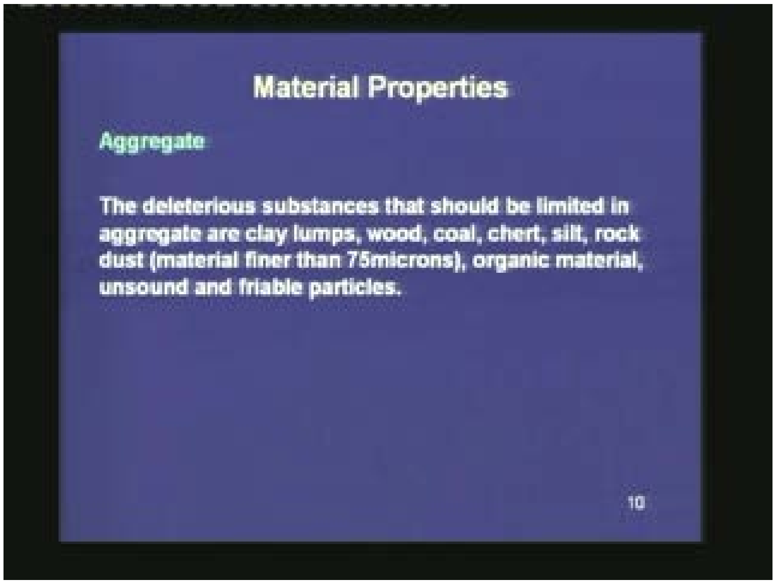

The code says that the coarse aggregate should be free of deleterious substances like clay lumps, wood, coal, chert, silt, rock dust, organic materials, unsound and friable particles. These types of materials reduce the bond between the coarse aggregate and the cement paste. They may also lead to the corrosion of steel, if those deleterious materials are corrosive in nature.

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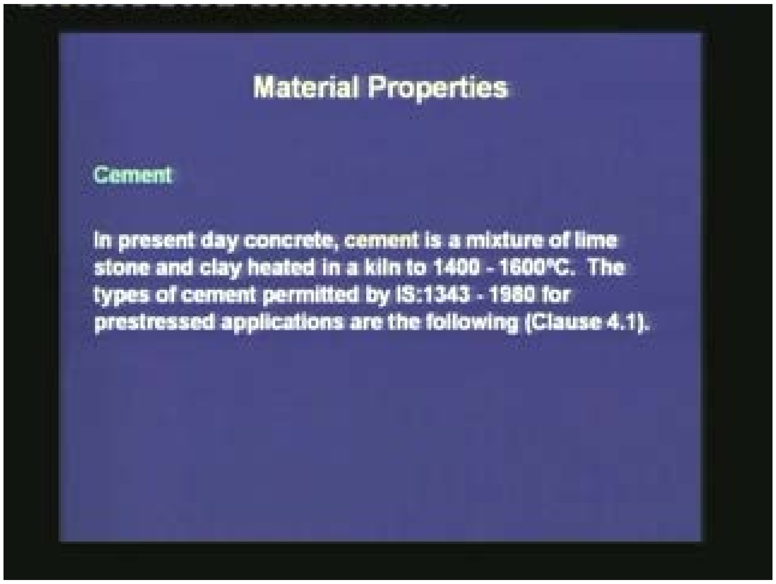

The third constituent of concrete is the cement. In present day concrete, the cement is a mixture of limestone and clay, heated in a kiln to 1400 to 1600ºC. The manufacturing of cement is a subject by itself, and it is one of the important inventions in the development of reinforced concrete. The type of cement that is permitted by the code IS: 1343 for prestressed applications are the following. This is given in Clause 4.1.

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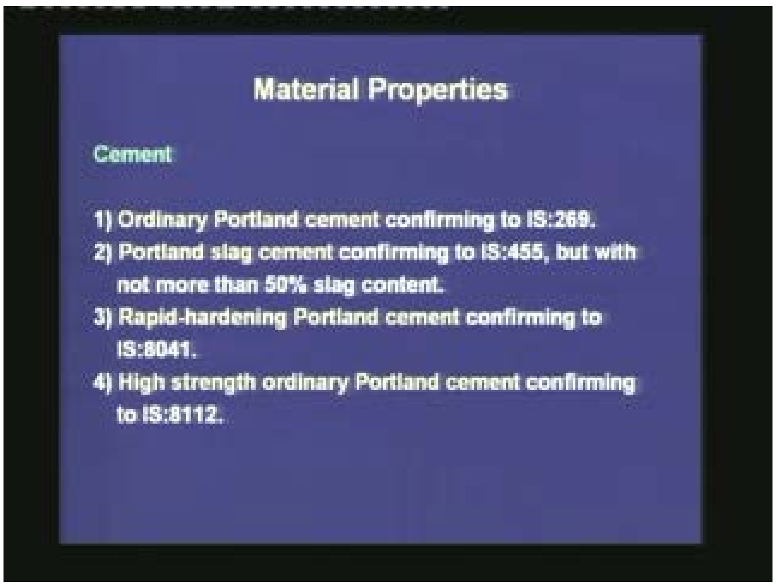

The most common type of cement is the 'ordinary Portland cement' which should confirm to IS: 269. The second type is the Portland slag cement, conforming to IS: 455, but with not more than 50% slag content. Slag is the by-product of steel production. This is used in the manufacturing of cement and that type of cement is called 'Portland slag cement'. The third type of cement is the 'Rapid-hardening Portland cement', confirming to IS: 8041. If there is pressure in the work schedule for producing prestressed members quickly, then the rapid hardening cement can be used, which gains strength quickly and the prestress can be transferred earlier. The fourth type of cement which is allowed is the 'high strength ordinary Portland cement', conforming to IS: 8112. This type of cement gains high strength, which gives higher strength concrete.

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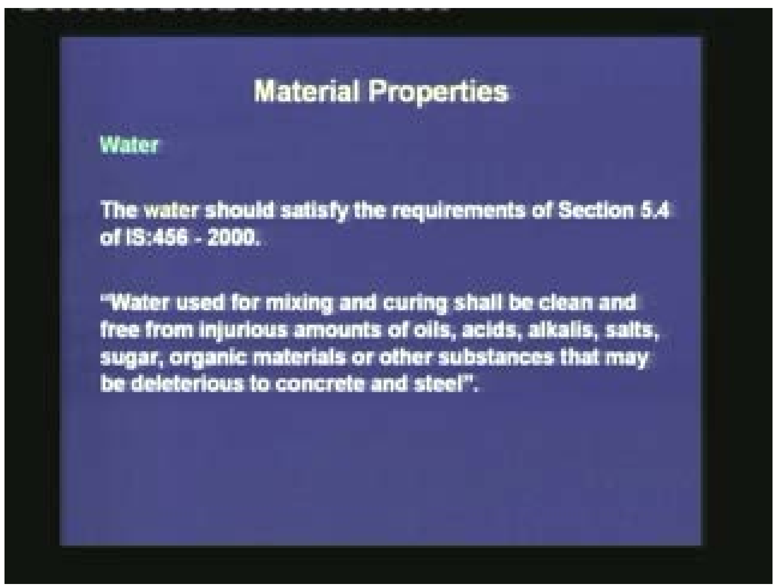

The three constituents, the coarse aggregates, fine aggregates and cement are mixed in a rotating drum and then, water is added. The water should satisfy the requirements of Section 5.4 of IS: 456 - 2000. The code clearly states that the water used for mixing and curing shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete and steel. Potable water is accepted for constructing concrete. The bottom line is that there should not be any deleterious material, which may reduce the bond and hydration of the cement, and also which may affect the corrosion of the steel reinforcement.

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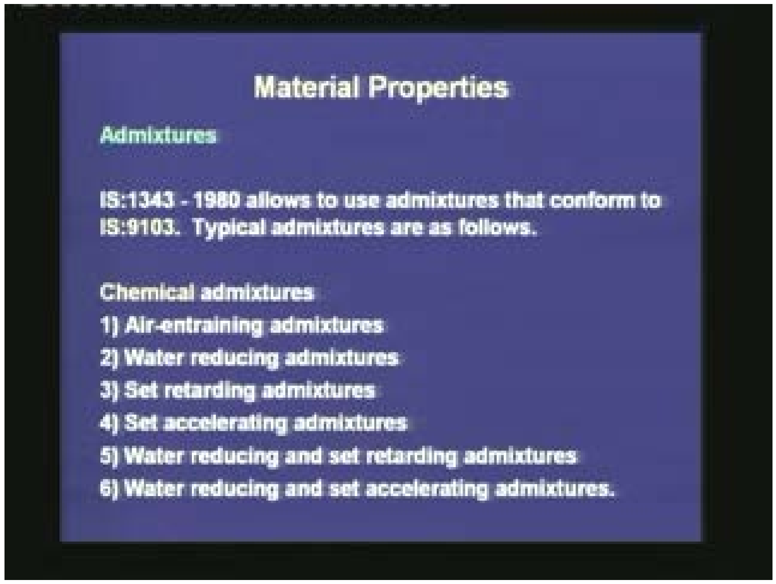

In addition to these four constituents, some admixtures may be added to concrete. IS: 1343 allows using admixtures that confirm to IS: 9103. The admixtures are broadly classified under two groups. The first group is the ‘chemical admixtures’. The different types of chemical admixtures are: air-entraining admixtures, which help to have small air bubbles inside the concrete; the second is water reducing admixtures, which help to reduce the water while maintaining the slump of the green concrete; the third is set retarding admixtures, which are used to elongate the setting time of the concrete; the fourth is the set accelerating admixtures, which accelerate the setting of the concrete; the fifth is a combination of two of the earlier types of admixtures − water reducing and set retarding admixtures; and the sixth is water reducing and set accelerating admixtures.

These admixtures are selected based on the specific need of the structure and the construction. Usually, catalogues are available with the suppliers of these admixtures. Specifications of how to use them, and what is the dosage of these admixtures are provided in these catalogues. The catalogues should be maintained while manufacturing the concrete.

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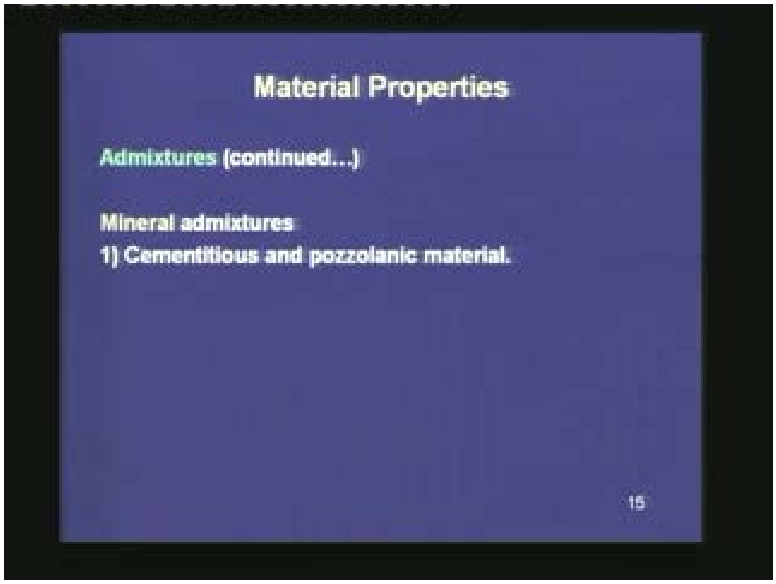

The other type of admixtures is the mineral admixture. The mineral admixtures can be cementitious and pozzolanic material. An example is fly ash. These types of admixtures are used to have some more cementitious material other than the cement, and also to utilise an industrial by-product.

Next, we are moving on to the properties of hardened concrete. In this course, we are not covering the properties of green concrete, because it is expected that the students are familiar with those properties. It is the properties of hardened concrete that influence the strength and the performance of a prestressed concrete member.

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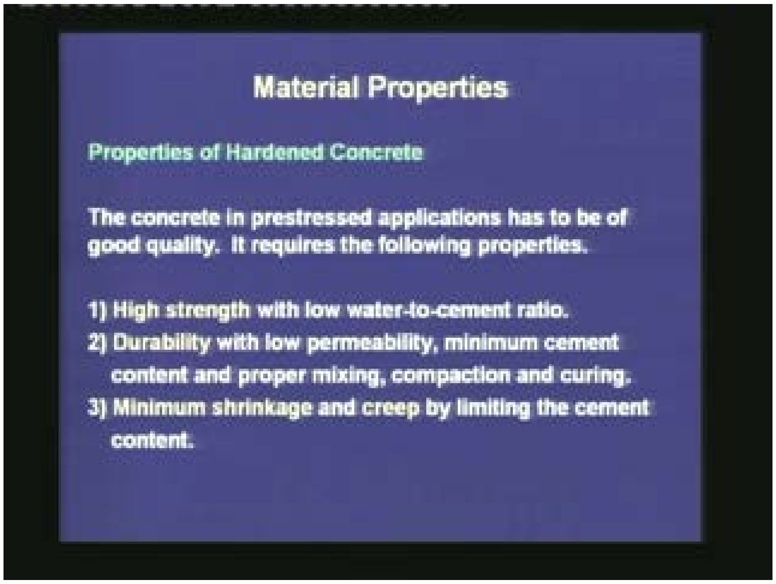

The concrete in prestressed applications has to be of good quality. This is a very important statement, because in prestressed concrete, the concrete is subjected to compression after the transfer of prestress. The concrete requires the following properties: first, high strength with low water-to-cement ratio – this is the primary requirement of concrete in prestressed structures that it has to be of high strength. That is why the code has a limitation on the minimum strength of the concrete, which we shall come to later.

The second is the durability with low permeability, minimum cement content and proper mixing, compaction and curing. At present, durability of concrete is being emphasized. It has been seen that the constructed structures are aging; repairing and rehabilitating those structures are very costly. Hence, importance is given to the durability of concrete. The durability involves some properties, out of which low permeability is the most important. If the concrete has low permeability, then the ingredients of water can be checked. The third property of concrete that is required in the prestressed applications is the minimum shrinkage and creep, by limiting the cement content. We learnt earlier that there is a loss of prestress over time, due to the compression of concrete due to shrinkage and creep. We have to have concrete, which has less shrinkage and creep, so as to reduce the loss in the prestress.

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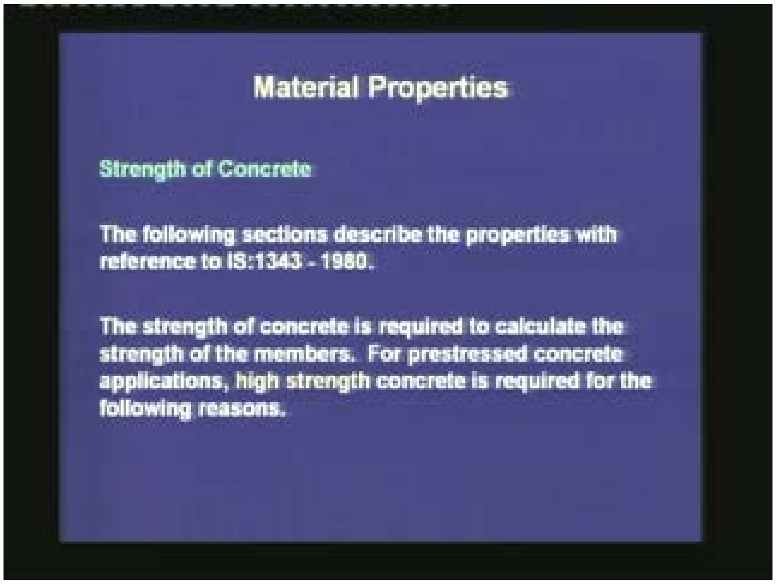

The following sections describe the properties of hardened concrete with reference to IS: 1343. The strength of concrete is required to calculate the strength of the members. For prestressed concrete applications, high strength concrete is required for the following reasons.

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Out of the properties of concrete in prestressed concrete analysis and design, strength is the foremost property that we need. We need high strength concrete for the following reasons. First is to sustain high stresses at anchorage regions. Last time we saw, that the concrete which is just adjacent to the anchorage block is subjected to high stress concentration. In order to sustain the high stresses, we need high strength concrete. The second reason is, to have high resistance in compression, tension, shear and bond. The forces in prestressed concrete can be substantially high and for that, we need high strength concrete. The third reason is, to have higher stiffness for reduced deflection. Usually, high strength concrete has also higher stiffness, which means we shall have lower deflection in the members.

Finally, a concrete which is subjected to less shrinkage will have reduced shrinkage cracks. Shrinkage cracks occur due to the restraint of the shrinkage. Since the restraints cannot be avoided, it is always advisable to have minimum shrinkage concrete so as to reduce the cracking due to shrinkage.

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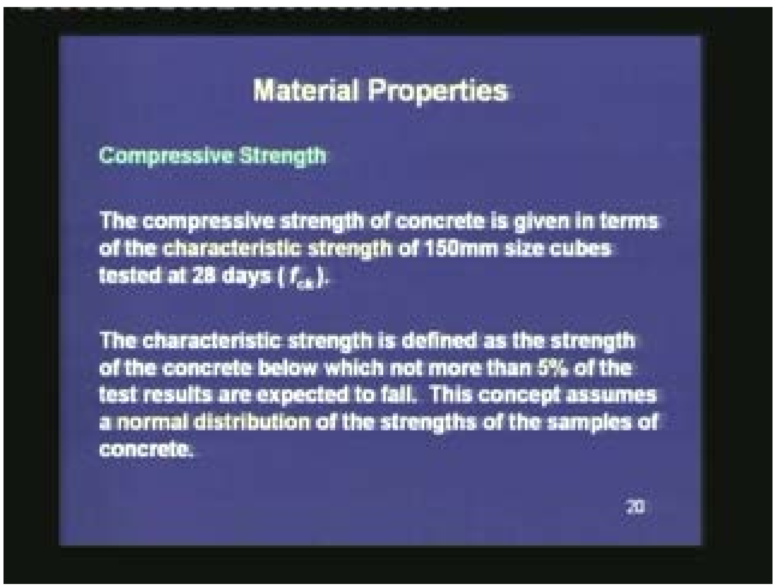

How do we quantify the strength of concrete? We all know that the strength of concrete increases with time. Most of the gain in strength occurs in the first four weeks, and gradually the gain tapers off. The compressive strength of concrete is given in terms of the characteristic strength of 150 mm size cubes tested at 28 days. This strength, which is a standardised measure of the compressive strength of concrete, is called the characteristic strength. This is denoted as f_{ck}.

The characteristic strength is defined as the strength of the concrete below which not more than 5% of the test results are expected to fall. This concept assumes a normal distribution of the strengths of the samples of concrete.

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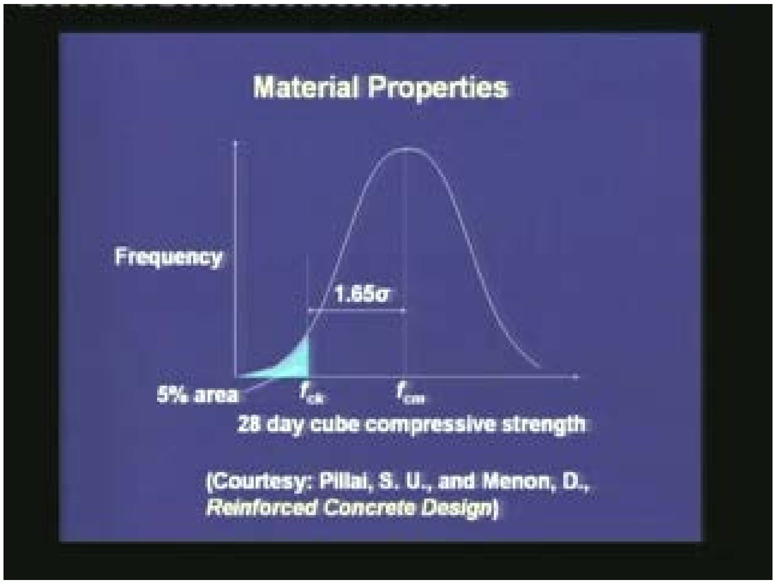

This sketch will help you to understand the meaning of the characteristic strength. If we sample several cubes, then it is expected that the strength of the cubes will fall into a normal distribution curve. On the horizontal axis, we are plotting the 28-day cube compressive strength. On the vertical axis, we are plotting the frequency or the number of samples for a given particular strength. The mean of this distribution is called the 'mean compressive strength', which is denoted at $f_{cm.}$ The characteristic strength is defined as the value below which only 5% of the test results will fall. This characteristic strength is lower than the mean strength by a value of 1.65 times the standard deviation of this distribution.

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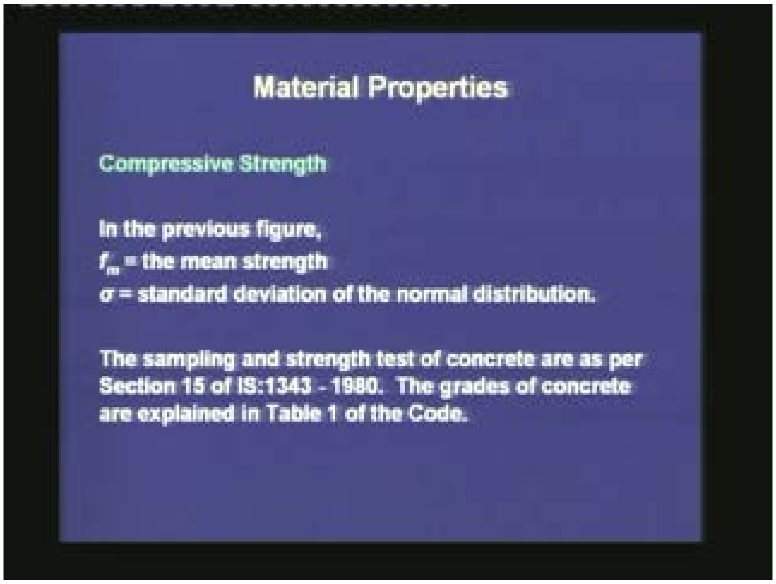

Instead of going into the details, the code gives us some simple guidelines for sampling and testing concrete. These guidelines are given in Section 15 of IS: 1343. Based on the strength of concrete, concrete is divided into several grades. The grades of concrete are given in Table 1 of the code.

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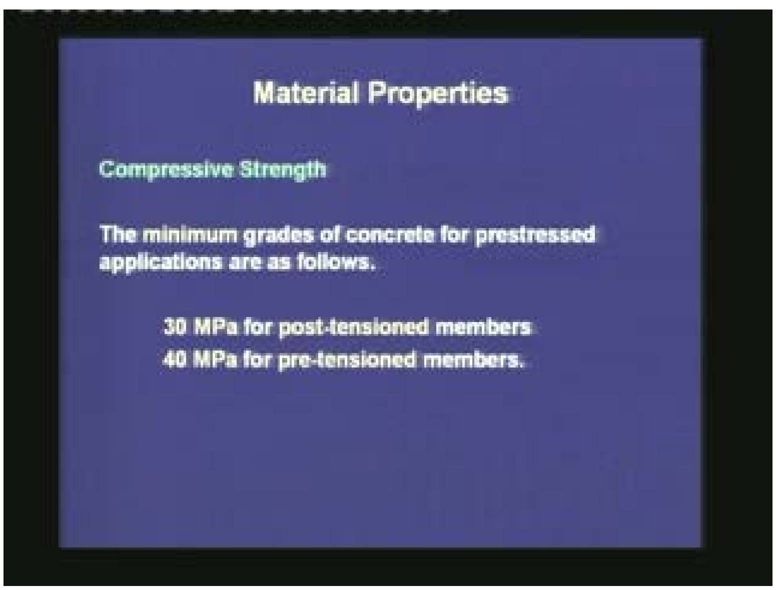

The minimum grades that the code allows for prestressed concrete applications are: 30 MPa for post-tensioned concrete and 40 MPa for pre-tensioned concrete. As we had seen while understanding pre-tensioned members, there is an obligation of applying the prestress at an early age, so as to remove the specimens from the prestressing bed. Since the prestress is applied at a relatively earlier age, the code specifies a higher minimum strength for pre-tensioned members; whereas, for a post-tensioned member, usually the transfer of prestress is after substantial amount of curing and hardening. Hence, the code allows us a lower minimum strength for post-tensioned members.

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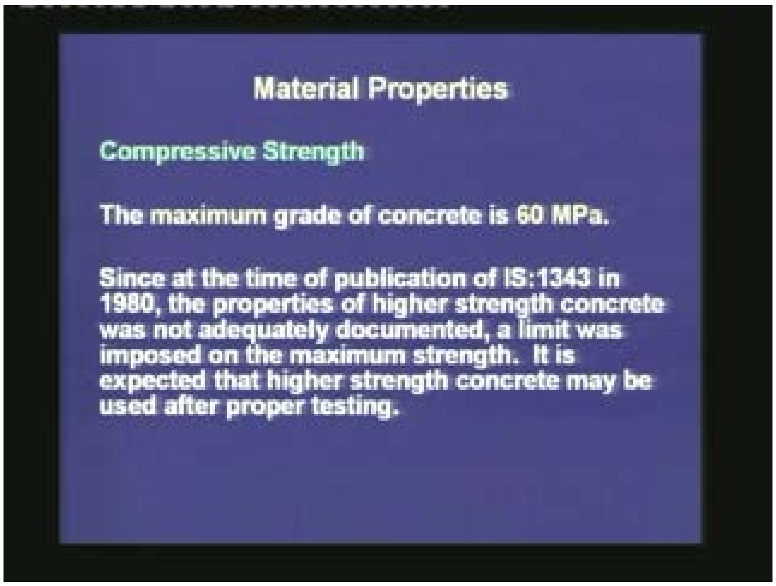

The code also gives us a maximum limit of the grade of concrete, that is, 60 MPa. This provision of maximum grade was imposed because when the code was written in 1980, the properties of high strength concrete were not adequately documented. Over these two and a half decades, high strength concrete has been studied. It is also expected that high strength concrete may be used for prestressed applications after proper testing. We have to be careful that the high strength concrete should meet the minimum requirements for prestressed applications. It should not have high shrinkage, the heat of hydration should not be excessive, and also it should not be brittle. If a high strength concrete satisfies these requirements, then it can be used for the prestressed applications.

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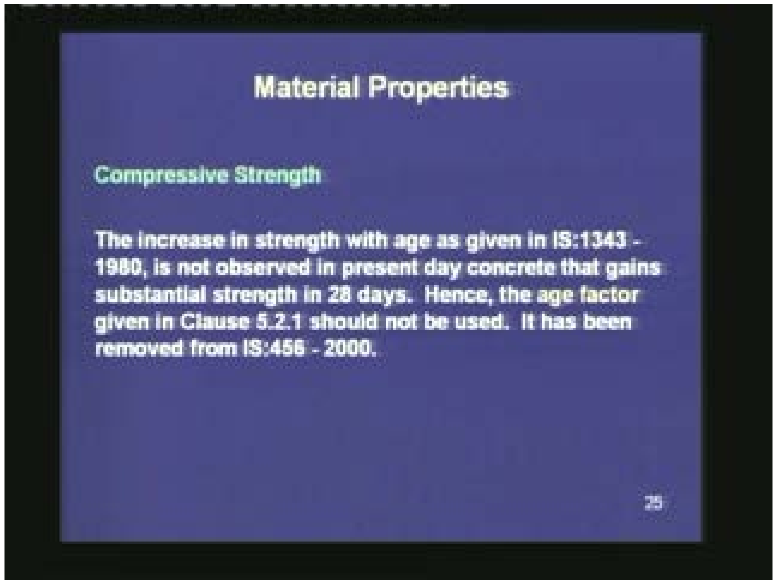

In the code, there is a provision of the increase in strength with age, but this provision is not observed in the present day concrete; in the present day concrete, the cement gains strength early and it does not increase in strength much beyond 28 days. Hence, this age factor which is given in Clause 5.2.1 in the code should not be used. In fact, this age factor has been removed from the latest version of IS: 456.

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Next, we come to the tensile strength of concrete. The tensile strength of concrete can be expressed by either the flexural tensile strength or the splitting tensile strength. The flexural tensile strength is measured by testing beams under 2-point loading. Sometimes, the 2-point loading is also called as a 4-point loading by considering the reactions. This is a simple test, where the beam is subjected to a uniform moment over a certain region. Let me explain this by a sketch.

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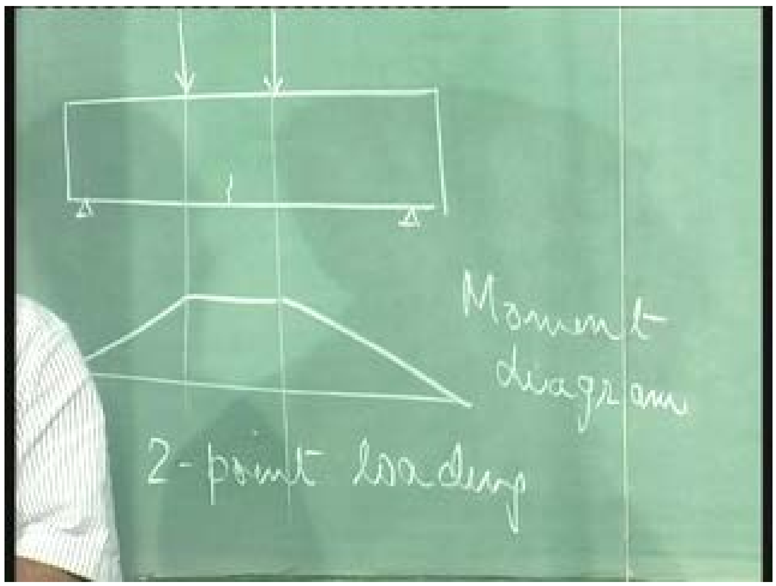

In a 2-point loading, a simply supported beam is subjected to two equal loads in the middle such that the bending moment is constant over the central region. As the load is increased for a plain concrete beam, there will be a crack at a certain location in the middle third region. The load corresponding to the initiation of the crack will give us the maximum stress that is occurring at the bottom, and that value is called the 'flexural tensile strength'. The second type of test that is used is the 'splitting tensile strength'.

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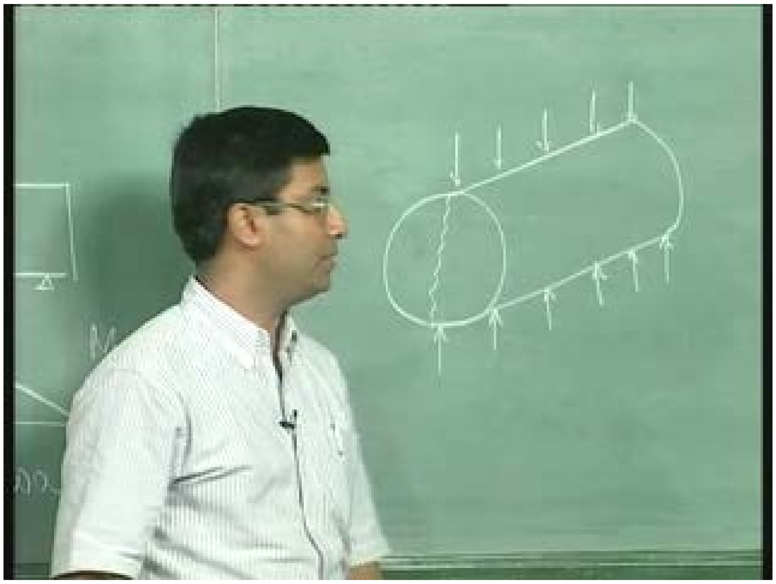

In a splitting tensile strength, a cylinder is laid horizontally and it is applied with a vertical load through its meridian. At a certain time after the load is increased, it splits along the vertical direction and the load corresponding to this splitting gives the splitting tensile strength. Both these tests are covered in detail in the concrete technology course. Hopefully, you should be aware of both these tests.

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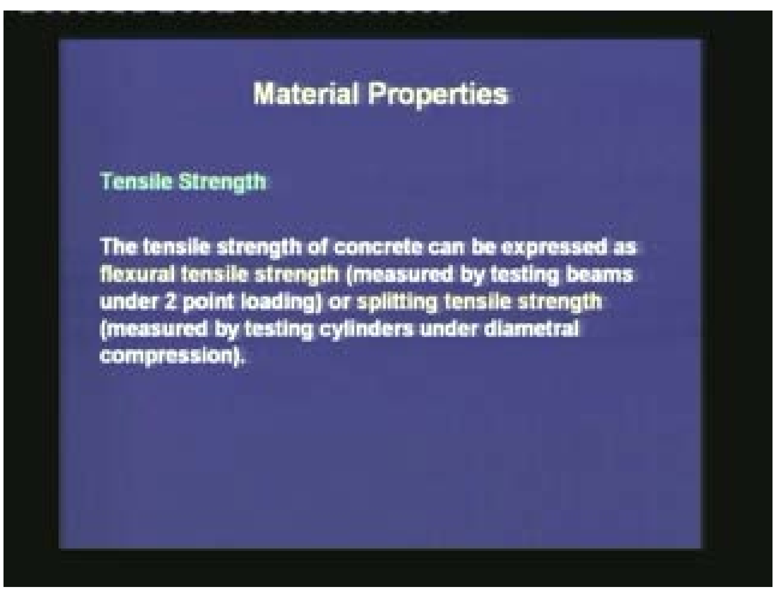

These two tests, the flexural tensile strength and the splitting tensile strength tests are easy to perform. There is a third type of test for calculating the tensile strength of concrete, that is, the ‘direct tensile strength test’. This test is more difficult to perform, but still, they are done for research purposes.

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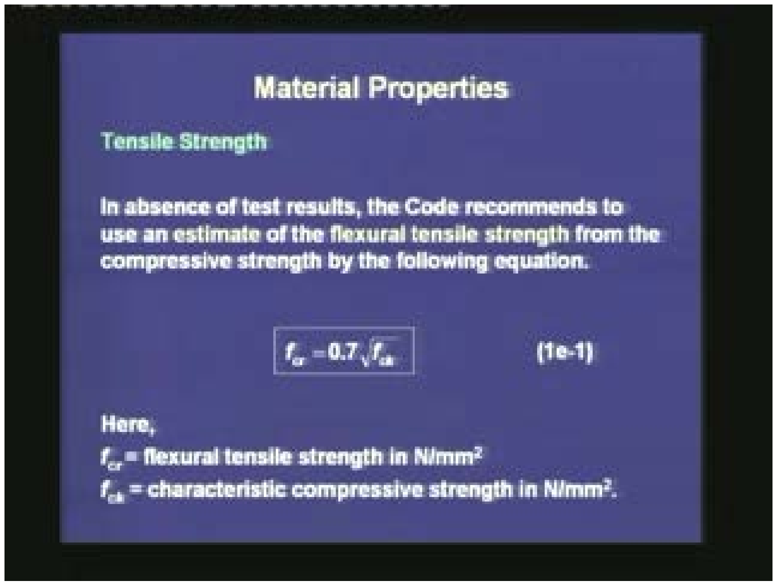

The code says that in absence of any test results, we can estimate the flexural tensile strength from the compressive strength by this following equation. The compressive strength is a more common test for concrete. If we are not able to perform anyone of the tensile strengths, then the flexural tensile strength which we need most of the time in our calculations can be calculated by this expression. Here, f_{cr} is the flexural tensile strength expressed in N/mm^2. It is given as $0.7\sqrt{f_{ck}}$, where f_{ck} is the characteristic compressive strength in N/mm^2.

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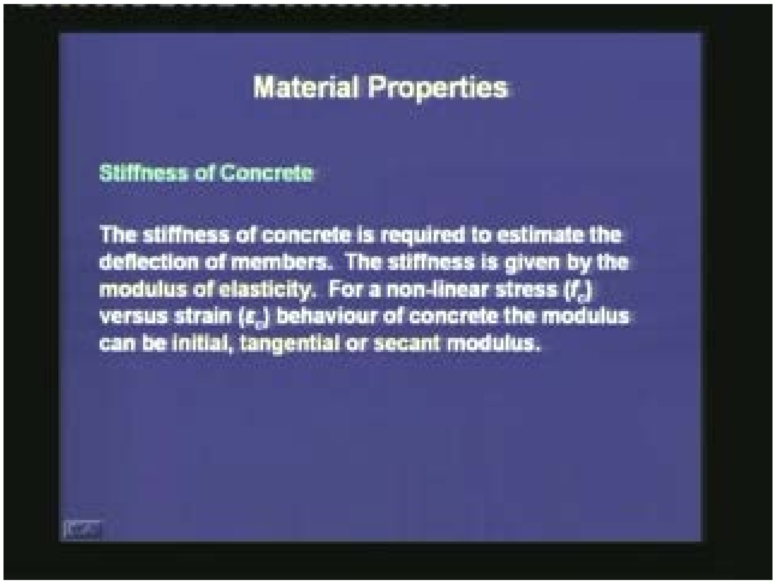

We move on to the stiffness of concrete. The stiffness of concrete is required to estimate the deflection of members. We expect that the prestressed concrete members should have reduced deflections, because of the upward thrust due to a curved profile. But, there may be a situation that since the prestressed concrete member is shallow, deflection can be of concern. At that time, deflections are calculated specifically, and we need stiffness of concrete to estimate these deflections. The stiffness is influenced by the modulus of elasticity. For a non-linear stress versus strain behavior of concrete, the modulus can be initial, tangential or secant.

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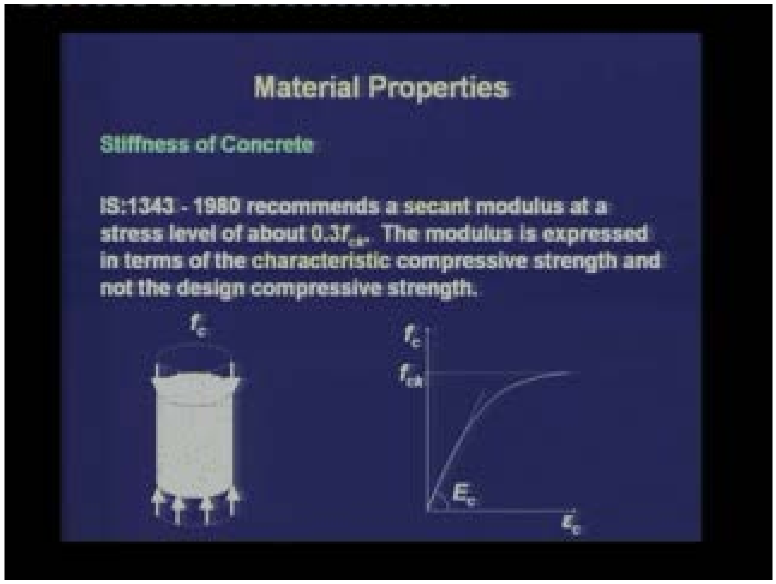

Let me explain these three types of modulus by the stress-strain curve of a cylinder under compression.

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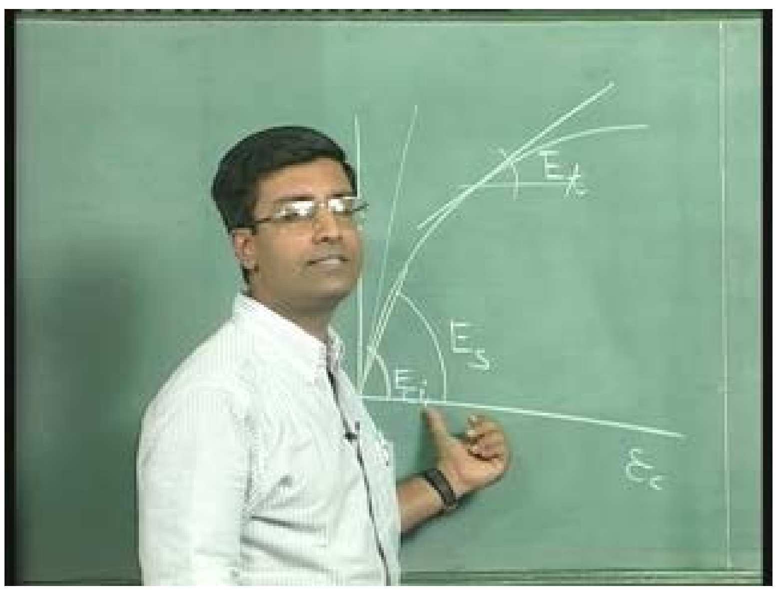

Since the stress-strain curve of concrete under compression is non-linear, we can define three types of modulus for this curve. The first one is the initial tangent modulus, which is also called in short as the initial modulus. The second one is a secant modulus for a particular level of stress, where we draw a line from the origin to the particular point in the stress-strain curve. The third is the tangent modulus, where we draw a tangent to the stress-strain curve at a particular level of stress. These are the three types of modulus which can be defined for a non-linear stress-strain curve of concrete.

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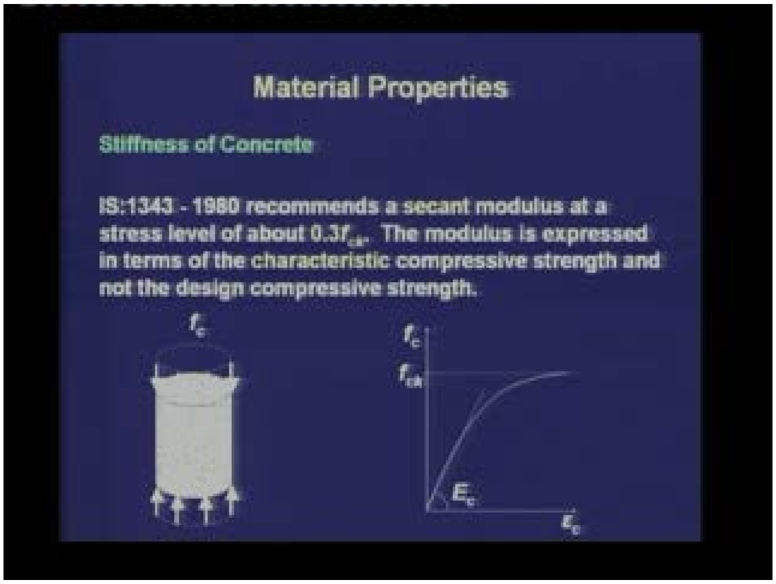

IS: 1343 recommends a secant modulus at a stress level of about $0.3f_{ck}$. The modulus is expressed in terms of the characteristic compressive strength and not the design compressive strength. I will explain this statement later, but let us try to understand the definition of the modulus of concrete as defined by the code. For a cylinder, when we test under compressive stress, we get the non-linear stress-strain curve. Then, the modulus of concrete as per the code is defined for a stress level of $0.3f_{ck}$ and it is in fact, a secant modulus of the stress-strain curve.

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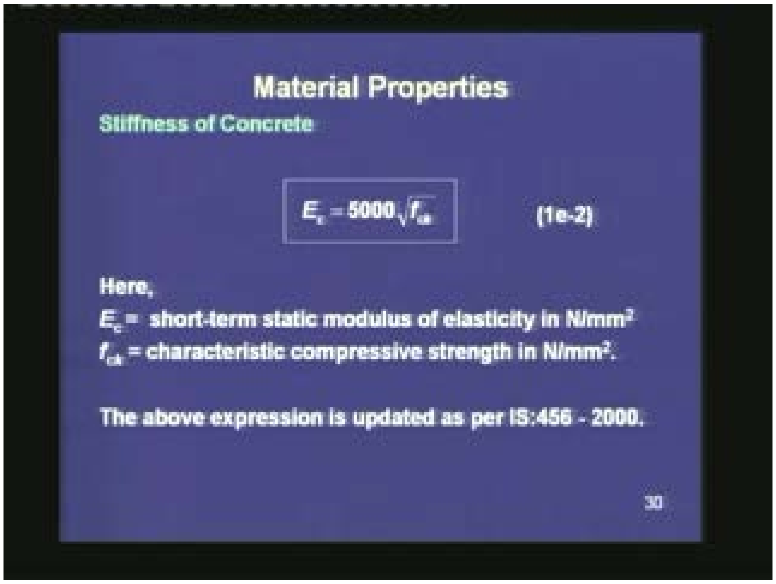

The modulus can be expressed in terms of the characteristic strength by this expression: $E_c = 5000\sqrt{f_{ck}}$, where E_c is the short term static modulus of elasticity and f_{ck} is the characteristic compressive strength, both in N/mm^2. Remember that, here, we are using the characteristic strength. We do not use any material safety factor for the strength in order to calculate the stiffness. This stiffness is the short term stiffness; that means, it does not consider any effect due to creep. This expression is an updated expression from IS: 456 - 2000. When IS: 1343 was published in 1980, an older form of this equation was used. But it is expected that in a newer version of IS: 1343, the expression will be same as that in IS: 456 – 2000.

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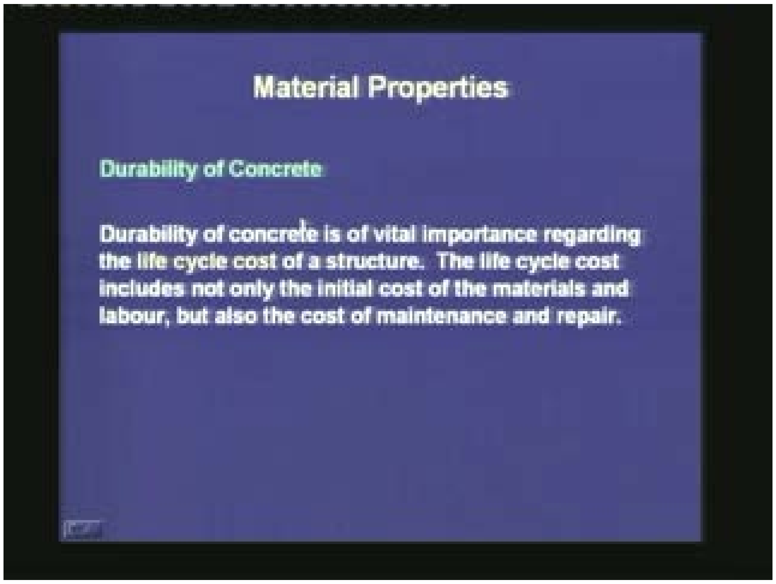

We move on to the durability of concrete. The durability of concrete is of vital importance regarding the life cycle cost of a structure. The life cycle cost includes not only the initial cost of the materials and labour, but also the cost of maintenance and repair. As I had said before, that at present more emphasis is being laid on durability of concrete. Since the aging structures are a problem to repair and to rehabilitate, we wish that the concrete should be durable enough to have less cost in the maintenance and repair.

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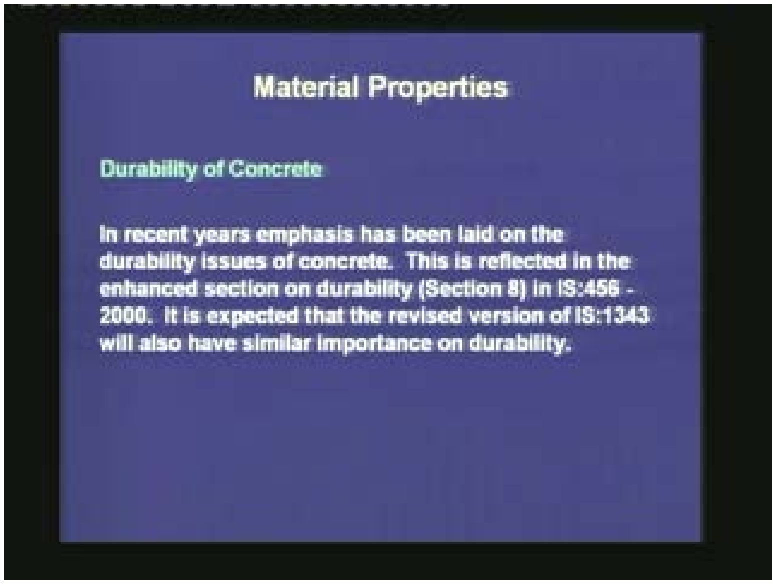

In the recent years, emphasis has been laid in durability issues and this is reflected in the enhanced section on durability in IS: 456 - 2000. It is also expected that the revised version of IS: 1343 will have similar importance on durability.

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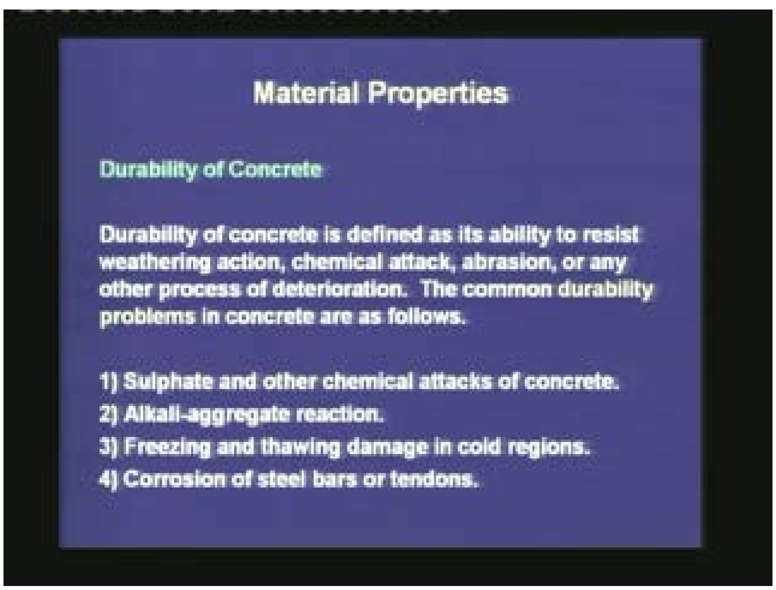

The durability of concrete is defined as its ability to resist weathering action, chemical attack, abrasion or any other process of deterioration. The common durability problems in concrete are as follows: the first one is the sulphate and other chemical attacks of concrete. The second one is the alkali-aggregate reaction; that is, if the aggregates are reactive with the alkaline environment, then it will lead to the reduction in strength of the concrete. The third is the freezing and thawing damage in cold regions. In cold regions, if water percolates within the concrete and if it freezes, then it creates a tensile stress within the concrete. The fourth is a very important durability problem, which is the corrosion of steel bars or tendons.

In prestressed concrete, as compared to reinforced concrete, the amount of steel required is much less. If the steel undergoes corrosion, then the problem in prestressed concrete is even more than in reinforced concrete. The reduction in diameter of a prestressing tendon is much higher in percentage, compared to the reduction in diameter in conventional reinforcing bars.

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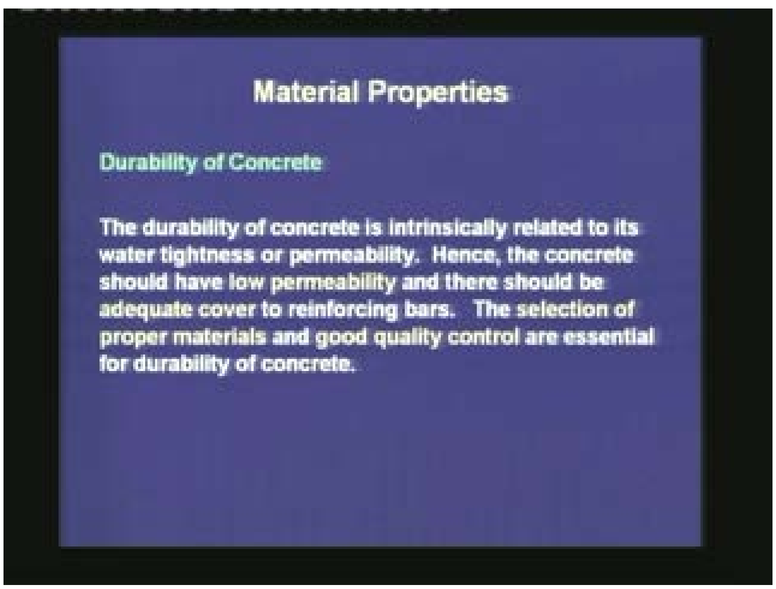

The durability of concrete is intrinsically related to its water tightness or permeability. There is a difference between permeability and porosity. Permeability means when there are inter-connected paths within the concrete, then water can ingress in the concrete and cause durability problems. That is why, in order to enhance the durability of concrete we need water tightness or low permeability. Also, there should be adequate cover to the reinforcing bars. If we have adequate cover, then it is expected that there will be less number of paths for water to come to the reinforcement. To ensure durability, the selection of materials and good quality control are essential.

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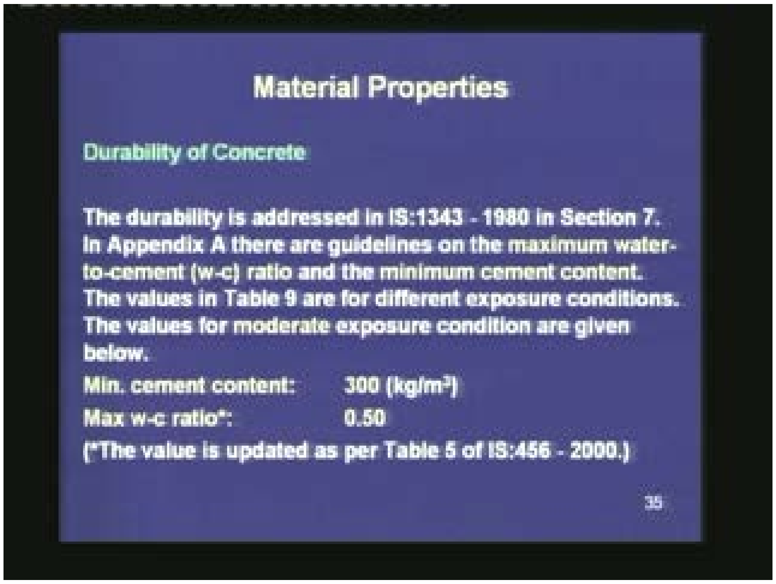

In IS: 1343, the durability is addressed in Section 7. Again, I am repeating that the section on durability in IS: 1343 is much smaller than compared to the section in IS: 456. It is expected that in a newer version of IS: 1343 more emphasis will be given on durability. In Appendix A of IS: 1343, there are guidelines on the maximum water-to-cement ratio and the minimum cement content. The values in Table 9 are for different types of exposure. In this lecture, we are just giving you some sample values from the table. The values for moderate exposure conditions are given below. The minimum cement content should be 300 kg/m^3 of concrete. The maximum water-to-cement ratio should be 0.5. The more cement we have, the better quality of concrete we can expect. If we reduce the water-to-cement ratio, then we expect the strength to be high.

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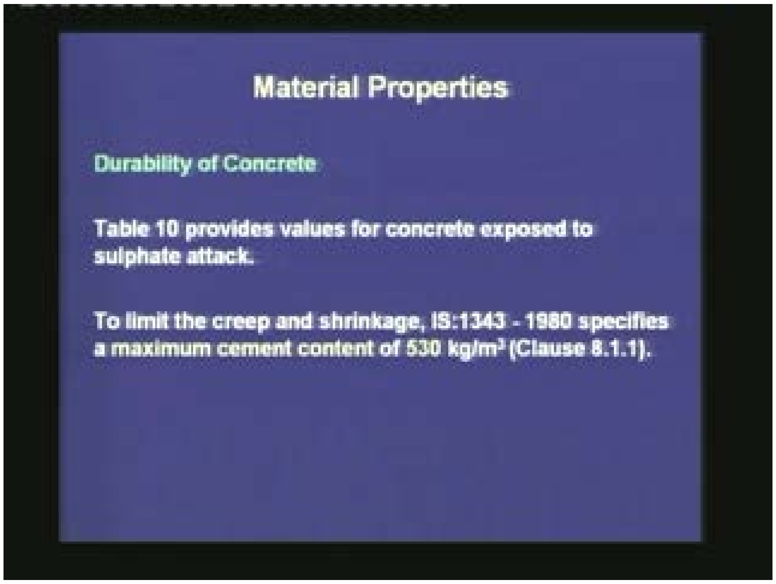

Table 10 of the code provides values for concrete exposed to sulphate attack. This is a special table which is required if we suspect that the concrete can be exposed to sulphate attack. We cannot increase the cement content without a limit, because if we have very high cement content, then the chances of shrinkage and creep also increase. To limit the creep and shrinkage, IS: 1343 specifies a maximum cement content of 530 kg/m^3. Thus, under moderate conditions, the range of cement content is from 300 to 530 kilograms, per cubic meter of concrete.

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Let us discuss in short, the high performance concrete. With the advancement in concrete technology, the high performance concrete is becoming popular. Especially for prestressed concrete, high performance concrete can be used. What are the attributes of high strength concrete? The attributes are: first, it should be of high strength. As I said before that a primary requirement of concrete in prestress application is that the concrete should be of high strength. The second criterion is the minimum shrinkage and creep; third is high durability; fourth is easy to cast; the fifth is that it should be cost effective.

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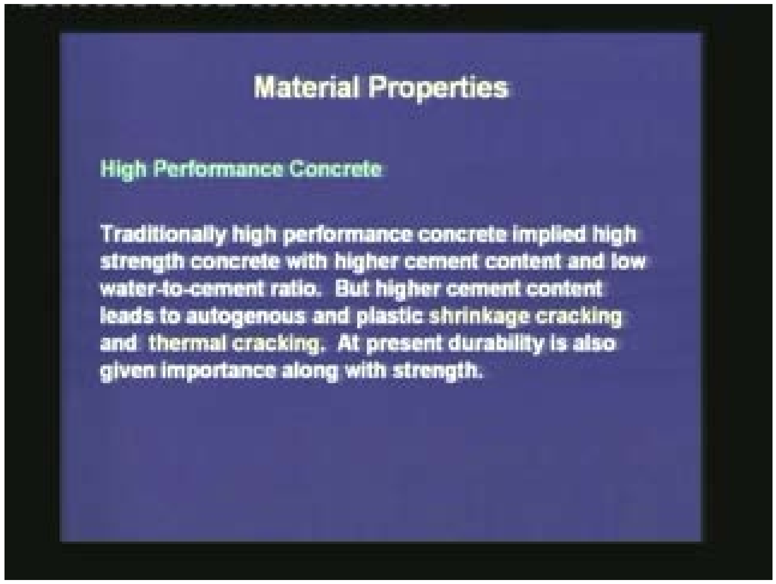

Traditionally, high performance concrete implied high strength concrete with higher cement content and low water-to-cement ratio. There is a problem if we use higher cement concrete. Higher cement concrete leads to autogenous and plastic shrinkage cracking, and thermal cracking. That means, if we are increasing the cement content in order to gain high strength, then it may lead to higher shrinkage cracking; and it may also lead to higher thermal cracking if the concrete is subjected to high diurnal temperature variation. That itself creates another durability problem. Hence, when we are looking into the durability issues, we are not just interested in the strength, but we are also interested in reducing the shrinkage cracks so that we do not create any permeability in the concrete for the ingress of water and moisture.

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Some special types of high performance concrete are described. The high performance concrete is a generic term which can be applicable for the following types of concrete. The first one is the high strength concrete with an upper limit of the cement content. The second one is the self-compacting concrete. Self-compacting concrete is like a flowable concrete which does not need sufficient vibration. The self-compacting concrete is used when there is congested reinforcement, especially in seismic regions, where it is difficult for the concrete to flow. In that case, self-compacting concrete can be used. The third one is reactive powder concrete which can give very high strength concrete.

The fourth one is the high volume fly ash concrete, which uses the industrial by-product of fly ash. It has several advantages. First of all, it has reduced shrinkage cracks. Although it gains strength slowly, but over the time it may achieve high strength. The fifth type of concrete is the fibre reinforced concrete. In this type of concrete, small fibres, either it can be of carbon or graphite or the more popular one is of steel, are poured into the concrete during its casting. The benefit of fibre reinforced concrete is that it reduces the shrinkage cracks. Since the fibres are oriented randomly, it can also be used for a region which is subjected to stress concentration and subjected to tensile stresses.

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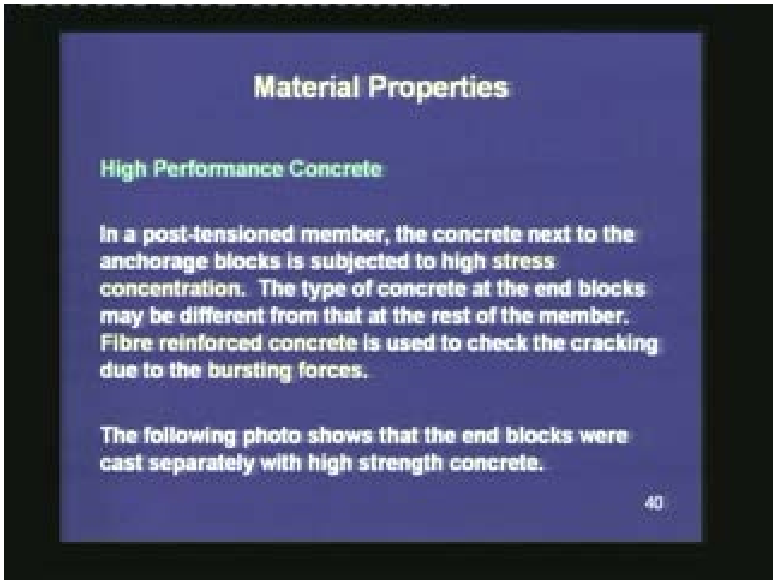

In a post-tensioned member, the concrete next to the anchorage blocks is subjected to high stress concentration. The type of concrete at the end blocks may be different from that at the rest of the member. I told last time, that the anchorage block actually bears against the concrete, and right next to the bearing plate, the concrete is subjected to high stress concentration. This leads to some transfer forces which are called bursting forces. These forces can create cracks within the concrete. In order to reduce the chances of cracking in these end regions, a special type of concrete can be used only for the end regions, and not throughout the member. Fibre reinforced concrete is an ideal form of concrete to check the cracking due to the bursting forces.

The following photo will show that the end blocks were cast separately with high strength concrete.

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In this photo you can see that the end blocks were cast separately, because these end blocks are subjected to high stress concentration. Hence, a high strength concrete was used for the end blocks. But to make the member cost effective, the rest of the member is not made of the high strength concrete. Conventional concrete will be used for the rest of the member. Here, we can also see the reinforcement and the layout of the tendons. On the end blocks, we can see the bearing plates, where the anchorage blocks will be attached.

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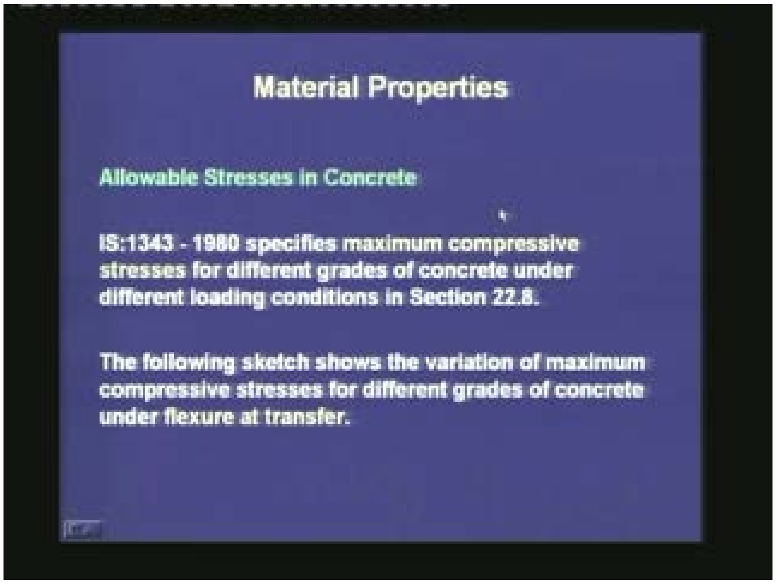

We move on to the allowable stresses in concrete. In prestressed concrete design, as we mentioned earlier, there are three important stages of loading. The first one is at transfer that is, when the prestress is being transferred to the concrete, the member should be able to sustain this high stress. The second stage is the intermediate stage, when a prestressed concrete member is transported from the casting site to its final location, then, it is subjected to stresses. Third, in the final location, the prestressed concrete member is subjected to the loads during the service life. There is also another condition which is the limit state, where the factored loads are used to calculate the demand within the concrete member. Out of these different load stages, the load stage at transfer and the load stage under service conditions are checked by the conventional elastic analysis. In using this elastic analysis, some allowable stresses are specified by the code. It is similar to the earlier working stress design of reinforced concrete. IS: 1343 specifies maximum compressive stresses for different grades of concrete, under different loading conditions, in Section 22.8.

The following sketch shows the variations of maximum compressive stresses for the different grades of concrete, under flexure at transfer.

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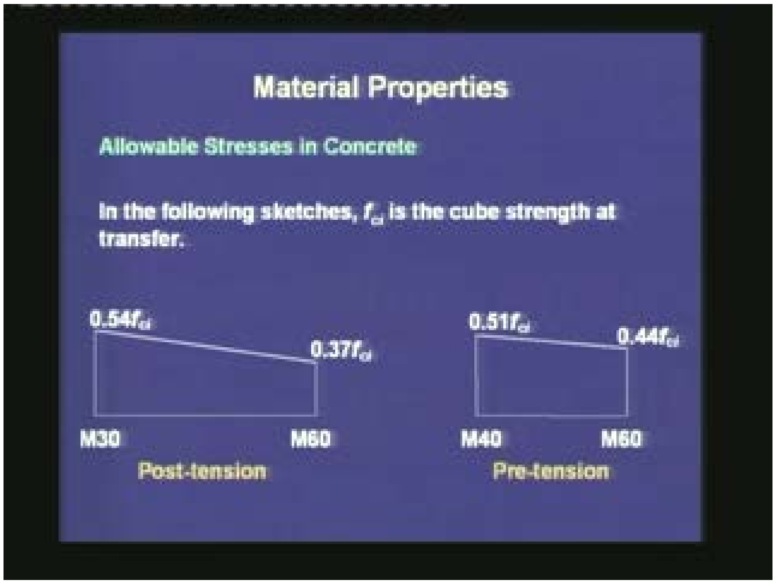

This sketch is used to calculate the maximum compressive stress under flexure at transfer. We have to remember the condition: that this is the compressive stress for flexure and this is applicable for the load stage at transfer. For a post-tensioned member, the concrete grade can vary from M30 to M60, and the allowable stress varies from $0.54f_{ci}$ to $0.37f_{ci}$. Here, f_{ci} is the cube strength at the time of transfer. That means, before the prestress is transferred, samples of the concrete are tested. The strength is found out, and from that strength, we calculate what is the allowable stress that the concrete can sustain, due to the compression under flexure. For pre-tensioned member, the grade varies from M40 to M60, and the allowable stress varies from $0.51f_{ci}$ to $0.44f_{ci}$.

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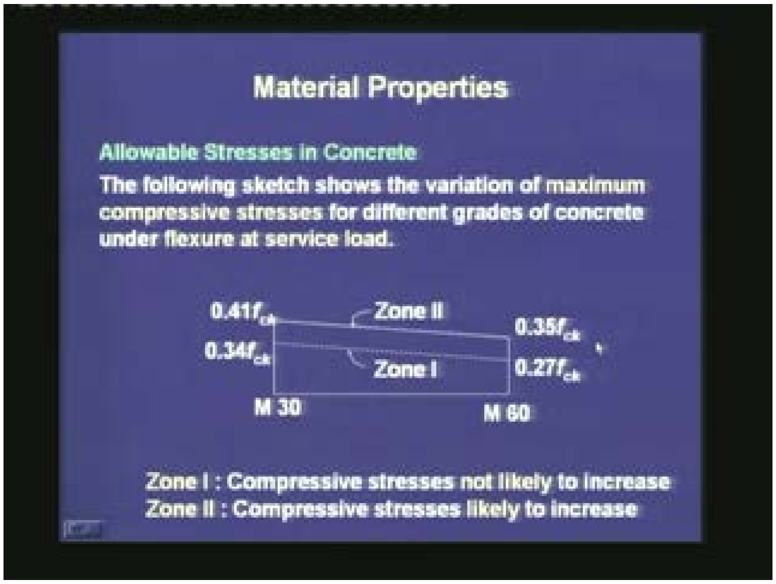

The code specifies maximum compressive stresses for the different grades of concrete, under flexure at service loads. There is no specific allowable stress specified for the intermediate stage, because for this stage, the loading is very case specific. Proper judgment has to be done to analyze a member for the intermediate loading. The code specifies values only for the service loads.

For the compression under flexure due to service loads, the variation of maximum compressive stress is given by the above sketch. This is applicable both for pre-tensioned and post-tensioned members. From M30 to M60, the allowable compressive stress varies from $0.41f_{ck}$ to $0.35f_{ck}$, where f_{ck} is the characteristic compressive strength of concrete. The top curve is applicable in a region where the compressive stresses are not likely to increase during the service life. But, if there is some region where the compressive stresses are likely to increase in the service life, then to consider this uncertainty, the code reduces the allowable stress, which varies from $0.34f_{ck}$ for M30 grade of concrete to $0.27f_{ck}$ for M60 grade of concrete.

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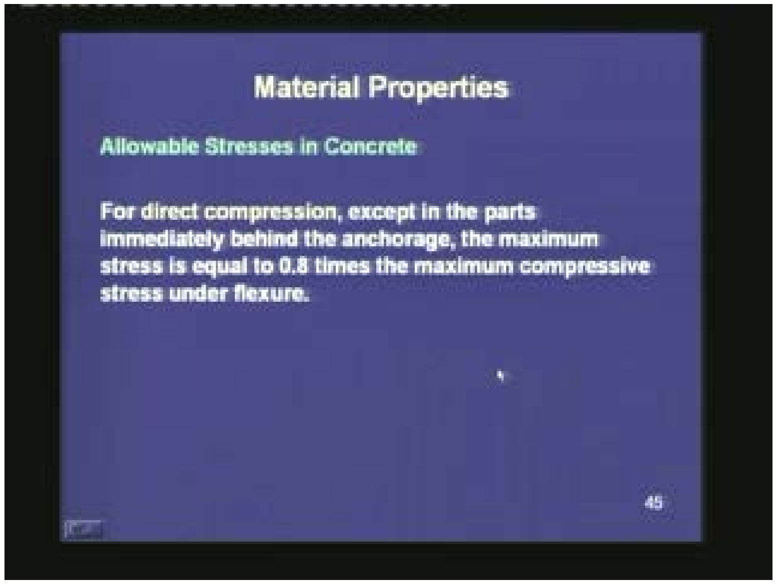

For direct compression, except in the parts immediately behind the anchorage, the maximum stress is calculated based on the maximum compressive stress under flexure. That is, the maximum allowable compressive stress under direct compression is taken as 80% of the maximum compressive stress under flexure.

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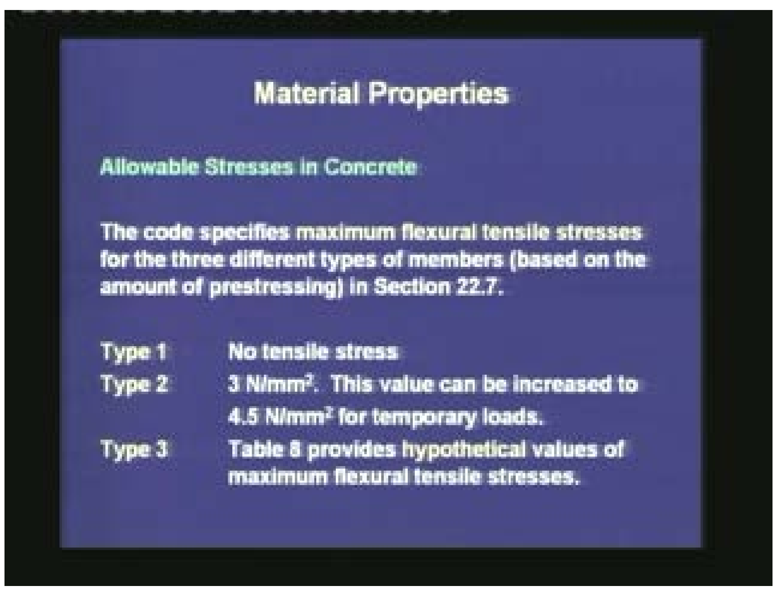

The code also specifies some maximum flexural tensile stresses. This is specified for three different types of members that we had learnt earlier. Type 1 member is the one where no tensile stress is allowed under service loads. Type 2 is a member where tensile stresses are allowed, but it is limited to 3 N/mm^2. This value of allowable stress can be increased to 4.5 N/mm^2 for temporary loads. For Type 3 members, the members are subjected to cracking under service loads, but the code specifies some hypothetical values of maximum flexural tensile stresses.

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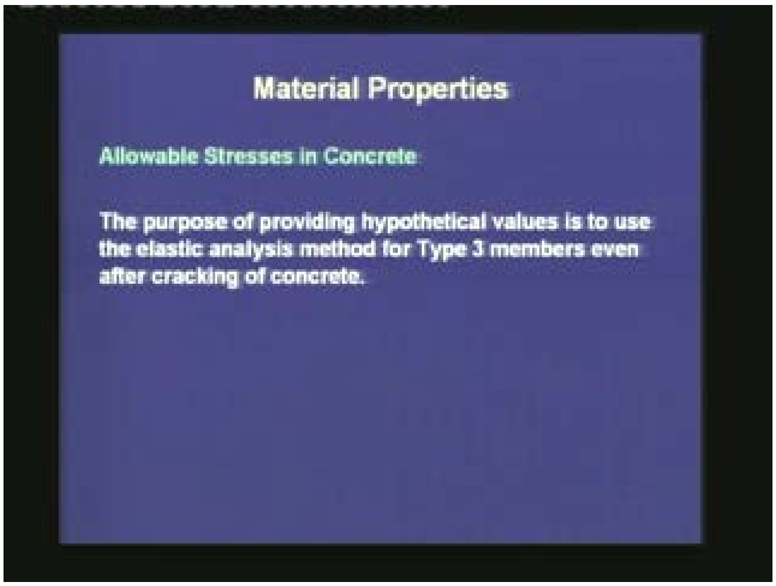

This is an interesting point to observe. After the concrete cracks, the elastic analysis cannot be used in its exact sense. But the code allows us to use the elastic analysis for the service loads, so that the analysis procedure is simple. It specifies some hypothetical maximum tensile stresses in the members which ensure that the cracking is not extensive in Type 3 members, and the crack width will be limited.

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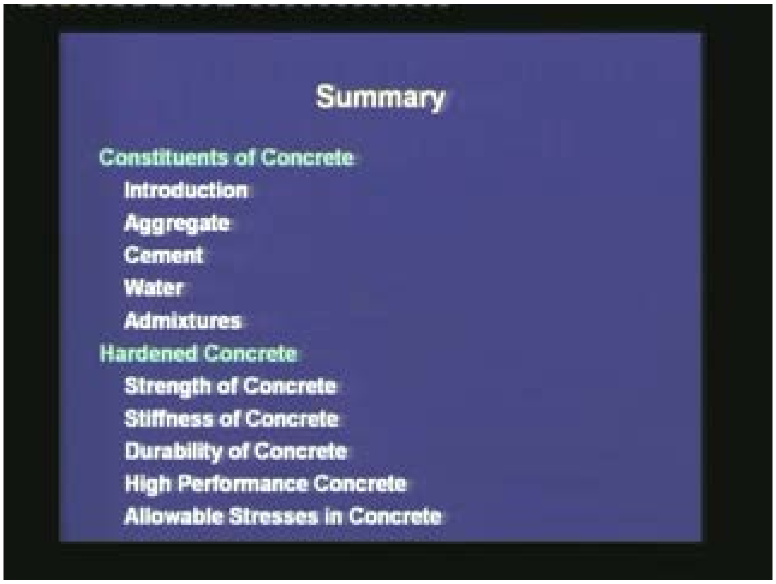

In today's class, first we covered the constituents of concrete. We learnt that the concrete itself is a composite material made up of coarse aggregates, fine aggregates, cement and water. There can be admixtures for different types of situations. The aggregates should be of good quality, that is, the shape and texture should be good for a high strength concrete. They should not have any deleterious materials. Regarding the cement, the code allows us four types of cement. The water also should be of good quality without any deleterious material. Potable water is acceptable for concrete. These constituents should be mixed properly, and then the concrete should be cast. There can be admixtures which are allowed by the code.

Next, we moved on to the properties of hardened concrete. The first property we studied, was the strength, which is the primary requirement in prestressed applications. For the strength, we studied two types of strength; the compressive strength and the tensile strength. We found that the compressive strength is quantified by a number called the 'characteristic compressive strength', which is based on a probabilistic distribution of the test results. The tensile strength is usually measured by two types of tests. The flexural tensile strength and the splitting tensile strength are calculated from a flexure test and a cylinder test, respectively, as I showed earlier. The tensile strength can also be calculated from direct tensile test. But, this test is relatively difficult to perform.

The second property that we studied was the stiffness of concrete. The stiffness of concrete is quantified by the elastic modulus. We need this quantity when we calculate the deflection of members. The calculation of deflections becomes important if the member is of smaller depth and longer span. Another very important criterion of hardened concrete is the durability. As a concrete structure ages, the cost of maintenance and repair can be substantial. In order to limit this cost, the durability issues are being emphasised at present. In IS: 456 – 2000, there is a separate section on durability which is quite comprehensive. It is expected that the code IS: 1343 will also be revised to have a more enhanced section on durability.

At present, IS: 1343 provides the durability requirements in the appendix. It specifies minimum cement content and a maximum water-to-cement ratio depending on the exposure condition. The exposure conditions are defined as moderate, severe, and extreme. These definitions, we are not covering here because they are already covered in IS: 456. Then, we studied the definition and the types of high performance concrete. As I said that at present, high performance concrete is becoming more and more popular, because we are able to quantify its properties. There can be different types of high performance concrete. The main requirements of high performance concrete are that it should be of high strength, it should be durable, there should be minimum shrinkage cracks, it should be easy to cast, and it should be cost effective. In a prestressed concrete member, different types of concrete can be used in the end blocks as compared to the rest of the member. The end blocks are subjected to stress concentration, and fibre reinforced concrete can be used in the end blocks to sustain the high stresses at the anchorage regions.

Finally, we moved on to the allowable stresses in concrete. These values are needed in the analysis of prestressed concrete members at transfer and at service stages. They can also be used for the analysis at intermediate loading stage with proper engineering judgment. We have found that the code has specified the allowable compressive stresses for flexure at two conditions, one at transfer and one at service loads. These allowable compressive stresses depend on the grade of concrete. The code also specifies the allowable tensile stress, which is based on the type of member that we intend to design.

For Type 1 members, no tensile stress is allowed in the concrete. For Type 2 members, tensile stress is allowed, whose value is limited to 3 N/mm^2 and it can be increased to 4.5 N/mm^2 for temporary loads. For Type 3 members, the members are subjected to cracking. In that sense, elastic analysis is not truly applicable. However, the code allows us to apply elastic analysis. For that, it specifies some hypothetical maximum tensile stresses. This simplifies our calculations, and the hypothetical tensile stresses are such that it limits the amount of cracking. It also limits the amount of crack width.

In our next class, we shall continue with the properties of hardened concrete. We shall see the stress-strain curves of concrete. We shall also study the two important properties of concrete, which is the creep and shrinkage. These two properties are very important for prestressed concrete members.

Thank you.