Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture – 05
Other Distress in Concrete

Hello friends, welcome to the NPTEL online certification course, retrofitting and rehabilitation of civil infrastructure. Today we will discuss module A, the topic for Module A is deterioration of concrete structures.

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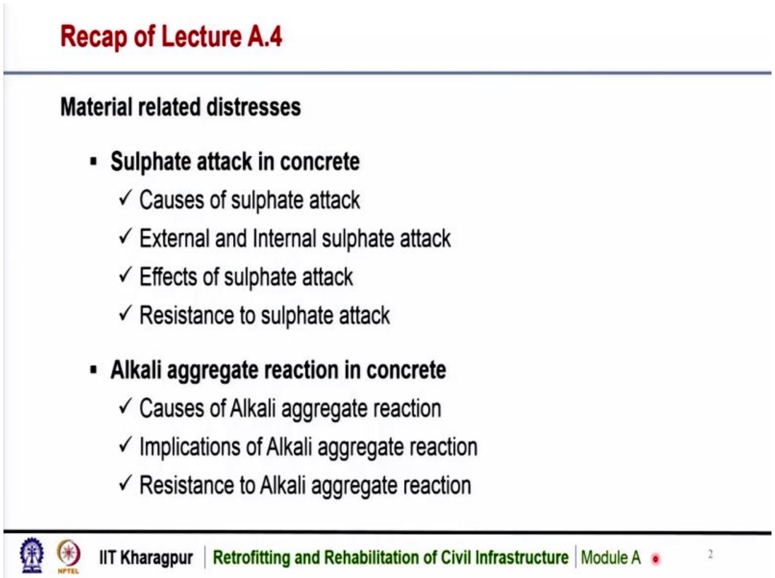

In the previous lecture, we have discussed two material related distresses that are found in concrete structures. We have discussed sulphate attack and alkali aggregate reaction in concrete. In sulphate attack, we have discussed the causes of sulphate attack depending upon the sources, external and internal sulphate attack, the effects of sulphate attack and how we can resist the sulphate attack in existing concrete structures.

In alkali aggregate reaction, we have discussed the causes and its implication and how we can resist the alkali aggregate reaction in concrete structures.

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Today, we will discuss some other type of distresses found in concrete structures. We will discuss today, freezing and thawing type of distress, the thermal effect in concrete, shrinkage and creep effect.

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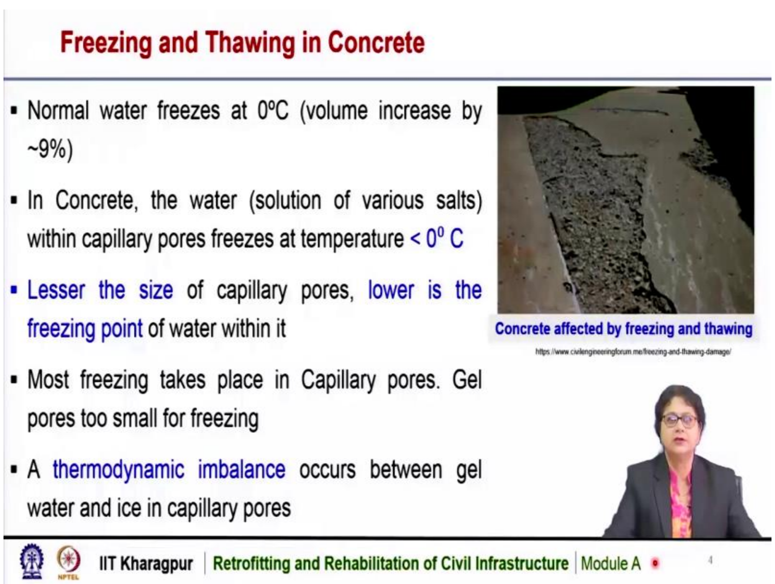

Freezing and thawing type of distress, is found in concrete structures, which are situated in very cold climatic region. Particularly where the temperature goes below zero degrees centigrade and water freezes into ice. If the structure is situated in that type of region, then they may get affected due to freezing and thawing type of distress. This is a typical picture of concrete affected by freezing and thawing type of distress.

The surface gets disintegrated and the structure is damaged. It is known that normal water freezes at zero degrees centigrade, and when it freezes into ice, there is an increase in the volume. And that increase is approximately 9 percent. So, quite a significant amount of increase. In concrete, water is present within the pore structures, which is consist of the capillary pores and gel pores. And this water is not pure water, it is actually a solution of various salts.

Therefore, when the outside temperature goes down, below zero degrees centigrade, this capillary water also tends to freeze. And this water freezes at temperature less than zero degrees centigrade, as they are not pure water. So, they freeze at a temperature lower than zero degrees centigrade. And most freezing takes place in the capillary pores. And gel pores are too small for freezing.

And lesser is the size of capillary pores lower is the freezing point of water within it. However, some portion of water may freeze, some may be still in the water stage. So, there is a thermodynamic imbalance occurs between the gel water and also the unfrozen water, and the ice in the capillary pores.

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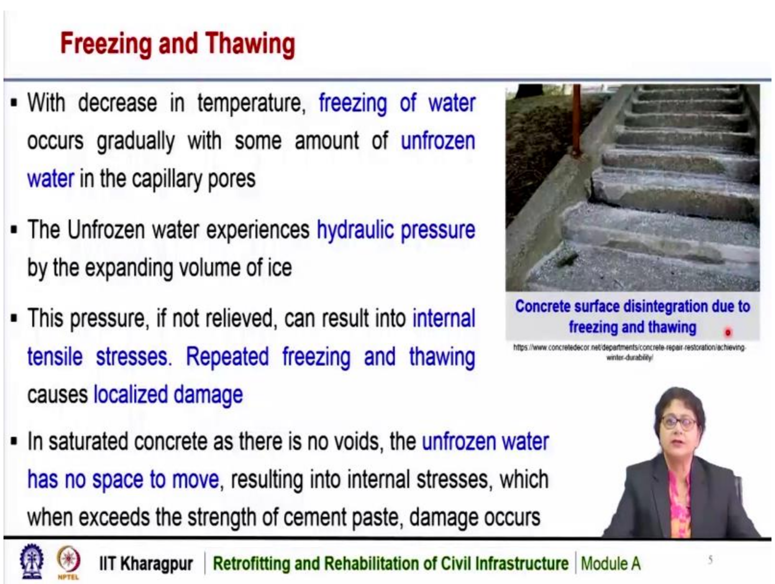

With decrease in temperature, freezing of water occurs gradually with some amount of unfrozen water in the capillary pores. Now, this unfrozen water experiences a hydraulic pressure by the expanding volume of ice. Some water within the capillary pores has freezed into ice, so, there is an increase in the volume. So, the unfrozen water within the capillary pores experiences the hydraulic pressure in it.

This pressure if not relieved, can result into internal tensile stresses. Now, repeated freezing and thawing cause local damage to the structure. In saturated concrete as there is no void, the unfrozen water has no space to move and that results into internal stresses, which when exceeds the strength of the cement paste, damage occurs. So, it is important that the internal stress that is developed should be relieved.

If it is not relived, even the stress exceeds the strength of the cement paste, there may be a damaged or cracking. So, here is also a picture of freezing and thawing type of distress in concrete structure. The surface gets disintegrated due to the effect of freezing and thawing.

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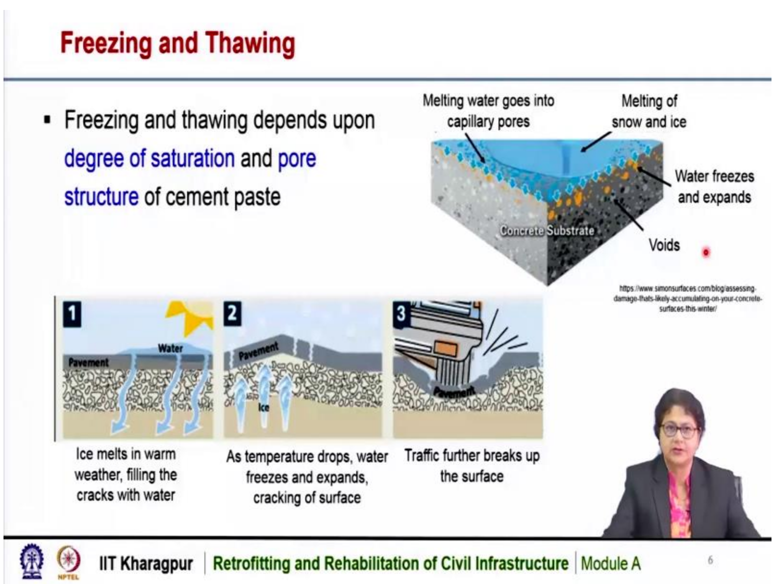

Freezing and thawing depends upon the degree of saturation and the pore structure of cement paste. The pore structure consists of the capillary pores and the gel pores. So, these are the schematic diagrams, you can see here this is a concrete structure. And it is placed on a region where there is formation of ice due to lower temperature. When the ice melts, that may go inside the structure through some cracks and this melting water goes then to the capillary pores.

And there are several voids you can see here. It is schematically shown and the melting water goes into those voids and capillary pores. Now, when the temperature further decreases, below zero degrees centigrade, the water present within these pores freezes and expands. So, that water or that ice actually with increase in volume, they exert a pressure to the other unfrozen water. So, this is also a schematic diagram shown.

This is a concrete pavement, there are several cracks on it and if water is percolating through these pores, and it can reach to the inner member. Now, as the temperature drops, water freezes and then it expands. And that results into further cracking of the pavement and this cracking further increases with traffic movement.

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So, freezing and thawing type of distress can be found in rocks as well. You can see here, this is also a schematic diagram shown, the here, the effect of freezing and thawing in rocks. This is a rock; you can see here with a wedge in it. And water may be collected in this portion. Now, when the temperature drops down, the water may freeze and because of that freezing, there is an expansion in the volume.

So, it expands and forcing the cracks to widen. So, we can see here that the ice actually forcing the crack to widen. Now with increase in temperature, ice thaws and then there is a contraction in volume and water goes deeper into the cracks again. So, you can see here water can go deeper into the cracks. Now with repeated freezing and thawing, results into repeated expansion and contraction, and which results into further cracking and ultimately it may break completely.

So, this type of repeated freezing and thawing can result into breakage of concrete or rocks. This is a picture of concrete bridge parapet wall which exhibits severe deterioration caused by repeated freezing and thawing cycles. We can see here that this is the bridge with the parapet wall and it is badly damaged due to the effects of freezing and thawing.

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Effect of freezing and thawing is significant, repeated cycles of freezing and thawing results into breaking down of the pore structure. And due to this breaking down of the pore structure, there is pop out and surface scaling and that results into gradual disintegration of the structure. Resistance to freezing and thawing. Dry concrete is comparatively better in resisting freezing and thawing type of distress.

The degree of saturation also plays an important role in freezing and thawing type of distress. It should not be fully saturated, the degree of saturation should be less than 80 to 90 percent, so that the unfrozen water can move to the voids present in the concrete. Air entrainment is also another technique by which we can resist freezing and thawing type of distress. This is a typical picture of a surface disintegration due to the effect of freezing and thawing type of distress.

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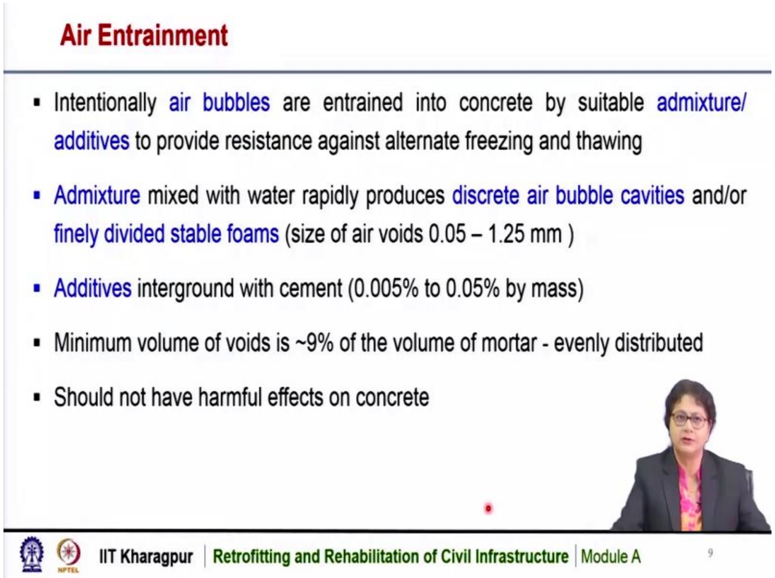

Air entrainment is a mechanism by which we can resist freezing and thawing type of distress in existing concrete structures. In this mechanism, intentionally air bubbles are entrained into concrete by suitable admixtures or additives to provide resistance against alternate freezing and thawing. So, here we are intentionally inserting some air bubbles, by suitable admixtures or additive.

These admixtures are mixed with water, rapidly produces discrete air bubble cavities and in finely divided stable foams. And the size of these air voids is very small, 0.05 to 1.25 millimeter. Additives may also be used and that is interground with cement. So, additives or admixtures are inserted into the concrete and mixed. They can act as a void space for resisting the freezing and thawing type of distress.

The minimum volume of voids is approximately 9 percent of the volume of mortar and it should be evenly distributed. The air entraining agents should not have any harmful effects on concrete.

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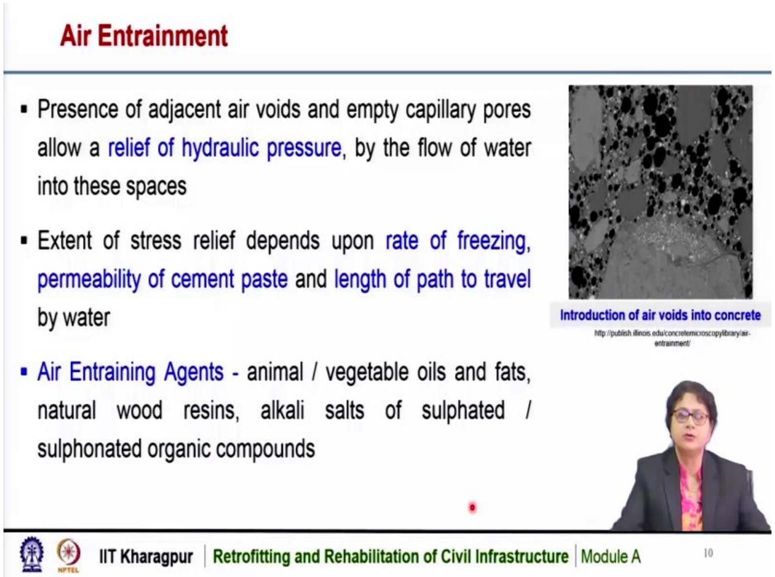

The presence of adjacent air voids and empty capillary pores allow relief of the hydraulic pressure by the flow of water into these spaces. So, these air bubbles or the empty capillary pores, actually allow the relief of the hydraulic pressure, so that the unfrozen water can go into these spaces to relieve the hydraulic pressure on it. The extent of stress relief depends upon the rate of freezing, the permeability of the cement paste and the length of path to travel by the water.

Air entraining agents are: animal and vegetable oils or fats, natural wood raisins, alkali salts of sulphated/sulphonated organic compounds etc. Here is a picture you can see that the air voids are introduced by some additives or admixtures within the mix of the concrete. So, that can resist the freezing and thawing type of distress and that we will see now.

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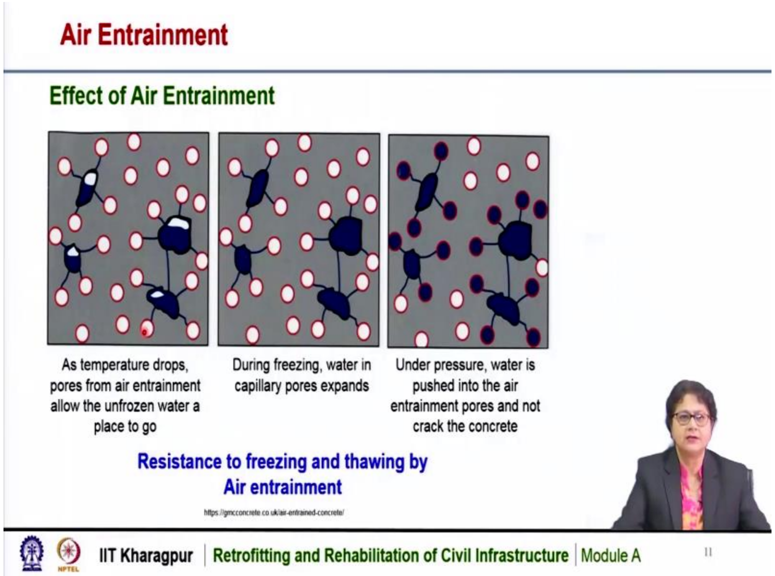

So, this is schematically shown, the effect of air entrainment. These are some of the capillary pores and these are the entrained air bubbles. As temperature drops, the pores from the air entrainment allow the unfrozen water a place to go. So, here we can see that within the capillary pores, some water is there and some water freezes into ice. Now during freezing, water in the capillary ports expands.

So, when it freezes into ice, there is a expansion in the volume. Now, under pressure, the water is pushed into the air entrainment pores and not crack the concrete. Now, since there are air voids or bubbles within the mix, so the unfrozen water now has the space to go. So, the stress is relieved and there is no cracking on the concrete. So, this way, we can utilize the air entrainment to resist the freezing and thawing type of distress in concrete structures.

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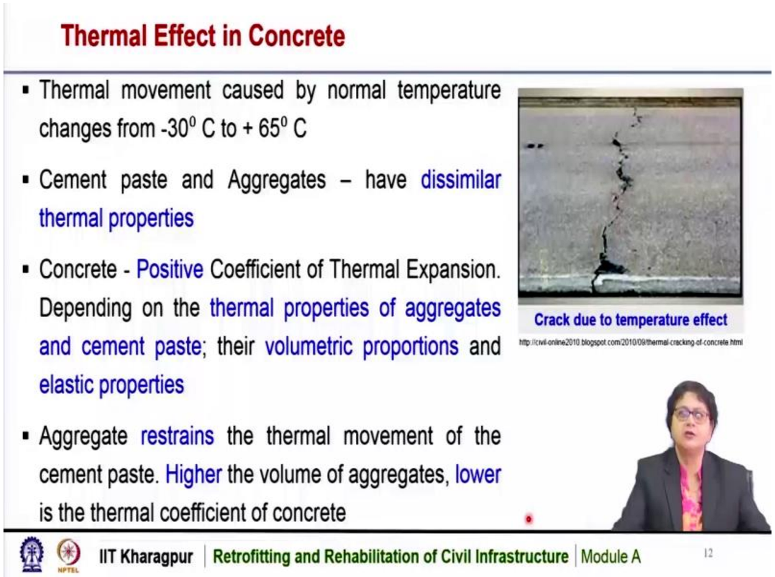

Now, we will discuss the thermal effect in concrete. The thermal effect is due to the variation of normal temperature from minus 30 degrees centigrade to plus 65 degrees centigrade. And the effect on concrete is to be examined in this range of temperature. The concrete has a positive coefficient of thermal expansion. The cement paste and aggregates which are the main ingredients of concrete have dissimilar thermal properties.

The thermal properties of concrete actually depend on the thermal properties of its ingredients, that is the aggregates and the cement paste and also on their volumetric proportions and their elastic properties. Aggregates actually restrain the thermal movement of the cement paste. And therefore, higher is the volume of aggregate, lower is the thermal coefficient of concrete.

So, the thermal properties of concrete depend on the thermal properties of its ingredients, that is the aggregates and the cement paste. Aggregate actually restraints the thermal movement of the cement paste. The coefficient of thermal expansion of concrete depends on the thermal properties of aggregates and cement paste and also on their volumetric proportions and their elastic properties. So, aggregates actually restraints the thermal movement of the cement paste.

Here is a picture, we can see that concrete pavement is scrapped due to the effect of temperature. So, the pavement or slab may have crack without any external load and due to the temperature, it may crack badly.

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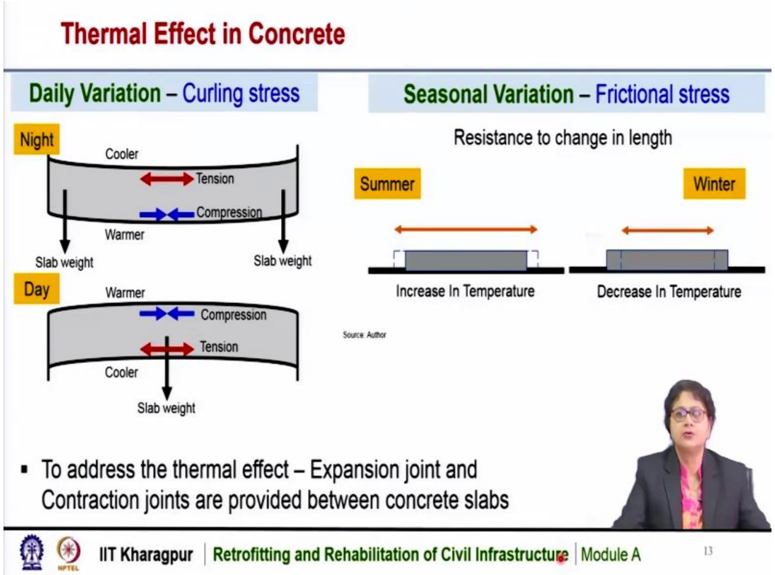

The effect of temperature in concrete is twofold. One is due to the daily variation of temperature and another is due to the seasonal variation of temperature. In daily variation of temperature, there is a difference in temperature in the daytime and in the nighttime. In daytime generally, the temperature is more as compared to the nighttime. So, when the temperature is more in the daytime, the concrete surface also is warmer.

And since concrete thermal coefficient is not high, so, the bottom surface is cooler. So, there is a difference in temperature between the top surface and the bottom surface; that means, there is a thermal gradient between the top and the bottom surface of the concrete member. So, as a result, there may be a development of curling stresses. And we can see that if there is no restraint, the concrete slab may curl like this, that is convex upwards.

However, this curling is restrained by the self-weight of the slab and also by the adjacent slabs. So, due to this restraint these curling stresses are developed. In nighttime the top surface is cooler and the bottom surfaces warmer. So, the slab curls like this, that means concave upwards. As a result, there is curling stresses developed and tensile stresses are developed at the top of the slab and compressive stresses are developed at the bottom of the slab.

Again, the self-weight of the slab is restraining this curling and also the adjacent slabs also restraining the curling. The seasonal variation, that means during the summer time and winter time, there is a significant difference in the overall temperature. In summer time the temperature increases whereas, in the winter time the temperature drops down. In summer time when the temperature increases, the slab tends to expand.

So, we can see that the slab tends to expand and in winter time as the temperature decreases, the slab tends to contract. So, there may be a restraining effect by the foundation. And as a result frictional stresses are developed at the interface. So, frictional stresses are developed at the interface due to the effect of seasonal variation of temperature.

Now, to accommodate this expansion and contraction, expansion joint and contraction joints are provided between concrete slabs. So, this is important that for longer slab, expansion joints and contraction joints need to be provided, so, that the expansion and contraction due to thermal effect can be accommodated.

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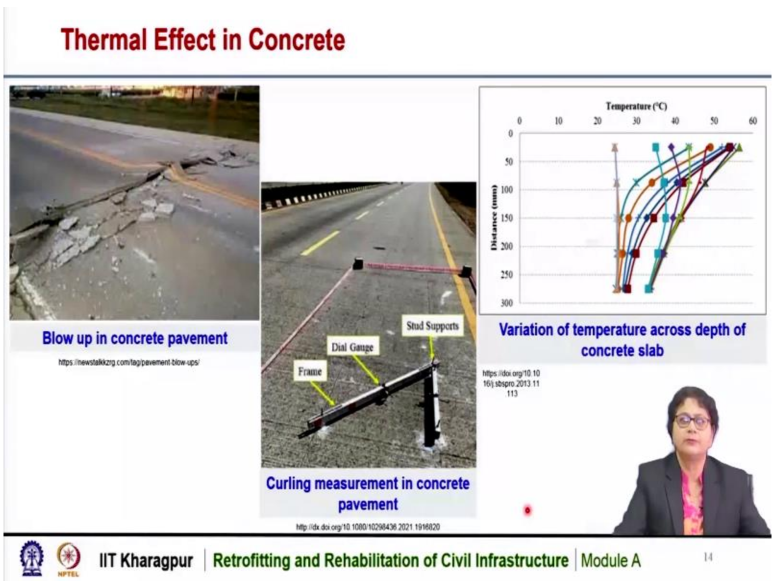

If the expansion joint or contraction joints are provided inadequately, then there may be distress in the concrete slab. Look at this picture, this is a picture of concrete pavement and the deterioration is due to the blow-up type of distress. This blow-up type of distress occurs when the width of the expansion joint or contraction joint is inadequate.

So, as the width of the joint is inadequate and when the concrete slab tends to increase in summer time then it has insufficient space for that, accommodating that increase in the length.

So, there may be a collision of the two at the same slabs. As you can see here, due to collision of the slab, there may be the two slabs may collide and there may be a blow-up type of distress here.

So, we can see here, the two adjacent slabs collide due to inadequate joint spacing and blow-up type of distress is observed. This is a picture of the curling measurement in concrete pavement, though the curling may be restrained due to the self-weight and the adjacent slabs. But some amount of curling can be measured. So, here we can see that the curling effect due to the daily variation of temperature is measured here in this concrete pavement.

And this is a variation of temperature across the depth of concrete slab. The variation of temperature is actually nonlinear as you can see here. This is the nonlinear variation of temperature across the depth of concrete slab. And so, when the temperature is increasing particularly during daytime, there is maximum temperature at the top surface whereas, at the bottom surface the temperature is much less.

So, as you can see that it is a nonlinear variation of temperature however, when the temperature is less in the top and more at the bottom, that variation is more or less linear. And this experiment we have done in our laboratory and we have observed that nonlinear variation of temperature across the depth of concrete slab. So, it is clearly visible from the experiment that the variation is nonlinear across the depth of concrete slab.

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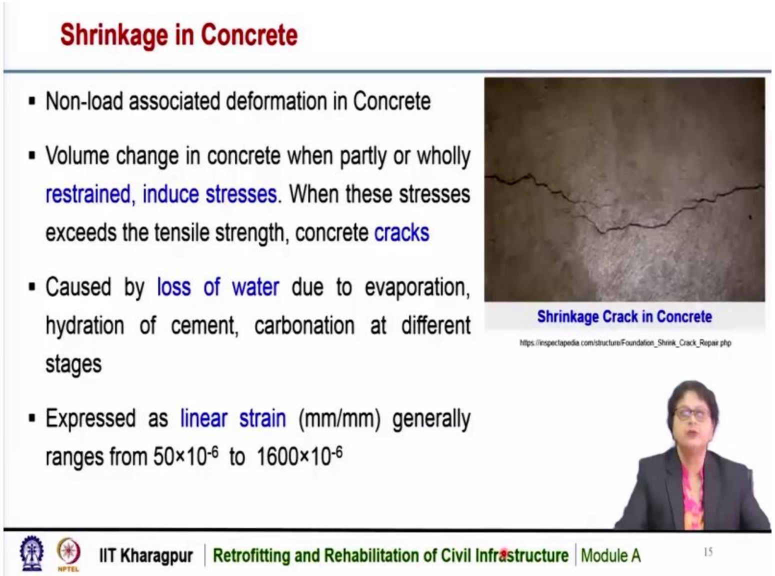

Now, we will discuss the shrinkage in concrete. Shrinkage is non load associated deformation in concrete. Shrinkage is quite common for all concrete structures. The volume change in concrete when partly or wholly restrained, that induces stresses. And when these stresses exceed the tensile strength, concrete cracks. Shrinkage is due to the loss of water and that is due to evaporation or hydration of cement or carbonation at different stages of concrete.

Shrinkage is expressed as linear strain and generally it is ranging from 50×10^{-6} to 1600×10^{-6}. So, shrinkage is quite common in all concrete structures. And if it is not controlled, shrinkage cracks are visible in the structure. Look at this picture this is a typical shrinkage crack in a concrete structure.

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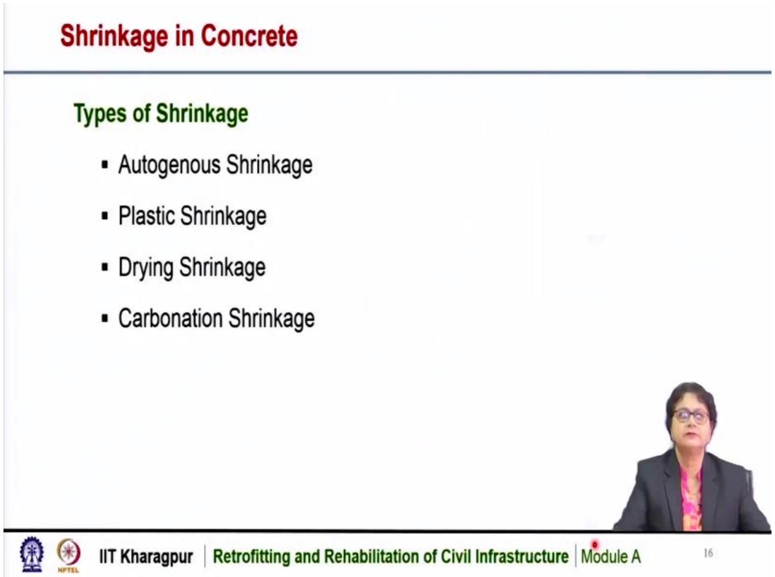

Shrinkage may be of different types, autogenous shrinkage, plastic shrinkage, drying shrinkage and carbonation shrinkage.

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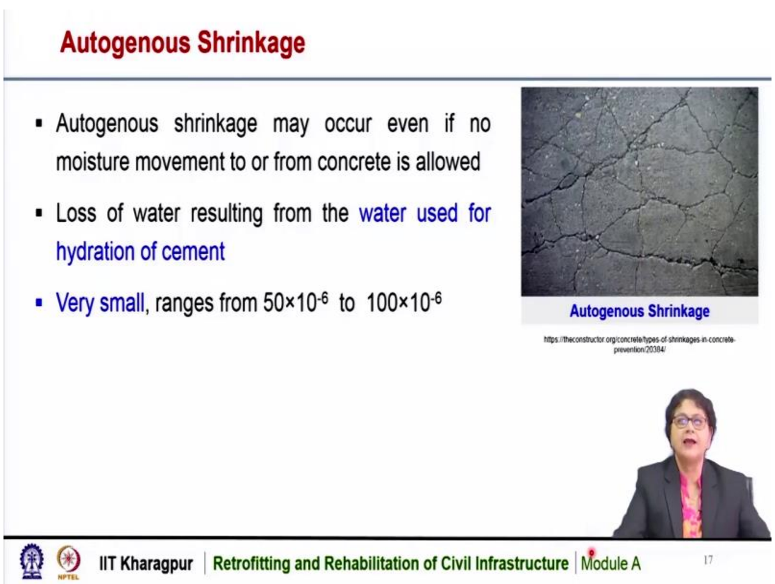

Autogenous shrinkage may occur even if no moisture movement to or from the concrete is allowed. It is due to the loss of water, that results from the water used for hydration of cement. So, hydration of cement is almost a continuous process and because of that water is used. The loss of water due to the hydration of cement that may cause autogenous shrinkage. Autogenous shrinkage is very small ranging from 50×10^{-6} to 100×10^{-6}. This is a typical picture of autogenous shrinkage in concrete.

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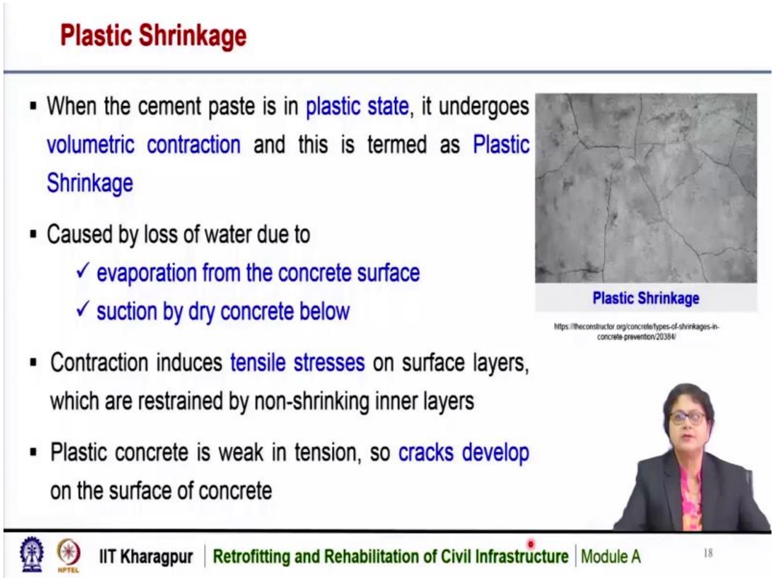

Plastic shrinkage occurs in concrete when it is in the plastic state. When the cement paste is in plastic state, it undergoes volumetric contraction and this is termed as plastic shrinkage. Plastic shrinkage is caused by the loss of water. And this is due to evaporation from the concrete surface and also by the suction of the dry concrete below.

Here we can see a typical picture of plastic shrinkage in concrete. The contraction induces the tensile stresses on the surface layers, which are restrained by the non-shrinking inner layers. The plastic concrete is weak in tension. So, cracks are developed on the surface of the concrete.

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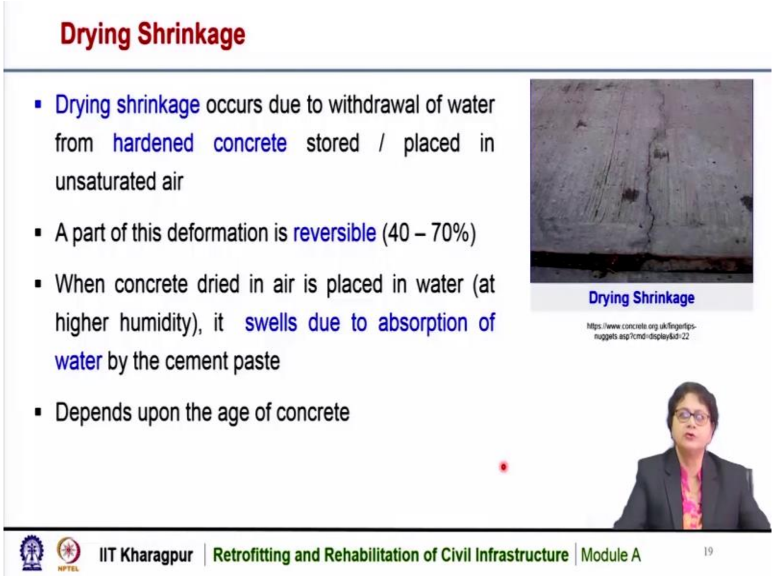

Drying shrinkage occurs in hardened concrete. It is due to the withdrawal of water from hardened concrete, when it is stored or placed in unsaturated air. However, some part of the drying shrinkage (40 to 70 percent) may be reversible. When concrete is dried in air and is placed in water or at higher humidity, it swells due to the absorption of water by the cement paste.

So, some amount may be reversible. Of course, it depends on the age of the concrete. So, drying shrinkage is also quite common and it is due to the withdrawal of water from the hardened concrete. Here is a typical picture of drying shrinkage cracking on hardened concrete structure.

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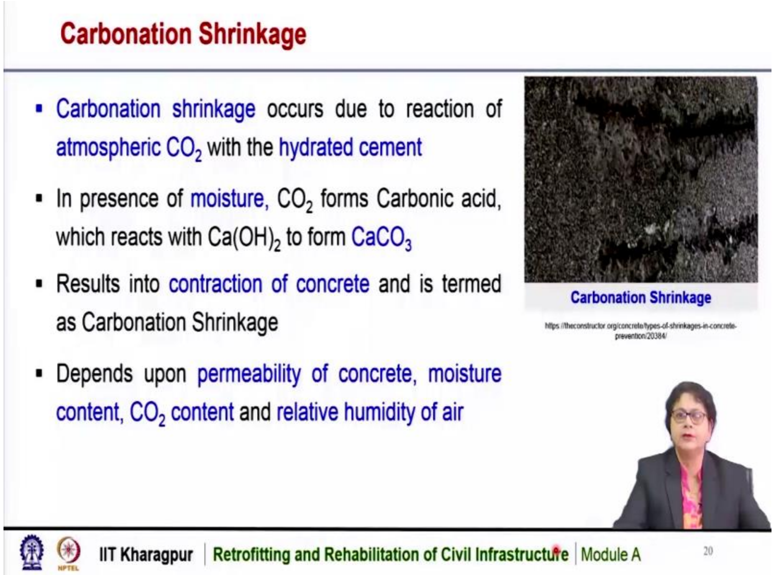

Carbonation shrinkage is also another type of shrinkage, that occurs due to the reaction of atmospheric carbon dioxide within the hydrated cement. In presence of moisture, carbon dioxide forms carbonic acid, which reacts with calcium hydroxide to form calcium carbonate. This results into contraction of concrete and is termed as carbonation shrinkage.

Carbonation shrinkage depends upon the permeability of concrete (because if the concrete is permeable, then water may enter), the moisture content, the carbon dioxide content (because it is due to the reaction of the carbon dioxide) and also all the relative humidity of air. Carbonation shrinkage, this is a typical picture of a concrete structure affected by carbonation type of distress and the reinforcements are exposed and the concrete is distressed.

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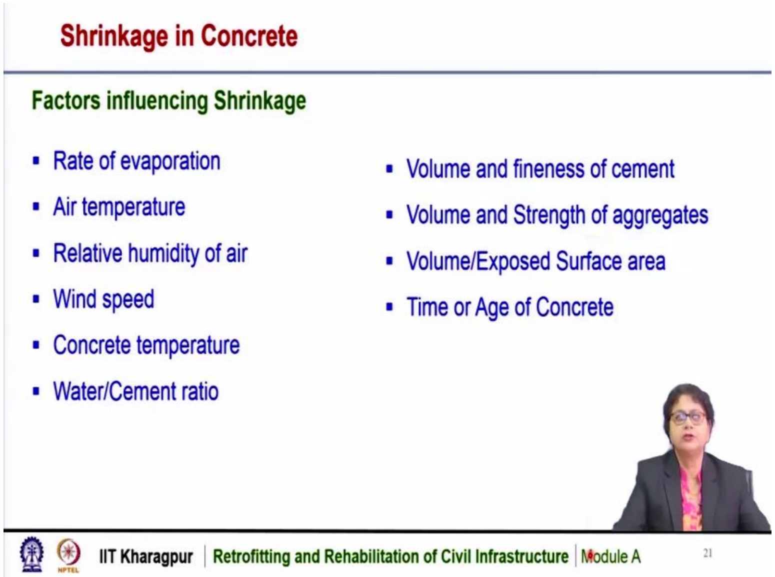

There are several factors which may influence the shrinkage. The rate of evaporation, the rate of evaporation influences the shrinkage significantly. If the rate of evaporation is high, more shrinkage will occur. Air temperature also plays an important role. If the air temperature is high, there will be more evaporation of water. So, more shrinkage will be there. Relative humidity of air is also important; if the relative humidity of air is high, then there will be less linkage.

Wind speed also is important, if there is more wind speed, then there will be more rate of evaporation. So, there will be more shrinkage. Concrete temperature also affects. Higher is the concrete temperature more is the shrinkage. Because more will be the loss of water. Water cement ratio, if water cement ratio is high, then the concrete will be subjected to higher shrinkage. Volume and fineness of cement also affects the shrinkage.

Higher is the fineness or more is the volume of the cement that leads to more shrinkage of the concrete. Volume and strength of aggregates, aggregates are actually restraining the shrinkage effect. So, if the volume of aggregate is more or the strength of aggregate is high, then it results into lesser shrinkage. Volume/Exposed surface area, this ratio is also important. If the exposed surface area of the member is high, then there will be more shrinkage. And time or age of concrete also is important, with increase in time there will be more shrinkage.

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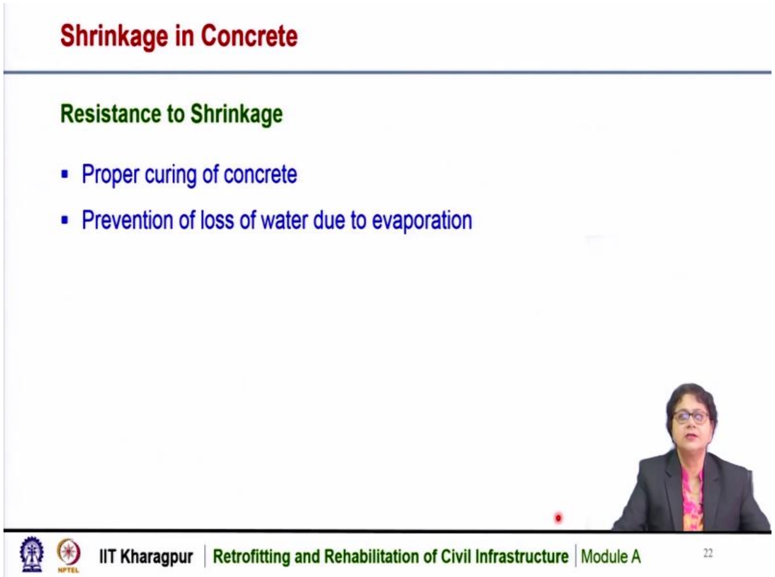

Now, resistance to shrinkage. It is very important for all concrete structures to have proper curing after casting. So, proper curing is necessary to control shrinkage type of distress. And also, it is important to prevent the loss of water due to evaporation. So, we have to prevent the loss of water due to evaporation from the concrete, either it is in plastic state or from the hardened state. It is important to prevent the loss of water and that may resist the shrinkage type of distress.

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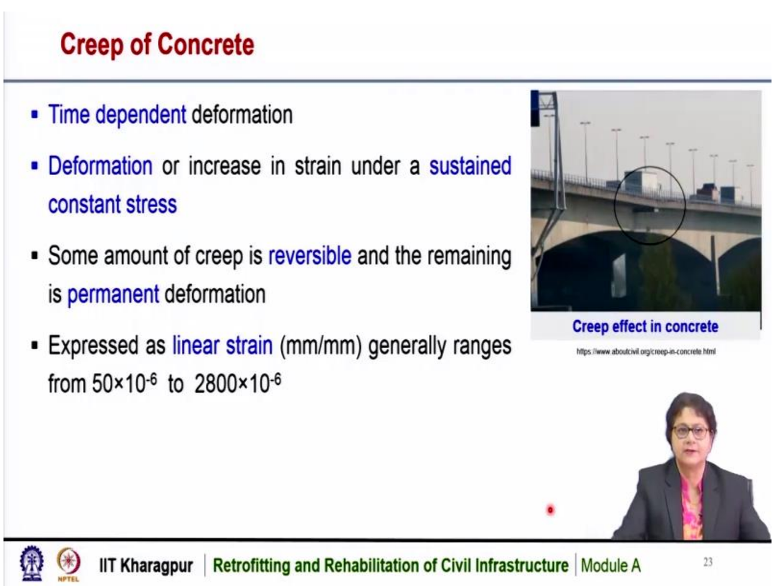

Now, we will discuss the creep effect in concrete. Creep is a time dependent deformation. This is the deformation or increase in strain under a sustained constant stress. So, creep is the deformation or it can be expressed in strain, under a sustained constant stress. Some amount of creep is reversible, but the remaining is permanent deformation. Here in this picture, we can see the effect of creep in a concrete bridge.

We can see here, this is the deck slab, this is the guarder and due to the sustained loading, due to its dead load and also due to the moving traffic, there is deformation and that deformation is due to the effect of creep. So, this is the deformation of the structure due to the effect of creep. The creep is expressed as linear strain like shrinkage and generally the range is from 50×10^{-6} to 2800×10^{-6}.

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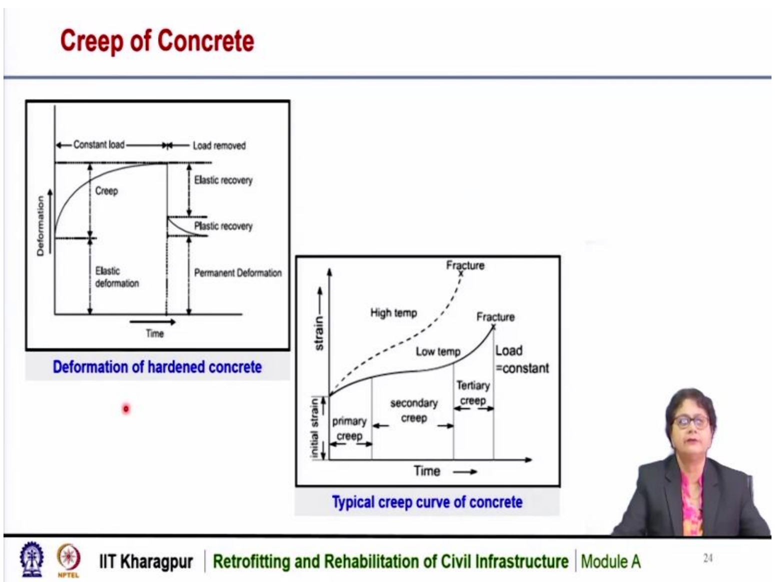

These are typical diagrams of creep; this is the deformation versus time of the hardened concrete. As we can see that if the structure is loaded under constant loading, we can plot the deformation with time, we can see here that the deformation increases up to its maximum and when the load is removed, there may be an elastic recovery.

So, under constant loading, there is a deformation. When the load is removed, some part may be recoverable, some part may have plastic recovery. That means, it can recover at a slower rate that is also called creep, creep recovery. But some part is permanent deformation that is due to the effect of this constant loading. So, this is the deformation of the hardened concrete with time.

And this curve shows the deformation or strain with respect to time this is typical creep curve of concrete. We can see that, initially the rate of strain is much less. So, this is the primary creep region, next is the secondary creep region and next to the tertiary creep region.

And in the secondary creep region, the rate of strain is increasing. And in this region, it is further increasing till complete failure or fracture. So, this is the variation of the strain under constant loading with time. And the effect is shown with higher and lower temperature. So, the effect of creep is shown here with time under constant sustained loading.

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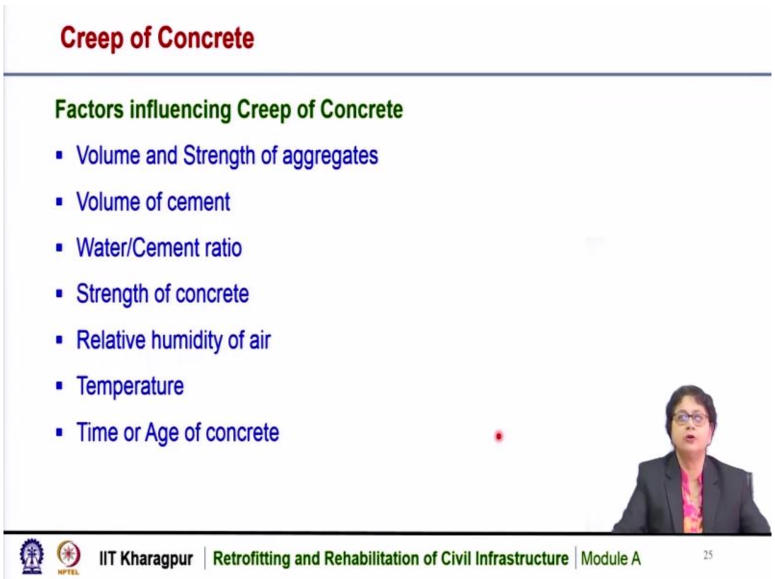

There are several factors, which may influence the creep of concrete. The volume and strength of aggregate actually restrain the effect of creep in concrete. The volume of cement, higher is the volume of cement, higher is the creep effect. Water cement ratio is also similar, more is the water cement ratio, more is the effect of creep. The strength of concrete; if the strength of concrete is high, then the effect of creep will be lower.

The relative humidity of air also affects the effect of creep. If the relative humidity is high, then there will be lower creep. The temperature also influences, higher is the temperature higher is the creep effect. And time and age of concrete, higher is the age of concrete, more is the effect of creep. So, these are the factors that may influence the creep of concrete in existing structures.

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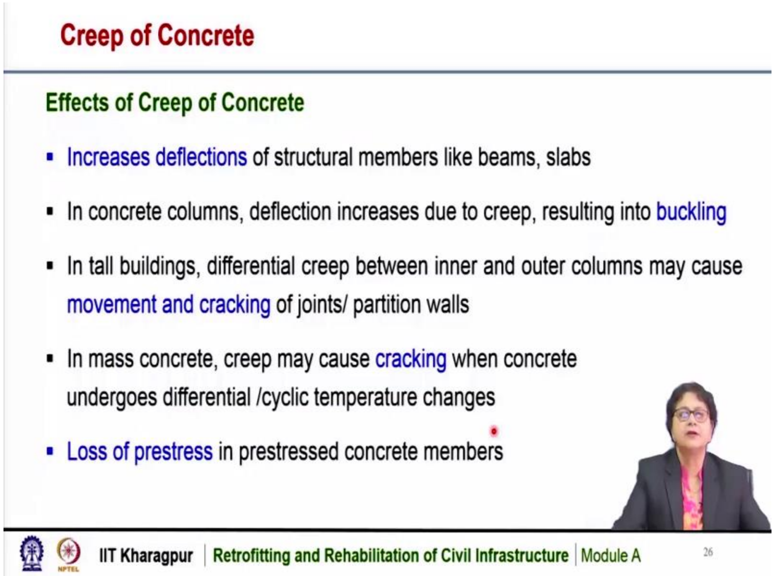

The effect of creep is quite significant in existing structures. Due to the effect of creep, there is an increase in deflection of the structural members like beams or slabs. In concrete column also the effect of creep may be there, the deflection may increase due to the effect of creep that may result into buckling of columns.

In tall buildings differential creep between inner and outer columns may cause movement and cracking of joints or partition walls. In mass concrete creep may cause cracking when concrete undergoes differential or cyclic temperature changes. In prestressed concrete member the creep effect may be seen and there may be loss of pre stress due to the effect of creep in pre stress concrete members.

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So, to summarize we have discussed, several distresses in concrete. We have discussed the freezing and thawing type of distresses. And, the causes and effects of freezing and thawing type of distresses, how we can resist freezing and thawing. And the effect of air entrainment in resisting freezing and thawing. We have discussed the thermal effect in concrete, the daily variation of temperature and the seasonal variation of temperature and their effect.

We have discussed the shrinkage in concrete, the types of shrinkages, the factors influencing the shrinkage and how we can resist shrinkage. The creep of concrete also has been discussed, what are the factors that may influence the creep and what are the effects of creep in concrete. Thank you.