Concrete Engineering and Technology
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Lecture - 18
Concreting in cold weather

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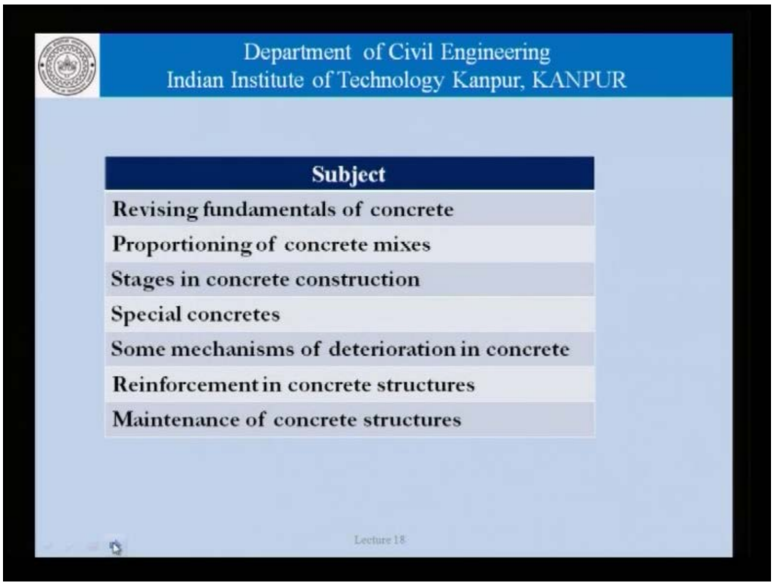

[FL] and welcome to this lecture on concrete Engineering and Technology, which is part of the module where we are talking about fundamentals, Proportioning, Stages of concrete construction, Special concretes, mechanisms of deterioration concrete, Reinforcement and Maintenance of concrete structures. The basic idea being that the modern day's civil engineer needs to be exposed to a wide variety of subjects related to concrete and concrete construction ranging from materials to construction, quality control and maintenance of structures made with this material. As far as our discussion on special concretes is concerned what we must understand to begin with is, what makes a concrete or a concreting operation special?

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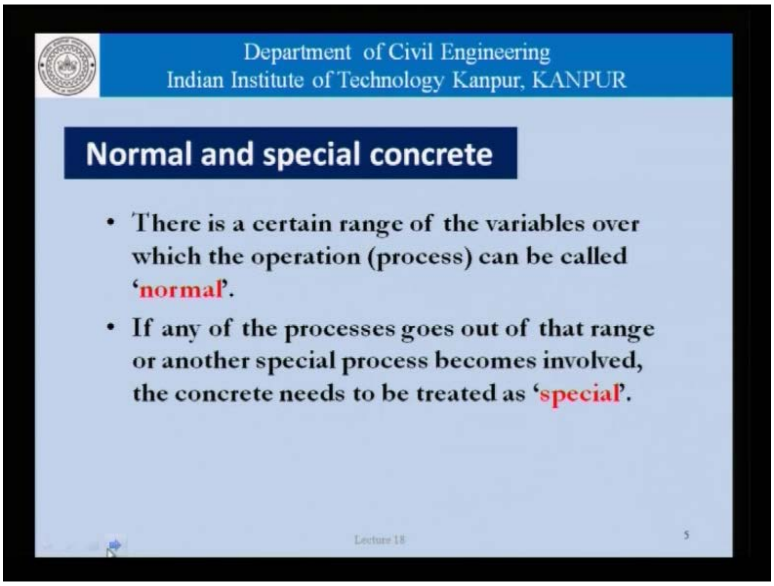

For that we need to distinguish between 'normal' and 'special' concretes. And as we have talked about earlier, there is a certain range of variables over which the operation can be called normal. And if any of the processes, be it the materials or material selection, mixing, transportation, curing, placing. If any of these processes goes out of that range or another special process becomes involved, the concrete needs to be treated as special.

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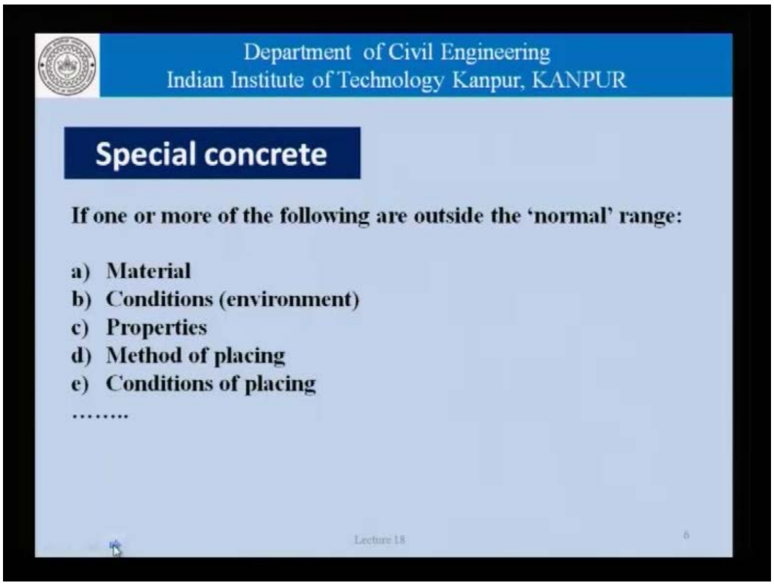

Now, what are the conditions of placing our environment in which the concrete is being placed? Is another consideration which could make the concreting operation special. Properties of concrete: Now, whether it is the strength, workability, density, any of these properties if they go beyond a normal range we will have to treat the concreting operation a special. Method of placing: Whether it is being placed using Fermi’s, shoots, short created, normally placed using pumps, any of these operations can make the concrete special. The conditions of placing: Whether it is windy or it is chilly and so on.

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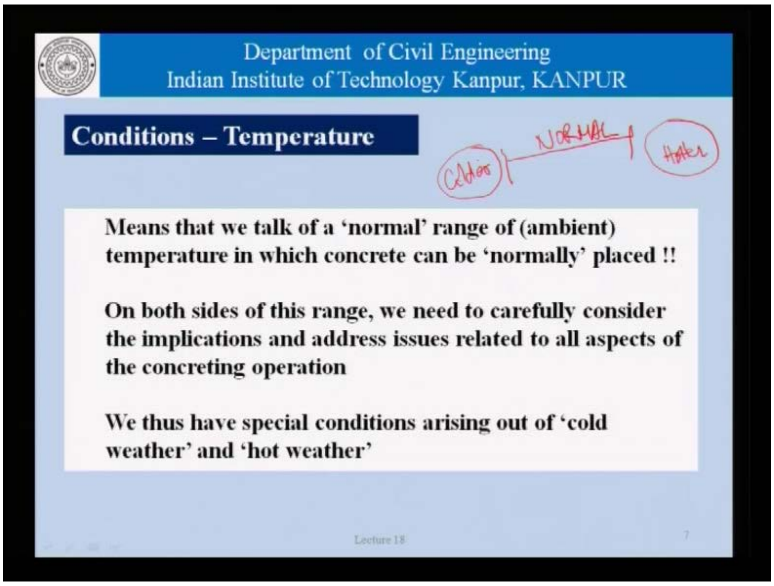

As far as conditions are concerned; Let us talk about temperature which is the subject of concern for a discussion today. What we mean to say is that we talk of a normal range of ambient temperature in which concrete can be normally placed. That is, we do not have to take any special precautions for the concreting operations so long as the ambient temperature is within a normal range.

On both sides of this range therefore, we need to carefully consider the implications and address issues related to all aspects of the concreting operation. If we have this range which tells us that, the concreting operation here can be treated as normal, the temperatures here are colder than that range and the temperature here are hotter than that range. And in both cases we need to consider the effect of ambient temperature on the concreting operation. We thus have special conditions arising out of cold weather or hot weather concreting.

Different countries have different average temperatures. The same country may have different average temperatures over a period of a year; that does not mean that the construction using concrete cannot be held if the temperature is not within the normal range. Engineering has now reached a stage where, so long as we take proper precautions and we are aware of the implications of cold weather or the hot weather concrete, we can continue with our construction operations.

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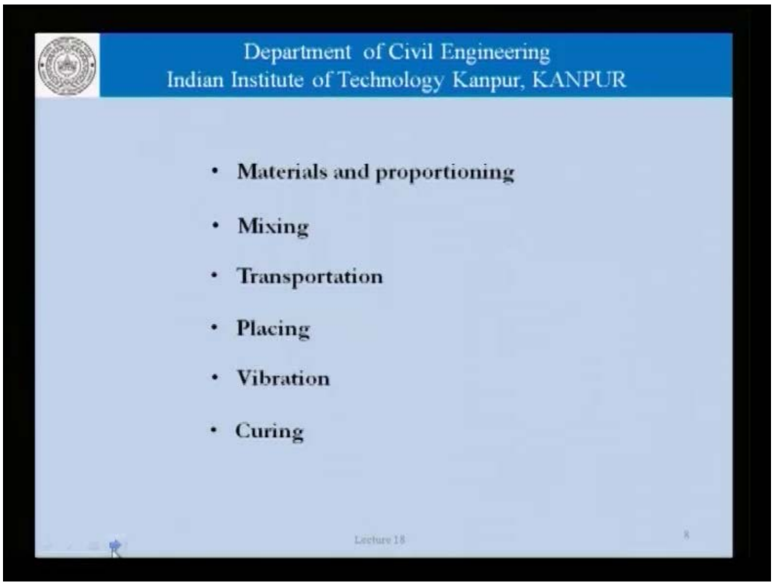

We need to talk about materials and proportion; we need to talk about mixing, transportation, placing, vibration, curing and everything. So, when we talk of hot weather or cold weather concrete, we need to take care of all the aspects relating to the concrete operation. Materials and proportioning, mixing transportation, placing, vibration and curing all these operations we need to examine in light of the implication as that colder weather or hotter weather. Then, the normally expected range imposes on this operation.

So, continuing our discussion, we focus on cold weather concreting today. And as per the definition of the ACI 306, American Concrete Institute Committee: Cold weather as far as concreting operations is concerned is defined as a period when, for more than 3 consecutive days the following conditions exist. The average daily temperature is less than 5 degree centigrade and the air temperature is not greater than 10 degree centigrade for more than half of any 24 hour period.

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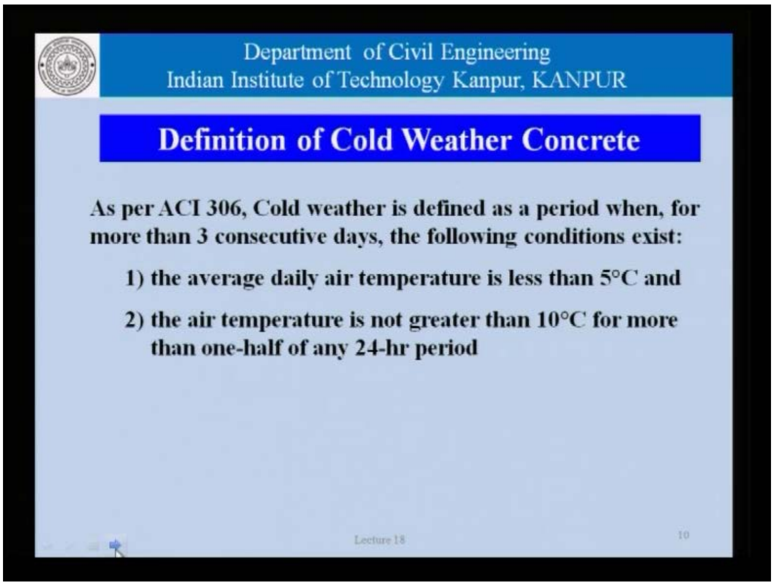

We need to have such a clear definition of cold weather because, only then weather can write our specifications properly, only then we can talk in terms of proper performance of concrete and those quality control methods that will apply under these conditions.

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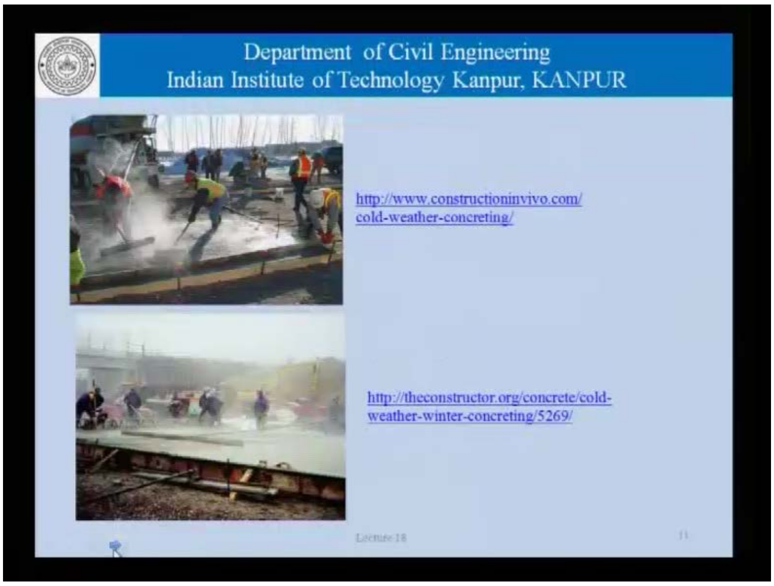

So, with this definition let us continue our discussion and see some of the illustrative example that we see here. From concreting operations going on in cold weather and it is possible to do this accept that we should be careful as to what we are doing.

The biggest problem with cold weather concrete is the fact that concrete has water and this water would tend to freeze and not be available for hydration of cement. And if cement does not hydrate, there is no point in talking about concrete construction, there is no strength development. Freezing of water has the implication of causing disruption as far as the pore structure whatever is formed in the concrete. That is also an undesirable threat.

We also need to ensure that, whatever heat that is generated as far as concrete is concerned form the hydration of cement, is not quickly dissipated into the atmosphere and the concrete remains in a condition that hydration can continue. So, we need to have a very very strong insulation that provides the right environment for the concrete to hydrate or for the cement in a concrete to hydrate. It is like trying to protect the concrete in the early stages and ensure that the concrete reaches the desired strength. Once that happens then, concrete can be treated as normal concrete subjected to cycles of cold weather or hot weather or whatever it is. But, the initial period is what requires very very careful attention of engineers.

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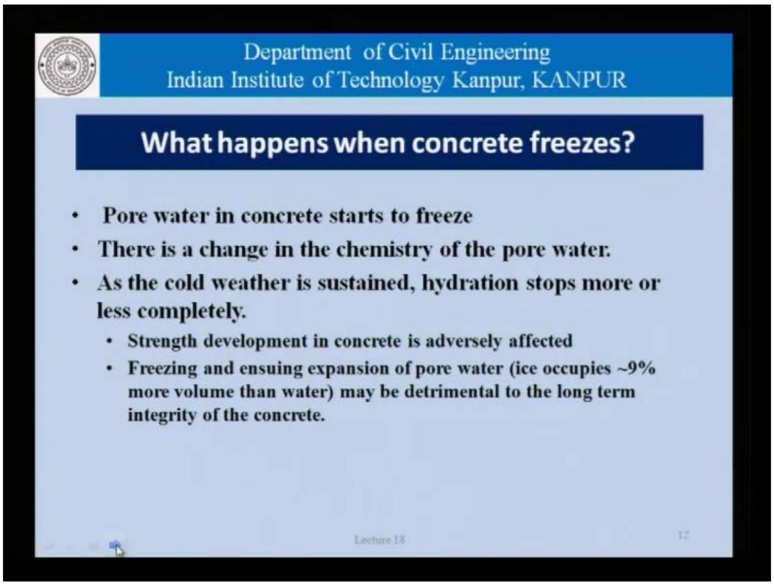

What happens when concrete freezes? Pore water in concrete starts to freeze. There is a change in the chemistry of the pore water. Because, once part of the water is frozen, part of the water is not, the concentrations of the ions in the different parts of water are different. The changes in concentration of ions in the pore water cause changes in the freezing point of the water and so on.

Now, if the cold weather is sustained, hydration more or less stops. And this adversely effects the strength development in concrete. And, freezing and ensuing expansion of pore water or ice occupying, slightly more volume than water as we know, may be detrimental to the long term integrity of concrete. So, we really do not begin on the right foot, if we do not take precautions that need to be taken in cold weather concrete. So, today's discussion will focus on, what really engineers need to do to ensure quality construction in cold weather.

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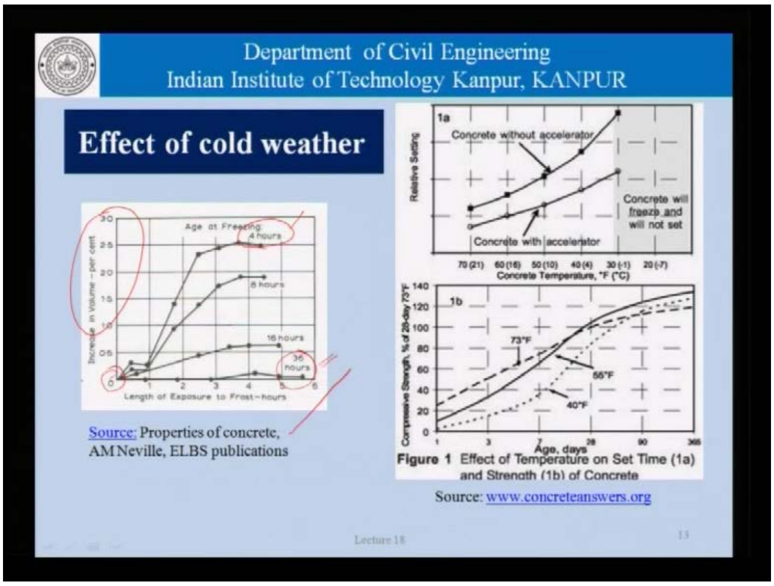

Here are some of the implications of cold weather concreting. If we look at this picture here, it says increasing volume versus the length of exposure to frost. If the age at freezing is small then, we see that the increase in volume is the largest. But, if the age at freezing is 36 hours, this being just 4 hours. So, if you are able to protect the concrete from freezing, for us little as 36 hours; we can more or less control expansion involving that we are likely to encounter. So, these kinds of diagrams or data help us understand, why we need to protect the concrete in the initial part.

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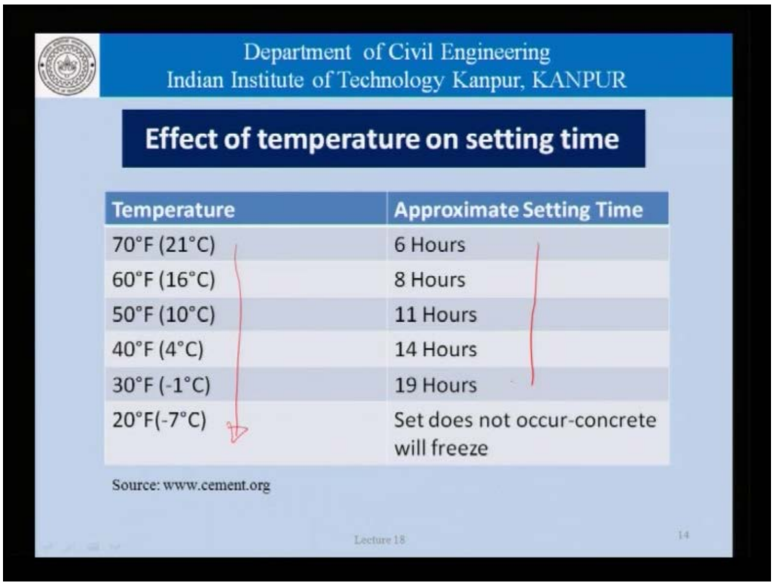

As far as the setting time of concrete is concerned: We have talked about, how the setting time of concrete is determined and is different from the setting time of cement. Concrete is being determined by wet sieving and having the same principle of penetration resistance. We find that, as the temperature reduces, as the ambient temperature becomes colder and colder, the setting time increases. And this has implications in terms of obviously strength development, form work removal and so on and so forth.

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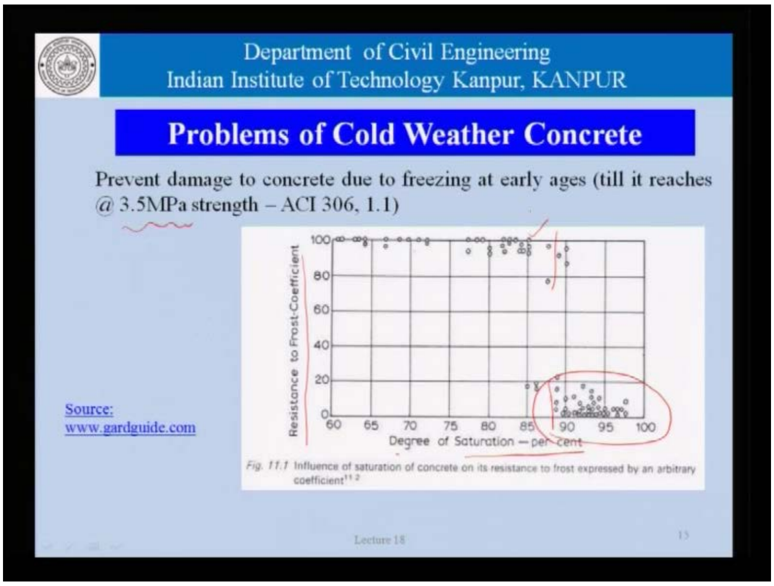

This here is another picture which shows, in order to prevent damage to concrete due to freezing at an early age we need to ensure that, at least till a strength of about 3 and a half MPa is reached, the concrete needs to be really protected. If this data is to be examined, we will find that the resistance to frost. As far as with the degree of saturation is concerned, anything beyond 90 percent of saturation is highly detrimental. The resistance to frost is very, very small. Whereas, if the saturations are lower than this; of about say 90 percent, we have a reasonable resistance to frost.

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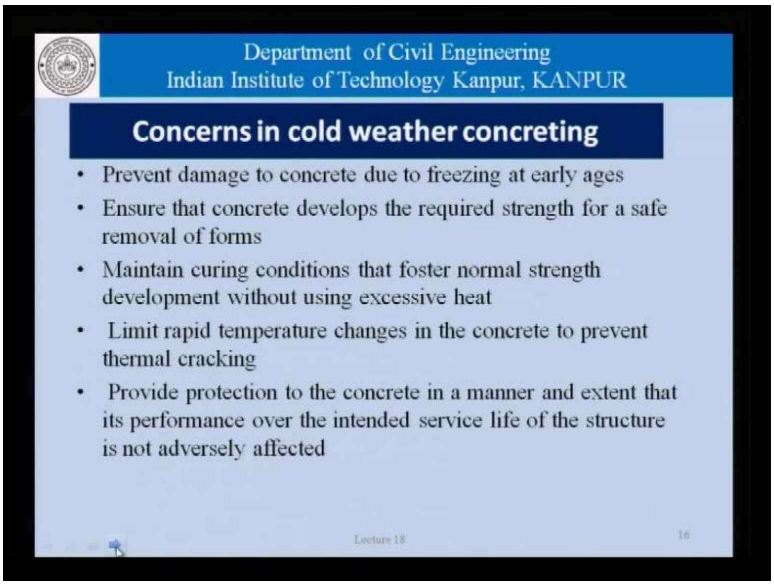

As far as our concerns in cold weather concreting, we need to ensure that we have appropriate damage control to prevent the concrete from freezing at early ages. We need to ensure that concrete develops the required strength for a safe removal of formworks. We need to maintain curing conditions that foster normal strength development without excessive heat being used from outside. We need to limit the rapid temperature changes in the concrete to prevent thermal cracking. We need to provide protection to the concrete in manner and extent that its performance over the intended service life is not adversely affected.

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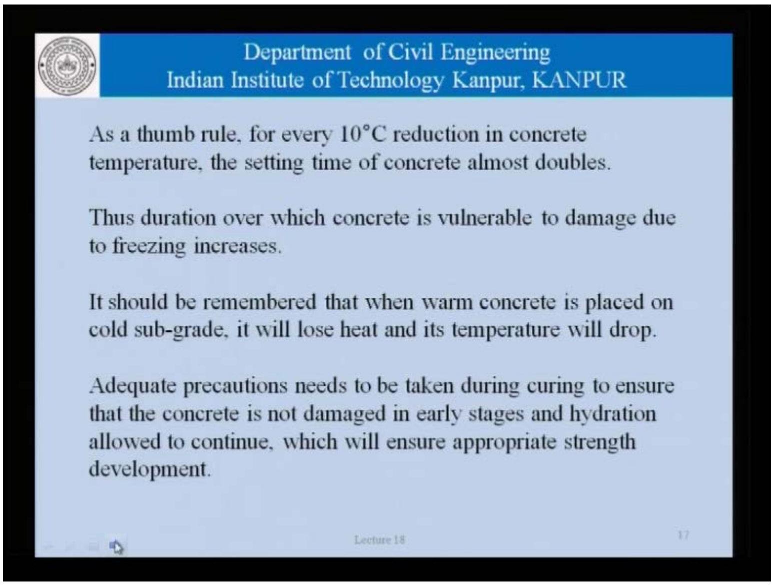

Now as a thumb rule, for every 10 degree reduction in the concrete temperature, the setting time of concrete almost doubles as we saw in a previous slide. Thus, the duration over which the concrete is vulnerable to damage due to freezing increases. So, long as the concrete does not set, the concrete is very vulnerable to freezing, the water there in is vulnerable to freezing. It should also be remembered that, when warm concrete is placed on cold sub-grade it will lose heat and its temperature will drop.

Concrete is often placed against the ground or against formwork. We need to ensure that the temperatures of this contact surface whether, it is the ground or the formwork is not abnormally low. This we can only ensure by heating the surfaces. And that is another of the concerns that we have. We need to take adequate precautions during curing to ensure that the concretes not damaged in early stages and the hydration is allowed to continue, which will only ensure the appropriate strength development.

Now, concrete that is protected and properly cured will obviously mature to its potential strength despite subsequent exposure to cold weather. So, it is only in the initial stages, the first few hours or may be a day or two that is when special attention needs to be paid to the curing regime to the temperatures that the concrete is exposed to and so on.

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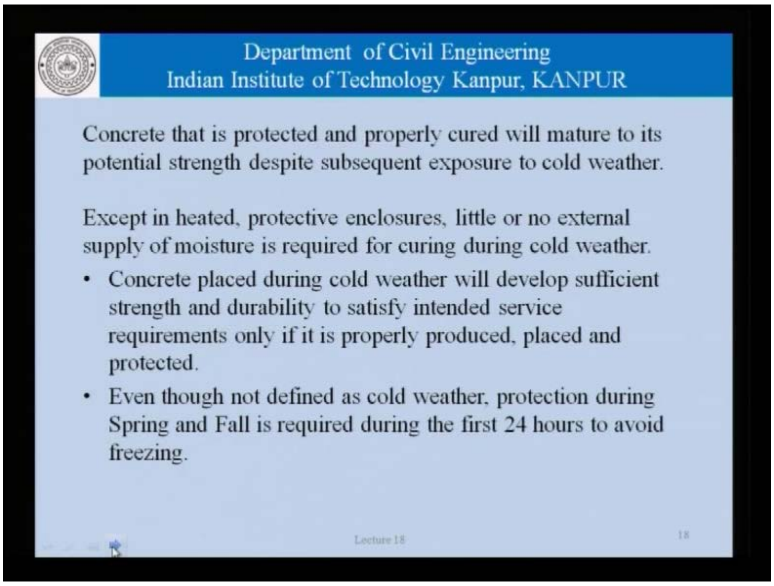

So, except in heated protective enclosures, little or no external supply of moistures are required for curing during cold weather. So, if you are using a closed enclosure to cast the concrete structures, there of course, we need to do moist curing as usual. But otherwise, we have to be careful that we do not need to provide too much water from outside which will only add to the problem of freezing of that water.

Concrete placed during cold weather will develop sufficient strength and durability to satisfy intended service requirements only if it is properly produced, placed and protected. As far as production is concerned, we need to take precautions to make sure that the concrete temperatures are such that, the placing operation can be taken place. The concrete does not cool while it is being transported. Even though not defined the cold weather, protection during spring and fall is required.

Now, let us come to, what are the actual things that an engineer can do or a builder needs to do in order to ensure proper construction during cold weather. So, we come to recommended practices. We must remember that, cold weather or hot weather or any such special conditions is after all a matter of practice. And, the practice has to be based on the understanding of the principles. And those principles are: Loss of water, water required for hydration, the temperature required to ensure that hydration continues and so on. And the practice basically means, what are the kinds of things that we need to do, in order that these conditions are appropriately maintained. First thing is that, we need to plan the operation very carefully.

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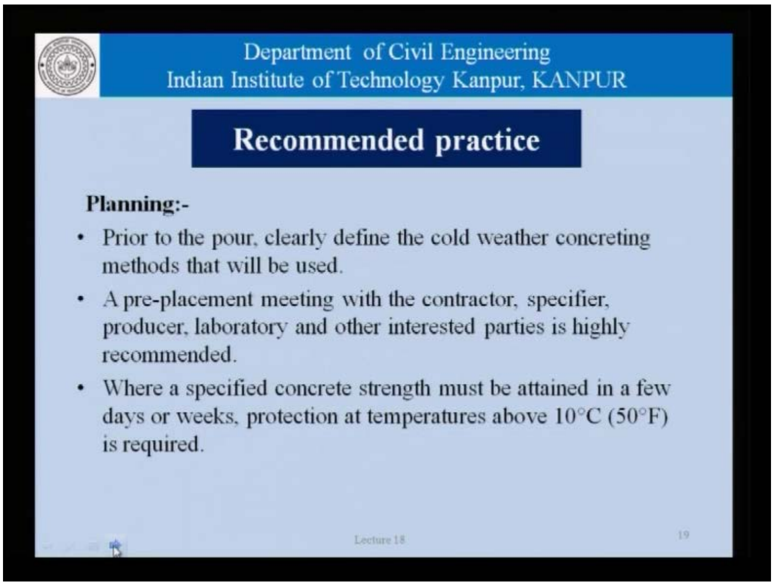

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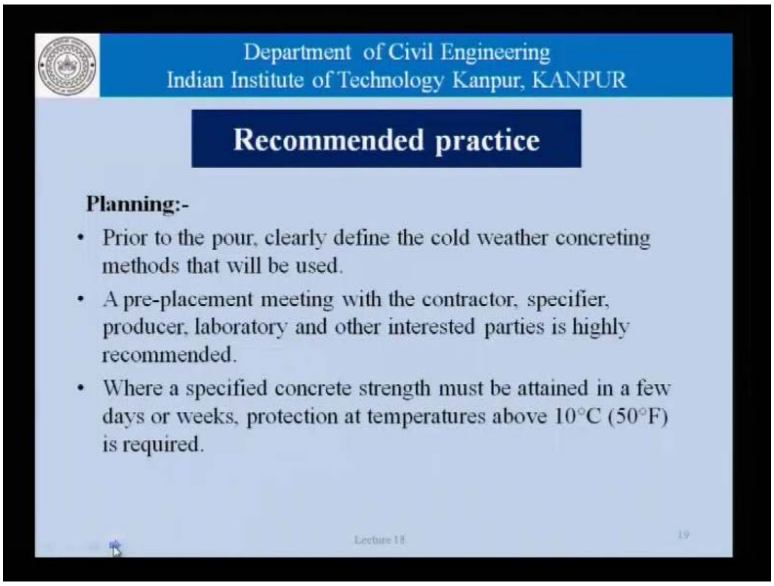

Prior to the pour, clearly define the cold weather concreting methods that will be used. What are the kind of precautions that will be taken at the batching plant during the transportation of the concrete to the site and while placing?

What are the kinds of curing methods that will be used? Do we have the kind of materials available at site to carry out all those operations that cause for a very, very careful planning before carry out the actual operation? This can be ensured through a meeting or a discussion where, the contractor, the specifier, the producer, the laboratories involved and everyone have a clear understanding of what their roles and responsibilities in the operation are. Where a specified concrete strength must be attained in a few days or weeks, protection at temperatures above 10 degrees is required.

So, basically what this 10 degree says is that; during the curing period, concrete in its real, the immediate neighborhood of concrete must be maintained at a temperature of about 10 degree centigrade. That obviously requires heating of the environment. Now, how we achieve it, is a different matter.

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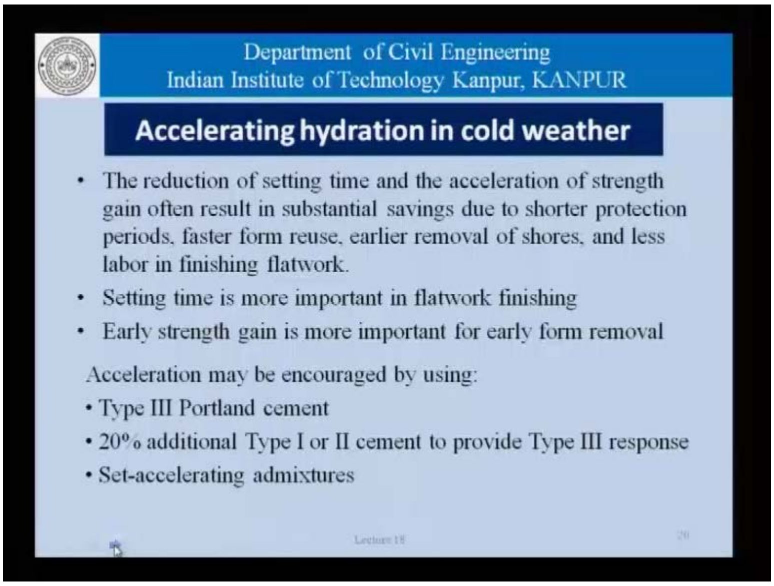

We could accelerate the hydration process in cold weather and that could be done by several methods. The reduction of the setting time and the acceleration of strength gain often results in substantial savings due to shorter protection periods, faster form reuse, earlier removal of shores, and less labor in finishing flatwork.

The setting time is more important in flatwork finishing. Flatwork finishing refers to structure such as, high ways or slabs in multistoried buildings and so on. Early strength gain is more important from the point of view of form removal. The economic system remains the same. If the formwork cannot be removed, the cycle time for the next pore is adversely affected. And that happens where there concrete is being done, in cold weather or normal temperatures. Therefore, if you are able to ensure early strength gain we would be able to get a more productive cycle. This acceleration, as far as the early strength gain is concerned, can be achieved by using appropriate port land cements. We can use additional cement or we can use set accelerating admixtures or accelerators.

Now, as far as accelerators are concerned, calcium chloride is perhaps the most economical accelerated we used. But, one must be very careful in using calcium chloride because of the presence of chloride ions. Now, these chloride ions are known to be deleterious from the point of view of corrosion of the reinforcement. And therefore, in cases when the structure is reinforced, calcium chlorides are often appropriated from use.

In other words, we should be careful in choosing the admixture. It should be chloride free and meet any other requirement that may be set by the designer, as far as the choice of materials is concerned, as far as the placing temperature is concerned and so on.

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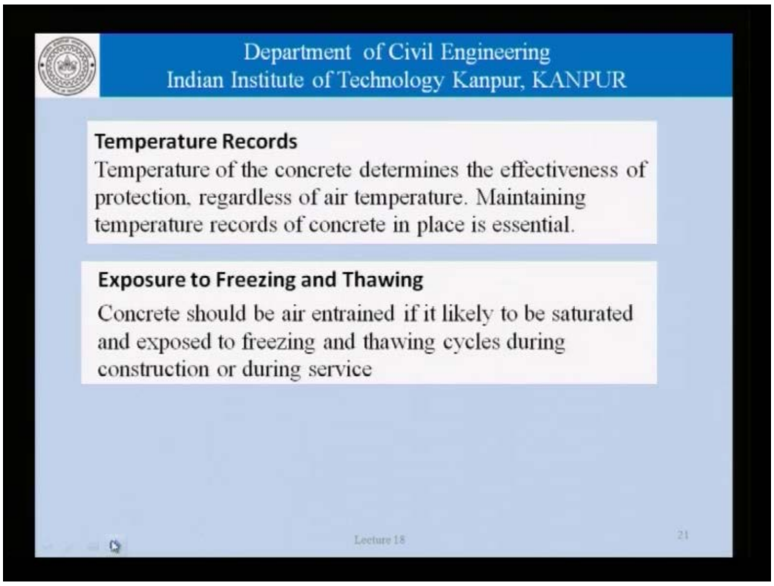

What are the records that need to be maintained? Temperature Records: Temperature of the concrete determines the effectiveness of protection, regardless of air temperature. Maintaining temperature records of concrete in place is very very essential. We shall see later on that, maintaining these records also helps us understand or relate to strength development through the conceptive maturity.

Exposure to Freezing and Thawing: An concrete obviously needs to be air entrained, if it is likely to be saturated and exposed to freezing and thawing cycles during construction or during service. So, we have seen graph which tell us that, if the concrete is saturated, the resistance to freezing and thawing is poor.

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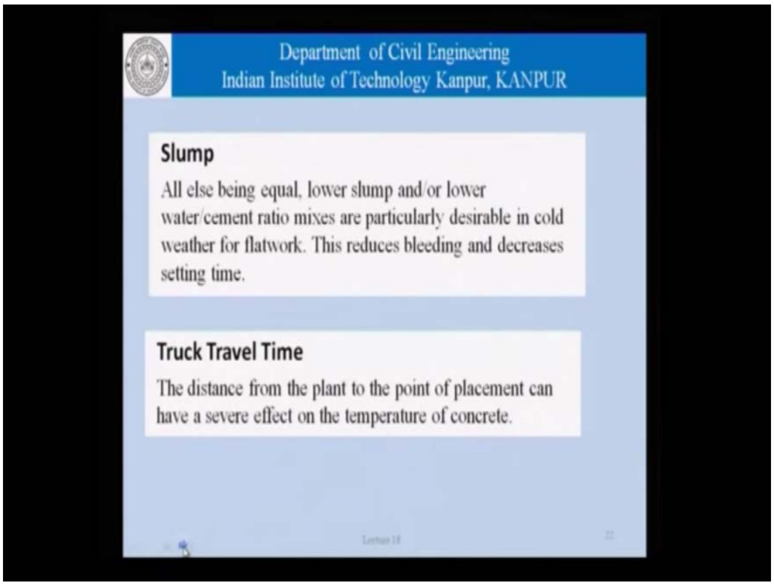

Coming to the properties of fresh concrete that can be used or that should be used in cold weather. Everything else being equal, lower slump and or water cement ratio mixes are particularly desirable in cold weather for flatwork because that reduces the bleeding and also has the effect of reducing the setting time. We need to take into account all kinds of things. Like the ‘Truck Travel Time’; how much time does the concrete need to be on the move during transportation? And that includes the distance from the plant of placement and so on. And, if these things are not accounted for the properties of the concrete can be adversely affected. Now, as far as the placement temperature and protection in cold weather is concerned, the ACI provides recommendations for the temperatures for placement and protection.

Now, depending on the air temperature whether, it is above minus 1, between minus 18 to minus 1 and below minus 18. Depending on the section size or the minimum dimension of the member in millimeters let us say, less than 300 or 300 to 900 and so on. This table here, gives us the minimum temperature of concrete as mixed. Then, there is a temperature as placed and maintained.

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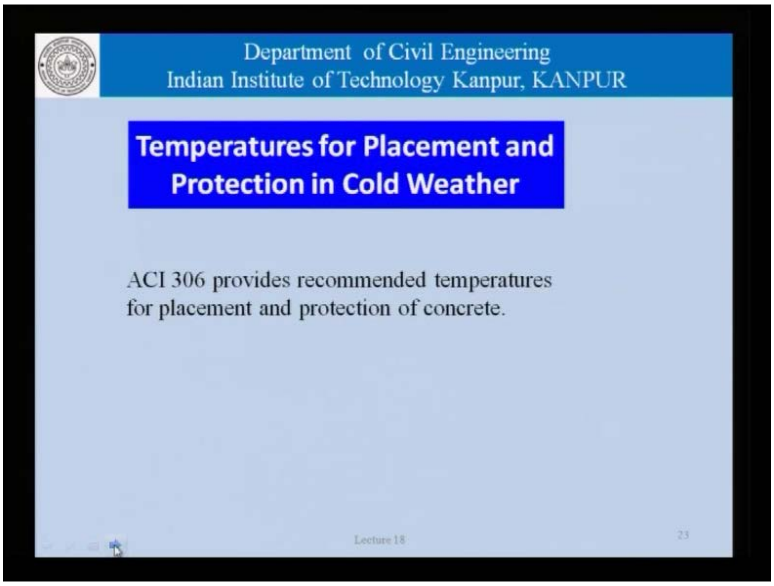

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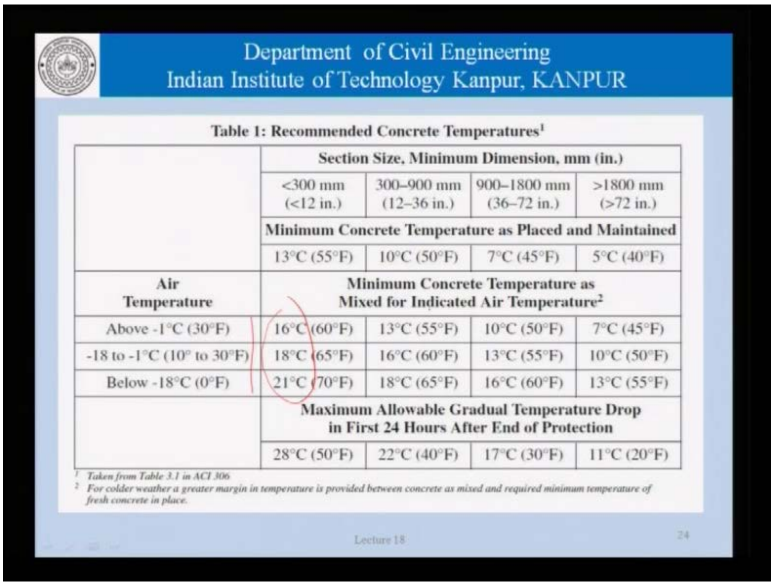

Table 1: Recommended Concrete Temperatures[1]

	Section Size, Minimum Dimension, mm (in.)			
	<300 mm (<12 in.)	300–900 mm (12–36 in.)	900–1800 mm (36–72 in.)	>1800 mm (>72 in.)
	Minimum Concrete Temperature as Placed and Maintained			
	13°C (55°F)	10°C (50°F)	7°C (45°F)	5°C (40°F)
Air Temperature	Minimum Concrete Temperature as Mixed for Indicated Air Temperature[2]			
Above -1°C (30°F)	16°C (60°F)	13°C (55°F)	10°C (50°F)	7°C (45°F)
-18 to -1°C (10° to 30°F)	18°C (65°F)	16°C (60°F)	13°C (55°F)	10°C (50°F)
Below -18°C (0°F)	21°C (70°F)	18°C (65°F)	16°C (60°F)	13°C (55°F)
	Maximum Allowable Gradual Temperature Drop in First 24 Hours After End of Protection			
	28°C (50°F)	22°C (40°F)	17°C (30°F)	11°C (20°F)

[1] Taken from Table 3.1 in ACI 306

[2] For colder weather a greater margin in temperature is provided between concrete as mixed and required minimum temperature of fresh concrete in place.

Let us look at this picture here or this data here which is the summary of the same table which was shown earlier. A, B and C are temperatures of fresh concrete as mixed. So, this is what is the temperature. These conditions are the temperatures of: The ambient temperature being minus, greater than minus 1 and in the range of 8 minus 18 to minus 1 and so on. And this is the temperature of fresh concrete as mixed.

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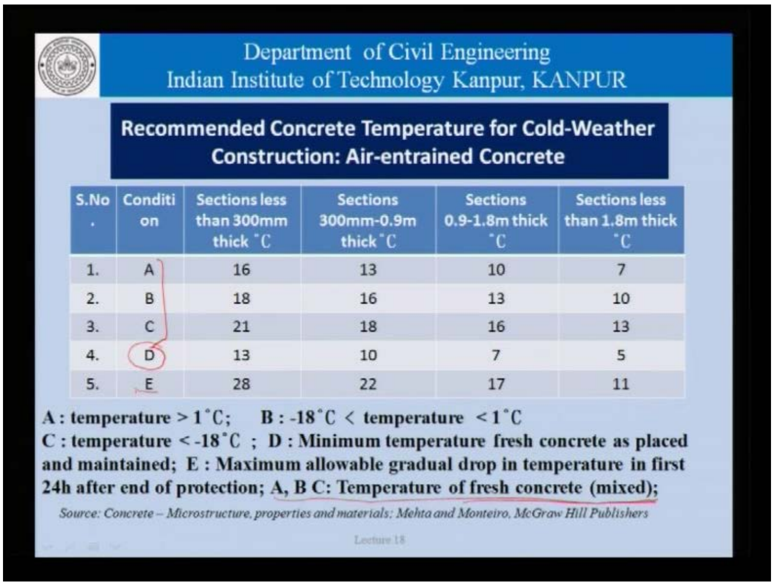

Whereas, D is the temperature, which is as placed and maintained. So, there is a mixing temperature, there is a placing temperature and there is a temperature at which the concrete needs to be maintained. So, ACI 306 gives us a clear guideline as to, what is the expected temperature which we need to maintained at which the concrete may be mixed. Because, the moment it has mixed and is placed it tends to lose heat on account of the very very cold atmosphere.

The condition E here is the maximum allowable gradual drop in temperature in the first 24 hours after the end of protection. So, there is within curing regime or within the duration of curing, there is a time where the concrete is protected and beyond that it is unprotected curing. So, during the protected curing period, there are certain conditions to be met. And beyond the protection period while the concrete is still being cured, the condition the set of conditions may be different.

Now, as far as preparations for concrete before the concreting operation is concerned, all snow, ice and frost need to be removed. Concrete should not be placed on frozen sub-grade. It must be thawed and if required compacted. Thawing can be done by Steaming, spreading a layer of hot sand of gravel, removing and replacing the unfrozen fill, covering sub-grade with insulation for a few days, using heaters under insolated blankets.

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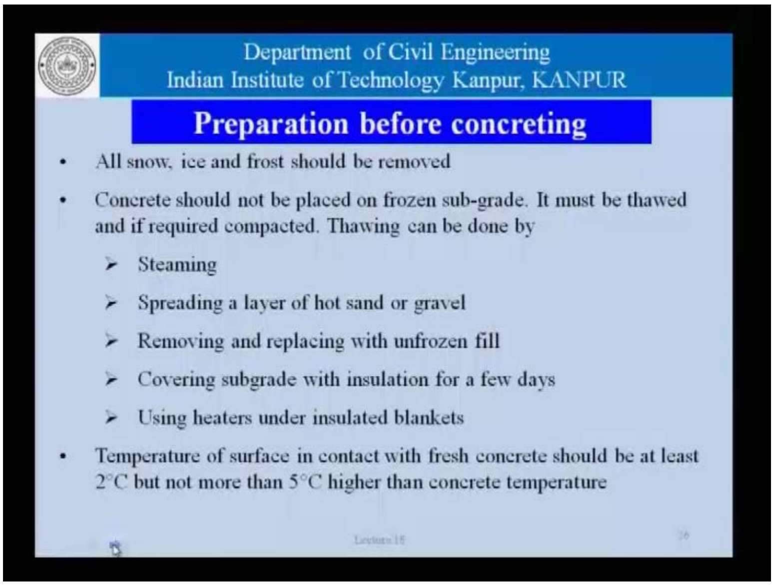

Many cases concrete cannot be placed on frozen or very very cold sub-grade. These issues or this aspect of concrete not being cast against a very cold surface should also be born in mind when we are casting concrete against formwork. Whereas, this kind of an operation or all these conditions are applicable when we are casting concrete against the sub-grade. For example, as may happen in the case of highway construction and so on. The principle should also be born in mind, when we are casting normal concrete in beam, slabs and so on.

The temperature of surface in contact with fresh concrete should be at least 2 degrees but, not more than 5 degrees higher than the concrete temperature. Having said that the surface should not be cold to a very large level, that does not mean that the surface can be heated or should be heated indiscriminately. A certain balance has to be maintained between the temperature of the surface against which the concrete is been cast and the temperature of the concrete itself.

One of the methods that is often used in cold weather concreting is heat the constituent materials. A constituent material means water. So, the temperature of water may be raised but, not more than about 80^0 C. The pipeline and the storage tank that hold the water obviously then, need to be properly insulated to avoid any heat loss for the water to literature the batching plant

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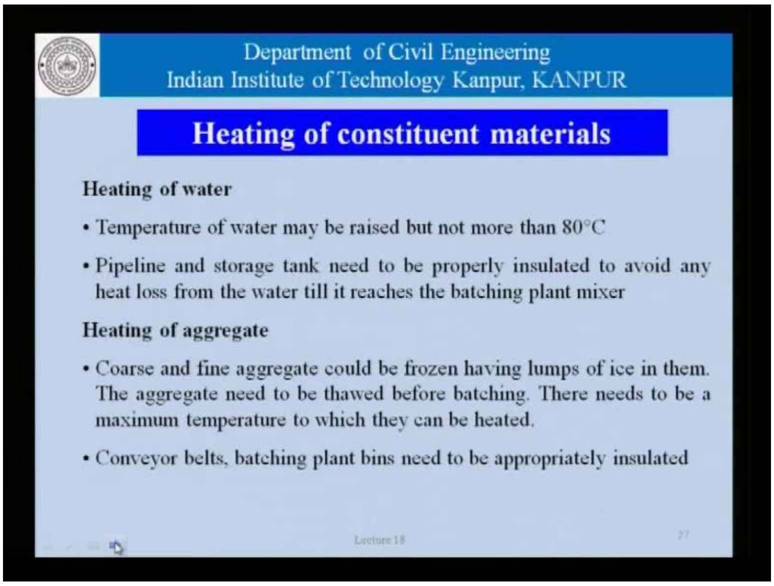

If the heating of water is not sufficient then, we may also need to resort to heating of aggregate: the sign the fine aggregate and the coarse aggregate. The coarse aggregate and the fine aggregate could be frozen having lumps of ice in them. And they need to be thawed before batching. There needs to be a maximum temperature to which they can be heated. As in the case of water, aggregate cannot also be allowed to be heated indiscriminately.

Depending on what method we are using for transportation of concrete: Conveyor belts, batching plant bins, agitator trucks and so on needs to be appropriately insulated. Let the time of transportation involved is equally important because, unless we know the time, we cannot talk in terms of the difference between the temperatures of concrete. As mixed, that is at the batching plant and as placed, which will be at the site.

This here is a picture of aggregate storage. This is an extended form. So, this part here, can be pulled all the way here, in order to create an enclosure which is like this and can be used to house the aggregate. Once we have enclosed the aggregate in a certain confine space like this, it is easier and more economical to maintain the temperature inside this enclosure and that goes a long way in maintaining the temperature of fresh concrete.

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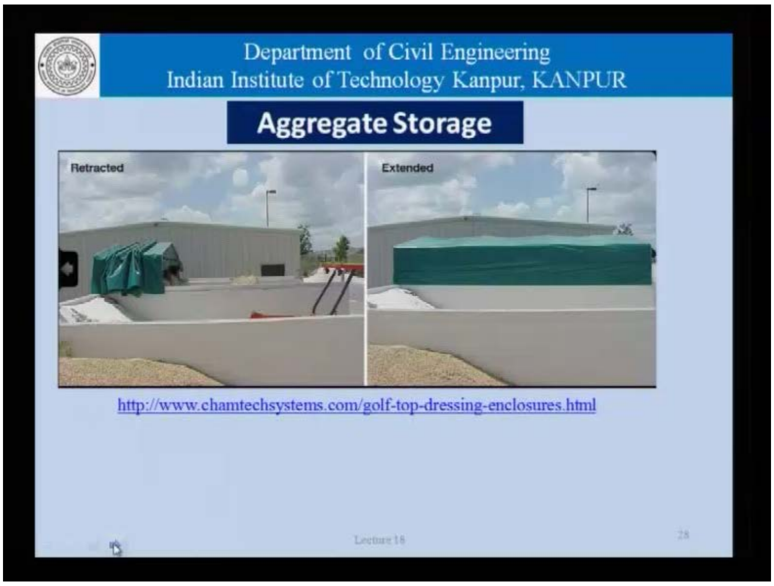

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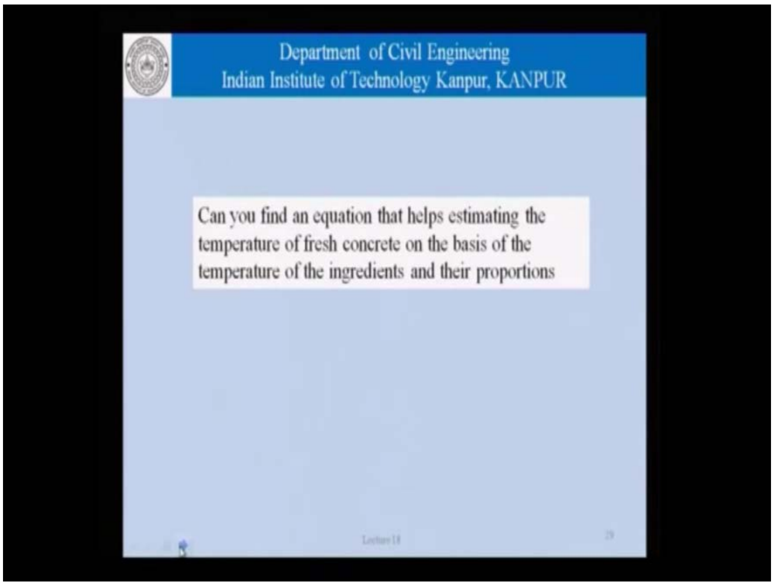

Here is an equation that helps us estimate the temperature of fresh concrete based on the temperatures of the constituents and their relative proportions. Using this equation and the kind of proportions that we are using, we can understand or estimate; that ok, if we want a certain temperature of fresh concrete, what should be the most economical way of achieving that? By the way of playing around with the temperatures of the constituent materials, whether, that is water or it is aggregates. It is very clear from our discussion that fresh concrete needs to be protected.

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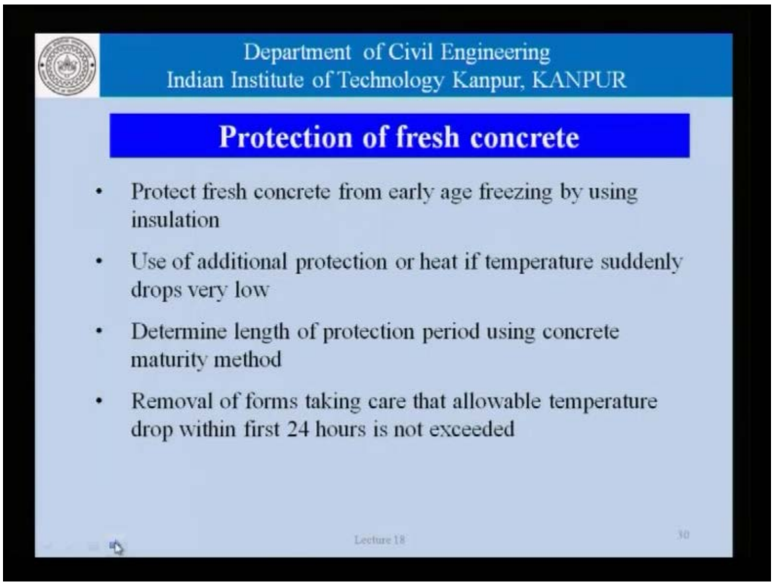

It needs to be protected from early age freezing by using insulation. We need to use additional protection or heat, if temperature suddenly drops very low. We need to determine or estimate the length of protection period using maturity. Maturity is a concept as we will see later, which integrates the time and the temperature.

We also need to ensure that, removal of forms is done taking care that allowable temperature drop within the first 24 hours is not exceeded. As far as the concrete is concerned so long as it is in contact with the formwork it is protected. We can even try to heat the formwork to ensure that the concrete is enclosed in an environment which is in an acceptable temperature range. Moment we remove the formwork, the concrete is obviously now exposed to ambient temperatures. And we need to ensure that, the temperature drop that occurs between the first 24 hours after the formwork has been removed is in an acceptable range. Sudden, cooling of the surface of concrete could be very, very detrimental from the point of view of the strength development or the integrity of the surface concrete is concerned.

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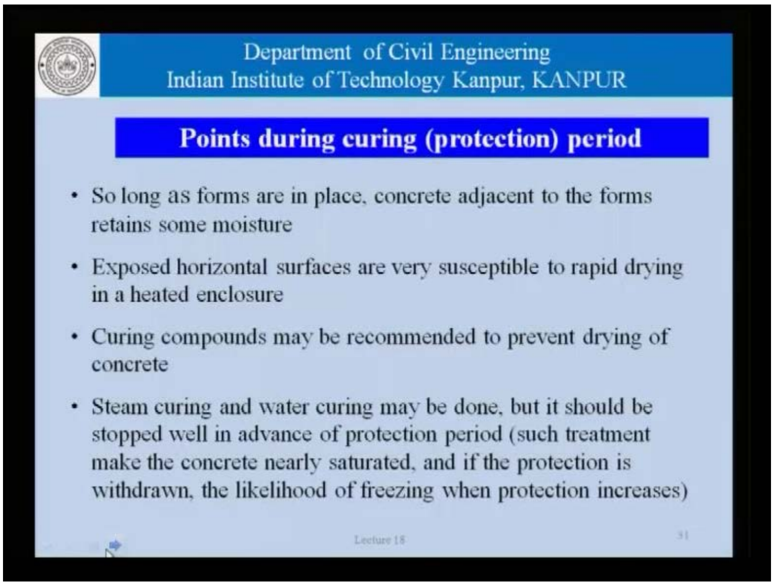

Continuing from that point, we have that so long as the forms are in place, concrete adjacent to the forms or in contact with the form work retains some moisture. And the moment the form work is removed, this situation changes. Exposed horizontal surfaces are very susceptible to rapid drying in a heated enclosure. So, either way if we are casting a slab and we are trying to heat the environment in which being cast, the surface will be susceptible to drying. If we are not heating the environment then, the surface water or the water in the layer closed to the surface is susceptible to freezing. So, it is a very, very difficult and a very thin line that an engineer has to walk to make sure that the concrete is appropriately protected at the surface. And therefore, we need to use or sometimes it is prescribed that we use curing compounds to prevent drying of the concrete.

Steam curing and water curing may be done but it should be stopped well in advance of protection period. Such treatment makes the concrete nearly saturated. That is, if we are curing it water or steam, the concrete is very nearly saturated to the surface as far as the levels of saturation is concerned. And if the protection is withdrawn while the concrete saturated, the likelihood of freezing when protection is removed increases and that is something which we need to watch out against.

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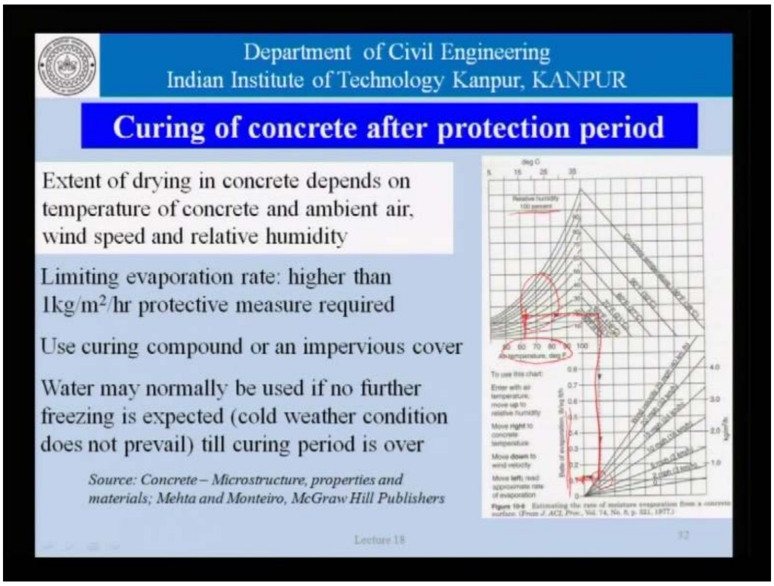

This here is a chart which has been developed to identify or better understand the curing of concrete after the protection period. The extent of drying in concrete depends on the temperature of the concrete ambient air, the wind speed and the relative and the relative humidity of the atmosphere. If the limiting evaporation rate is higher than a kg per square meter per hour, we need to have protective measures.

How do we use this chart? We enter this graph at the air temperature level, go up to an appropriate humidity level here, as shown here. We go up to humidity level, turn right and come to the concrete temperature, wherever we want to go. And then, come to the bottom and see, what is the wind speed. And corresponding to that wind speed, we get the rate of evaporation in terms of kg per square meter per hour. And if this rate is unacceptability high, we need to have special measures in place to protect the concrete.

Continuing with the recommendations for cold weather concreting: If the ambient temperature is more than 5 degrees, the conditions are more or less normal. We do not need to heat the materials. We can have a limit under placement temperature; no insulation is required, no curing during protection is required, time of protection is no specific limit. And there is curing after protection is normal water curing is all right.

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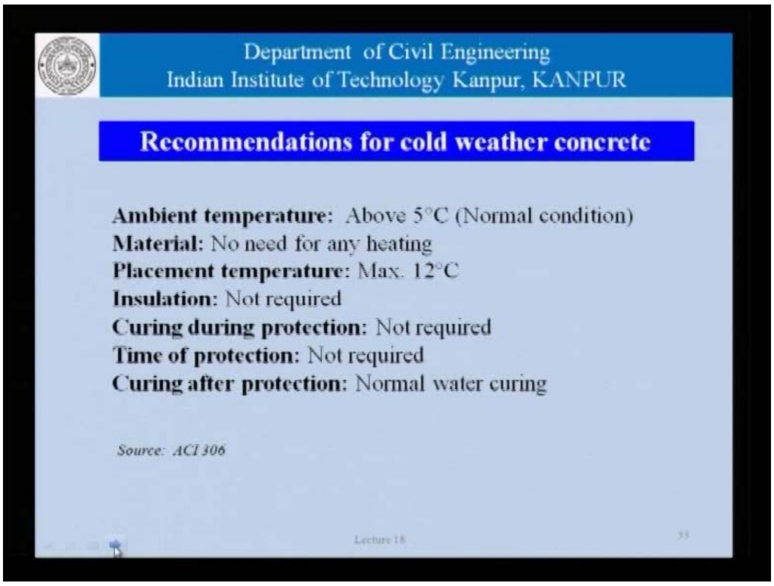

So, here too if you see, we are trying to divide the curing period into 2 parts: The part when the concrete is protected and the part, when the concrete is not protected. That is, curing after protection.

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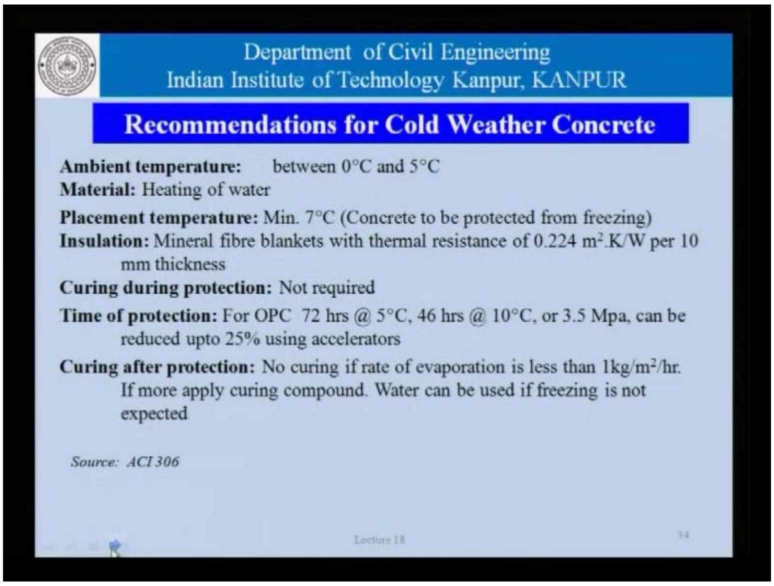

Now, if the temperature is between 0 and 5 degree centigrade, we may like to resort to heating of water to get the temperature of concrete in a manageable range. Placement temperature: We could put a minimum of 7 degree, in order to ensure the concrete is protected from freezing. As far as insulation is concerned, we may prescribe the use of mineral fiber blankets with a certain thermal resistance. We may say that, however we do not require curing during protection. As far as the time protection is concerned, we can lay down limits in terms of hours or in terms of strength development. We can relate that to the use of accelerators. And as far as curing after protection is concerned, we do not need to do anything special, if the rate of evaporation is less than a kg per square meter per hour. But, if it is more, we could always use a curing compound.

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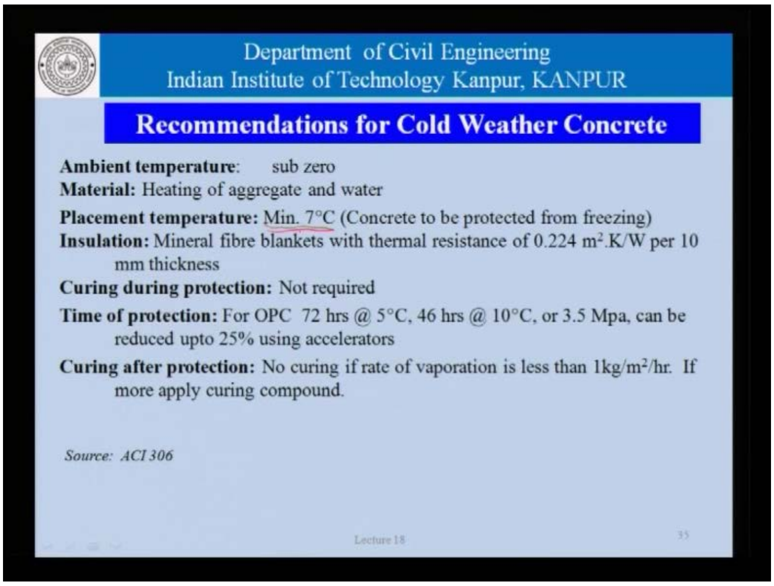

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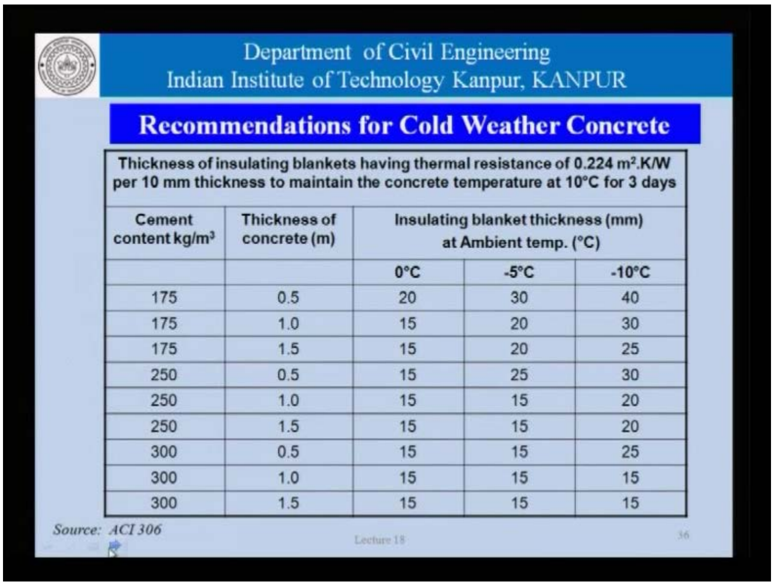

When the temperatures are sub 0, we may need to resort to not only heating water but, also the heating of aggregates, in order that the concrete needs the minimum temperature. Similarly, we need probably need to have mineral fiber blankets for insulation of the concrete and we of course, have and we can of course, prescribe the time of protection in terms of time or in terms of strength and talk terms of the curing after the protection.

This table here, gives us a variation of the thickness of insulating blankets which may be required to maintain the concrete at a temperature of 10 degree centigrade for 3 days. We would recall that, we talked about maintaining the temperature of 10 degree centigrade, in order to ensure that the strength development or the hydration continues at an acceptable rate. So, this is temperature can be maintained, if we have proper insulation. And that insulation depends upon, what is the cement content that we have. If the cements are higher, if the cement content is higher, we may be able to make do with slightly lesser insulation because the amount of heat that is generated on account of cements is higher. It also depends on the thickness of the concrete and the ambient temperature of air.

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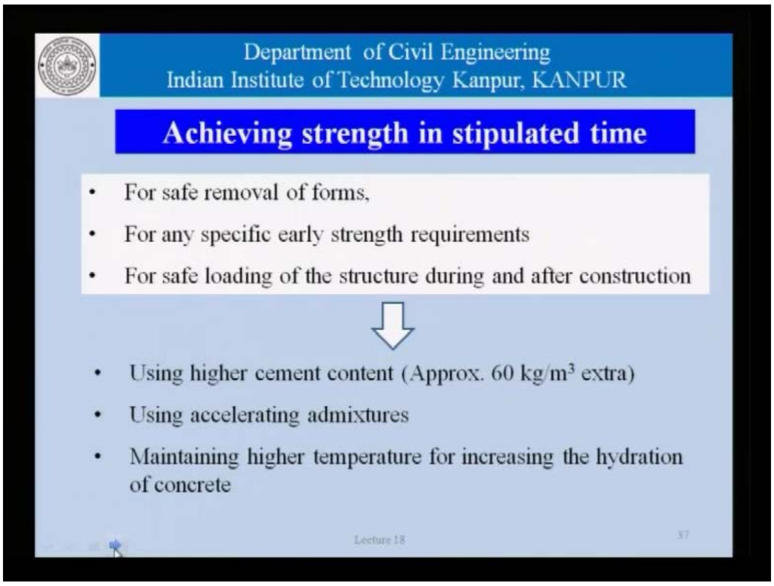

As far as strength is concerned, we need to have a handle on the strength for safe removal of formwork. For any specific early strength requirements that we may have from the service point of view and at the end of it for safe loading of the structures during and after construction. We can achieve this by using higher cement content, using mineral admixtures, using accelerating admixtures and maintaining higher temperatures for increasing the hydration of concrete.

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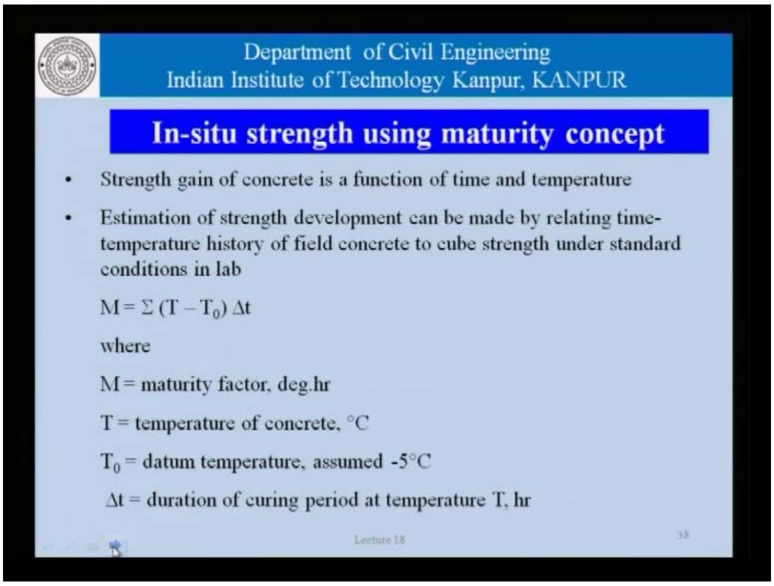

Now, explaining the concept of maturity which we have related to the previous discussion just now. The strength gain in concrete is a function of time and the temperature. The estimation of strength development can be made by relating the time temperature history of field concrete to cube strength under standard conditions the lab.

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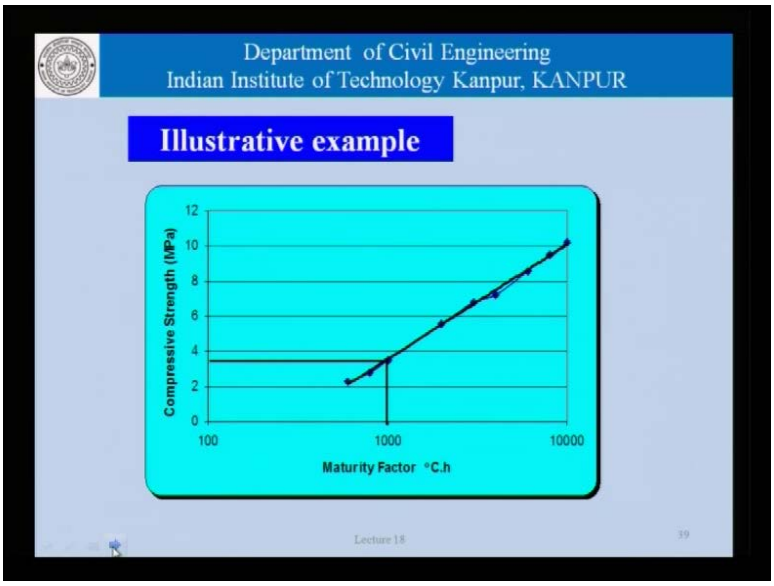

What is really done is, we calculate the maturity of concrete which is the sum of a temperature component and the time component. And once we have this maturity, we try to relate this maturity to the compressive strength. T 0 here, is a datum temperature, which is the reference temperature, which is taken as minus 5 or minus 10 degree centigrade.

And here is an illustrator example where, we talk in terms of a maturity factor which is degree centigrade time’s hour and the compressive strength. Note that, the maturity has been plotted on the logarithmic scale. So, log m versus the compressive strength has been found to be a more or less linear relationship. And therefore, as far as cold weather concretes are concerned, in order to get a particular strength, we can estimate the time and the temperatures. In order to obtain a particular strength, we can calculate or estimate the maturity that we need and this maturity is related to the time and the temperature.

So, if we know the time that we want to achieve a certain maturity in 3 days or 5 days, we know what kind of temperature regimes we must have. Or, if we know the temperature regimes, we can find out the time that it will take for a particular maturity to be reached which in turn would give us the estimated strength.

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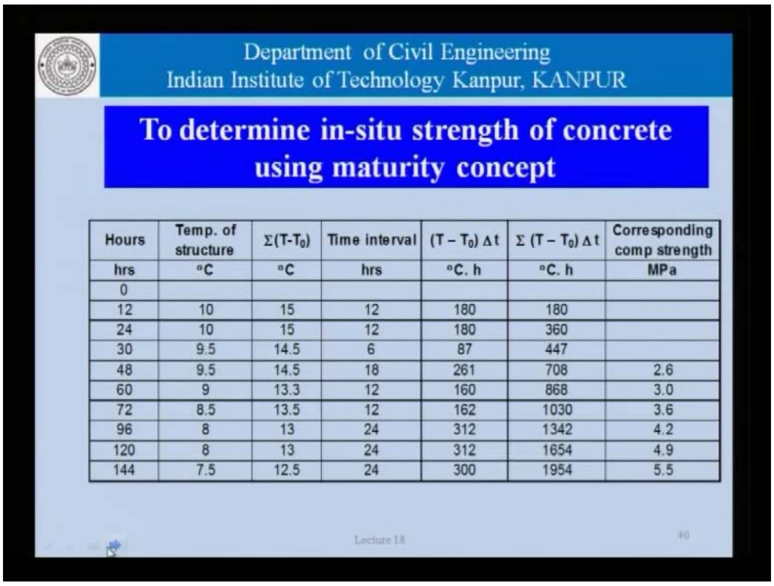

Hours	Temp. of structure	Σ(T-T_0)	Time interval	(T – T_0) Δt	Σ (T – T_0) Δt	Corresponding comp strength
hrs	°C	°C	hrs	°C. h	°C. h	MPa
0						
12	10	15	12	180	180	
24	10	15	12	180	360	
30	9.5	14.5	6	87	447	
48	9.5	14.5	18	261	708	2.6
60	9	13.3	12	160	868	3.0
72	8.5	13.5	12	162	1030	3.6
96	8	13	24	312	1342	4.2
120	8	13	24	312	1654	4.9
144	7.5	12.5	24	300	1954	5.5

This of course, is just the example of the estimation of easy to ease strength of concrete using the concept of maturity. So, if we know this temperature of the structure, if we know the temperature history, we have these time intervals, we can calculate the maturities and find the estimator strength. In order to calibrate it of course, we would like to; in order to calibrate this relationship or establish the relationship first time, we need to carry out tests which would involve the same kind of cement, the kind of aggregates and so on being used at site. Now let us, take a look at some illustrative examples which is basically, pictures of cold weather concreting which tell us, what kind of methods we need to use.

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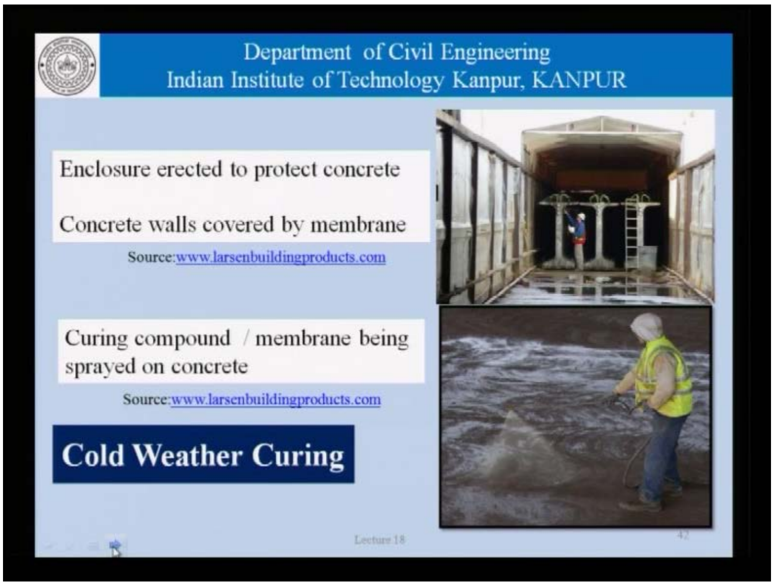

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This picture here for example, shows a enclosed structure which has been erected, in order to protect this concrete. Similarly, as far as panels are concerned, we could see the covering of membranes. As far as this picture is concerned, it is just an application of curing compounds being spread on concrete to service effective sealants.

The picture on the left hand side here is that of a concrete footing pedestal being covered with a tarpaulin to retain the heat of hydration. So, if this concrete is just allowed to dry or allowed to be exposed to the atmosphere which could be very cold, the strength development is highly retarded. We can address that issue by covering appropriately with a tarpaulin. Similarly, as far as the pictures my right is concerned. We need to carry out extensive preparation to build enclosures and insulate equipment, in order to ensure that construction in cold weather can be carried out unimpeded. So, we can see all these claddings and the kind of temporary structures that have been erected around the structure under construction. Or, for that matter the batching plant, the agitator truck and so on.

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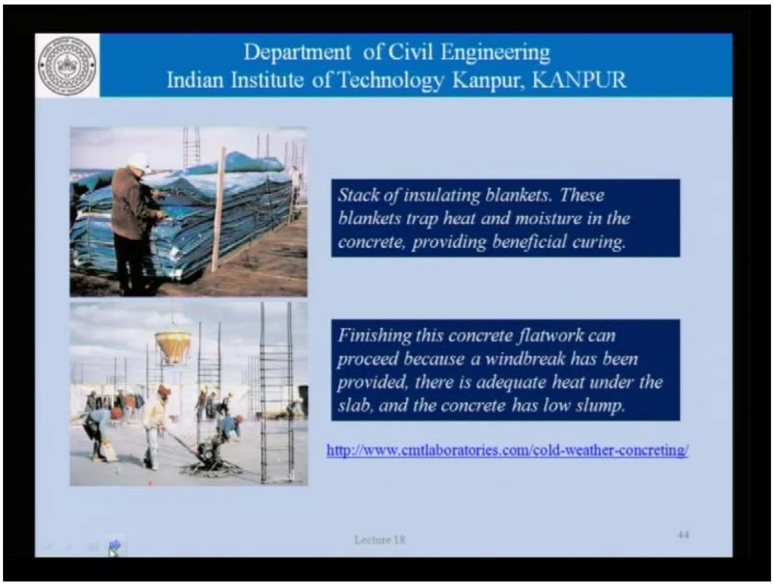

The picture on the top here is a stack of insulating blankets. These blankets trap heat and moisture in the concrete and provide beneficial curing. The errection of these kinds of wind barriers helps us protect the concrete slab which has been cast here and enable us to carry out the finishing operation. In this case of course, the silver lining in the cloud is that because, the concrete remains workable for a longer period of time the finishing operation can be carried out with a little more relaxed pace.

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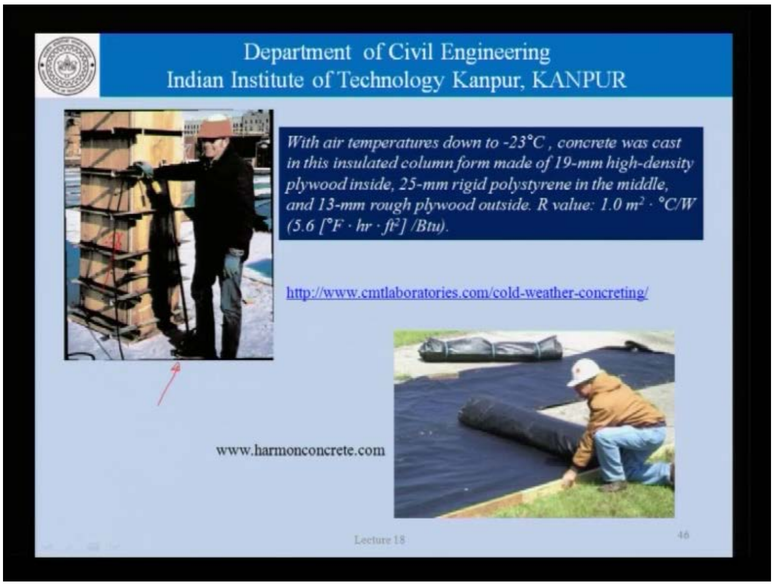

On the top here, we see tarpaulin heated enclosures maintains an adequate temperature for proper curing and protection during severe and prolonged winter weather. And at the bottom, we see polyethylene plastic sheets admitting daylight are used to fully enclose a building frame. And the temperature inside is maintained back again at 10 degree centigrade. So, if we carry out these kinds of precautions, if we maintain these precautions that are absolutely origin to not be able to carry out construction and cold weather. But, if we do not then, we are severely compromising the quality of construction.

This picture here is that of insulating formwork. In this case, we are talking of using an insulated column formwork made of 19 mm high density plywood inside, 25 mm rigid polystyrene in the middle and 13 mm rough plywood outside. So, the formwork used in the columns here is specially designed. It is not simply a timber or a steel plate. What specially designed insulating formwork which has 2 layers of timber or plywood filled in between is something else. The picture on the bottom here, shows the spreading of blankets or insulating sheets.

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This picture here is that of a hydronic system showing hoses on the left, laid on the soil to defrost the sub-grade and on the right here, we have these pictures in the formwork to warm the forms well the concrete is being pumped. So, largely from the discussion that we had today. We see that, cold weather concreting is really a highly engineering operation. In the sense that there are practical issues that need practical solutions and engineers need to be very careful in choosing the solutions. Economics is at the back of the mind but, not at the cost of quality. Whether, it involves the heating of the materials whether, involves heating the materials or using insulating formworks or the sub-grade.

We need to understand, we need to understand the basic principles of concrete and concrete engineering from the point of view of hydration, strength development and curing. If these things are understood, we are doing pretty good as far as cold weather concreting is concerned.

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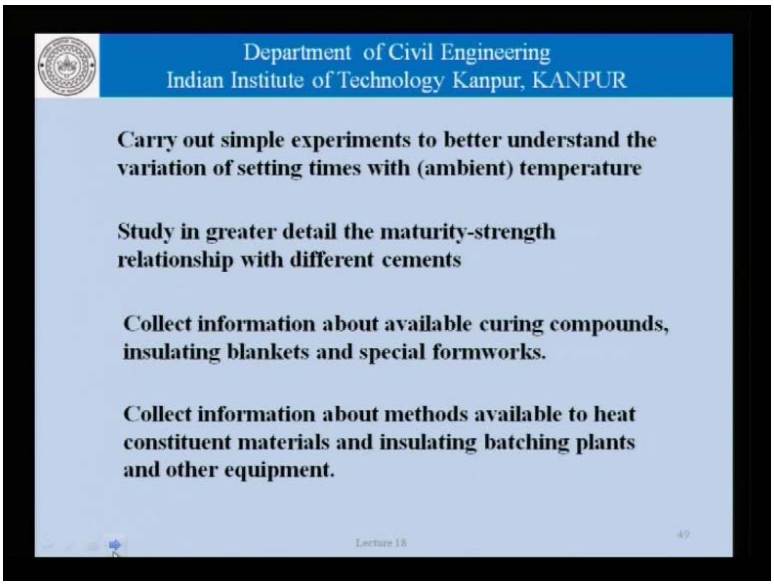

So, before we close let us just take a look at some of the things which we could do from here onwards. We could carry out simple experiments to better understand the variation of setting times of concrete with ambient temperature. We could study in greater detail the maturity-strength relationship and how that changes for different cements. We could collect information about the available curing compounds, insulating blankets and special formworks like the once that we saw in the case of the column. We could collect information about the methods available for heating constituent materials and insulating batching plants and other equipment. With this, we come to an end of our discussion today.

Thank You.