Development and Applications of Special Concretes
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Lecture 11
Cold Weather Concreting

Namaskar and welcome back to another lecture in our series on development and applications of special concrete. In the last class we have talked about curing, its importance, methods and the principle. Today we will continue that discussion into a logical direction when we are dealing with cold weather concreting. This is lecture 11 and the second in our third module.

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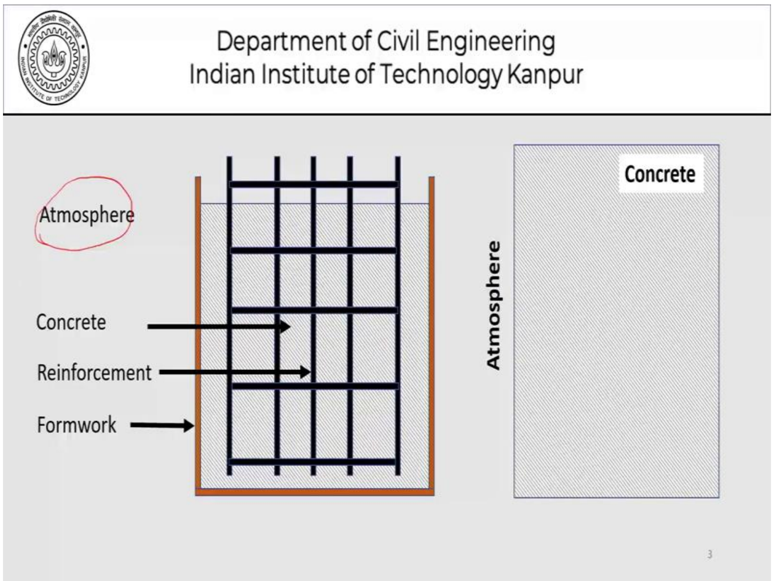

This is a picture which we are familiar with I am taking it from last time concrete being cast using a certain formwork with reinforcement in a certain atmosphere, now that is the crux of our discussion today cold weather so the atmosphere is such that there are cold weather conditions whatever that means. And for the purpose of simplification, I have removed the reinforcement I have just talked about concrete being cast in the atmosphere that is what is the root of our discussion today in terms of cold weather concreting.

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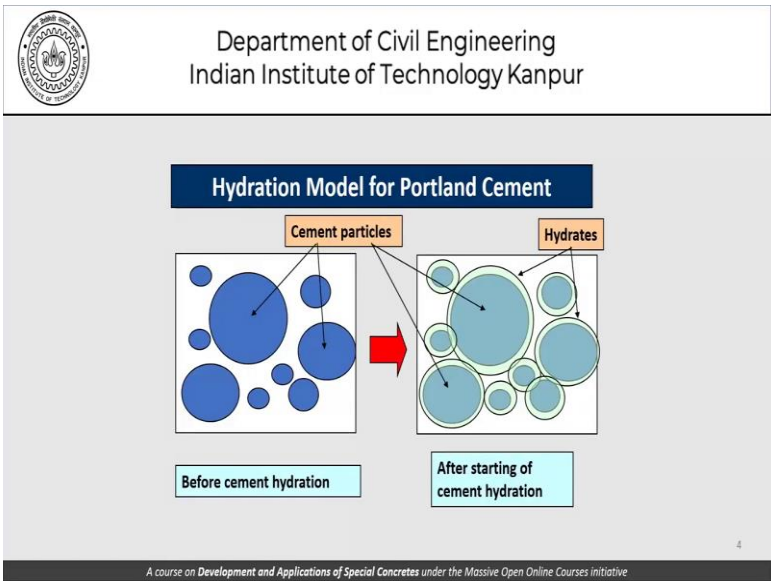

Once again let us recall the hydration model cement particles surrounded by water converting to hydration products being formed around the cement particles as the time goes on. Now the issue is that if the atmosphere becomes such that the temperature is very low what happens to this water. And how does that impact the hydration process, that is what is the root of our cold weather concreting discussion.

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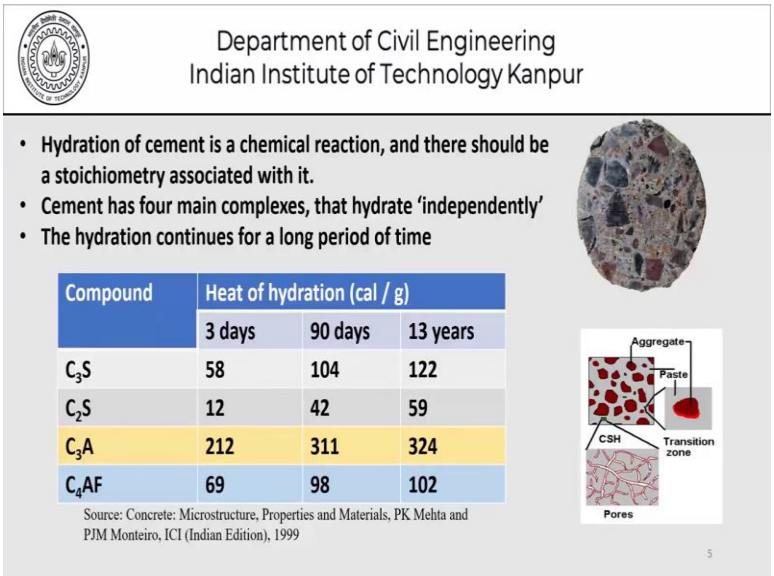

Compound	Heat of hydration (cal / g)		
	3 days	90 days	13 years
C_3S	58	104	122
C_2S	12	42	59
C_3A	212	311	324
C_4AF	69	98	102

This picture also we have seen at that time we had looked upon this picture from the point of view that hydration goes on for a long period of time 13 years is what is cited here in this document. What we are interested from our point of view today is the fact that even at three days a substantial amount of hydration has actually happened. So therefore, if the concrete is cast under conditions which are adverse this hydration does not happen and hydration is not something that is added or subtracted at will.

You cannot say that I am not going to have hydration in the beginning let the hydration happen after a certain amount of time and it will follow your whims and fancies no that does not happen. So, we have to keep this part of the discussion in mind that cement has different components all of them undergo a substantial amount of hydration early as far as the age is concerned early means within one day three days and if the conditions during the first few days or the first few hours are adverse that has long term implications and that is what we are trying to study today.

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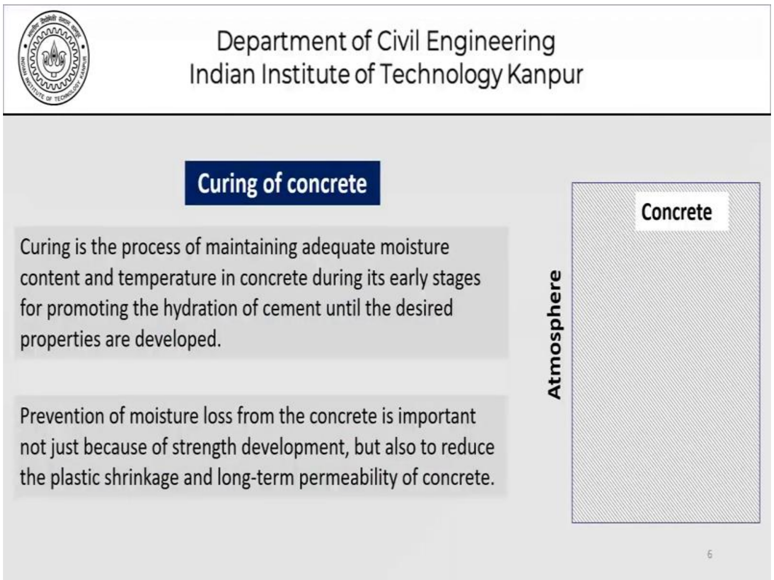

Curing of concrete something which we have done last time is the process of maintaining adequate moisture content and temperature in concrete during its early stages for promoting the hydration of cement until the desired properties are developed. So, the objective of curing is prevention of moisture loss from the concrete not because of strength development alone but also from the point of view of reducing plastic shrinkage and long-term permeability.

So, what we are interested to do we discuss this extensively when we talked about the curing discussion last time something happening at the surface something happening in the middle of concrete here, they are quite different. The idea of curing is not to supply water to concrete but to have a situation where we create conditions at the surface outside here such that water does not migrate or run away from the concrete. And concrete is able to hydrate throughout that is cement is able to hydrate at all locations.

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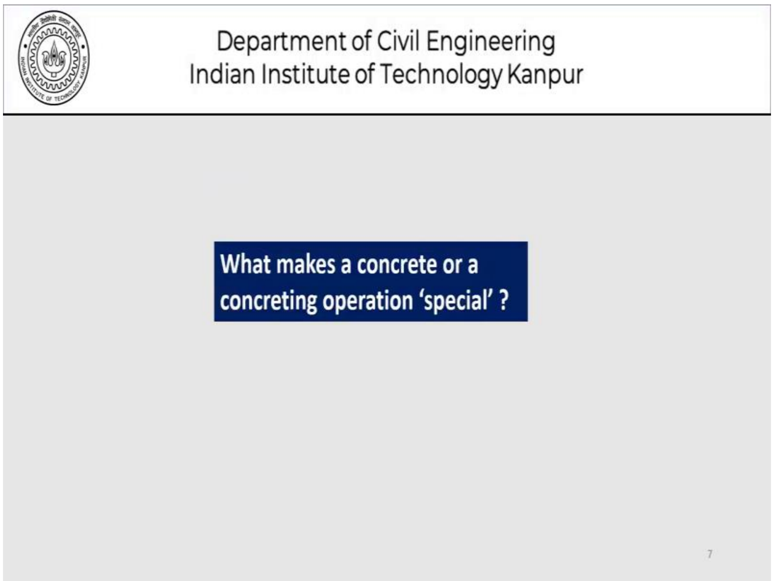

Now let me have a bit of discussion with you on what makes a concrete or a concreting operation special after all this course is named development and applications of special concretes. Now what is special for that we must understand what is normal for that we have to understand the basic steps in the concrete construction process.

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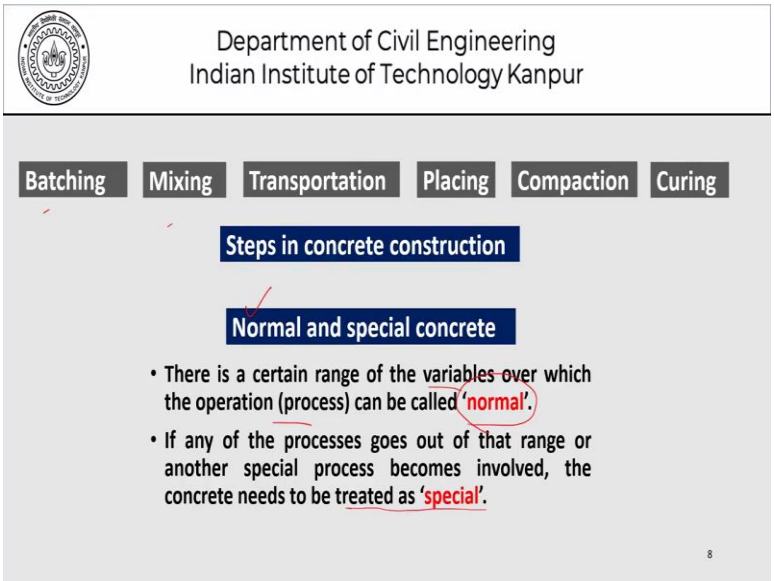

Batching of materials, mixing of those materials, transportation of the concrete that is produced placing of that concrete at site, compaction of that concrete in position and finally curing of that concrete. These are the steps which are invariant almost in all kinds of concrete construction now the difference between normal and special concrete would arise from the fact that a certain range of variables over which the operation or the process can be called normal.

For each of these processes batching, mixing, transportation, placing, compaction and curing there are variables that can be assigned of parameters that can be used to define that. For example, for mixing we can mix it by hand we can mix it by a mixer of a certain power a certain size, transportation can be by conveyor belt, it could be by hand wheelbarrows, it could be by transit mixers.

Compaction could be by internal vibrators, damping rods, external vibrators, roller compaction and so on. Curing also has different dimensions. So, what we have to understand is that what is normal because anything that is not normal will take you to the regime of special, if any of these processes goes out of that range or another special process becomes involved the concrete needs to be treated as special.

Batching means materials we could have different materials. We have said that as far as we are concerned normal concrete would be taken to mean water, cement, sand and gravel anything over and above this would be treated as special concrete. The moment we have mineral admixtures or chemical admixtures or any other material being brought into the concrete as mix fibres for example it will become special concrete.

And the rules that apply for normal concrete may or may not apply. The basic principles will apply but the applied principles will not the basic principle for example being that all the material together should total to 1000 litters that will apply. Cement has four basic components that will apply hydration it will apply but depending on the curing things will change so that is the kind of backdrop under which or in which we are talking about this course on development and applications of special concretes.

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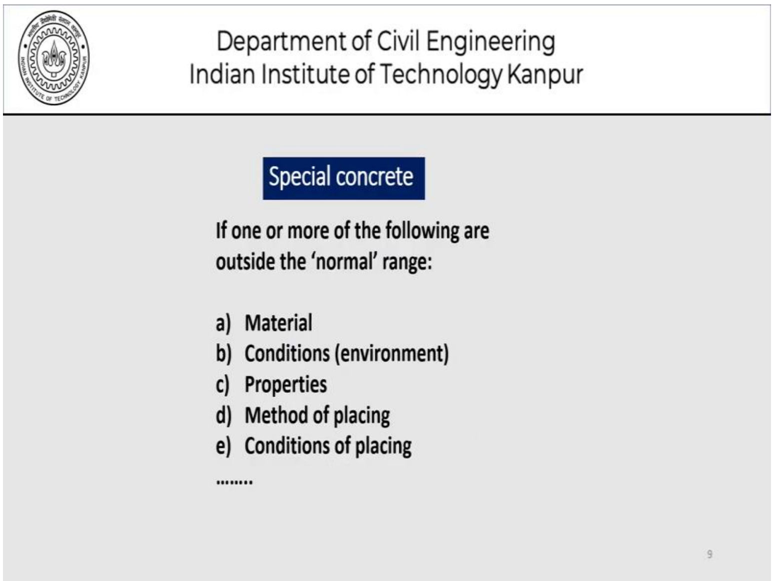

To reiterate if one or more of the following are outside a normal range the concrete would be called special materials, conditions that is environment properties, method of placing, conditions of placing and so on. So, what is in question today is conditions of the environment that is what is making the concrete and the treatment special.

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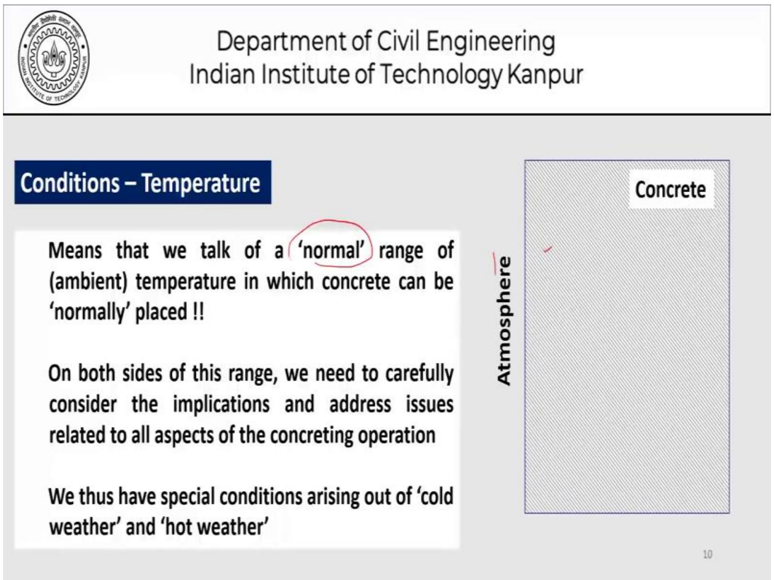

The condition that we are talking about is temperature there can be other conditions but temperature is what we are talking about this concrete is being placed in an atmosphere where the temperature, we have to determine or decide what is the normal range. And on both sides of this range, we need to carefully consider the implications and address issues related to all aspects of the concreting operation.

All aspects mean proportioning of the mix, transportation, compaction, curing everything has to be considered once one of the processes goes into the special range. So, we thus have a special condition arising out of cold weather and hot weather. So today our attention is largely confined to cold weather concreting.

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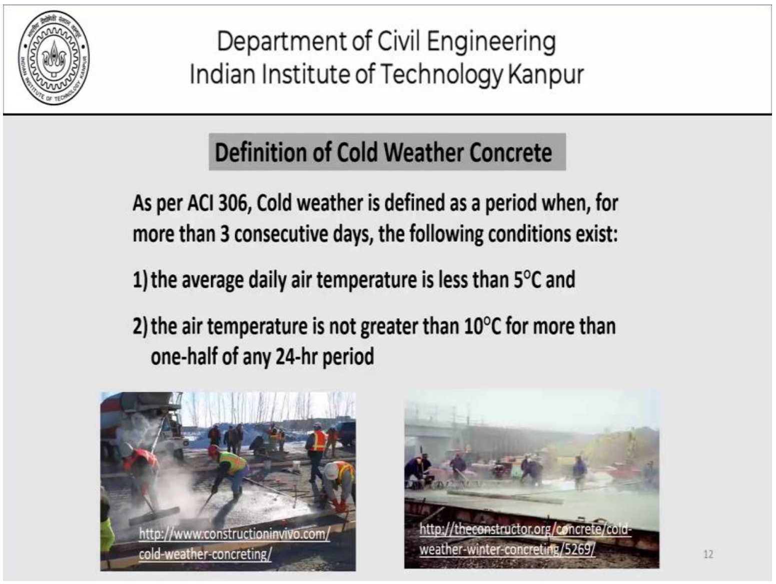

Moving forward the ACI 306 defines cold weather as a period when for more than three consecutive days the following conditions exist. One the average daily air temperature is less than 5 degrees centigrade and the air temperature is not greater than 10 degrees centigrade for more than one half of any 24-hour period. So, this is how the specifications or a document a professional document it could be any other document I have just taken ACI 306.

As a reference ACI 306 says that if these conditions are there then concrete should be deemed as cold weather concreting and the kind of precautions and the kind of processes that are prescribed for cold weather concreting should be followed.

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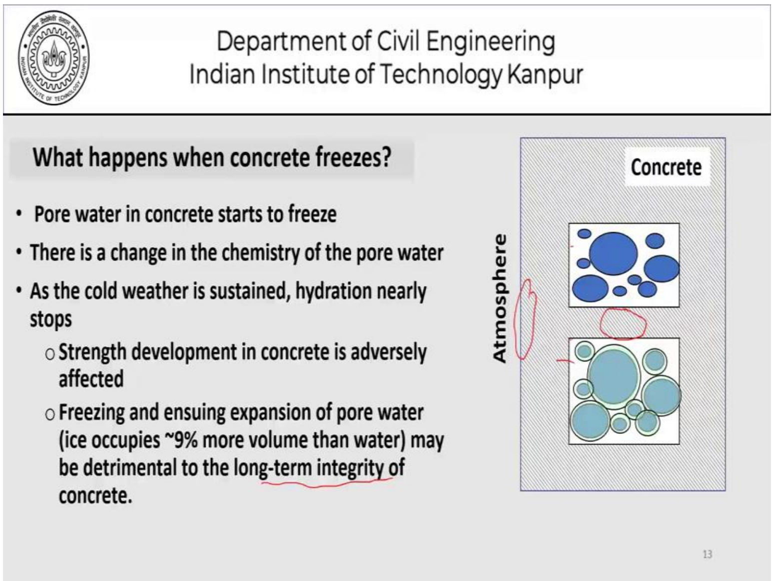

What happens when the water in concrete freezes? I am just putting this picture here the un-hydrated cement surrounded by water and the hydrating cement where hydration products are formed along the cement particles on the surface of cement particles. And this obviously is a different thing happening for cement particles here and for cement particles here keep that in mind when we do the further discussion.

The pore water and concrete starts to freeze, there is a change in the chemistry of the pore water, as the cold weather is sustained hydration nearly stops and we look at some of the numbers in subsequent slides. Strength development in concrete is adversely affected obviously once the hydration stops the strength development will be adversely affected. Freezing and the ensuing expansion of pore water ice occupying about 9% more volume than water may be detrimental to the long-term integrity of the concrete.

So, these are the kind of implications of concrete freezing that is the water in the concrete freezing.

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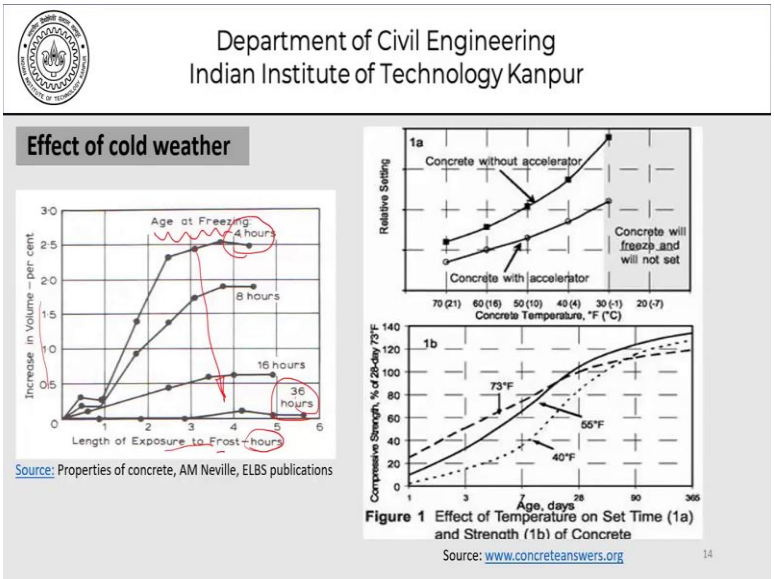

As far as the effect of cold weather is concerned the increase in volume by percentage given in some of the textbooks over the length of exposure to frost in hours is shown here. So, if we can see if it is age of freezing is varied that is 4 hours to 8 hours to 16 hours to 36 hours the effect is largely minimized that is if you are somehow able to protect the concrete from freezing for 36 hours then we can almost have no effect as far as the increase in volume is concerned.

Therefore, the concrete is quite alright but if we are not able to protect it even for four hours then we are looking at a serious change in or the increase in volume and that has its detrimental impact. This picture here is about setting and the compressive strength development in concrete at different temperatures.

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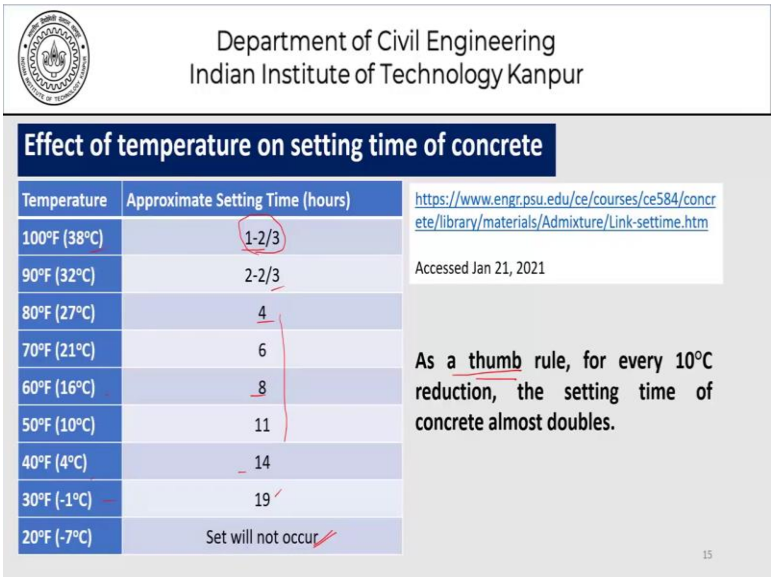

Temperature	Approximate Setting Time (hours)
100°F (38°C)	1-2/3
90°F (32°C)	2-2/3
80°F (27°C)	4
70°F (21°C)	6
60°F (16°C)	8
50°F (10°C)	11
40°F (4°C)	14
30°F (-1°C)	19
20°F (-7°C)	Set will not occur

Here is the effect of temperature on the setting time of concrete. So, you can see that at 38 degrees centigrade let us say which is reasonably hot. Of course, in India 38 degrees may or may not be considered very hot we have places where the temperatures could be as high as 45 or 50 degrees. But at 38 degrees the approximate time of setting is about 1 to 2 hours at 32 it is 2 to 3 and it goes up all the way to 18, 19 hours if the temperature goes to about minus 1 degree centigrade at minus 7 the setting does not happen.

So that is what we mentioned in one of the previous slides that the setting is adversely affected if the temperatures become very low. You will notice that as a thumb rule it can be said that for every 10 degrees reduction in the temperature the setting time of concrete almost doubles. We can see that here from 38 to about 28 it goes from about 1 to 2 hours to about 4 hours and from 27 to about 16 it goes to about 8 hours from 16 to about four it goes to about 14 hours.

So, this is just a thumb rule. Engineers love these thumb rules as a ballpark number how does temperature impact the setting time. We have some numbers for 27 degrees 30 degrees whatever it is and we know that for if the temperature is different lower by 10 degrees that setting time value will be doubled.

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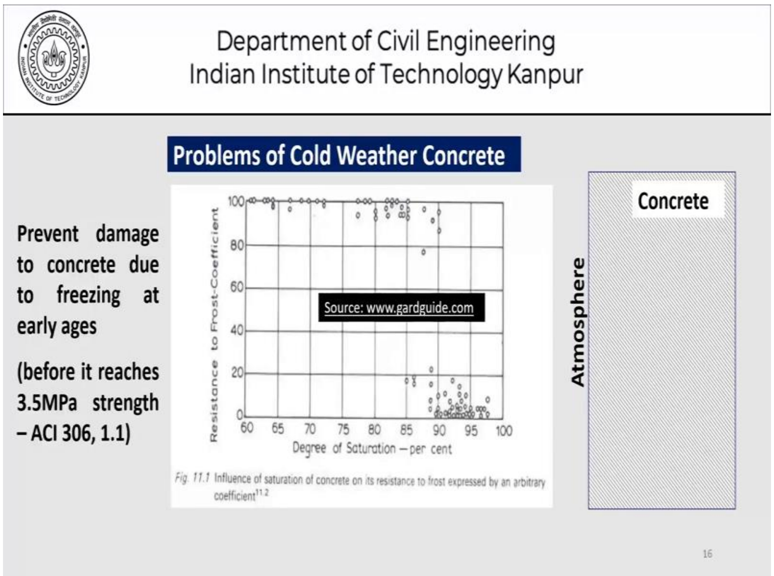

This picture here shows the damage to concrete due to freezing at early ages and here the player in the game is degree of saturation. So, degree of saturation if it is very high the resistance to frost is pretty much non-existent but if the degree of saturation is low, we can get a reasonable resistance to frost.

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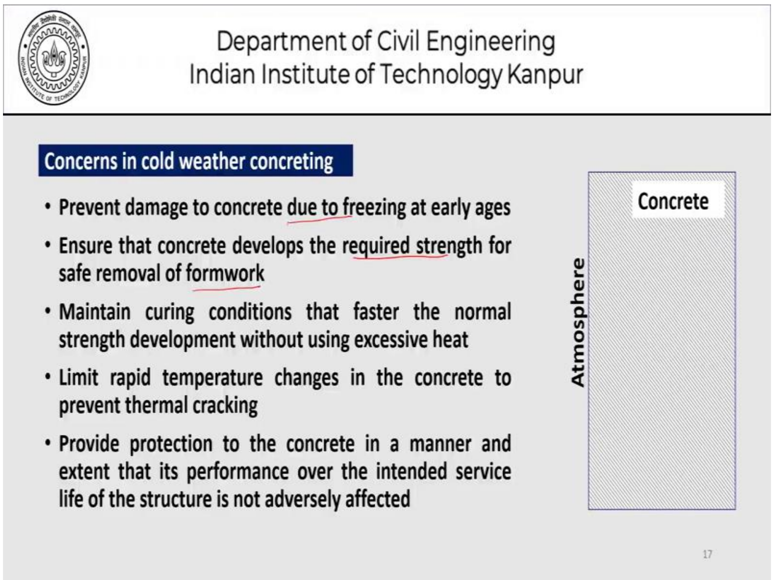

Now what are the concerns in cold weather concreting. If you reiterate prevent damage to concrete due to freezing at early ages. Ensure that concrete develops the required strength for safe removal of formwork. Maintain curing conditions that faster than normal strength development happens without using excessive heat. Limit the rapid temperature changes in the concrete to prevent thermal cracking and provide protection to the concrete in a manner.

And extent that its performance over the intended service life of the structure is not adversely affected. So, these are some of the concerns that we need to keep in mind very clearly and quantitatively if we want to do good quality cold weather concrete.

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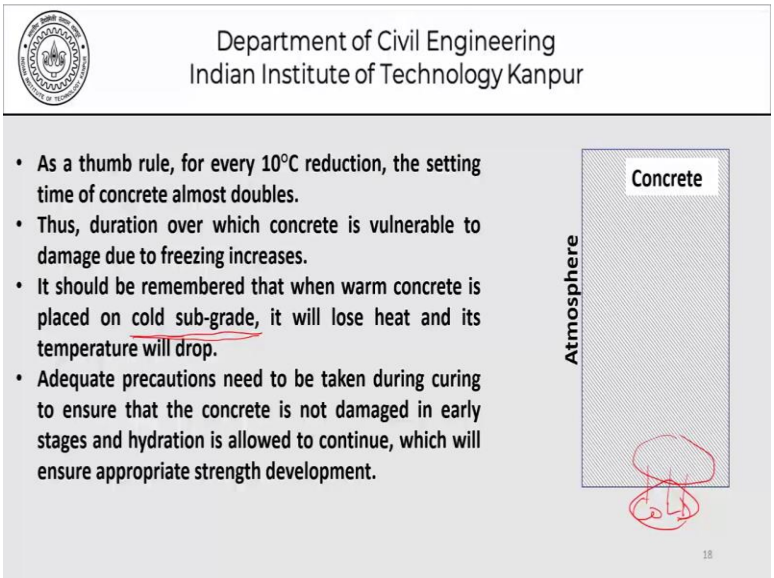

Containing the concerns as a thumb rule we have already seen for 10 degrees reduction the setting time of concrete almost doubles. Thus, the duration over which the concrete is vulnerable to damage due to freezing increases as the temperature goes down. It should be remembered that when warm concrete is placed on the cold subgrade it will lose heat and its temperature will drop.

So, one of the methods that we need to use or be careful about is what is the temperature of the subgrade? What is the temperature of the surface at which this concrete is being cast? That is if this part here is very cold then we pour concrete on this a lot of heat will be lost and the temperature of this concrete will be lowered that is what we are talking about in this point here. Adequate precautions need to be taken during curing to ensure that concrete is not damaged in early stages and hydration is allowed to continue which will ensure a proper and appropriate development of strength.

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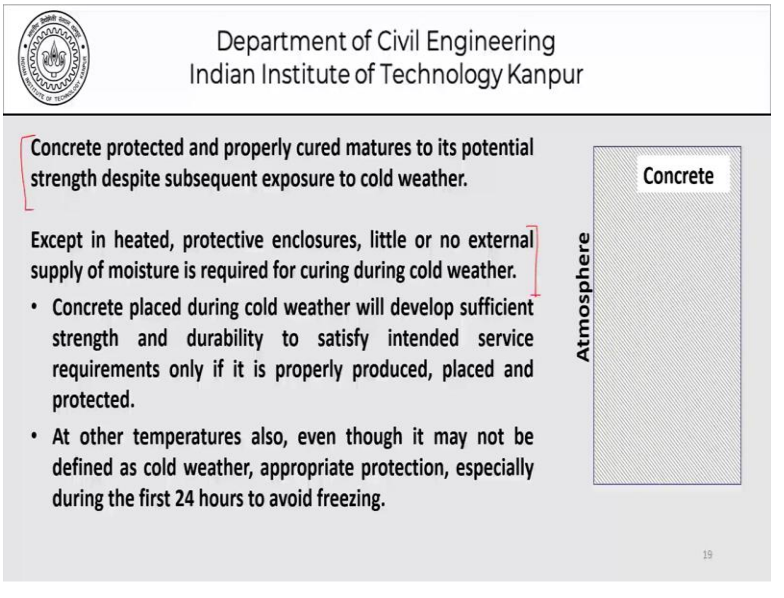

Concrete protected and properly cured matures to its potential strength despite subsequent exposure to cold weather. So, the idea here is that so long as we are able to protect the concrete initially from freezing. The rest of it there is enough water inside the concrete and that is true we know that we do place in concrete enough water for hydration of cement. It is just that initially that water should not be freezing.

Once we are able to take care of that then concrete will continue to gain strength and move normally almost despite subsequent exposure to cold weather. So, it is the initial part that is very, very crucial and except in heated protective enclosures little or no external supply of moisture is required for curing during cold weather. Like I said there is enough moisture inside the concrete for ensuring hydration.

And all that we have to ensure is that initially the concrete is protected. We should not heat the concrete beyond a certain point and even if we are heating it, we should be very careful as to what happens to the moisture inside. So, if we heat it and the moisture is lost then of course we have to supply some moisture we have to kind of make sure that enough moisture is available in concrete for the hydration of cement.

Concrete place during cold weather will develop sufficient strength and durability to satisfy intended service life requirements only. If it is properly produced placed and protected and at other temperatures as well may not be the cold weather conditions as specified in ACI 306 or whatever if there is a doubt in the mind of the engineer that there may be cold weather conditions we need to take or we should take special precautions at least in the first 24 hours to avoid freezing in the concrete.

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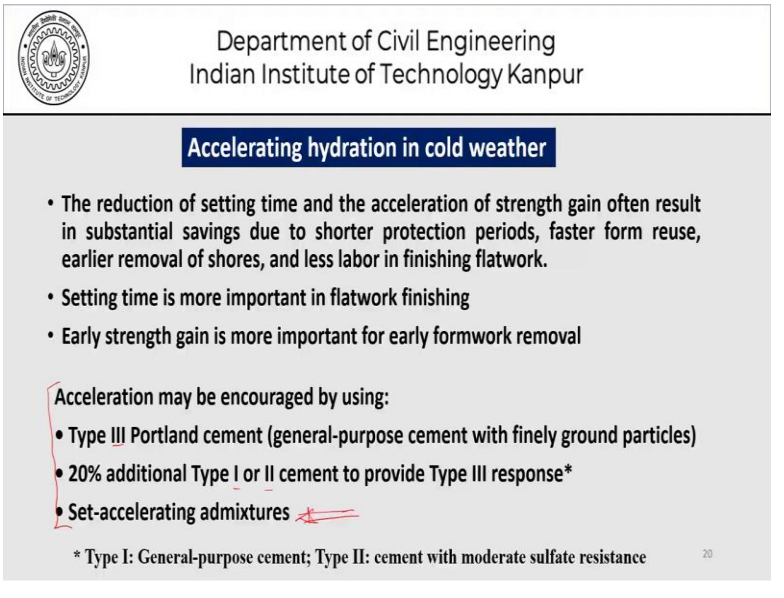

Accelerating hydration in cold weather what are the things that we could do, reduction is setting time and the acceleration of strength gain often results in substantial savings due to shorter protection periods faster form reuse earlier removal of shores and less labour in finishing flat work. Setting time is more important in flat work finishing, early strength gain is more important for early formwork removal.

Acceleration may be encouraged by using type 3 Portland cement which is general purpose cement with finely ground particles or 20% additional type 1 or type 2 cement to provide type 3 response and set accelerating admixtures. So here is a combination or here are some of the prescriptions that one can use of course type 3, type 1 and type 2 these are all American nomenclatures and I am leaving it to you to find out what is a type 1 cement or a type 2 cement or a type 3 cement in terms of its chemical composition.

As we have discussed different constituents of cement hydrate at different rates and in cold weather because we want certain amount of hydration to happen, we need to choose our cement carefully and this here shows the kind of considerations that go in choosing that cement and of course there is a provision for using the set accelerating admixtures. So, we try to ensure or we try to see that the setting process is accelerated.

So that the concrete is able to move forward as far as normal hydration is concerned even if the cold weather conditions continue to prevail. Now what is the recommended practice.

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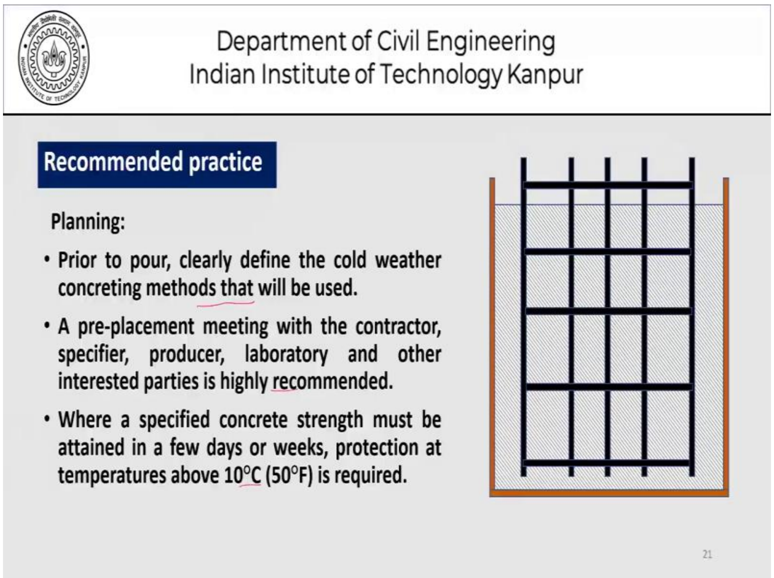

At each step we have to plan now planning means prior to the pour clearly define the cold weather concreting methods that will be used what will be the strategy of pouring everybody should be on board they should know exactly what their role is. A pre-placement meeting with the contractor, specifier, producer, laboratory and other interested parties is highly recommended.

If everyone sits across the table and decides on what exactly is to be done. Reviews the kind of situation which is likely to be encountered half the battle is own. Whereas specified concrete strength must be attained in a few days or weeks protection at temperatures above 10 degrees is required. So, you must ensure that the protection at 10 degrees and above is available to the concrete at least initially.

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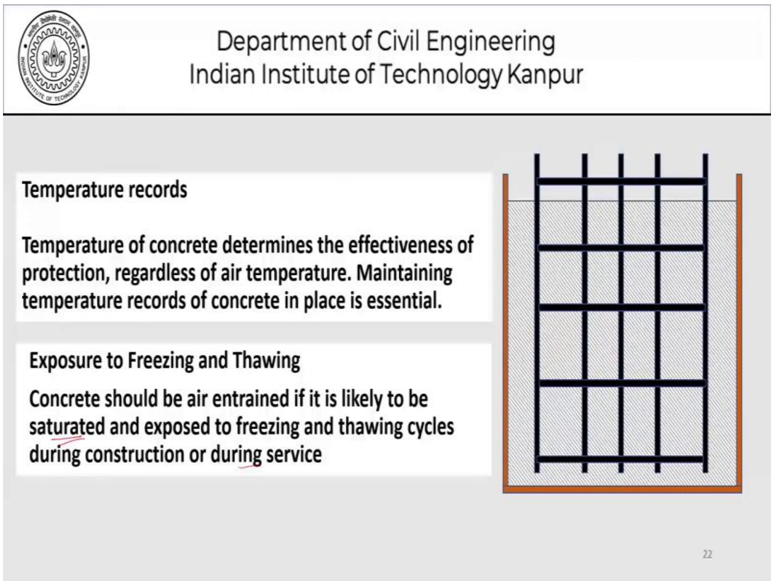

The temperature records are very important the temperature of concrete determines the effectiveness of protection regardless of the air temperature. So, we are not so much bothered about the air temperature once the concrete has been placed but we are bothered about the concrete temperature that should be recorded and those records should be maintained as a matter of archival. Exposure to freezing and thawing should be avoided especially if the concrete is non-air entrained or has less air.

Concrete should be air entrained if it is likely to be saturated and exposed to freezing and throwing cycles during the construction or service. So, we saw that picture there which said that okay if the concrete was highly saturated the likely damage is a lot more than a concrete which is less saturated.

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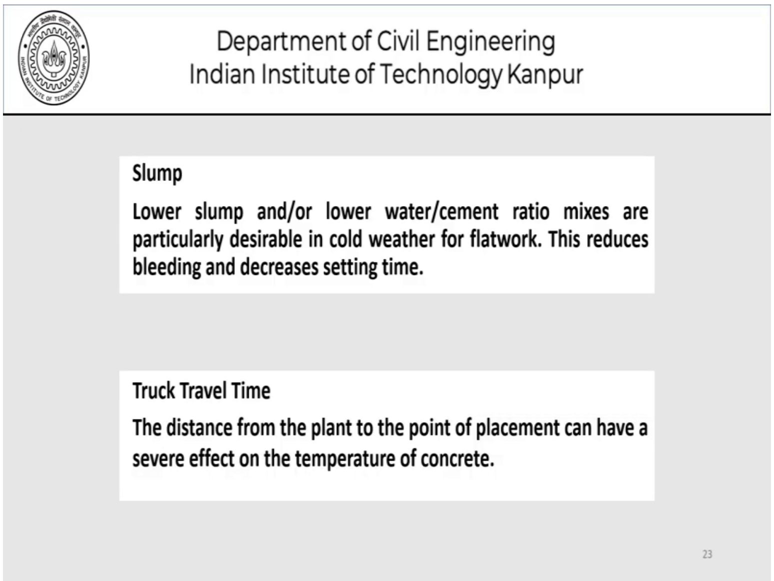

Lower slump and or low water cement ratio concrete mixes are particularly desirable for cold weather or flat work this reduces bleeding and decreases the setting time. Truck travel time is another variable the distance from the plant to the point of placement can have a severe effect on the temperature of concrete.

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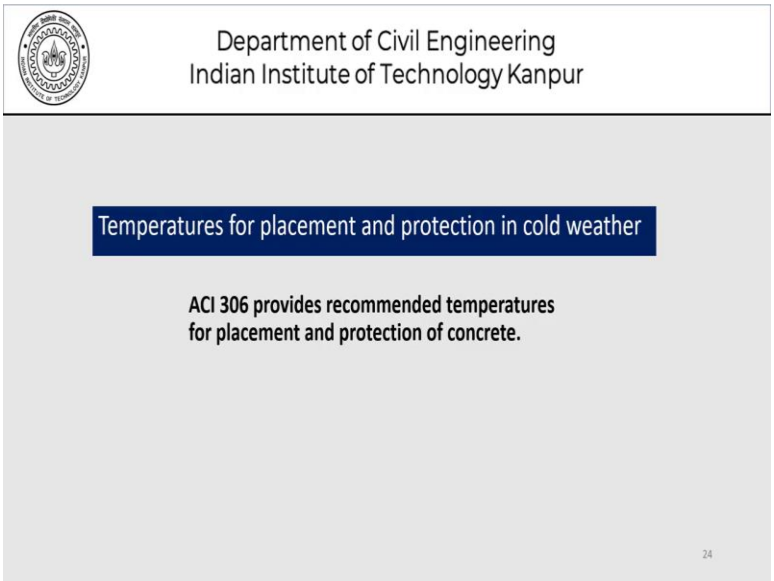

Now temperatures for placement and protection and cold weather as far as the ACI 306 is concerned provides for recommended temperatures for placement and protection of concrete.

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Table 1: Recommended Concrete Temperatures[1]

Adapted from ACI 306	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.

This table has been adapted from this document ACI 306 which talks in terms of recommended concrete temperatures for different sizes of the section of concrete that we are talking about. if it is small not so small and large then we can see that the temperatures recommended here are 13 and as we go to larger members it becomes 5. The minimum concrete temperature as mixed for indicated air temperatures is shown in this part of the table.

If the air temperature (in degrees Celsius) is above -1 between -18 and -1 and below -18 then the minimum concrete temperatures are given here. So, these values for smaller section sizes are much larger here we can get too much smaller values. Similarly, there is another provision here which is the maximum allowable gradual temperature drop in the first 24 hours after the end of protection. This also is related to the section size minimum dimensions in terms of millimetres 28 degrees here to 11 degrees here.

So, these are the kind of things that go on as far as engineering is concerned in cold weather concrete.

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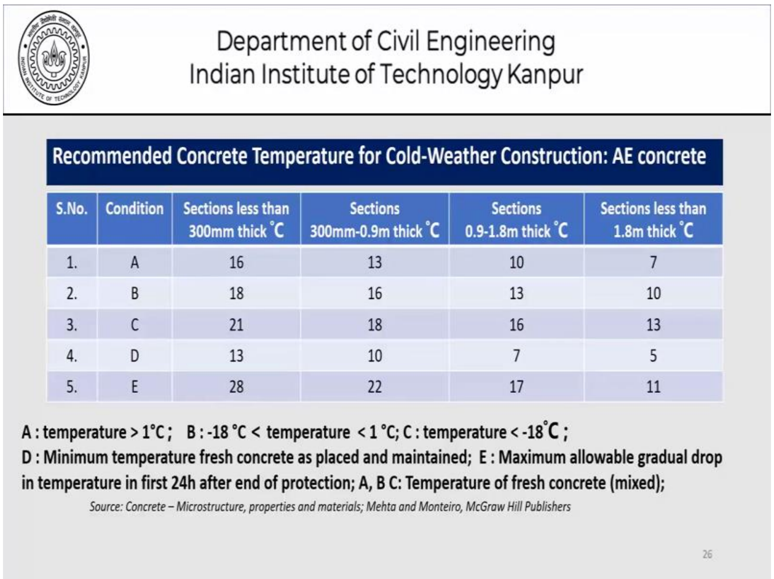

S.No.	Condition	Sections less than 300mm thick °C	Sections 300mm-0.9m thick °C	Sections 0.9-1.8m thick °C	Sections less than 1.8m thick °C
1.	A	16	13	10	7
2.	B	18	16	13	10
3.	C	21	18	16	13
4.	D	13	10	7	5
5.	E	28	22	17	11

Recommended concrete temperatures for cold weather construction for air entrained concrete if we have conditions A, B, C, D and E which are defined as A being temperature greater than 1, B mean -18 to 1, C is less than -18 and D is that minimum temperature of fresh concrete has placed and maintained E is the maximum allowable gradual drop in temperature in the first 24 hours after the end of protection.

Then A, B and C is temperature of fresh concrete mixed concrete. Then this is just a summary of what we saw in the previous discussion for air entrained concrete. Now please remember that this is for air entrained concrete.

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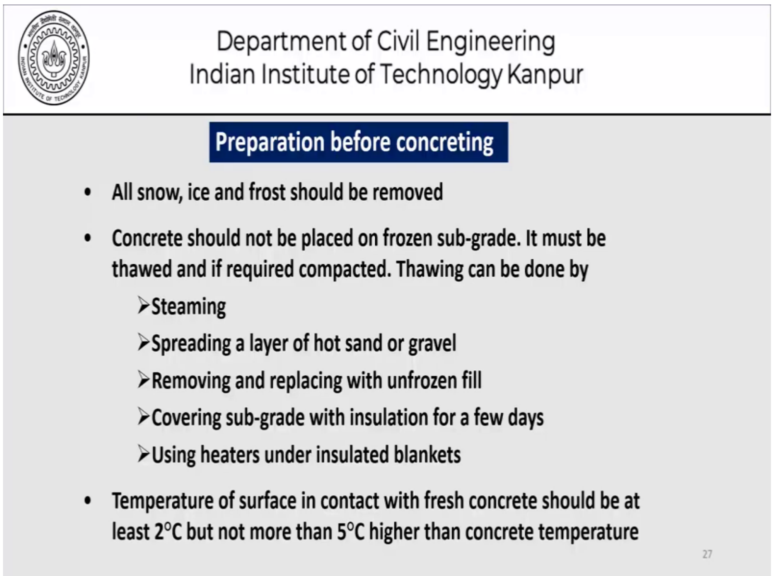

As far as preparations before concreting us concerned all snow ice and frost should be removed concrete should not be placed on frozen subgrade it must be thawed the subgrade and if required compacted. And this thawing can be done by steaming spreading a layer of hot sand or gravel removing and replacing with unfrozen fill, covering this upgrade with insulation for a few days that is not allowing it to freeze.

Using heaters under insulated blankets and the temperature of the surface in contact with fresh concrete should be at least 2 degrees but not more than 5 degrees higher than the concrete temperature. So, you cannot have a very hot formwork just because you want to increase the temperature. So, there is a limit on this as well as the lower bound on the temperature of the formwork.

So, we have to be careful about the formwork and the temperature of the subgrade on which the concrete is to be placed.

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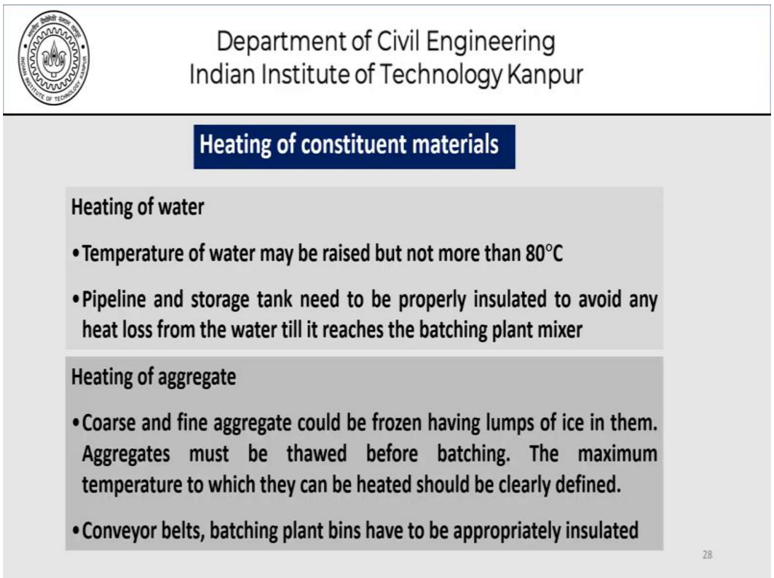

Heating of constant elements is another dimension to this problem or this challenge of concreting in cold weather heating of water the temperature of water may be raised but not more than 80 degrees centigrade. Pipelines and storage tanks need to be properly insulated to avoid any heat loss from the water till it reaches the batching plant mixer. Heating of aggregate more difficult but if it has to be done it has to be done.

Coarse and fine aggregate could be frozen having lumps of ice in them aggregates must be thought before batching the maximum temperature to which they can be heated should be clearly defined conveyor belts, batching plant bins have to be appropriately insulated. In regions which are cold there is very little that we can do to increase the temperature there except if we want a certain temperature range, we just might have very few windows.

So, if we do not want those windows to constrain our construction process this is the kind of things that we need to do.

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Here is a photograph showing aggregate storage. We have a retracted situation here where this is flexible and if it is extended, it covers the aggregate the way it is shown. Now this helps us try to control the temperature inside this chamber. Instead of trying to manipulate or trying to maintain the temperature of aggregate in open air it becomes a lot easier if it was covered.

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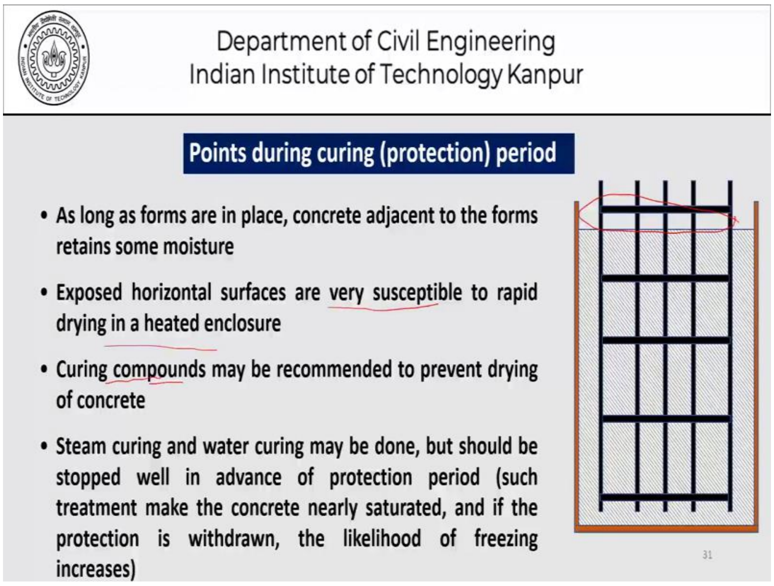

Protection of fresh concrete means that we need to protect the fresh concrete from early age freezing by using insulation. Use of additional protection or heat if temperature suddenly drops very low is another option which is available to us. But we need to determine the length of protection using the maturity method that is something which we had very briefly talked about in the last class and we are going to touch upon it again today.

Removal of forms taking care that the allowable temperature drops within the 24 hours the first 24 hours is not exceeded. As long as forms are in place the concrete adjacent to the forms retains some moisture exposed horizontal surfaces are very susceptible to rapid drying in a heated enclosure. So, if we want to heat the concrete somehow then we have to make sure that this horizontal surface which is exposed to the air is properly protected.

Exposed horizontal surfaces are very susceptible to rapid drying in a heated enclosure. Curing compounds may be recommended to prevent drying of concrete. We saw what curing compounds are and how they function they are sprayed onto the surface they prevent water from within the concrete from escaping that is what is curing compounds. So, we need to actively consider the possibility of using curing compounds in cold weather concreting simply to protect the concrete.

Steam curing and water curing may be done but should be stopped well in advance of the protection period such as the treatment. Because such treatment makes the concrete nearly saturated and if the protection is withdrawn the likelihood of freezing increases. So, one has to be very careful and each of these operations has to be very, very carefully planned.

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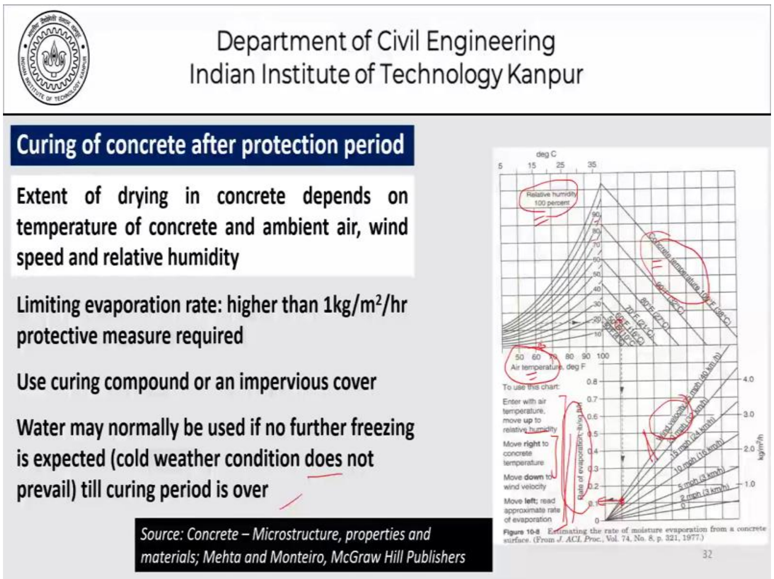

The curing of concrete after the protection period is another very interesting dimension to cold weather concreting. The extent of drying in concrete depends on the temperature of concrete and the ambient air wind speed and relative humidity. So here, we can see air temperature here concrete temperature here and the wind speeds here. How to use this chart is very clearly given here.

Enter the chart with the air temperature you have an air temperature here enter the air temperature move up vertically to the relative humidity that you are talking about. So, these are humidity values 100%, 90%, 80% and so on. So, you come to humidity value turn right to the concrete temperature. So, this is how we are moving right towards the concrete temperature come to this value move down vertically to the wind velocity value that you are talking about and move left to read the approximate rate of evaporation.

So, this is how we need to evaluate quantitatively the rate of evaporation of water from the surface as a function of the air temperature, the relative humidity the concrete temperature and the wind velocity. So, charts such as this are an extremely important part of the arsenal of a concrete engineer trying to work under special conditions. Limiting the evaporation rate higher than rate of 1 kg per square meter per hour.

We need to have protective measures using curing compounds or an impervious cover these are options available to you and water may normally be used if no further freezing is expected cold weather conditions do not prevail till the curing period is over. So that is how we look at the issue of curing of concrete or the curing period after the protection of concrete.

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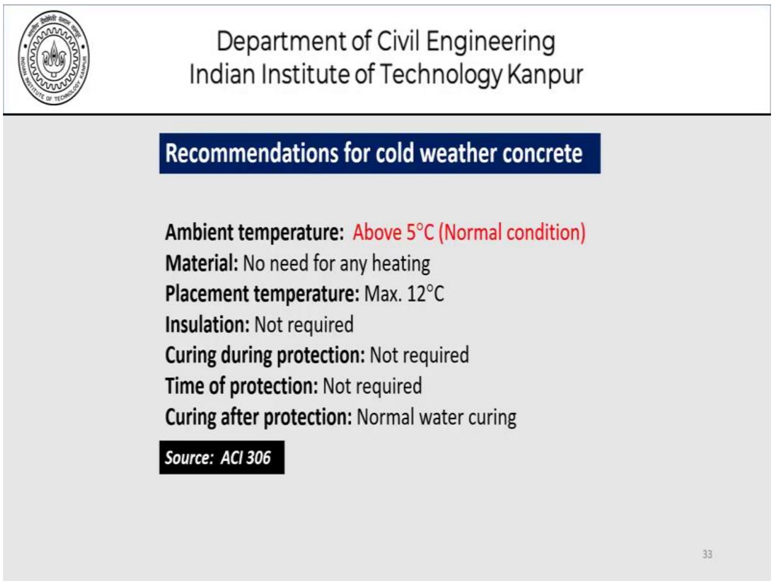

As far as recommendations for cold weather concreting is concerned again the source is ACI 306 ambient temperature above 5 degrees centigrade considered normal no heating is required for the material placement temperature should be a maximum of 12 degrees. No insulation required curing during protection not required time of protection not required curing after protection normal water curing. So, this is the situation for normal conditions as far as ACI 306 is concerned.

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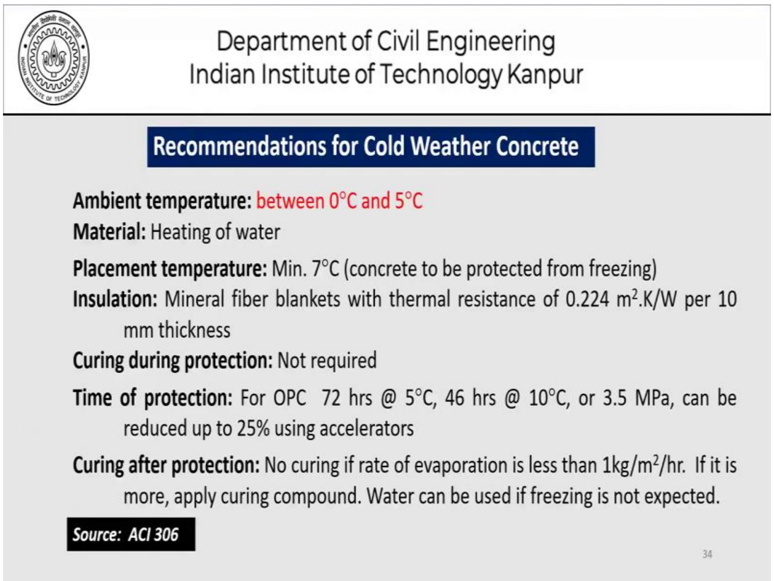

Coming to cold weather the ambient temperature is between 0 and 5, heating of water is recommended placement temperature minimum 7 degrees concrete to be protected from freezing, insulation, mineral fibre blankets with thermal resistance of a given value. Curing during protection is not required time of protection depending on the temperature is different for OPC 72 hours for ordinary Portland cement 72 hours at 5 degrees, 46 hours for 10 degrees, 3.5 MPa the strength can be reduced by 25% by using accelerators.

Curing after protection, no curing if the rate of evaporation is less than this value. And if it is more apply curing compound. Water can be used if no further freezing is expected. So, this is how it's a prescriptive discussion that if this happens, please do this. So, this is a very engineering way of looking at the problem. Now continuing the cold weather discussion if the temperature becomes sub-zero the previous was zero to 5.

Here we go into the situation where not only the water but also the aggregate may have to be heated, placement temperature is a minimum of 7 degrees insulation with mineral fibre blankets curing during protection is not required. Time of protection is given to you in this document already curing after protection again no curing. If the rate of evaporation is less than a kg per square meter per hour if it is more apply curing compound.

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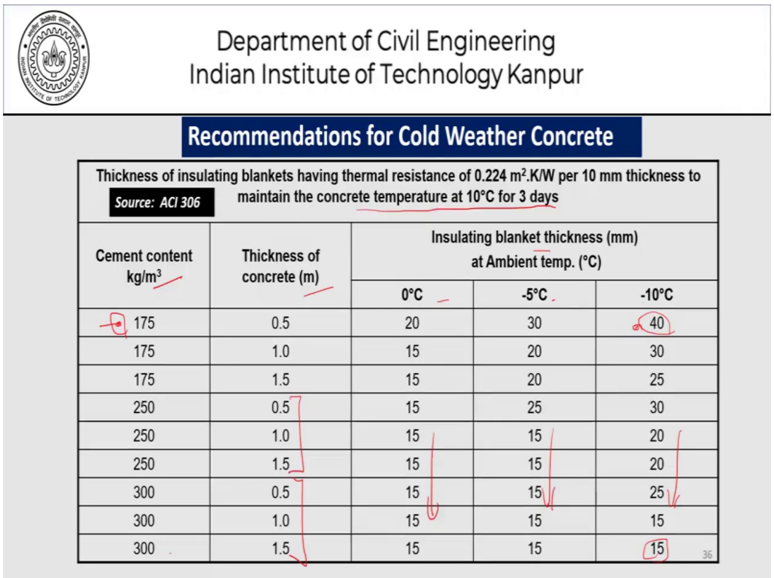

Cement content kg/m³	Thickness of concrete (m)	Insulating blanket thickness (mm) at Ambient temp. (°C)		
		0°C	-5°C	-10°C
175	0.5	20	30	40
175	1.0	15	20	30
175	1.5	15	20	25
250	0.5	15	25	30
250	1.0	15	15	20
250	1.5	15	15	20
300	0.5	15	15	25
300	1.0	15	15	15
300	1.5	15	15	15

This table here gives you the ACI 306 recommendations for the thickness of insulating blankets having a certain thermal resistance. In order to maintain the concrete temperature of 10 degrees for 3 days. What are the variables considered, the cement content per cubic meter of concrete? The thickness of the concrete member and the ambient temperature zero, -5 and -10 degrees centigrade.

So, we can see that the amount of thickness reduces 2, reduces here 2 and the amount of reduction is the maximum if we go from -10, that is if the temperature is higher means lower as a matter of fact if the temperature is lower -10 then in a case like this where the cement content is low it could be as high as 40 mm. But if the cement content is high, it will be 15 depending on what is the thickness of the concrete.

So, you can see here for 175 three thicknesses are given for 250 three thicknesses are given for 300 again three thicknesses are given. So, given this thickness given this cement content what should be the insulating blanket thickness this is a recommended value and that is how recommendations should be used. If we carry out an analysis and are able to convince ourselves and the clients that we do not need these values.

We can make two with something else we are free to do that provided the discussion or the analysis is sound in the absence of such analysis. These specifications or this kind of tables or guidelines are an extremely valuable tool as far as construction engineers are concerned.

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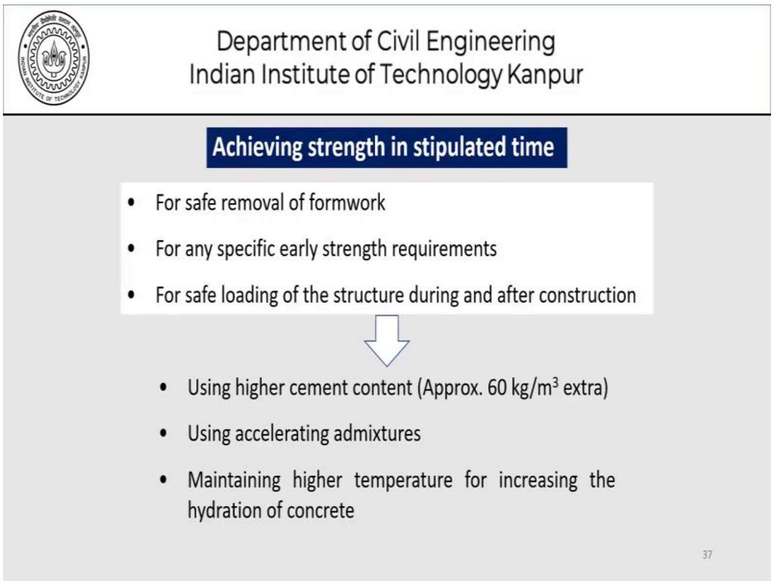

Now achieving strength in the stipulated time so that a safe formwork removal can be done for any specific early strength requirements that may be there or for the safe loading of a structure during or after construction. What we need to do is either use higher cement content use accelerating admixtures or maintain a higher temperature for increasing the hydration of cement or concrete.

The number given here is 60 kgs per cubic meter of extra cement. The type of cement of course is another player which will significantly influence for makes proportion or the kind of requirement whether it should be 60 or something else.

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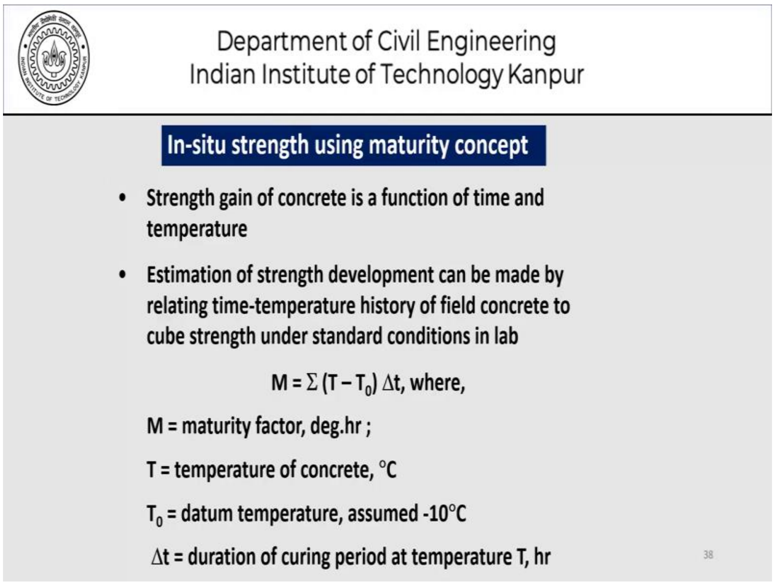

Let us revisit the concept of maturity once again it is the strength gain of concrete as a function of time and temperature. And estimation of strength development can be made using the time temperature history of the concrete in the field to the cube strength under standard conditions in the lab. In the standard conditions means we already know the temperature in the lab which could be different from the temperature in the field.

So, the time temperature graph that we get in the lab can be related to the time temperature graph from the field and an effort made to relate the strength that we get through this concept of maturity (M),

$M=\sum(T-T_0)\Delta t$,

Where; the small delta T is the duration of curing period at temperature *T* in hours. And *T* is the temperature of concrete and T_0 is the day temp temperature taken to be -10. And *M* is the maturity factor and obviously the unit is degree hours.

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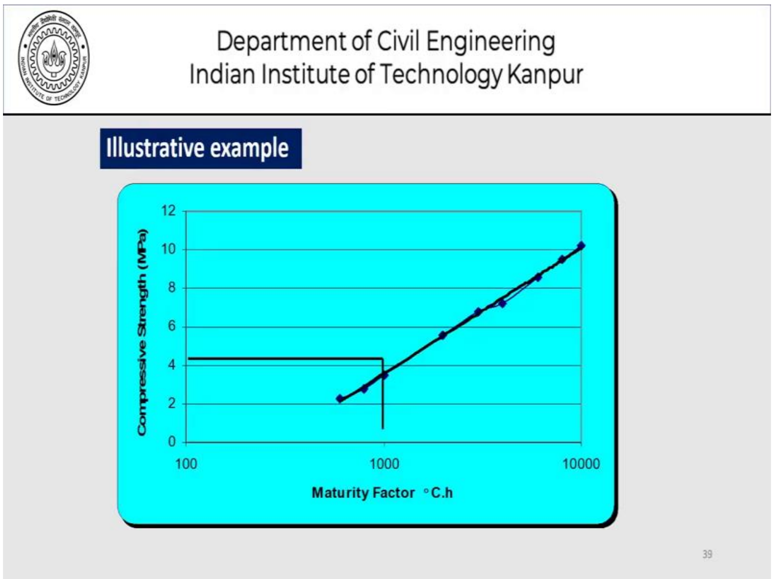

Now once we have that then we try to get a graph of this nature maturity factor being plotted on the log scale you can see that this is a 100, 1000 and 10000 and the compressive strength in MPa. So, this is what is giving us the strength at different maturity factors. So, we know this graph from the laboratory studies and then in the field we know what is the maturity because the time temperature graph is known to us. We can estimate the strength in the field using this kind of an approach.

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Department of Civil Engineering
Indian Institute of Technology Kanpur

To determine in-situ strength of concrete using maturity concepts

Hours	Temp. of structure	$\Sigma(T-T_0)$	Time interval	$(T - T_0)\,\Delta t$	$\Sigma\,(T - T_0)\,\Delta t$	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

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To determine the institute strength of concrete using maturity concepts this what is a table which I am leaving it to you to study and understand for yourself the hours, the temperature of the structure that is then you come to the sum of T-T_0. The time interval is known then you go to $(T-T_0)\Delta t$ then you have the summation here and we have the corresponding compressive strength.

So, this is just an illustration of how we can estimate the in-situ strength using maturity concepts.

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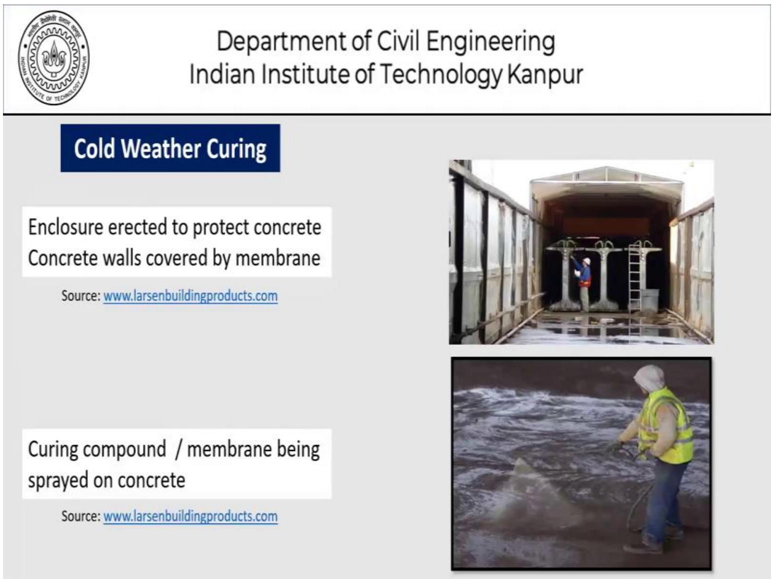

As far as illustrative examples and photographs are concerned this is pictures of a curing compound or membrane being used to protect the concrete against freezing. This is an enclosure to protect the concrete or concrete walls using membranes.

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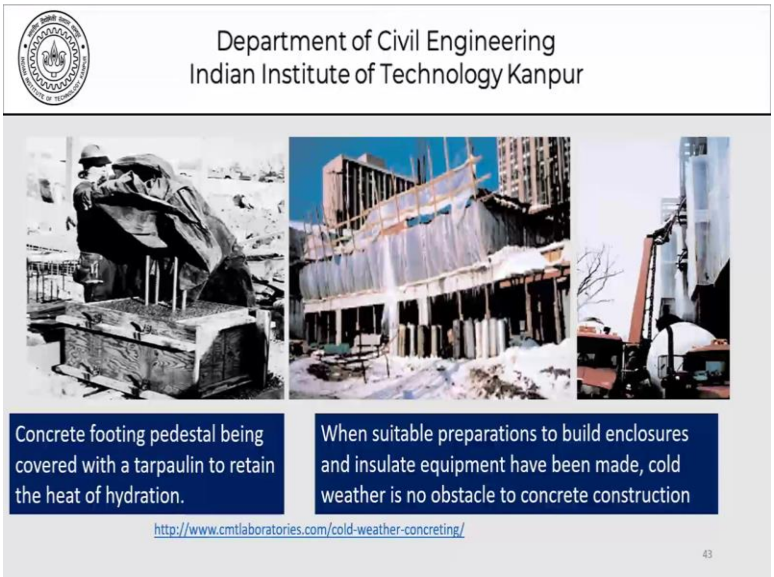

Concrete foot pedestals being covered with tarpaulin to retain the heat of hydration. Here we have cast a pedestal and we are trying to cover it using topologies to keep the heat within the concrete and not allowing it to escape. When suitable preparations to build enclosures and insulate equipment have been made cold weather is no obstruction for normal construction.

Those of us who are in the northern part of Canada and other such places they encounter it all the time and they know exactly how to handle it.

In India we possibly do not have such conditions at many places except perhaps in some reaches of the Himalayas.

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Stacks of insulating blankets this is the kind of blankets that we talked about when we talked about the thickness and so on. These blankets trap heat and moisture in the concrete providing beneficial curing. Finishing this concrete flat work can proceed because of wind break has been provided there is an adequate heat under the slab and the concrete has low slump. So, these are some of the applications that we can use in order to carry out our operations as usual under cold weather.

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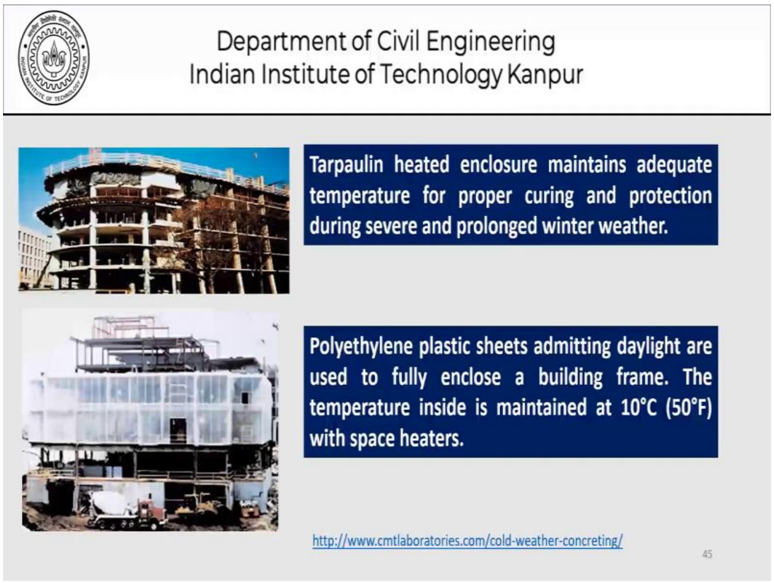

This Tarpaulin heated enclosure maintains adequate temperature for proper curing and protection during the severe and prolonged winters in cold regions where concreting and construction cannot be held at ransom just because of the temperature variations. Polyethylene plastic sheets admitting daylight are used to fully enclose a building frame and the temperature inside is maintained at 10 degrees with space heaters.

So, once we cover open spaces with this kind of polythene sheets or something then it is so much easier to control the temperature inside. And there the construction work can proceed in the normal manner regardless of the temperature outside.

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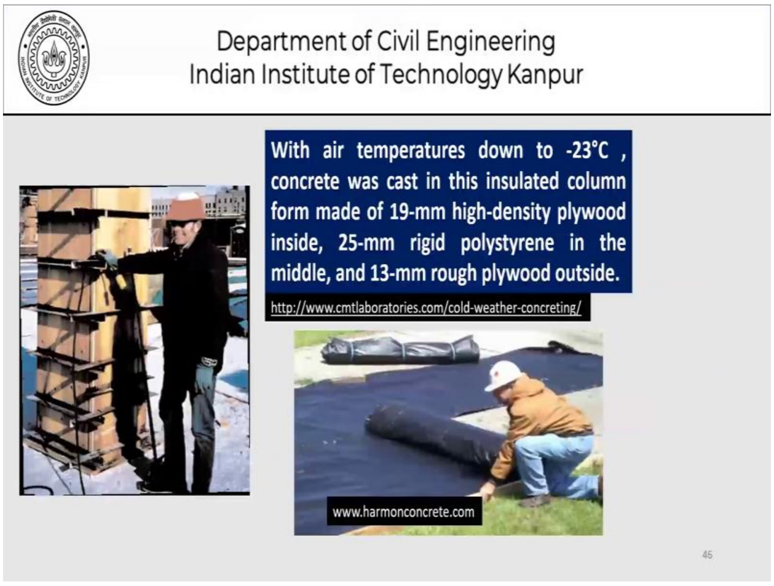

With air temperatures down to minus 23 degree centigrade in this case as shown here concrete was cast in this insulated column form made with 19 mm high density plywood inside 25 mm rigid polystyrene in the middle- and 13-millimetre rough plywood outside. So, there is a special formwork which has been developed here to enable the casting of such columns at temperatures as low as minus 23 degrees centigrade. Here of course we see some membranes being spread.

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Here is the hydronic system for hose laying on earth to defrost the subgrade and on the right-hand side we have warming forms while fresh concrete is being pumped. So, these are all technological advances or technological solutions for cold weather concreting.

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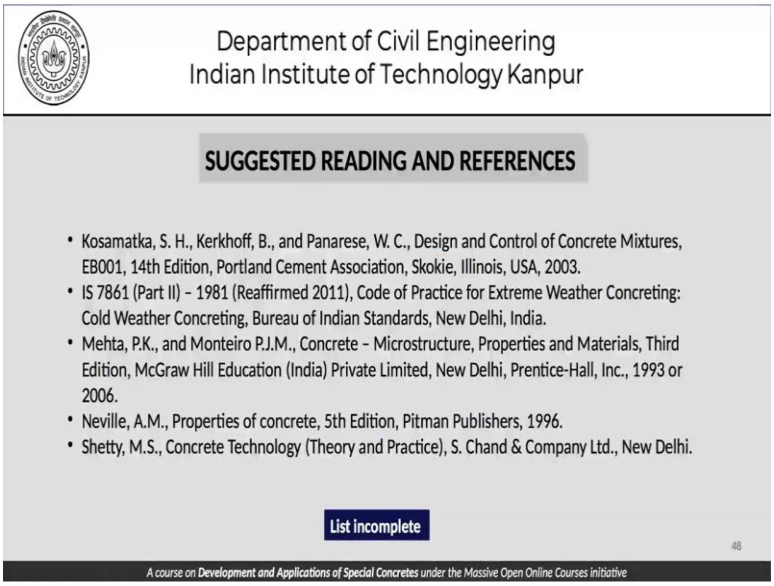

This slide gives the suggested reading and references which you might find useful in following the material which has been presented today. However, this list is by no means exhaustive and in fact it is for that reason that I have written this incomplete. And you are requested and encouraged to look at the internet look for more relevant material and try to understand the subject matter better.

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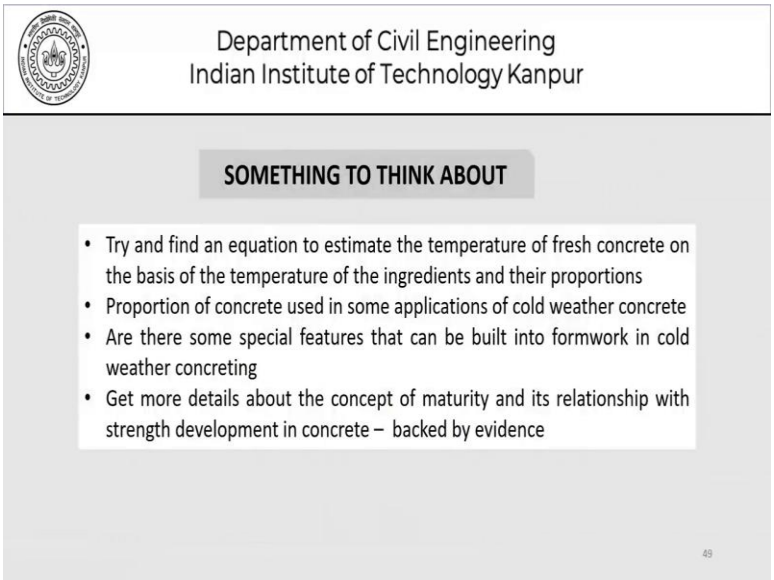

As far as something to think about is concerned try to find an equation to estimate the temperature of fresh concrete on the basis of the temperature of the ingredients and their proportions. Try to find out the proportion of concrete used in some applications of cold weather concrete. Are there some special features that can be built into formwork in cold weather concreting what kind of formwork may be used.

One of them was just mentioned a couple of slides ago get more details about the concept of maturity and its relationship with strength development backed by evidence that is real data which may be reported in literature.

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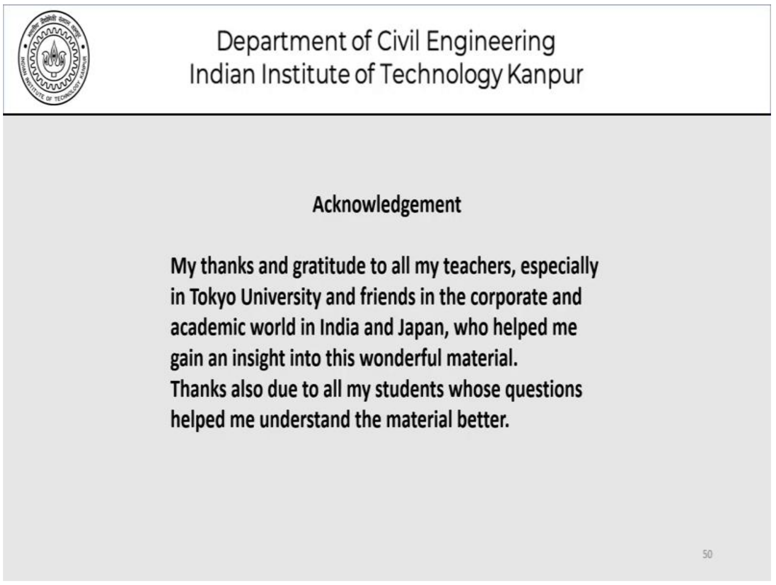

Once again, my acknowledgement to my friend's, teachers and colleagues, students of course with that I come to an end of the discussion today, thank you all and I look forward to seeing you the next time when the pendulum will swing the other side and we will talk about hot weather concreting. Thank you once again.