Building Materials and Construction
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Module - 3
Lecture - 5
Concrete: Production
(Curing, Prefabrication)

Having looked into the other process of the concrete production; namely the mixing, batching, transportation placing last of it that is the curing; the most important part will be looked after today. Today we shall look into curing, this is the most important. Quite often people tend to ignore this, but this is most important as we shall see in a short while. Also we will discuss about prefabrication right. So, let us see what we what is going to be our general outline of our discussion today.

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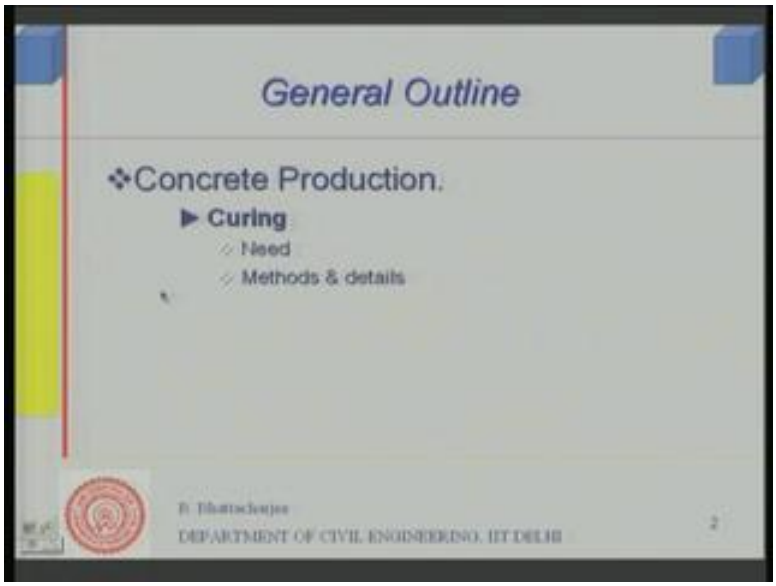

First of all we will look into curing as I mentioned, then we will look into what is the need of curing essentially and then we will look into details of various methods of curing. In prefabrication; we will look into the process and we will mention something called modular coordination. So, let us look into curing. Why do we need curing?

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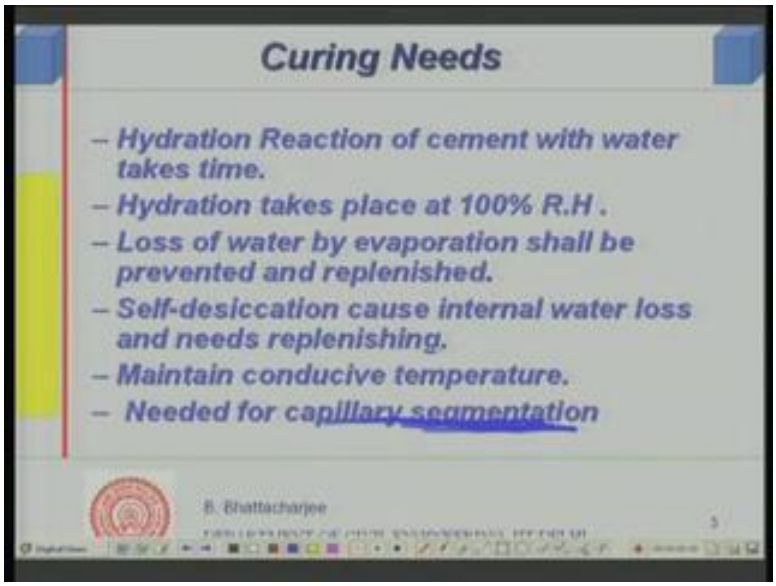

Now, if you remember when we talked about cement; we said that, it is you know is produced from lime and clay binding both of them together. Now, such material when bind together, forms a kind of solid solution about which we will discuss in later on and we said that, when you mix water with it, there is a reaction and we call this reaction as hydration reaction. And then through this reaction it becomes solid. Now this reaction is never instantaneous, it takes time. And therefore, this reaction since it takes time, the condition must be conducive for reaction to continue.

Now, these reactions since it is a reaction with water, it can takes place only in presence of moisture, that is, vapor. In other words, in case of you know the 100 percent relative humidity in the pores of the cement based system is required for this reaction to continue. So, hydration takes place at only at 100 percent relative humidity. Now when you mix water with the cement, what happens is; since the reaction is not instantaneous, only a part of this water reacts, rest all remains there. But if you expose it to atmosphere, most of it will leave operate. So, there is a loss due to evaporation. So, there is loss due to evaporation.

So, therefore, there is 100 percent relative humidity condition will not be maintained. And that is the saturated; you know pores will not be saturated with moisture, unless you replenish the water that has been lost by evaporation. Besides, chemical reaction of cement with water also consumes some amount of cement. So, supposing I stopped the

evaporation process, even then there will be some amount of loss of this moisture, due to the chemical reaction of the cement with water, because some of the water will be consumed. And that we call as self desiccation and it is actually internal loss of water and we must replenish this water, if the pore has to remain saturated with moisture vapor. So, therefore, this is the, these are the basically the needs.

Now some time it may be also needed to maintain a temperature, because you see the concrete being at very high temperature; it is not desirable you do not want to concrete at a very high temperature. Or even after we have cast the concrete, we would like to control the temperature; especially in tropical areas or hot conditions hot and dry condition hot conditions particularly. And there we might may have to you know maintain the temperature of the concrete, through replenishment of water or by supplying water.

So, curing therefore is needed to continue the hydration process, to rather avoid loss of water or reduction of this relative humidity. So, what we do; we actually add water to it. So, curing is the process in which we add water or prevent the loss of water from the concrete or the cement paste or whatever it is of the similar sort of thing. You know right now, we are mostly talking of the cement paste loss of water, although its concrete has got mainly water would be lost reacted with cements, because aggregates as I mentioned earlier they are inert.

So, cement paste to which actually water reacts that consume some amount of water, other water is lost by evaporation. So, this water has to be replenished or supplied from outside and its evaporation loss should be restricted. So, this process by which actually we prevent loss of water through evaporation or drying of concrete and also supply additional water to replenish the loss of water; that process we call as curing and it takes place over a period of time.

So, we have seen the needs of curing and also you know how you do it. 1 more additional important point related to curing is; you see as we shall see in 1 of our later lectures, that hydraulic cement when it when reacts with water, since all water do not react instantaneously, some of the water will evaporate, we replenish this water alright, but the space that was originally occupied by water; it has to be gradually filled by the product of the reaction.

Now, this takes time: it takes days, months and up to even year or more. So, this space which was originally occupied by water must be filled in by the reaction product. Now, this only can occur if curing is taking place or if reaction is taking place, curing is being done and reaction is taking place,. Now if I do not cure it, the space that was originally occupied by water; that will remain as capillary pores, capillary sized pores. Sizes we will discuss later on, but they are capillary pores, because water can enter there by capillary suction.

Now this capillary pores will allow water to come in and as again we will see later that, most of the degradation process in case of concrete is due to ingress of aggressive chemical agents from outside, mostly through water. Therefore, this pores, their presence is harmful from point of view of long time durability of concrete. The capillary pores that is formed by the space occupied by the water that has not reacted in the long run; these pores pole space allows water to come in and therefore, allows aggressive chemicals to come in, which we shall discuss again. And therefore, they are harmful to long term durability.

So, if you do curing sufficient curing, this capillary pore space will be filled up. But even though if it is not filled up, at least they will get segmented and will not remain interconnected. So, segmentation of the pores, that is, separation of 1 pore to another pore; that means, they should not remain interconnected, is most important from durability point of view of concrete right, you know this capillary segmentation, this is very, very important. Capillary segmentation is very, very important from durability point of view of concrete.

So, as you can see for strength development 1 thing is for you know the curing is necessary to prevent loss of water and this in the process actually hydration reaction will take place and this will actually ensure that, capillaries are segmented and strength developmental properties development of concrete is possible. So, that is what is the need of curing and importance of curing right. So, next we look at the next slide. If I do not do curing then, what will happen? Let us look at them.

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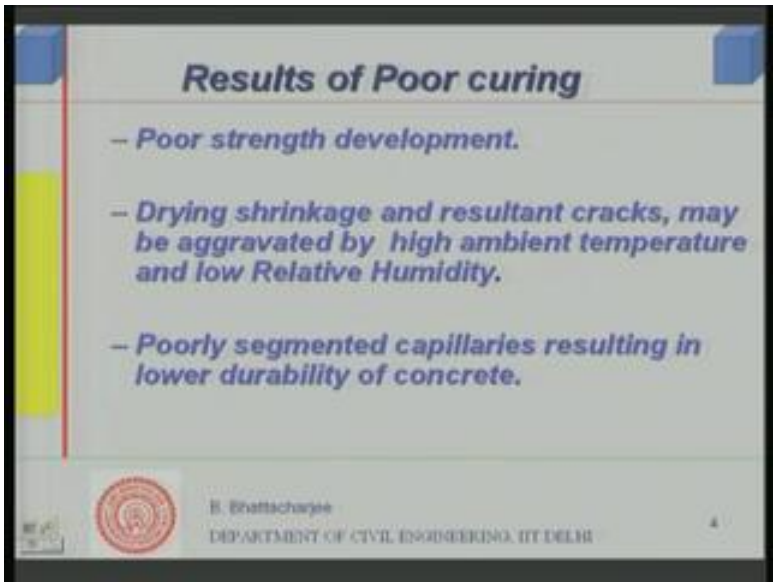

First of all since pores are the inherent flow, in the structure of concrete, this will be explained in detail later on when we talk of strength of concrete. Therefore, if I do not reduce down this pores, strength will not be proper adequate. So, it will result in core strength development this will get. So, poor curing will result in poor strength development right. Then if I allow water to evaporate from the concrete surface, what will take will happen; it will get dried up. And when concrete dries, especially in the early stage even later on of course, it can take place.

So, drying of concrete can result in its shrinkage. Phenomena of shrinkage we will look in details, but let us understand for the time being that drying, when it dries it will shrink it can shrink. And this shrinkage since the surface dries may be the inner core inside the concrete specimen, it may not dry so much. So, there can be differential shrinkages; top shrinks more, bottom does not shrink so much resulting in formation of cracks at the surfaces. So, drying shrinkages cracks can come, if you have allowed the top surfaces to dry rapidly. And to prevent that again, we do the curing or replenish the water at the surface especial in the early age. Once things have become stable and the capillary are segmented well, the water you know like the drying effect would be relatively less.

So, in the beginning it is important that we avoid drying shrinkage and could result in crack. And therefore, if you do not do pre curing, this can actually result in drying and result at shrinkage and this by aggregated created by thermal effects. For example in hot

arid sort of climate in the northern north western part of the country India, we have high ambient temperature, low relative humidity in summer, very low relative humidity. You know hot dried dessert sort of climate, you may have about 40 percent relative humidity even in the morning and in the peak temperature time; it can be 10 percent also. And the temperature could be as high as 40 plus. And in such a situation, if you have not replenished the water or not at least covered the surface of the concrete, then it will quickly dry off and both shrinkage and even you know shrinkage cracks can result in formation of you know defects in the on the surface of the concrete.

So, this is important issue, if I do not do curing properly I can have drying shrinkage, where sometimes only fine cracks placing at the surface, but aesthetically they are poor. Sometimes in thin sections they can be flowing through cracks, because of drying shrinkage, you know very thin section drying shrinkage cracks can be flowing through of course, there are other ways of actually tackling the cracks, but curing is you know it helps in preventing such sort of crack formation.

Now, last 1 I mentioned earlier that, if you do not curing, you know if you do not do proper curing; the capillaries will not be segmented, they will remain in interconnected. And interconnected capillary pores are not good for long term durability of concrete, because water can come in through this pores and result in detoriation of the concrete along with aggressive chemicals water will come in. So, interconnectivity of the capillaries in concrete system should be prevented and that can be done by segmentation of capillaries through proper curing.

So, curing of course, there are other means,, but curing is also helps in segmentation, 1 must remember that, if you do pore curing there could be no segmentation. And therefore, it may result in poor durability of the concrete right. So, let us see diagrammatically what happens. So, how this strength development issue like people have done experiment

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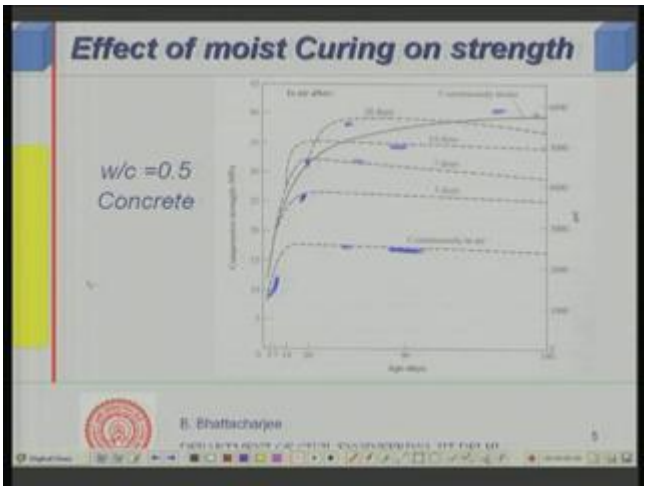

Past experiments have shown that, you know the strength development of concrete takes place in this manner. Say let us look at this say; if you keep continuously near this is the curve, this is curve continuously near. See this side is the composite strength of concrete in MPa, this is same thing in psi and this is the age. So, with age you see the strength of concrete increases, but if you do not supply replenish this water, the strength do not increase beyond a point. In fact, it will have a slight decrease.

Now, you do curing for 3 days. So, we can see that initial of course, the strength here also 7 days strength increase takes place just look into a continuous year. So, some amount of loss would be there, but it would be it would be dependent on the type of test that was done. So, in a specific case it shown that, actually temporary you know it increases up to about 14 days and after that you have studied. But it will depend on what is the condition of the air; what is the temperature, what is relative humidity, is there any wind and things like that. So, in a very dry condition, high temperature this may not be even this much, there may be much less reaction and therefore, you know, but then qualitatively this is fine.

Now see this case the same concrete when it was kept in water for 3 days; that means, you have done a moist curing for 3 days. Then it is shown at increasing strength much higher, even in the same time much higher strength increase. Then of course, beyond that it is shown reduction and so on so forth. And if I keep it for 7 days, it is something like this, if I keep it for 14 days in water the design curing for 14 days, for 20 days this is how it is.

So, you can see that, more the number of days I keep it in water or I cure it, actually there is an increase in strength development. Now, if I keep it continuously moist forever. So, here I started you know I keep kept it for 28 days beyond that I put in air, there is a slight increase after that the strength increases slightly, but then finally, it decreases. But if I keep continuously in moist condition the strength will go on continuously increasing of course, you can see that, this is asymptotic to certain value, I mean it is just not infinitely increasing something of that kind.

So, what happens when you are continuously in moist condition, there is of course, there could be some sort of redistribution and more little bit of more hydration or reduction of porosities and pore sizes, slight increase in strength and there comes and that is reduction and. So, what we see from and this shows for water cement ratio 0.5 concrete. For another water cement ratio, the strength exactly will not be like this. And you can see the relative strength; this was about 40 MPa close to 40 MPa, when you have done a curing for 28 days. So, ultimate strength the maximum strength attained was 48 MPa. And if you keep it for continuously moist, the maximum strength attained will be something like about 20, 23, etcetera.

If you keep it for 7 days, you know it is somewhere around 30, somewhere around 32 or 33. So, this is the relative ratio of the relative ratio of the strength that it 1 attains 1 can get when it is cured. So, for another water cement ratio thing could be different, but qualitatively we understand that, if we the more the days of are curing, I get the long term maximum strength enable is high. We of course, mostly concerned with 28 days strength, because concrete is specified in terms of 28 days right.

So, generally this idea is kept in mind while specifying the number of days required for curing right. So, that is what it is, it says how the strength development is actually governed by curing conditions right. Now, let us look now into. So, what we have understood so far; what is the curing actually, what is the need of curing and how curing helps in strength development and what happens you know if you do not do curing that is it. So, let us now look into methods of curing, right.

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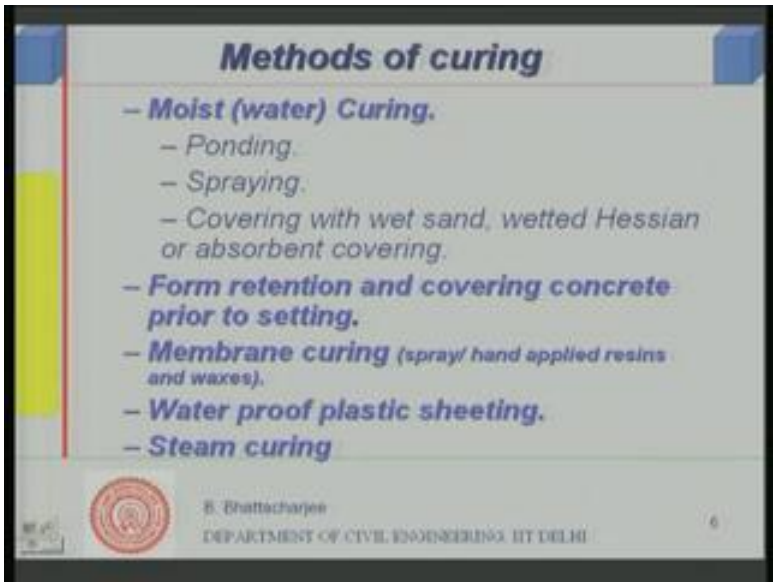

So, since we are supplying water 1 method; obviously, would be using water or moist curing. But that can be done in several ways; we can do it by ponding, we can do it by spraying water on to the surface, we can do it by covering with wet sand wetted Hessian clothes or absorbent covering. So, we can use moist curing you can use in different ways, you know ponding is very suitable for flat surfaces, let us say a bridge deck or even a slab you know the roof slab or floor slab. So, what you can do you put sort of a barrier at the boundary of the flat surface and just pond the surface with water and keep it ponded for the time you decide. And that is a very good way of doing curing, especially for flat surfaces.

If you can't pond, you do not that much of water of course, you have to go for some other sort of way and water might evaporate at very fast rate, then ponding also becomes very difficult. So, in such situation you can do something else; you can come cover it with wet sand, you can cover it with wet sand or you know sand its drying off spray again water sand will hold on to the water for longer period of time. And you repeatedly periodically you go on wetting that sand and that is what is this is.

Then wetted Hessian or absorbent covering, so you have put some sort of you know gunny bags for example, old jute gunny bags or similar 1, which can absorb water, which can keep water in position, some jute or similar sort of thing cotton ways or Hessian you know was the old gunny bags were used very often. So, wet them; keep them over the

surface and this can be done not only for the horizontal surface. Sand is of course, horizontal flat surfaces, but Hessian can be done for vertical surfaces as well.

So, for example, when you call and you wrap up the Hessian or gunny bags or the older kind and you know the cement bags those were jute bags those days, so 1 would actually wrap it around and the column and spray water to it sprinkle water on to it keep wet all the way, for the required number of days. Spraying is also useful in some cases for example; where you can't you know like wet Hessian. That is very effective wet Hessian or something of that kind, sometime you can spray for example, in an automatic pre cast factory pre cast factory, I will talk about pre-cast or pre fabrication later on.

In pre cast factory, 1 might have sprinklers to continuously spray water on the pre cast element. So, you can have such sort of situation; continuously maintain a 100 percent relative humidity while spraying water. Spraying water can be done even, otherwise many places spraying of water is used. You have small pump which will through which you know you can just spray water or sprinkle water on to the surface. So, this is the other method right.

Now that you can do provided you have sufficient water available. If you do not have water available, then what you do; at least you can do is you can cover, you can cover you know the concrete, first of all prior to setting that curing does not start you know till the concrete is sort of solid. So, it has to be a solid after which you start sprinkling water, but even in its plastic or watery conditions slightly, soft condition plastic condition not solid condition the water can evaporate. So, you can cover the surface so that, no water no moisture can evaporate from the surface of the concrete. Then keep the form walled the mould, you know we discussed about the form work earlier. So, we said we will put in the mould and get in the right shape for the concrete specimen or the concrete element.

And you can keep the form for example, for a vertical member you can keep the side shuttering on for certain a long period of time. If, you think that you can't do curing. So, this will ensure that, there is no loss of moisture from those surfaces. But remember, you are only blocking you know evaporation loss, you are preventing loss due to evaporation. What about self desiccation? That water will still be consumed by the concrete internally.

So, relative humidity will not be 100 percent, it will not be as good as spraying water or replenishing the water, but it would be better than not having anything right. So, you can retain the form, cover the concrete. And there are something called membrane curing. Now you see membrane curing is a again, where you have lack of water also is also used in pre cast industry, pre cast industry like a metro construction that was there in that is going on or that was going on in Delhi. And in their pre-cast elements they were using this. So, many in similar pre-cast situation, one can use this membrane curing. So, it could be either spray or hand applied; that is with through brush, some sort of a coating like thing, usually could be resins or waxes, which will prevent loss of moisture from surfaces.

So, 1 has to be this are actually chemicals or waxes or resins as I said, they are applied on to the surface of the concrete to prevent your proportion less. But remember, they their temperature stability has to be seen, there should not melt away or peel off from the surfaces, because of the effect of the temperature. The curing compound as they are called which might be effective in let us say; a cold climate of Europe may not be effective in tropical climate. So, 1 has to be careful about such things, because tropical climate the temperature at the surface effective temperature, what we call sole layer temperature, because the radiation coming on to the surface of the concrete, in addition to the surrounding temperature can be as good as 60 degree centigrade.

So, in northern Indian, say dry summer season, it could be as good as that. So, in such situation, if you are curing compound is not stable, it will not be effective at all. So, 1 has to be careful and cautious about such curing methods 1 being applied, the compound has to be chosen appropriately. So, membrane curing is other kind, it is also again not replenishing the water, but essentially what it is doing; it is actually preventing water loss, where you have no way you are not getting water, you know in dessert say. This could be a good useful thing provided you have taken care of the situation of the temperature.

Second aspect is quickly you apply and leave it there. So, therefore, you can you know you do not have to employ people for long term curing. So, that is an advantage quickly you can apply and if you have taken care of it design properly, you have taken you know taken sort of cushion for lack of strength development and so on properly, it can be used.

So, depending upon the situation this can be used this can find its solution. If possible, there is nothing like better than moist curing. So, that is it.

Then you can have plastic sheet: covering polythene covers. You can use polythene covers or something of that kind, in order to prevent loss of water. Where you have no water what we do? We use either the membrane curing compounds or water proof plastic sheeting. So, that is the other curing. Another way of curing is using steam because; from Le Chatelaines principle; the chemical reaction this particular chemical reaction which is exothermic in nature, is favored by high temperature condition. Now, steam is at higher temperature, when cement reacts at a faster rate with water at higher temperature.

So, steam curing is again keeping it 100 percent saturated, relative humidity remains 100 percent and ensuring the temperature itself is also high. So, that is what is steam curing. Now that can be used if you want quick strength development, early strength development. You want to release the moulds or you want to do pre stressing or similar situations, where you want early strength development steam curing is used, because you can attain the same strength early strength and by doing this curing. So, steam curing is used specifically in certain places where you want early strength development right. So, we look into details of steam curing a little bit more, because that process you should see.

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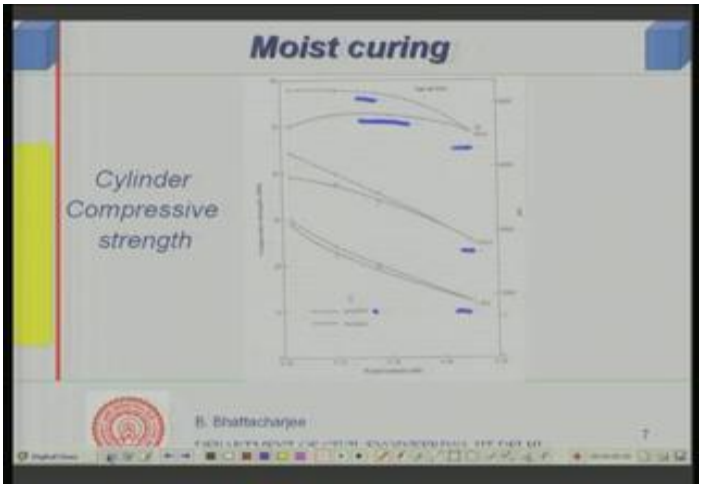

Now let us see what happens further effect of moist curing. Now this is for cylinder compressive strength against water cement ratio This side is water cement ratio and you can say; this is pounded now this is pounded, you can see that, this is line this

corresponds to dotted line corresponds to pounded, that is, this 1 is pounded. And the thick line this 1 corresponds to the Hessian. Now pounded is a continuous supplier pounded there is 100 percent water. Hessian means well it would become dry and then you make it wet again.

Now, it has been observed that, this result is 1 day result, this is 3 days and this is 28 days result. The cylinder compresses strength when clotted against water cement ratio, pounded tends to give you always higher strength than the Hessian. And this difference increases with the age. So, 1 day age you see this difference is relatively less and it is, but what happens when you have high water cement ratio, this affects our relatively less pronounced.

So, at high water cement ratio, this affects our less pronounced, because after all very high water cement ratio, this is somewhere around 0.42 or 4 3 may be somewhere around that kind of situations, well pounded at Hessian tends to do the same, because there are you know like capillaries would be relatively more and generally the effects of curing by pounded and Hessian methods and. So, we can see that the pounded is better especially when you have low water cement ratio, but anyway any case pounded means 100 percent equation you see. Hessian is quite good.

So, this idea one can use, commonly Hessian is used in vertical surfaces and also on horizontal surfaces, but it is still whatever is possible one can do, both will give you equally good results right. Now let see other methods.

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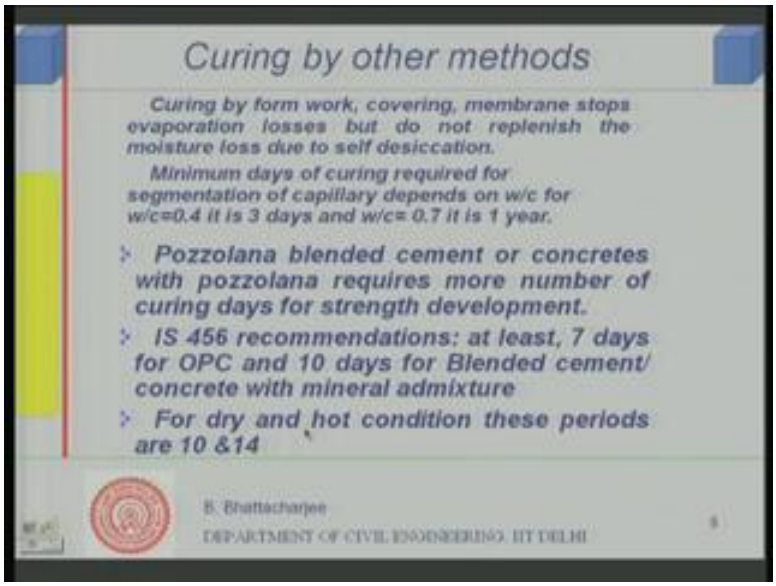

I mentioned to you curing by form work; covering with membranes and you know all this would actually covering form work and covering with the membranes etcetera, covering with you know this covering membranes form work, all this actually stops evaporation loss, but do not replenish the moisture loss due to self desiccation. So, they can be as good as the moist here right. So, that is I have mentioned already and explained.

Now, the code specifies the minimum number of curing days. Code specifies minimum number of curing days, because as we shall see higher the number of days of curing, you will have strength better strength development and also segmentation would be its other criteria, also initially few days you must do curing, otherwise drying shrinkages cracks might appear. So, based on these considerations the code specifies number of days of curing.

Now, it has been seen that, for segmentation of the capillary, the amount the number of curing days required is a function of water cement ratio as well. For example, with water cement ratio 0.4 when you have, because 0.4 means less water fill space in the beginning. So, less capillaries to start with you know, because it is the water excess water which does not react. That forms capillaries. So, we will come to this again and again, because this is very important from the point of view of concrete. So, higher the

water cement ratio more will be the capillaries. And therefore, you require longer period of time to segment these capillaries.

So, you can see that, with water cement ratio 0.4, we need only 3 days for capillary segmentation, where as with water cement ratio 0.7 you need about 1 year of curing to segment this capillary, because you have large amount of capillary when the water cement ratio is so high. When your water cement ratio is so small like 0.4, in fact, below 0.4, you would require very little, because there is an capillary pores would tend to be 0 at much lower water cement ratios. So, we can see, theoretically will do like this you can do like this actually.

So, segmentation refer curing days for segmentation, would depend upon the water cement ratio as well right. But then, you can't you know develop practices or recommend practices based on this kind of details, the code give you simple formulae or or as per IS 456 Indian standard code of practice IS 456 2000, it simply gives you number of days required for of curing. So, that is it.

And then, initial information 1 more thing; when we talked of cement, we talked of some other you know when just introducing concrete, I said there are admixtures and the admixtures of the kind of chemical admixtures. And the other kinds of admixtures are the mineral admixtures. Now this is mineral admixtures we call them pozzalonas, perhaps this was mentioned earlier. We will come to this again in relatively more detail.

Now, this pozzolanas are actually pozzolana, this are materials silica essentially Si O2 silica, which can react with lime forming same product as cement with water, similar not same, similar product as cement and water. Now, this reaction; however, is relatively slow. This reaction is relatively slow compared to that of cement and water. And not only that, when you some amount of this material is used in conjunction with some amount of cement and then add water to it, cement itself produces some amount of lime, so its chemical reaction. Again this will be discussed we will talk about it. And this lime can react with the pozzolana.

Now this reaction is a slow process, so this requires longer time more number of curing days for, this requires more number of curing days for strength development. And therefore, our code suggests following values; 7 days for ordinary Portland cement no blending, 10 days for blended cement; that means, where you have used pozzolana

together with the ordinary Portland cement clinker or you have used mineral pozzolanic admixtures, but it does something more, it says if it is a dry and hot condition, corresponding periods will be 10 and 14, because you know evaporation rate will be higher and it gives you higher.

Now British code of course, goes in a slightly more elaborate way, but does not matter I think we are concerned about the Indian codes, other codes some other codes, we will give some formulae etcetera all. That is not our consent at the moment, but Indian code does it in this manner. So, that is how based on the need of curing the codes to its equation.

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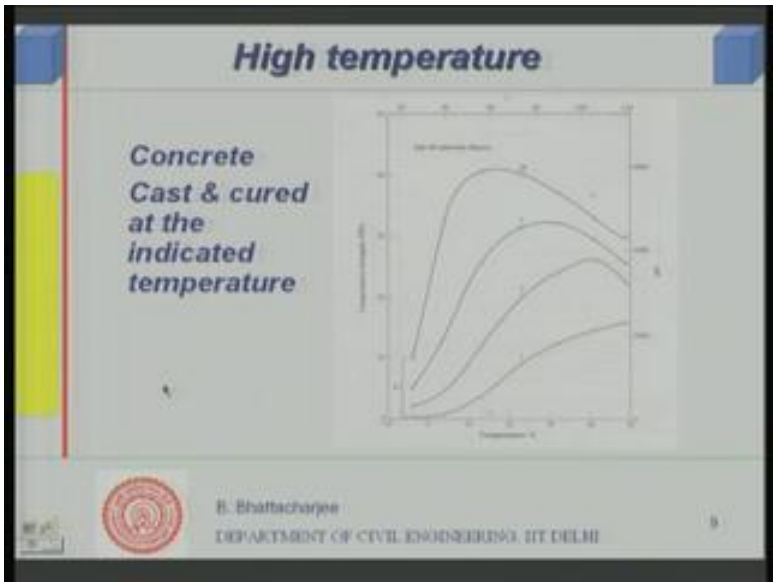

Now let us look at high temperature situation, high temperature curing. You see if I subject concrete to high temperature, that is concrete cast and cured at the indicated temperature, as you can see That is let us say at 30 degrees it is cast and cured for 1 day right, this is 30 degree centigrade right, its cast at 30 degree centigrade and cured for 1 day is that is shown. Its cast at 50 degree centigrade and cured for 1 day, you get this line. Same concrete at 3 days, you will get this strength, 7 days and 20 days.

Now you cast at 20 degree centigrade, this is 10, 20 would be somewhere here. And you will find that the strength here is nearly the maximum. So, if you cast a concrete at higher temperature, I mean cast and cure at higher temperature, especially cure of course, the casting has also the effect. You do not really recommend casting of concrete at high

temperature, similar reasons basically. So, cast and cure the concrete at high temperature, what happens is; initial strength is high, but later strength is low up to 20 degree centigrade or around 20 23 centigrade perhaps, this strength is relatively high, beyond that if you increase the temperature 12, it does not show you high strength at 28 days.

And if long term, in other words you can conclude from this that, if you want high early strength, you can go for high temperature, but you want high long term strength high temperature is no good may be up to 23 degree centigrade 20 23 degree centigrade is good. So, high early strength if you desire, then you can do high temperature curing, but at the cost of long term strength. This is, because the hydration process you know which is a chemical reaction and favored by high temperature; it is non uniform when you do at high temperature, in fact, this effectively very pronounced if you cast the concrete at high temperature. Curing after few hours of casting at higher temperature still is better than casting and curing at the same temperature.

So, you know this gives you the composite strength in MPa as same here. So, concrete should be cured at high temperature, casting of course, beyond a particular temperature you do not really know but recommends that, you know this ways high temperature high temperature concreting is done, but temperature is usually controlled. But curing can be at high temperature to attain high early strength. But long term strength it may not be as good. So, this is where the role of steam curing comes. You know steam curing gives you high early strength.

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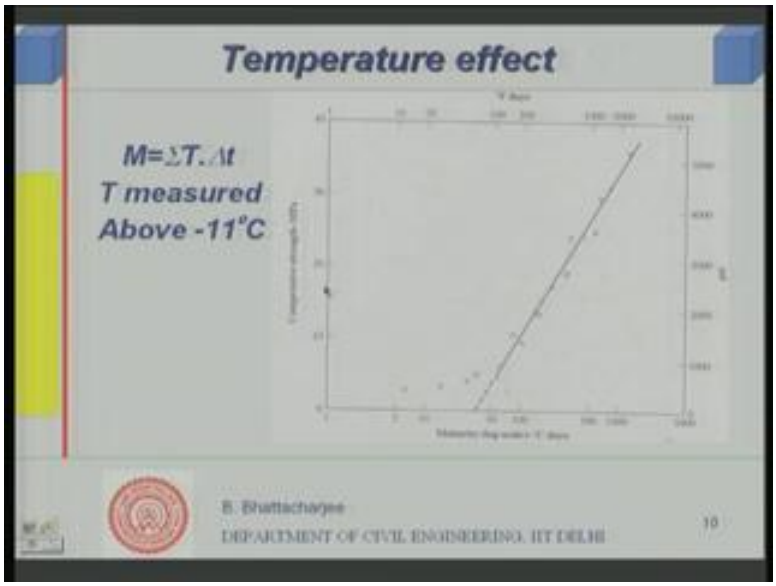

A formula is there which is called maturity right So, when its being absorbed that maturity is defined as sum total of temperature into the product of the time for which the temperature was actually maintained. For example, if you have 2 hours at 20 degree centigrade. So, 20 into 2 plus say 8 hours at 80 degree centigrade 8 into 80, that is total mature of the concrete which has been subjected to 2 hours of 20 degree centigrade in the initial period, then 80 degree centigrade for next 10 hours or whatever it is.

So, this assumption is made that, if you have such concrete with equal maturity, they will develop same strength. This strength is a function of maturity and that is what a curve shown through this a sort of curve, you see this side is a maturity log scale degree centigrade days and that side is composite 1. So, what you assume; if you have the same maturity, you will have the same strength. It has been observed that curve is something like this and this is log of maturity versus composite strength, there is a kind of linear relationship follows beyond certain point with the maturity.

So, that is the idea about steam curing. Now this maturity is measured as T about minus 11 degree centigrade, datum is taken as minus 11 degree centigrade, because below that concrete will never hydrate, the cement will never hydrate and strength of concrete development, you know strength development of concrete will not take place. So, this is the concept of maturity. And based on this actually steam curing is done right. And as I said that initially we do not prefer.

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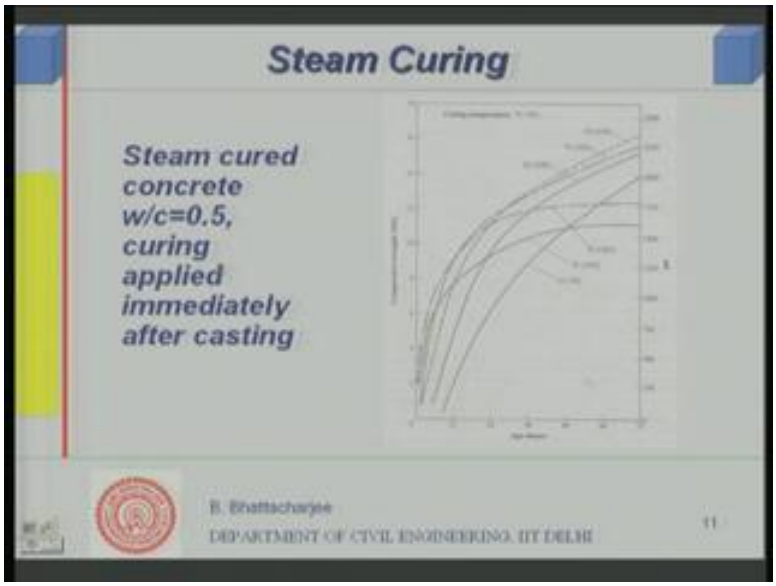

You know it is this can this diagram show you what happens steam cured concrete at water to cement ratio is 0.5, curing will take immediately after casting. And again if you see this it will tell us that, this is the, this is at 23 degree centigrade, this is at 91, this is at 85 etcetera, you know this curve is for 85, corresponding temperatures are shown here and this is at 21. So, this goes on increasing, this strength goes on and this is the age 72 hours. So, its 3 days strength actually we are looking at and this is at 54 degree centigrade etcetera.

Now, if you go on increasing the temperature; 85 degree centigrade 91, so beyond a point actually when the 3 days starts coming down. So, very high temperature again is not desirable. This is the effect of steam curing on water cement ratio point 0.5 and this is applied immediately after casting. So, this sort of several results are available in literature, it has done by various kind of people. So, the idea followed from this is of course, the steam curing cycle that is been recommended in many places, is something like this.

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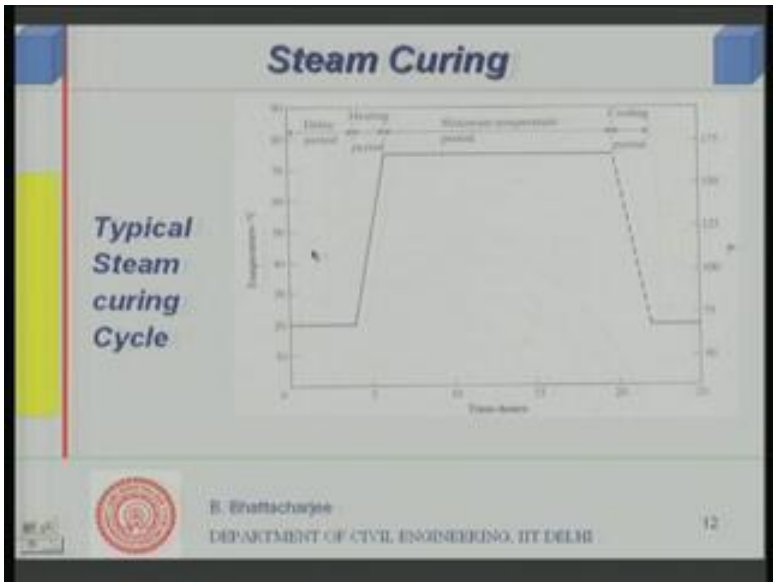

First 2 hours you do not touch, because if you heat up the concrete at that period of time the hours strength development and as well as other properties of concrete performance of concrete in the long term, will be affected totally. So, first delay period, first about 1 hours about 2 and half hours, you know even 3 to 4 hours you have a delay period, then of course, you heat it up through using steam right and temperature increases.

So, this is the heating period; steam is circulated usually through pipe or even through a cover, you just put a cover and steam is just circulated through pipes within that cover even, people will start the link covering the element in pre-cast industry especially. And then supply steam just below the turbulent. So, it will just steam is just passed on to the surface of the concrete. So, this is heating period; temperature increases, maintain this period maximum temperature period for about 7 8 hours. You see for example, 5 to it would be around 7 hours, that 7 and 7 to about 20. So, about 13 hours, this has been maintained it could be different; depending upon the situation should be different the maximum temperature period.

And then you allow it to natural decrement. So, naturally cools of course, it will rarely come to 20, it will be asymptotically going down to 20 over a long period of time, but it will require at least 7 8 hours to come down to close to the ambient temperature. So, based on the fact that, if you use too much of high temperature during the early stage of

concrete is long term properties are affected, long term performances in not good if you heat it up. And but, if you want high early strength, then you can use steam curing.

So, therefore, high early strength supposing you want to release the mould or you want to do prestressing; steam curing can be good solution. You want to place the pre-cast element right on to the you know erect it straight away, very early in 3 days or 4 days time or release its prestressing release it from prestressing bed. So, such situation where you want high early strength development steam curing is a good solution. In normal courses it should not be it is costly also, your investment would be there; boilers and steam generations system, supply of the steam there lot of losses. So, all those part is there.

So, therefore, steam curing is adapted where you want high early strength and this could be the typical regime. Remember if you do high temperature curing, this can affect the long term performances right. So, that is all about curing.

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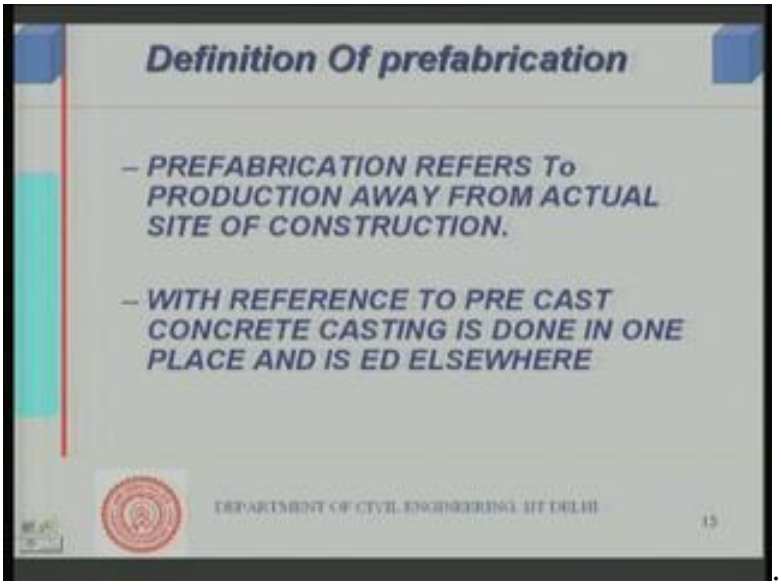

Let us look at the next part of our topic, that is, pre-fabrication. Prefabrication refers to production away from actual site of construction, which refers to production away from actual site of construction right. And idea is that, you cast in 1 place and use it elsewhere and use it and this and can be used elsewhere right, you can use it elsewhere. What are the advantages? Advantages of pre-cast concrete, you see parallel activities first of all; that means, you do the casting, when you are doing the casting of let us say in case of a

bridge, when you are doing the casting of the deck portion, those could be beams or segments or whatever it is.

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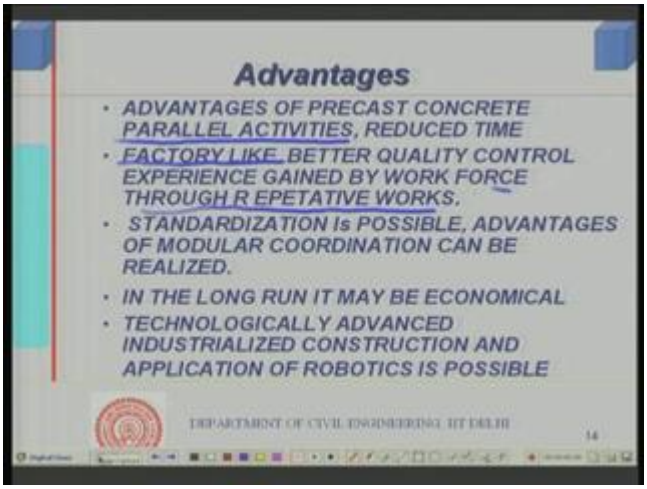

Advantages of pre-cast concrete, you see parallel activities first of all; that means, you do the casting, when you are doing the casting of let us say in case of a bridge, when you are doing the casting of the deck portion, those could be beams or segments or whatever it is. When you are doing casting, you can actually construct the foundation. Normally in casting what will happen, we will cast the foundation and then you can only cats the super structure, you know substructure cast the foundation, then the substructure you know like the peer or something like that in case you have bridge.

And then top deck after that, so it is sequential. There is a technological sequence, but in pre-cast you can do parallel activities. So, that is the biggest advantages. So, that can be very fast. It can be very fast, it can be very fast that is the first thing right. It is used in buildings industrialized buildings you can use them. For example, you can have all pre-cast products, just bring them and assemble them like steel or similar sort of material. So, reduce time very fast construction can go for. Factory like situation casting of concrete is done in factory like situation. Therefore, you can have really better quality control. All quality control procedure you can adapt and therefore it can have much better quality of concrete production.

Then experience gained by the work force through replicative you know repetitive works. So, you repeat the same works and time again and; that means, that experience is gained that, after some time it is all set, it is factory like. So, produced quality would be

much better everything is set. So, that is what is another element is. Standardization is possible, you can standardize things, standardize the size standardize the sizes right. Or rather you should use it where standardization is actually possible.

So, see buildings are not necessarily say look alike, but if you can standardize on certain things, it would be the advantageous, big advantages. And they are something called modular coordination can realized, which I will just mention later on. It may be economical in the long run, because you are producing same thing again and again, so it can be economically on the long run, you can take technologically advanced industrialized construction practices and this is realty in many countries and the western developed wall and robotics and similar sort of advanced technologies can be used in case of pre-cast construction practices right. Just this is an important issue, modular coordination we can actually apply here.

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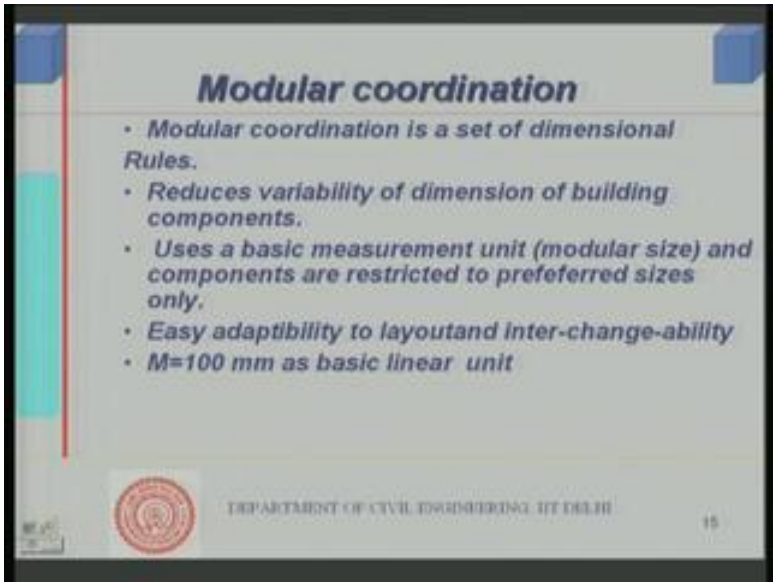

Modular coordination is nothing, but it is a set of dimension or rules and it reduces the variability of dimension of building components. So, what you do you have a basic unit, basic module and everything is repetitive. So, your layout will also be modular layout so that, you can use one part one component, you know you can use interchangeably the components building components.

For example, if the beam sizes are modular sizes, you can put in the modular grids. So, that will become as possible, usually you have got an unit which is called modular size

and it helps in industrialization. Industrial building construction relies you know relies heavily on modular construction. So, everything can be standardized really, dimensions and things like that well. So, it can change to all kind of layout design easily, you should you know modular coordination does this. Usually M 100 millimeter is used as the basic unit in some cases. Now let us look at of disadvantages of the pre-cast construction well.

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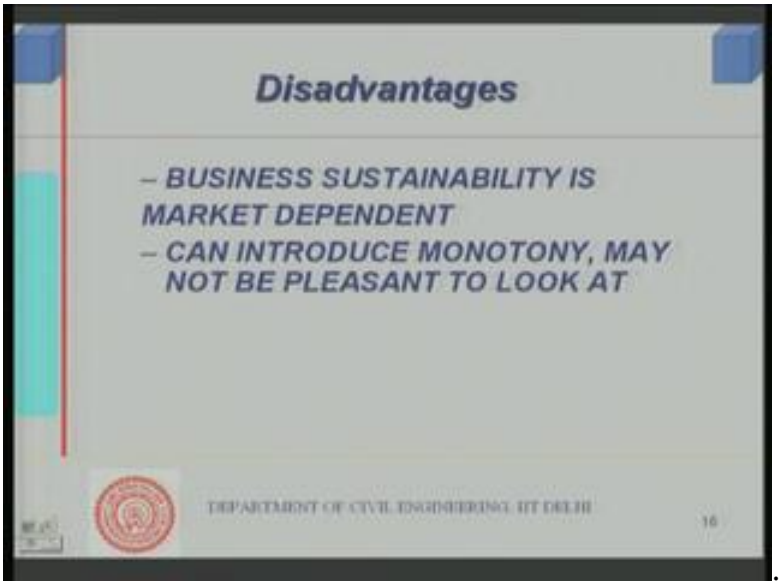

If it is a building, then business are sustainability is market dependent. So, the market likes your product. There are examples where pre-cast factories have been closed down, because the market did not accept it. They can introduce monotony because; everything is same replicates, several times you producing the same thing. So, they may not you know they may not look aesthetically nice especially in buildings, but architect architects can take care of this by various means; there are several other advantages of using this. So, if properly planned and designed the monotony can be 1 can get rid of, but they can introduce.

Third disadvantage is not been actually listed here; is the cost, you have initial high cost. So, there is a breakeven point beyond which actually it will become cheaper, up to certain point it is never cheaper.

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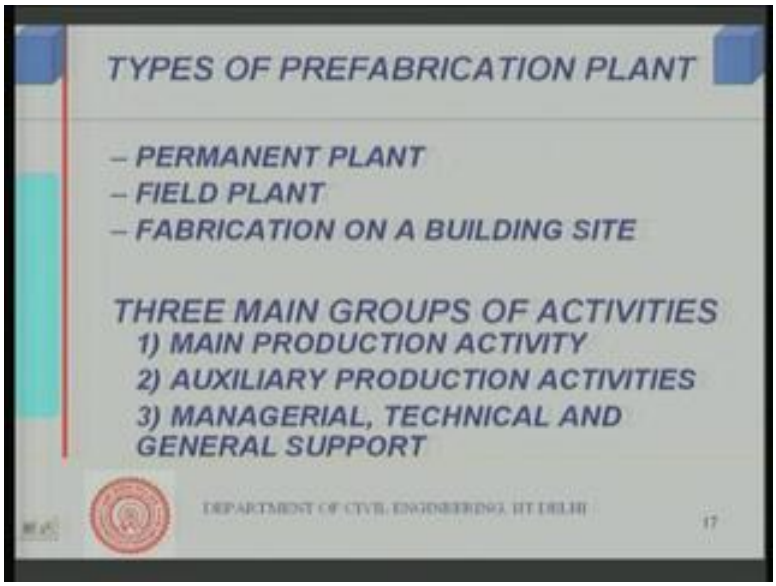

The plants types are permanent plant, field plant and fabrication on a building site. Permanent plant is 1 particularly used in building, which will sell components; valves, roof system, hollow core roof system, columns linear systems and then 2 dimensional systems. So, there are varieties of system. So, permanent plant would be producing this 1, which could be sold and erected at site. Field plants are used let us say for large bridges, sometime you can have a field plant and this would produce temporary for may be 4 5 bridges together.

So, 1 after another it could be you know field plant is of that kind, which is not totally permanent, but it is quite for some time it is permanent. And sometime for a single may be a state or something of that kind, a building site it is for project based 1 project the plant is there and then despentary. There are 3 main groups of activities in a prefabrication plant; main production activity; that is main concreting activity, auxiliary production activities and managerial technical and general support.

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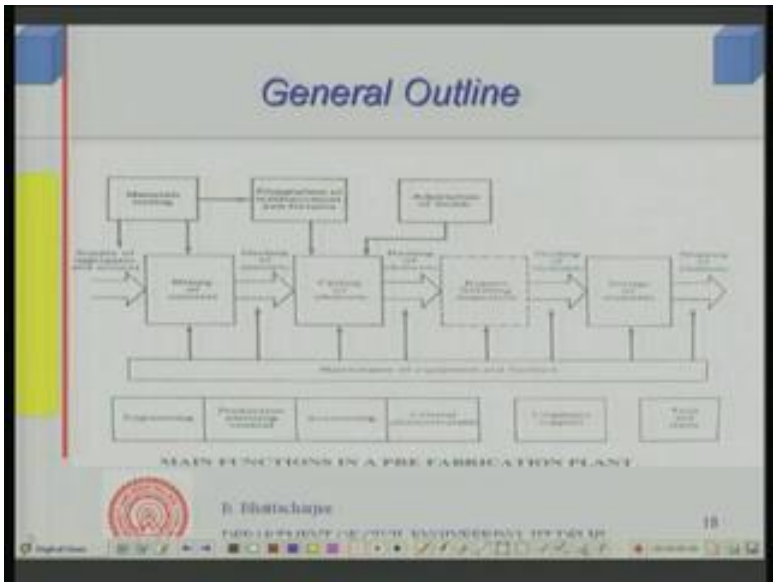

Now, let us look at these activity situations. See this line shows the basically main activities; that is concrete production right, casting of elements, mixing of concrete, then preparation you know and transport basically inspections etcetera, then it is going out. So, this slide denotes mixing, calling of concrete, casting and then calling of the elements then they are inspection and any minor repairs required and then of course, calling of elements storage and then it goes off.

So, this is the main activity of the casting year or a general plan. Now you can see, these are maintenance materials testing, these are auxiliary unit, and then you have got preparation of the moulds or reinforcement etcetera, adaptation of moulds. So, these are the you know if you remember the previous 1; we said this is the main activity, this is the auxiliary activities and this also is also auxiliary activities, maintenance of equipment etcetera facilities as it is shown here. And this is the supporting activities like engineering production, planning, accounting etcetera.

So, 3 levels we mentioned earlier, these are the 3 levels in a general situation of pre-cast you know pre-fabrication casting or pre fabrication plant right, so main functions of the pre fabrication plant is shown here.

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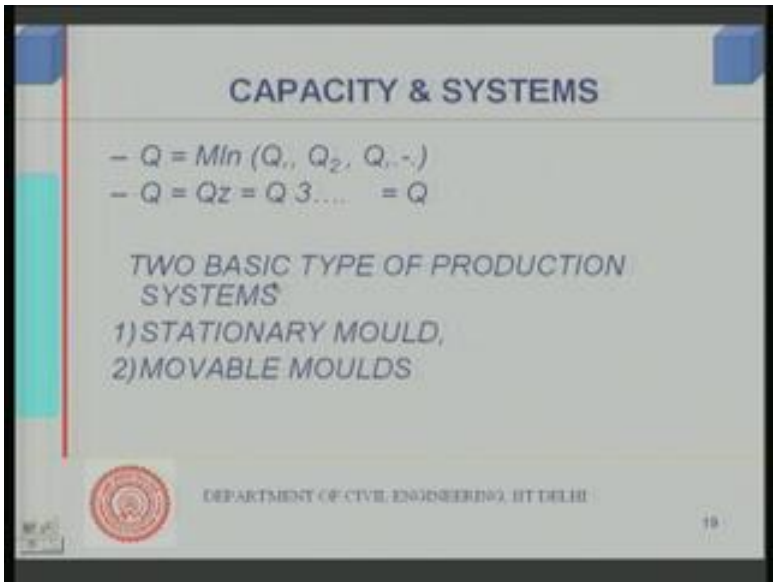

The capacity depend upon there are several sequence for example, mixing capacity, capacity of casting, capacity of holing concrete, capacity of holing elements. All this the overall capacity of the system would depend upon the minimum of all, you know if Q 1 Q 2 Q 3 etcetera are the capacity of each individual components which are in sequence, the minimum will be the overall capacity governed by the minimum. The best situation will be when Q 1 is equals to Q 2 equals to Q 3 and all equals to Q. There are 2 types of basic system. So, 1 is called stationary mould, other is called movable moulds.

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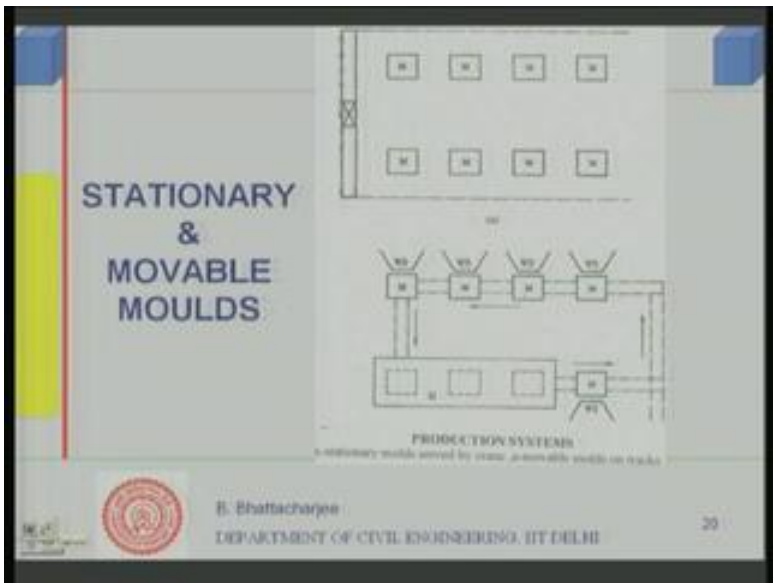

See this is stationary mould. So, my moulds are stationary, as you can see these are stationary mould situations, these are moulds are stationary, this are stationary moulds stationary mould and there is a overhead crane. So, the casting is done here on to the mould, the crane takes it out and then shifts it. So, this is called stationary mould. This is movable mould, where it is like an assembly line, assembly line of a car or something of this kind, where this is you know work station 1, work station 2 etcetera like this. So, the same mould moves along this direction and then finally, the for example, here the mould moves, then may be the reinforcement is placed, next it moves. So, it is on a either on a rail supported somewhere supported, basically will get rail supported, so that the mould can move.

So, as it moves at a given speed, here the reinforcement is placed, the concreting is possibly done, the clear repair inspection etcetera and it is a curing and then it is actually heat, you know could be heat curing, here its steam curing is very suitable thing, ideal thing. So, heat curing is done, then any observable anything inspection etcetera and then it goes out. So, this is this are the other kind of principle that is possible right.

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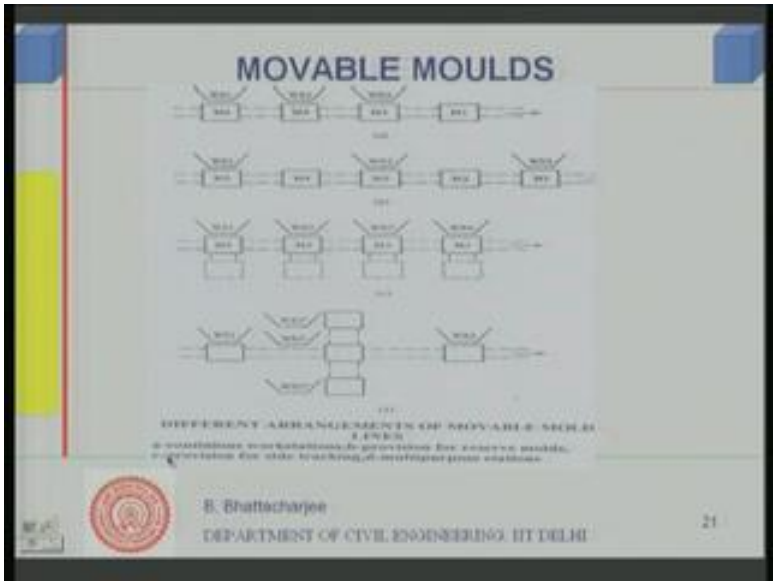

But then whoever moulds when you are doing as a fast process that is a very fast process, highly industrialized situations, there you can apply your planning has to be good, engineering has to be really good right. Commonly used for building parts; industrialized building construction, high tech building constructions. Now, you see there is 1 problem,

since they are all in single line, so if there is a disruption in any point, whole system can get stopped.

So, therefore, you have station, you know you have stations you have stations like this stations, where if there is a problem, you shift it out, shift it out everywhere you play have station. Similarly, if there are other arrangements. So, various kinds of there may be 1 in between sort of a dummy station in between. So, if there is problem, it can be shifted other 1 can go on while this is rectified and so on so forth.

So, there are various ways to tackle this, different arrangement for movable moulds right can have continuous work stations, then provisions for reserved moulds, the second 1 is the reserved moulds, third 1 is the provision for side tracking, so we have side tracking, fourth 1 is multipurpose station. So, many things can be done. So, this is taken care of by you know this problem of breakage topages of work, due to breakdown is taken care of by this sort of arrangement right.

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The elements handlings are generally done by mountain mounted gentry; portal cranes, wheel mounted, ported crane gantry crane, overhead cranes, tower cranes and mobile cranes etcetera. They are the basic ideas.

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So, where they can be applied? Industrialized building construction, now this is 1 place where it has found its big use not in India of course, at the moment, but you can produce it at a very fast rate, many countries even in countries like Israel or say in northern Europe Sweden, they have they have industrialized building constructions. So, it is very fast, it if the concrete has to compete with the steel, because steel construction is very popular in many places, because you can do it just very quickly and erection is very easy, you have all pieces brought together and just erect them, weld them or do whatever it is .

Now, if similar system can be replicated by pre cast concrete industry. And with the advent of high strength concrete systems and other development in concrete, this is a very useful thing, this can make things cheaper very cheap in the long run and the production process can be very fast, I mean the erection process can be very fast. So, you can get your house built in may be 1 day or in a 18 storey building built in a month or 1. There are other methods, but this is also this is a bigger method.

Bridges has been used here also in India right from 1970s, segmental construction of bridges piece you bring in cast in and casting here, bring them up at the site, erect them and join them by pre-stressing or various means. There can be long line short line casting. In short line casting you can cast 1 element and then cast the next element by the side of it, what is known as match casting and then remove that 1, but in long line, say complete 1 span, you have moulds placed in you know the mould placed for the whole

span and then each elements are cast 1 after another together. So, that is what it is long line casting.

So, bridges this has been used in India, I know a Ramjhula bridge over Ganga is recent bridge and is long line casting, short line casting has been used in many Ganga bridge in Patna is 1 of them, many in Delhi, Delhi flyovers many of them are segmental construction of this kind. Railway sleepers have been used for many years and many other miscellaneous items, industries and sport complexes. So, these are the possible application of pre cast industry, it has got big pre-cast concrete, you know pre-fabrication in construction.

If, the concrete construction is engineered fully, then this would be very useful thing, but 1 has to remember that initial cost could be high, but after a number of them, it will break even, it will generally break even after a number of them. So, therefore, advantage is a very much there and in this 1, 1 can take advantage of the hi-technology in the concrete material science like high performance concrete, because they requires very good quality control, over other kind of development in cement based composite, other kind of developments in cement based composites etcetera 1 can actually take advantage of this situations right. There are of course, things like sport complexes built in the country like Kanteerava stadium in Bangalore, this is made of pre-cast elements and dome structures its beams etcetera those are pre-cast.

So, this has been already in practice, industry has building that is yet to come, but they have they big advantage in terms of the first construction. So, that is about prefabrication and curing. With this we generally conclude to summarize the whole thing. We looked into the curing, the methods, the need; the methods. And we have looked into ill-effects of not doing proper curing. Also we looked into steam curing, then we have looked into pre-fabrication; basically what are the types of plants and advantages and disadvantages. I think with this we will conclude.