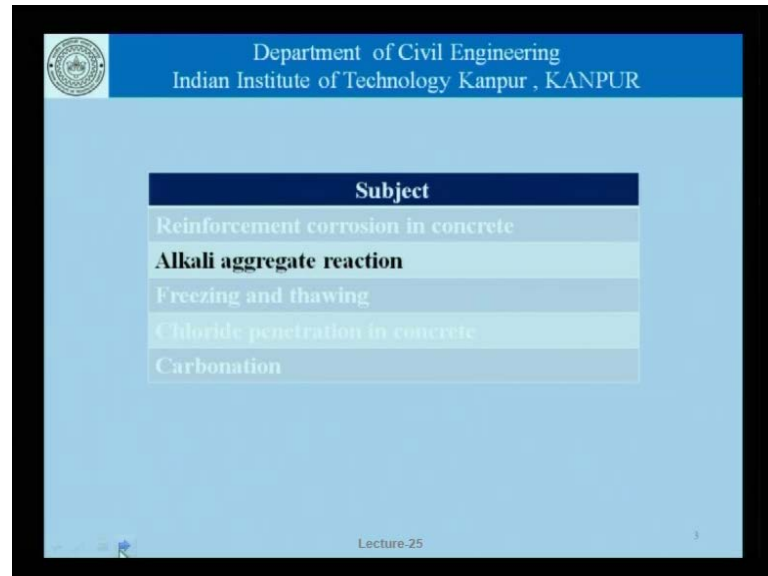


Concrete Engineering and Technology
Prof. Sudhir Misra
Department of Civil Engineering
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Lecture - 25
Alkali – aggregate reaction (Part 2 of 2)

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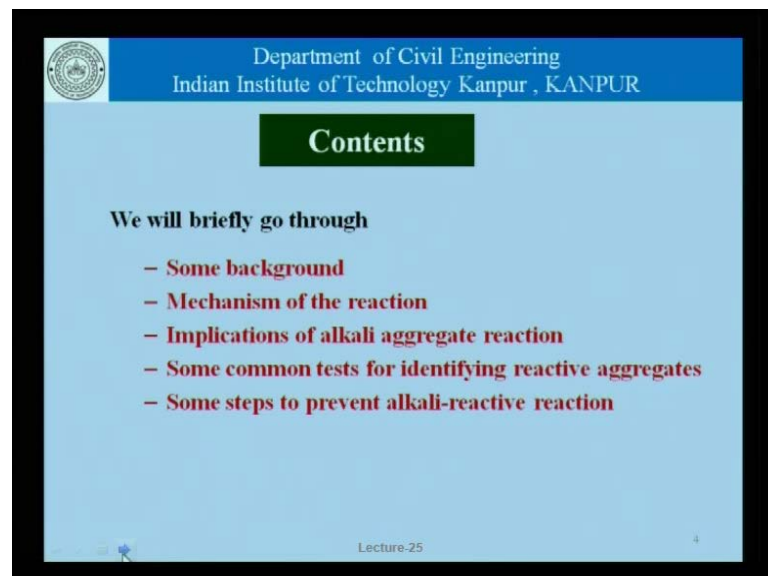
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Subject

- Reinforcement corrosion in concrete
- Alkali aggregate reaction**
- Freezing and thawing
- Chloride penetration in concrete
- Carbonation

Lecture-25 3

(Refer Slide Time: 00:32)



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Contents

We will briefly go through

- **Some background**
- **Mechanism of the reaction**
- **Implications of alkali aggregate reaction**
- **Some common tests for identifying reactive aggregates**
- **Some steps to prevent alkali-reactive reaction**

Lecture-25 4

Namaskar, and welcome back to our discussion on concrete engineering and technology. Continuing our discussion on mechanisms of deterioration in concrete, we were talking about alkali aggregate reaction.

We will briefly go through some back ground, mechanisms of the reaction, implications of the alkali aggregate reaction, common tests for identifying reactive aggregates. And steps to prevent alkali aggregate reaction, out of these we have already seen the background information mechanisms some part of implications, and we have discussed the quick chemical test, and the mortar bar expansion test which are two of the more commonly used, standard tests to identify reactive aggregates.

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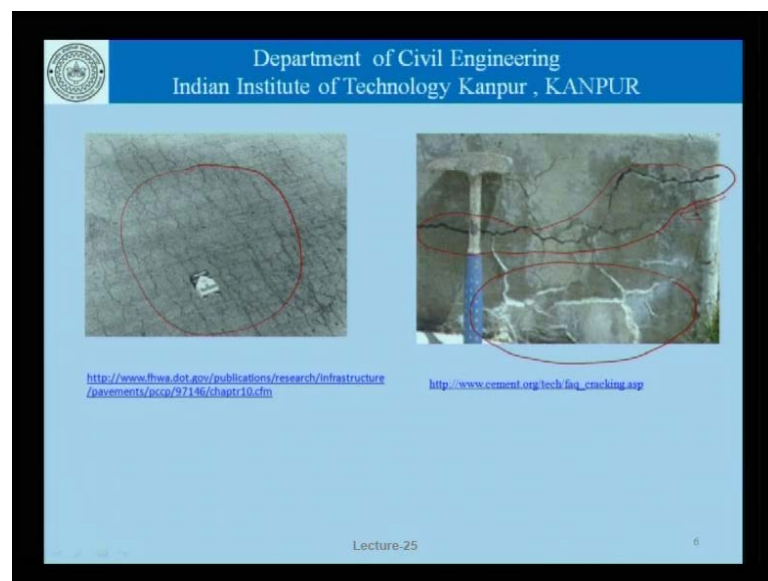


So, we will continue our discussion from that point onwards, and we revise some of the fundamentals we look at concrete as the multiphase composite from the point of view of the fact. That now we are not trying to do the volumetric's which we did when we looked at this slide from the point of view of proportional of mixes. Now, we will try to study the immediate neighborhood of a given aggregate, I have drawn the circle here around the coarse aggregate which is easier to draw. Of course, it should be understood that when we talk of alkali aggregate reactions, we are talking of the reaction of fine aggregates or coarse aggregates.

So, it is not really a matter of what aggregate we are talking about in the sense that our fundamental understanding was that sand and coarse aggregate, that is the fine

aggregates and the coarse aggregates are both inert. And do not take part in any chemical reaction they do not react with the cement or its hydration products; they basically act as only fillers. This understanding is precisely what changes when we talk about alkali aggregate reactions when the reactive components in terms of the minerals that comprise the fine aggregate or the coarse aggregate they react with the pore solution formed as a result of the hydration of cement.

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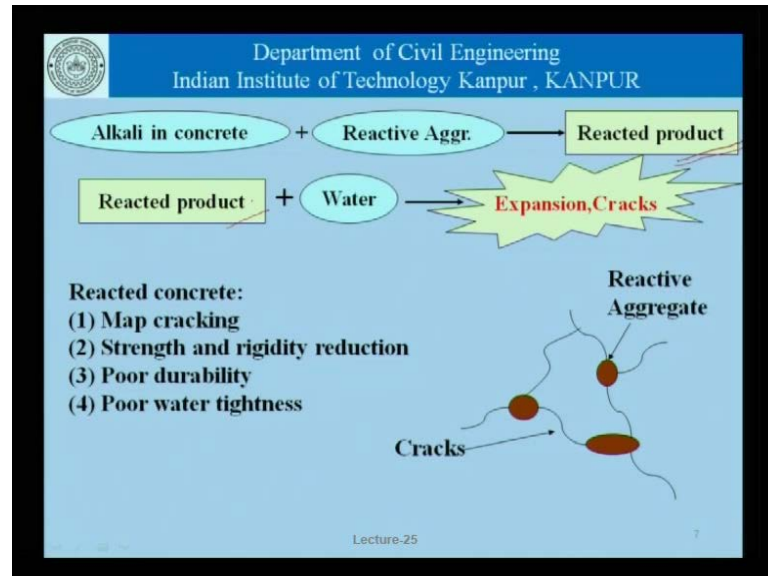
These pictures here they show some cracks which are formed on account of alkali aggregate reaction will go through the mechanisms a little bit in detail once again.

But these pictures show us the kind of map cracking or an all round cracking that occurs in a structure when it is afflicted by alkali aggregate reactions. This is the picture which is from a pavement which was cast using concrete which had reactive aggregates. This picture here is a slightly different representation of what happens when alkali aggregate reaction occurs, we can see here that this crack here is fairly void crack so aggregate. So, alkali aggregate reaction induced cracking in structures is not insignificant it is not something which we would like to ignore, because such cracks have a structure implications they have durability implications and so on.

In this picture in this part here we also see the deposit of the white gel that is the reaction product of the reactive silica and the alkali metals that a part of the pore solution. So, the gel that is formed that absorbs water and gives rise to cracks that gel moves around;

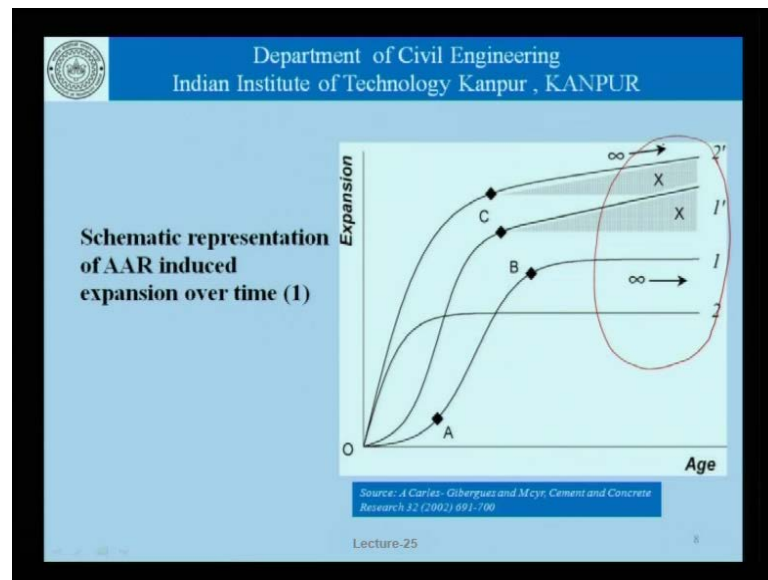
obviously, in the cracks and fishers that are formed within the concrete. And this is manifestation where we see that gel exuding to the surface of the structure.

(Refer Slide Time: 04:45)



This picture we are see in the previous discussion where we saw that the alkali aggregate reaction is basically a reaction of the alkali in concrete which is the sodium and potassium ions which are present as impurities in the ordinary Portland cement and the reactive aggregate. The reactive aggregate means aggregate which has certain reactive minerals not all forms of silica is reactive only certain minerals like opal, cristobalite some forms of class they are the reactive minerals. And if they we are present in the rock they aggregate that we use we have the aggregate which is reactive. And once they come together in a concrete we have a reaction product and this reaction product is basically a gel and which in itself is innocuous. But it has the tendency to absorb water and once at thus absorb water it swells and induces cracks of the verity that we so in the picture just now. So, the alkali aggregate reaction in concrete needs to map cracking reduction in the strength and rigidity or the module of velocity of the concrete poor durability and water tightness.

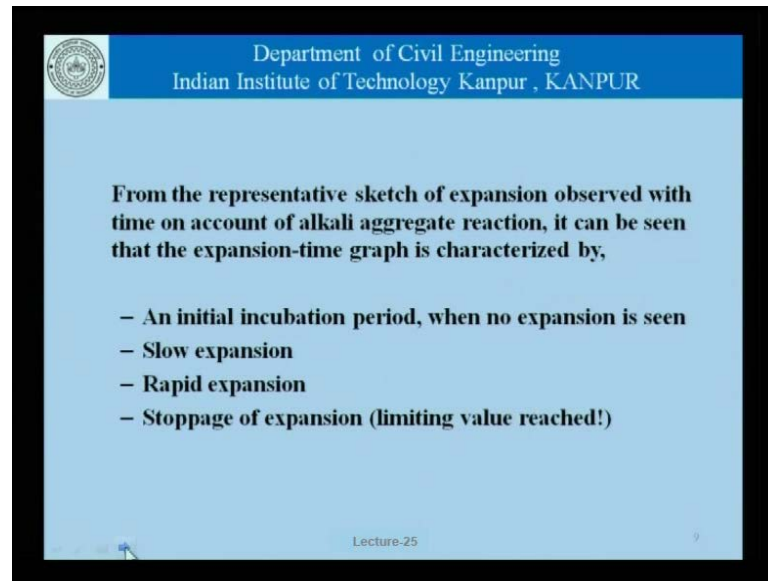
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This picture again is schematic representation of the expansion that we see on account of alkali aggregate reaction over a period of time. This picture shows that most of the time the reaction tends to stop that is the expansion tends to stop after a certain period of time and there is a limiting value to that expansion. This is something which is of interest to engineers, because in a lot of structures where inadvertently reactive aggregates are used, one must be light to know whether the reaction is still continuing. And we can expect further deterioration or more formation of cracks or it has reached a situation where no more expansion is likely. Given the fact of course, that alkali aggregate reaction cannot be reversed. Today we will spend some time looking at a model or discussing as to how this reaction tends to stop or slow down over a period of time?

Other characteristics that we can see from that graph of from that picture is that there is an initial incubation period when no or very little expansion is seen followed by some slow expansion then rapid expansion. And finally, a stoppage of the expansion after the limiting value has been reached.

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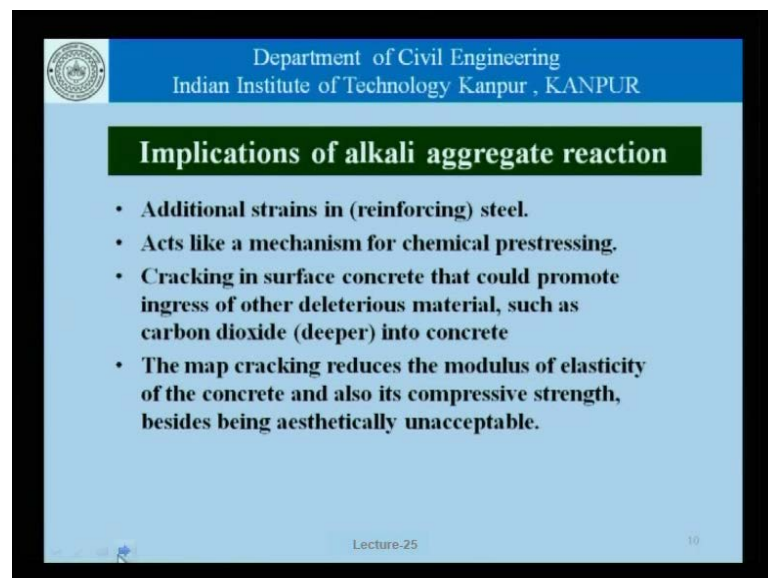
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From the representative sketch of expansion observed with time on account of alkali aggregate reaction, it can be seen that the expansion-time graph is characterized by,

- An initial incubation period, when no expansion is seen
- Slow expansion
- Rapid expansion
- Stoppage of expansion (limiting value reached!)

Lecture-25 9

(Refer Slide Time: 07:44)



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Implications of alkali aggregate reaction


- Additional strains in (reinforcing) steel.
- Acts like a mechanism for chemical prestressing.
- Cracking in surface concrete that could promote ingress of other deleterious material, such as carbon dioxide (deeper) into concrete
- The map cracking reduces the modulus of elasticity of the concrete and also its compressive strength, besides being aesthetically unacceptable.

Lecture-25 10

As for as implications are concerned we talked about additional strains in terms of the strain in reinforcing steel and that something which we will again talk about today. We will try to discuss a little more detail of that aspect and try to discuss certain the light that alkali aggregate reaction in reinforced concrete is something similar to that of introducing or inducing chemical pre stresses in the concrete. The cracking in the surface concrete could promote ingress of deleterious material such as carbon dioxide a chlorides into the concrete and the map cracking reduces the model of velocity of the concrete and the strength.

(Refer Slide Time: 08:30)

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DESTRUCTIVE ALKALI-SILICA REACTION IN PAVEMENT
Alkali-silica gel in a 2-mm void in a lapped slice from the pavement in A. The dark aggregate is siltstone. (Photographs by M. C. Thomson, PennDot.)


<http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/pecp/97146/chaptr10.cfm>

Lecture-25 11

Now, this here is a picture of or is a close up of another structure which is afflicted with the destructive alkali silica reaction again from a pavement. And we can see that there is this alkali silica gel in the 2 millimeter void in a laps splice from a pavement. The dark aggregate which is shown here this aggregate the dark aggregate which is shown here is a siltstone aggregate. So, this is the kind of gel that forms and gets deposited in the voids within the concrete or if there are continues pores connecting into the surface, it also immerges at the surface as we saw in the picture acouple of slights ago.

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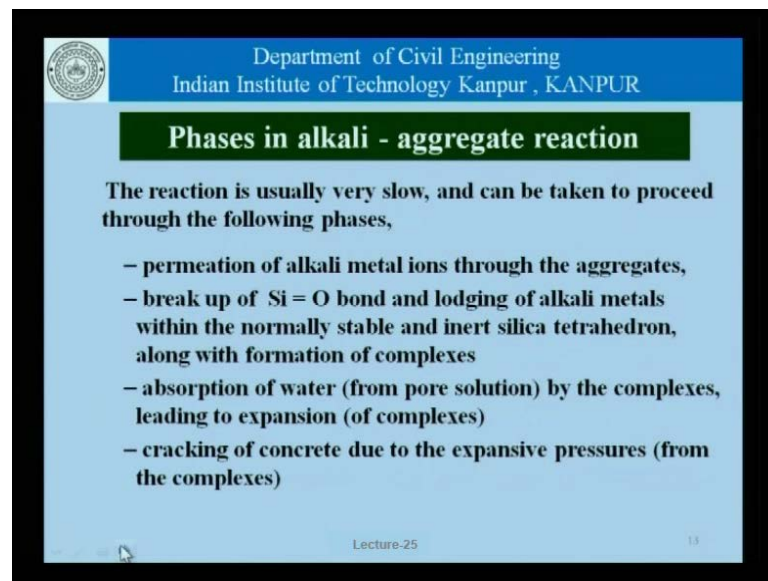
ALKALI-SILICA REACTION PAVEMENT CONSTRUCTED WITH DARK METABASALT AGGREGATE: 4-in. core that fractured on this surface on removal from a pavement affected by alkali aggregate reaction. Notice the dried, white, carbonated gel around each piece of aggregate.

<http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/pecp/97146/chaptr10.cfm>

Lecture-25 12

This here is another picture of alkali silica reaction in the pavement with the dark in metabasalt aggregate. And we can see that around these aggregates, all these aggregates here which are reactive we can see a very clean description of a carbonated gel. And this is the gel that is formed on the rim of these aggregates and that what we were talking about the previous discussion and also today earlier on.

(Refer Slide Time: 10:04)



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Phases in alkali - aggregate reaction

The reaction is usually very slow, and can be taken to proceed through the following phases,

- permeation of alkali metal ions through the aggregates,
- break up of Si = O bond and lodging of alkali metals within the normally stable and inert silica tetrahedron, along with formation of complexes
- absorption of water (from pore solution) by the complexes, leading to expansion (of complexes)
- cracking of concrete due to the expansive pressures (from the complexes)

Lecture-25 13

The alkali aggregate reaction is usually very slow and proceeds through the processes where the alkali in the pore solution permeates through the aggregates. And this processes of permeation of alkali through the aggregates can be modeled as diffusion process. Of course, the diffusion through the rock is not easy rocks are after all not all that pores even though they are pores. So, the coefficient of diffusion in rocks is very very small and therefore, it takes time for these reactive or deleterious alkali ions to permeate through the rock. Once they have reach the rock or even once they have reached the inside of rock, because break of the otherwise very stable silica bond. And the logic of alkali metals in the inert silica tetrahedron along with the formation of complex complexes. As we saw from the previous pictures the reaction really starts at the surface and gradually proceeds inside.

So, basically we are looking at a processes which is starts at the surface, the reaction rim is formed and gradually more and more alkali metal ions permeate through this reaction rim and also the rock and attack or modify the silica tetrahedron deeper and deeper inside

the aggregate. Once these gels are formed on the surface or may be inside the aggregate they absorb water from the pore solution again. And this leads to swelling and expansion of these complexes and finally, cracking of the concrete on account of alkali silica reaction. We must remember that water in concrete is available in plenty it could be the water which is present from the time that it was mixed or cured or it could be replenishment by way of rain water or any other form of water which is present. And finally, of course, as we have seen there is a cracking in concrete due to the expansive pressures.

(Refer Slide Time: 12:40)

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Simple model for alkali aggregate reaction

Assuming the aggregates to be spherical, and that the reaction thickness is small, reaction ratio α is:

$$\alpha = \frac{R^3 - (R-X)^3}{R^3}$$

$$= 1 - (1-X/R)^3$$

$$= 1 - \{1 - \sqrt{kCt/R}\}^3$$

Reaction ratio of aggregate depend on diffusion coefficient (k), concentration of alkali (C), time (t) and radius (R) of aggregate.

Lecture-25 14

Now, if we look at the simple model of aggregates where we discuss this slide briefly in a previous discussion. And we know recapitulate that discussion and put it in light with the model that we have just talked about. We are looking at potassium and sodium ions in the atmosphere or environment around aggregate. And if we take this aggregate to be spherical, we can assume that as far as spherical aggregate is concerned in the neighborhood we have sodium and potassium ions.

Now, initially the reaction takes place at the surface and we get reaction products that are formed and are deposited on the surface. After that position is taken place for additional surface to be attacked. If this reaction thickness of the thickness of the aggregate which has been compromised or where the reaction has already taken place? And they aggregate has undergone the alkali aggregate reaction, this part is still unreacted. So, basically at

each time step the reaction occurs at a fresh surface of an aggregate and the surface of that reaction keeps shifting inwards.

So, now over a period of time if the reaction products are dense enough then the permeation of the sodium and potassium ions through those reaction products would become more and more difficult. Because the reaction products are being formed and are deposited within the pore structure of the rocks which as it is has pretty low porosity. As a result of which the reaction really ceases. Arguing this point slightly differently if we have a reaction where A and B are reacting to form a product C when will we say or when can we say that the reaction has stopped, either A should finish that there is no more A or B should finish that there is no more B or the A and B should not be able to come in contact with each other. And in that case even though that may be A or there may be B, but there may still be no reaction.

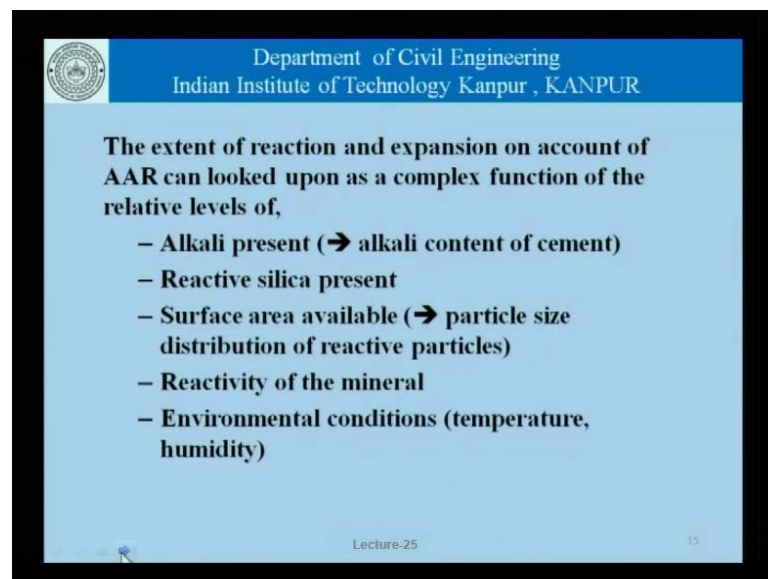
So, in the case of an alkali aggregate reaction kind of in the scenario like that of an alkali aggregate reaction, the situation translates to do we run out of reactive minerals in the aggregate. The answer is pretty much no, because there are enough aggregates. And therefore, enough reactive minerals within the concrete for the reaction to go on, do we run out of alkali metals in the pore solution?

The answer could be yes or no depending on what is the amount of alkali which is present in the pore solution to begin with. And that is related to the amount of alkali present in the cement and the quantity of cement in the concrete. The third possibility that is, we still have reactive minerals; we still have alkali in the pore solution. But this thickness has reached a level where it has made it very difficult close to impossible for the fresh surface to be approached by the alkali present in the system. And that would be the place when the reaction would seem to stop. And this simple qualitative description is what we can offer to explain, why the expansion of the alkali aggregate reaction follows an S-curve kind of a behavior? Initially when the sodium and potassium ions are permeating this may take some time when the reaction picks up. And we gradually the rate of reaction increases, but at a certain point in time it ceases.

There is another characteristic depending on what the aggregate configuration is the rate of reaction is very rapid initially. And that also can be built into our system or into the model that we talked about when we say that initially the surface that initially the

surface area available is large. And the reaction proceeds rapidly, but as the reaction proceeds its rate slows down as it becomes more and more difficult for the alkali ions to diffuse into the aggregate and cause further reaction. So this kind of discussion, we can summarize that the reaction ratio which is essentially the ratio of the volume of aggregate which has been reacted with to the original volume of the aggregate that would depend on parameters such as the diffusion coefficient k of the rock, a concentration of the alkali C , the time and the size of the aggregate.

(Refer Slide Time: 18:49)



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The extent of reaction and expansion on account of AAR can be looked upon as a complex function of the relative levels of,

- Alkali present (→ alkali content of cement)
- Reactive silica present
- Surface area available (→ particle size distribution of reactive particles)
- Reactivity of the mineral
- Environmental conditions (temperature, humidity)

Lecture-25 15

Would I get slightly differently extent of reaction and expansion in account of alkali aggregate reaction can be looked upon as a complex function which is to the alkali present that is the alkali content cement. The reactive silica present the surface area available which governs the total concentration of alkali's per surface area or the per unit surface area of the coarse aggregate or the fine aggregate, the reactivity of the minerals and they environmental conditions like temperature and humidity.

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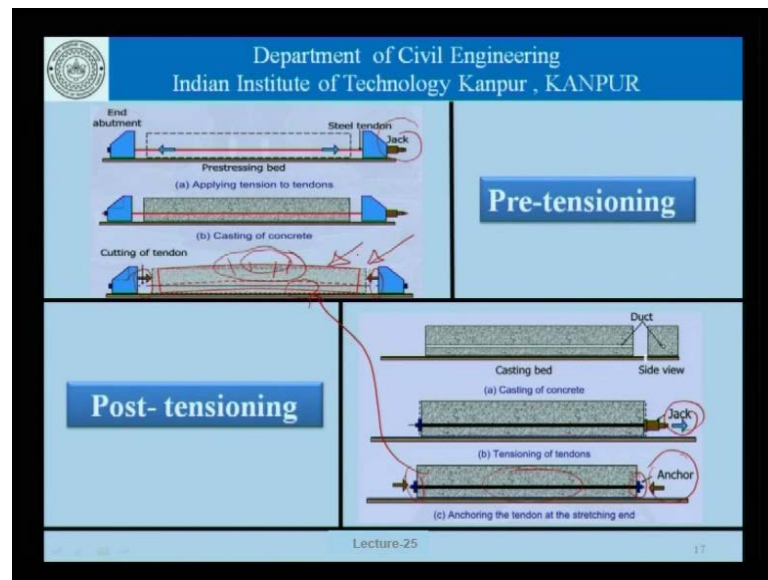
Prestressed concrete

- Method to overcome concrete's weakness in tension
- Tensile force applied on steel bars
- When anchorage cut, transferred as a compressive force in concrete
- Concrete is under stress prior to use

Lecture-25 16

Now, let us try to discuss the issue of alkali aggregate reaction in reinforced concrete. Before we get into the reinforced concrete and the discussion of alkali aggregate reaction let me discuss a little. Before we continue our discussion with reinforced concrete and alkali aggregate reaction in that concrete we will make a digression. We will talk a little bit about prestressed concrete and we will soon see, what is the relevance of this? What happens in prestressed concrete? If we take a beam which is supported like this and loaded the weight is shown the beam sags like this and if we are able to have forces in the reinforcement which are tensile. Then what we are basically doing is casting this beam to hog without the action of external load. And if the beam gets into a hog position before the application of load then once the load acts this hogging tends to be balanced and that is the method commonly used to overcome concrete's weakness in tension.

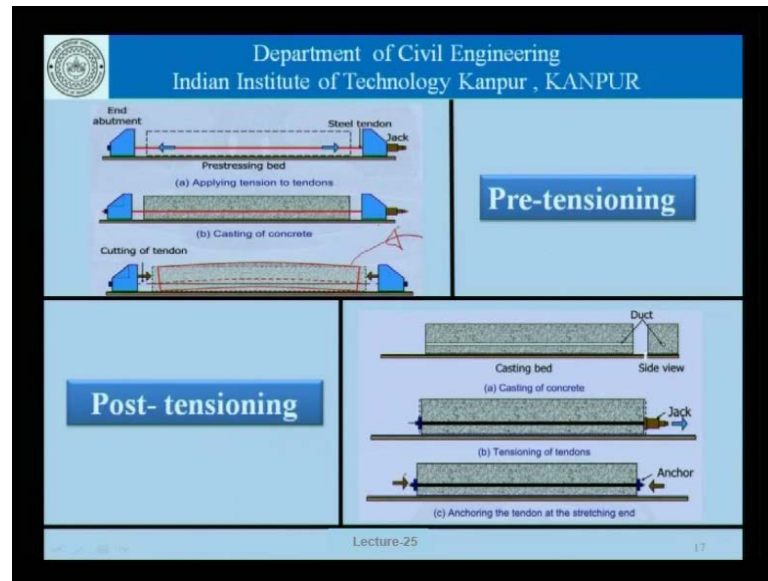
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And there are two basic methods of applying this pre stress when one is pre tensioning and the other is post tensioning. Now in pre tensioning what is done is that we have a still and we tension it we have these checks through which we pull this sill to a certain location. And then we cast the concrete and once the concrete has been cast and it has hardened, we cut the still tendons as result of which the beam tends to hog the weight is shown.

So, basically what is going on is the fact that concrete if it was not reinforced would like to go back to its original position which is something which is prevented by the presence of steel. And since the degree of restrained at the top surface here is a smaller then the degree of restrained at the bottom the beam tends to hog. And if this hogging is not controlled we could have cracks initiating at the top the weight is shown here. Now, if we look at the post tensioning system we cast the concrete without any steel. Then we have a steel tendon which is inserted and a jack is used to introduce tension in the steel. And the steel is allowed to go back to its original position using anchors. Now, once the steel wants go back to its original position that is something which is resisted by the presence of all these concrete here. As a result of that the situation is very similar to something which is shown here the beams tends to again hog. Now as for as alkali aggregate reaction and the reinforced concrete is concerned the situation is something similar.

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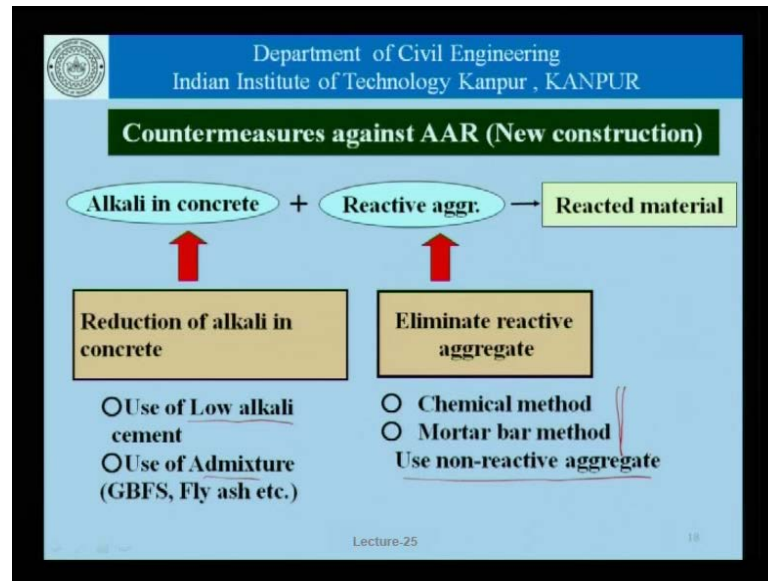
Now, the situation in the case of alkali aggregate reaction in reinforced concrete is something similar. Once the concrete expands on account of alkali aggregate reaction, this expansion is resisted by the presence of the reinforcement. If these reinforcement was centrally placed then all that will happen is the amount of expansion would be reduced compare to the amount of expansion that would take place in plain concrete. But we know that in concrete members particularly beams and slabs, the reinforcement at the bottom is more than at the top in a normal simply supported cases and so on.

Apart from cantilevers where the situation is reversed, but not getting into that detail the fact remains that the degree of strain to de expansion is higher where the reinforcement is higher. And that is what would cause a situation which is close to this there would be an additional strain in the reinforcement and they would be a hogging as for as concrete is concerned. Therefore, now we know that as for as the pretest concrete is concerned the pre stress is introduced in the concrete when we cause stresses in the steel and those stresses in the steel in the transferred to the concrete. In the case of alkali aggregate reaction in reinforcement concrete there stresses a generated on account of expansion of the concrete and transferred to the steel.

The net result is still the same hogging of a simple RCP and that is something which we must keep in mind. When we try to study the strains that are formed in the steel on account of alkali aggregate reaction, something very, very similar would follow in a

normal concrete. If we were to introduce chemicals in the concrete which cause expansion and that is what is called chemical pre stressing. In chemical pre stressing, we introduce a expansion in the concrete through the presence of some chemicals. And that expansion in concrete is again registered by the reinforcement present and we get a more or less similar situation as we get a pre stress concrete.

(Refer Slide Time: 25:44)



With this now we come to the last part of the discussion on alkali aggregate reaction which deals with countermeasures against this phenomenon or this mechanism of deterioration as far as new structures or new construction is concerned. We will try to deal with this problem of countermeasures against the alkali aggregate reaction at two levels. One is for new structures where we can more or less take steps to ensure that the effects of alkali aggregate reaction are kept to a minimum the deleterious effect is minimized. And that in the case of existing structures where inadvertently reactive aggregates were used and there is a problem of alkali aggregate reaction. So, as far as new construction is concerned if we revise over fundamentals alkali in concrete and reactive aggregate gives you reactive material and that is this thing which we need to control, So, the options that we have are very limited as far as alkali is concerned reduction of alkali in concrete is more or less the only option that we have.

If we are able to control or we are able to reduce the amount of alkali in the concrete we have come the problem of alkali aggregate reaction or will be simply eliminated reactive

aggregates from use. Now, this is something which is easier set them done we have talked about it earlier that the choice of aggregates is not something which in engineer is completely free to make at least from the point of view of economics, aggregates in a particular region may be reactive. And therefore, it implies that all concrete in that region which uses aggregates from that core here that particular area would finally, have reactive concrete unless we are taking measures to control the reaction it may not be always economically possible.

But that is the only choice that I have is in engineer as for as reduction of alkali in the concrete is concerned. We have the option of using low alkali cement using add mixtures, we will try to see that in movement, as for as the elimination of reactive aggregates is concerned, we can use these methods to evaluate the reactivity of the aggregates, and finally of course, use non reactive aggregates.

(Refer Slide Time: 28:32)

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Controlling alkali aggregate reaction

- Using non-reactive aggregates
- Mixing reactive and non-reactive aggregate
- Controlling alkali content in concrete
 - Use of low alkali cement ✓
 - Using supplementary cementitious materials ✓
 - Controlling cement content ✓

Handwritten notes on the right side of the slide:

For Na_2O
 $= Na_2O + K_2O$

Concrete $\frac{250}{100} = C = 300 \text{ kg}$

0.5% $\frac{0.5}{100} \times 300 = 1.5 \text{ kg/m}^3$

Lecture-25 19

Using non reactive aggregates is perhaps the best option that gets rid of the problem at the route itself mixing reactive a non reactive aggregates. Now, this is a very interesting option that immerges as a compromise between economics and technical understanding or technology. If we have the constrained of having to use reactive aggregates for having to use aggregate s available in the neighborhood which is reactive, can we mix some part of it with non reactive aggregates which may be brought from a which we need to be brought from a greater distance. And what will be the impact of that mixing on the

ultimate expansion? That something which we need to study, but that is in option which is worth exploring, controlling the alkali content in concrete. Now, this can be done using low alkali cement and just two recapitulate, what is low alkali cement? Low alkali cement is defined in terms of the Na_2O equivalent of the cement and that is nothing but the Na_2O that is present in the cement plus 0.658 times the K_2O that is the potassium oxide.

So, the sodium oxide and certain fraction of the potassium oxide contribute to define what can be called the equivalent Na_2O in a cement. Now, once we have this number is specification as far as cement is concerned. Define a low alkali cement as something as a or as a cement which has less than, let us a 0.6 percent of equivalent Na_2O 0.7 percent equivalent Na_2O and so on. We could use supplementary cementitious materials as a substitute for some part of the ordinary portland cement we could control cement content.

So, the basically the bottom line as for as all these methods is concerned is the following we have concrete which has a certain amount of cement let us say 300 kg's. And this cement let say has 1 percent of equivalent Na_2O as for as this concrete is concerned. This concrete now has 3 kg's of equivalent Na_2O per cubic meter of that concrete inverter to control these 3 kg's per cubic meter of equivalent Na_2O . We can use any of these options, if we are using a low alkali cement what we are doing is that instead of this 1 percent. If we use a cement which has 0.5 percent of equivalent Na_2O we would have reduced this 3 kg to 1.5 kg. Similarly, if we were to use supplementary cementitious materials whether it is blast furnace slag or it is silica fume or it is rice husk ash or it is fly ash, what we are doing is instead of this 300 kg we are able to reduce it 250 kg or 200 kg by that token even if my equivalent Na_2O remains at 1 percent.

Now, let us look at the option of using supplementary cementitious materials, going back to the previous example when we said that my Na_2O is 1 percent, my unit cement content was 300 kg's in a cubic meter of concrete. If I am using supplementary cementitious materials which allow me to reduce this cement content to say 200 kg's then even if my equivalent sodium oxide content remains at 1 percent. My total alkali content in the concrete would only be 2 kg's per cubic meter instead of the 3 kg per cubic meter that I had if I was using 300 kg's per cubic meter of cement. Now, how is controlling cement content different from using supplementary cementitious material.

(Refer Slide Time: 32:30)

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Controlling alkali aggregate reaction

- Using non-reactive aggregates
- Mixing reactive and non-reactive aggregate
- Controlling alkali content in concrete
 - Use of low alkali cement ✓
 - Using supplementary cementitious materials ✓
 - Controlling cement content ✓

Handwritten notes:
Fly Ash
 $\text{Na}_2\text{O} = \text{Na}_2\text{O} + \text{CaSO}_4$
 $W/C \rightarrow 17\%$
 $C = 300 \text{ kg/m}^3$
200
2 kg/m³ (3 kg/m³)

Lecture-25

(Refer Slide Time: 33:29)

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Controlling alkali aggregate reaction

- Using non-reactive aggregates
- Mixing reactive and non-reactive aggregate
- Controlling alkali content in concrete
 - Use of low alkali cement ✓
 - Using supplementary cementitious materials ✓
 - Controlling cement content ✓

Handwritten notes:
Fly Ash
 $\text{Na}_2\text{O} = \text{Na}_2\text{O} + \text{CaSO}_4$
 $W/C = 17\%$
 $C = 300 \text{ kg/m}^3$
200
100
250
300
250
150
250
Chem. adm.
 $W = 200 \text{ kg/m}^3$
 $W/C = 17\%$
 $C = 250$
FA
150
Slag

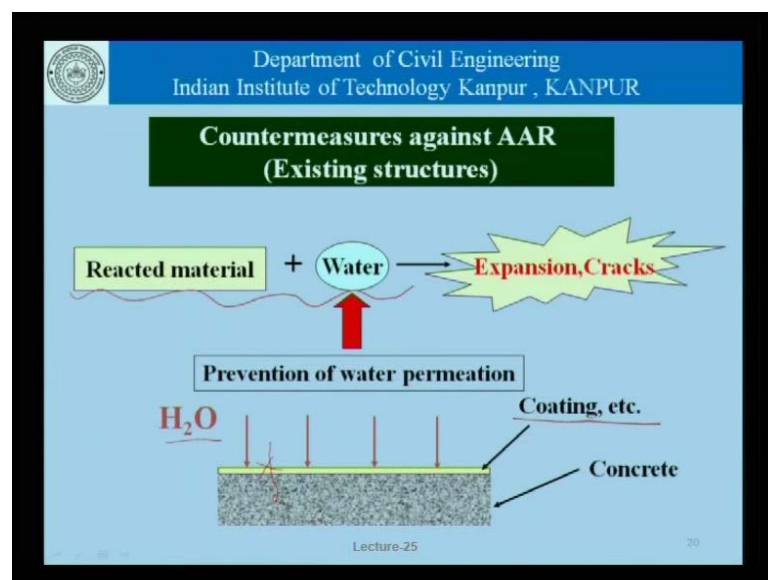
Lecture-25

It is different in the sense that in the previous example we said that instead of 300 kg's of cement we will use 200 kg's of cement plus another 100 kg's equivalent of cement in terms of fly ash or slag or any other supplementary cementitious material. When I talk of controlling cement content here what I am saying or what the engineer wants to do is to reduce the cement content required instead of 300 we reduce the cement content require to lets a 250 kg's, how do we do that? We do that by using let us say chemical mixtures that is we go back a step further and say that if the water demand that I have for a certain workability was 200 kg's. And the water cement ratio that we needed was let

say 50 percent, my cement content require they are would be 400 kg's. But if I am able to reduce my water demand from 200 kg's to let say 100 and 80 kg's to let say at the same water cement ratio I will use only 360 kg's of cement.

Basically this is the cement reduction that we are talking about, controlling the cement content that is we are trying to reduce the cement used. In this discussion here we are not really reducing the cement content we are reducing OPC content alright. But we are not reducing the equivalent cement content when we are talking of controlling the cement content here what we are talking about is the reductioning the equivalent cement content itself without using mineral add mixtures. In this side we are using mineral add mixtures, in these side we are not using mineral ad mixtures and at we are able to get the same result, we are able to reduce our cement consumption where able to reduce our cement content in the concrete. And finally, we have the option of preventing the structure from coming in contact with water. We discussed earlier that the gel may be allow to form, but it is the expansion of the gel which has to be prevented and that can be done. If we effectively prevent this structure from coming in contact with water, it may be possible in certain cases it may not be possible in certain cases, but that surely is an option which is available to the engineer.

(Refer Slide Time: 36:20)



Now, coming to the count a measures against alkali aggregate reaction in existing structures. All that we can do is to try and control this part because the reacted material is

already within the concrete the potential to form reacted material is already within the concrete. We can change the aggregates there we cannot remove the alkali within the concrete. And therefore, all that we can do is prevent water permeation and that we can try to do by applying a coating on the concrete surface. And that is an option which is available even in fresh construction in a new construction. We can try to apply a coating on the surface of concrete which will prevent ingress of water into concrete if we are able to do that fine. But that is more or less the only option that is available to control alkali aggregate reaction in a existing structure.

(Refer Slide Time: 37:23)

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Deterioration of Coating due to Ultra-Violet Rays

Resins deteriorate due to ultra-violet rays. When they are exposed to sunlight for long period of time, surface portion of the resins spalls off and reduces the thickness.

$$X = A T^n + B$$

X : deteriorated depth A, B : constants
T : time after exposure n : experimental constant

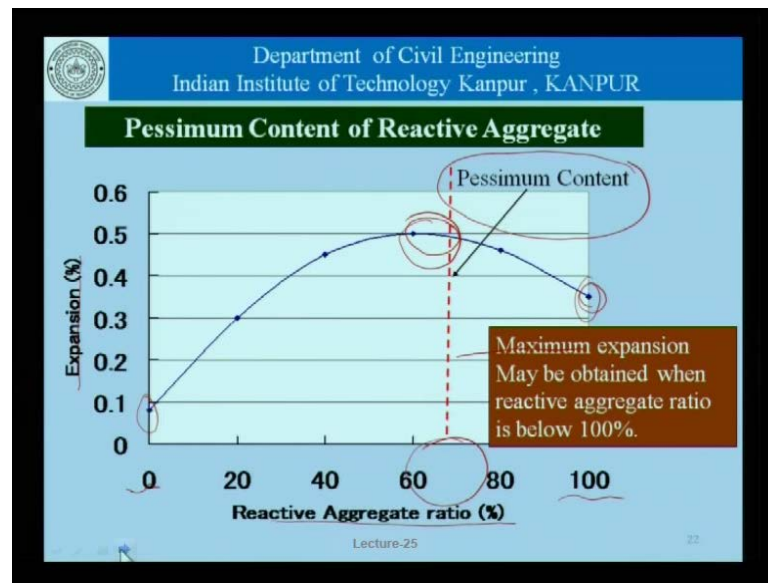
Ultra-Violet Rays

Coating etc.

Lecture-25

In this context we must also remember that as for as the coatings is concerned there often having resins in them. These resins tend to deteriorate due to the ultra violet rays and when they are exposed to sunlight for long periods of time, surface portions of the resins tends to spalls off and reduces the thickness. So, if we are using coatings we should be also concerned about the durability of the coating itself in terms of its ability to with stand ultra violet radiation, we talked about the option of mixing reactive and non-reactive aggregates.

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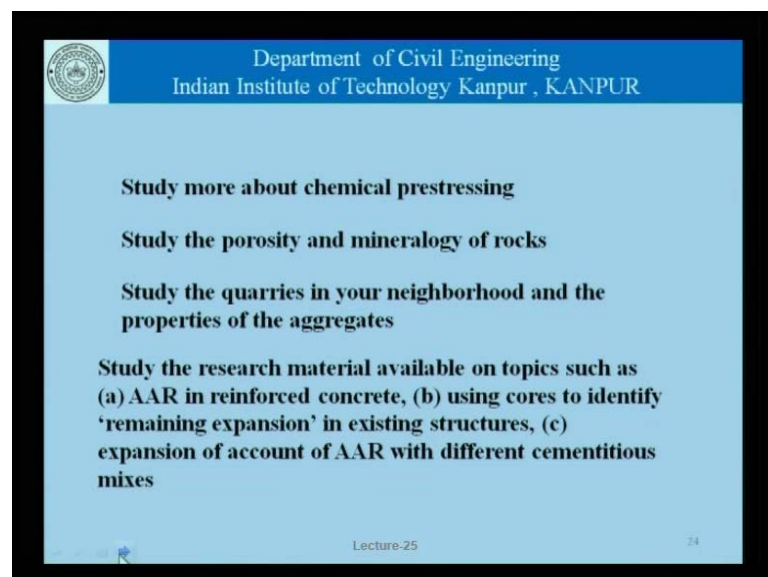


This here is a picture of what is the likely expansion that we get if we vary the reactive aggregate ratio from let us say 0, 200 percent that is we do not use any reactive aggregate. And still will get some amount of expansion for different reasons and using 100 percent of the reactive aggregates. We must remember that we get what is called the pessimim content? The pessimim is opposite of optimum, because that something which we do not really want. The pessimim content is the content of reactive aggregates where we expansion is maximum where we get even more expansion. Then what we would get if the reactive aggregates were to be used only that is only the reactive aggregates were to be used.

We get this kind of an expansion here, but if only a small amount of non reactive aggregates were to be mixed the expansion would be higher. This is something which should be loss site of if we are choosing to mix reactive and non reactive aggregates, because mixing non reactive aggregates does not necessary or may not necessarily bring about reduction in the total expansion. If we try to do a numerical model, we would understand this in terms of how the amount of alkali available in the concrete changes as the surface area of the reactive aggregates changes. As the reactive surface area reduces and that is what will happen if you use some amount non reactive aggregates without changing the amount of alkali they concentration available for the attack on the reactive minerals would be larger.

And therefore, the reaction would tend to on the reactive minerals would be larger. And therefore, the reaction would tend to cause more expansion however if at the end of it the reactive area becomes smaller than a certain value then it is not enough to be able to cause as much expansion. If the reactive aggregate surface area was to reduce below or certain value. Then of course, the phenomenon changes and the total expansion is now being governed by the surface area available and not the concentration of the alkali per surface area which is governing in the case when the surface area was the reduced in the initial part that is here. Now with this become to our close of the discussion and as we usually close.

(Refer Slide Time: 41:16)



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- Study more about chemical prestressing**
- Study the porosity and mineralogy of rocks**
- Study the quarries in your neighborhood and the properties of the aggregates**
- Study the research material available on topics such as (a) AAR in reinforced concrete, (b) using cores to identify 'remaining expansion' in existing structures, (c) expansion of account of AAR with different cementitious mixes**

Lecture-25 24

We can do some more work and study a little bit about chemical pre stressing. And that is what we talked about in our discussion today. We can talk about or study more about the porosity in the mineralogy of rocks which will give us a better understanding of the alkali aggregate reaction itself. We can study the core is in our neighborhood and the properties of the aggregates there. We could look at the maps of different regions of the world which have been identified as producing reactive aggregates.

We could study the research material which is available on topics such as the alkali aggregate reaction and reinforced concrete use of course to identify the remaining expansion in a 16 structures and study the expansion on account of AAR with difference cementitious mixes. And that is the kind of discussion which we were doing or which is

relevant from the point of view of controlling the expansion on account of alkali aggregate reaction by manipulating the cement content or the alkali content in the cement, controlling the cement content, using chemical admixtures or mineral admixtures to control the overall alkali content in the concrete. And with this we conclude our discussion for today.

Thank you.