Basic construction materials

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Lecture 24
Cement and Concrete 1 - Part 1

Hello everybody, and welcome to the next chapter of our course on basic construction materials. This chapter deals with cement and concrete. Now in most construction sites, we will come across the concrete. Concrete is probably ubiquitous. It is found all over the world, and people are using cement concrete in different applications. Moreover, as I have said in the introductory lecture, concrete is the second most used material in the world or second most consumed material in the world after water.

Moreover, concrete is made of several different ingredients that are cement sandstone water. Today, we also use some additives that enhance the properties of the concrete and fresh and hardened state. So in this chapter, we will go over the properties of these individual materials and how the composite behaves once we combine these individual materials in a particular fashion.

Furthermore, what are the governing factors responsible for the performance of concrete in real-life applications? We will also look at some concrete construction as to how the process of putting together a concrete structure unfolds on a construction site so that we have some association with the material and its usage.

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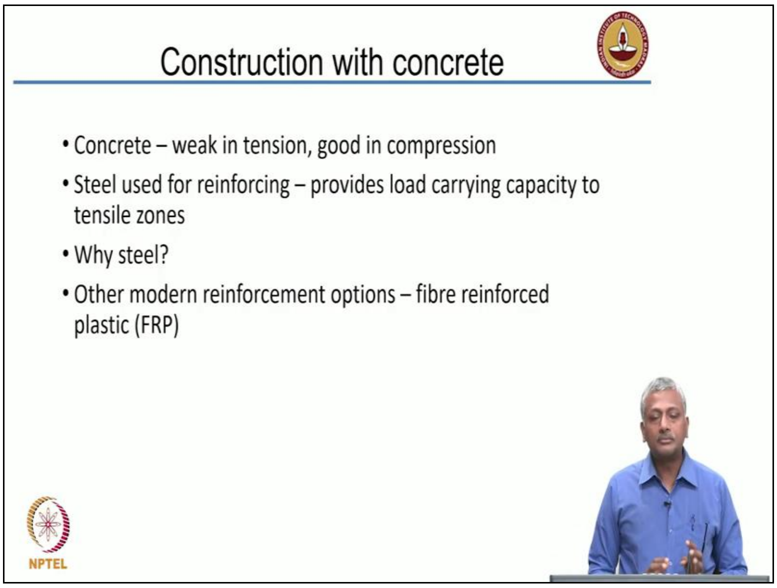

So now, one essential fact with concrete, as it is true with other construction materials like stone or brick concrete, is fragile in tension. So it is used primarily for compression-related applications that means wherever it can bear compressive loads, it is happy. Nevertheless, as soon as we get tension into concrete, it starts cracking. So concrete is weak in tension and good in compression, and because of this, we usually combine concrete with steel.

Steel is used as reinforcement for concrete to ensure that we take care of the tensile loads. So steel provides the load-carrying capacity to the tensile zones. So if we have a beam, let us just draw a bent beam, when the beam bends, the bottom is in tension, and the top is in compression. So, if the concrete is without any steel, it will start cracking here, and the crack will very quickly propagate to the top, and our beam will split into two.

However, when we put in the steel here, as soon as the crack reaches the steel surface, the tensile load is transferred to the steel, and the steel takes up the tension. We will learn this concept a lot better when we come across the subjects on reinforced concrete design. However, essentially the purpose of the reinforcement is to take away the tension from the concrete.

So why do we use steel for this purpose? Why cannot we use any other metal, for example, aluminum? It is a very good metal; it has a high strength; it has a much lower weight or density than steel; why do we not choose aluminum? The main reason is that steel is very well compatible with concrete steel, and concrete is compatible. So steel has nearly the same coefficient of thermal expansion or alpha as concrete.

So in case, there is a temperature change, the concrete and steel both will expand or concrete to depend upon whether we have an increase in temperature or a decrease in temperature. So if they concrete or expand at different rates, we will get incompatibility. So if they have the same thermal expansion rate or the same coefficient of thermal expansion, they will expand at the same rate or concrete at the same rate in indicating that we will not get any failures and the composite will be proper.

So that is why steel is ideal for contrary that it has nearly the same coefficient of thermal expansion. However, in terms of engineering properties like modulus of elasticity, the two materials are entirely different. Much of the reinforced concrete design is done by keeping in mind that our modulus of steel is much greater than the modulus of elasticity of concrete. But nevertheless, they are highly compatible steel also provides excellent tensile strength, which is, of course, provided by many of the metals. However, they do not have the same compatibility properties with concrete.
Further, the concrete protects the steel from corrosion, so they are mutually helping each other out. Finally, it is crucial to understand that the composite that we produce the reinforced concrete behaves to take up both compressive and tensile loads. So steel is good in tension; steel and concrete have a similar coefficient of thermal expansion. These two are the properties that we desire the most, and concrete protects the steel from corrosion, which is another aspect that we talk about.

And reinforced concrete becomes a little ductile because of the presence of steel. If steel were not there, concrete would behave in a very brittle fashion; it would break suddenly without warning. Now, of course, we know that steel corrodes steel will eventually corrode steel has to corrode because the iron in steel wants to get back to its natural state of iron oxide. We have to design the structure with concrete to protect the steel from corrosion, at least until the useful life of the building is over.

For example, when we are building a house and using reinforced concrete, we want to build the house to last at least our lifetime. A typical human being would probably build their house when they are around 40 to 45 years old, and assuming we have a good long life up to about 85 to 90 years, we have an additional 40 to 50 years to design. So the house should serve your needs for the next 50 years, and we design your structure so that the steel is protected from corrosion for 50 years by the concrete surrounding it.

So both are ideally compatible with each other, producing an excellent composite that we know as reinforced concrete. Of course, I should also add that steel bonds quite well with concrete other modern reinforcement options are also available. We will talk about the composites polymers and plastics chapter, like fiber-reinforced plastic where we have fibers embedded in a plastic matrix.

Furthermore, these form very lightweight, excellent tensile strength composites, but there are certain disadvantages about using these; we will talk about that when we get to the chapter on composite materials. And meanwhile, of course, my colleague Dr. Pillai will cover the aspect of the steel itself construction with steel and steel as a reinforcing material, and Dr. Pillai will cover the corrosion problems. So let us proceed with our discussion on cemented concrete.

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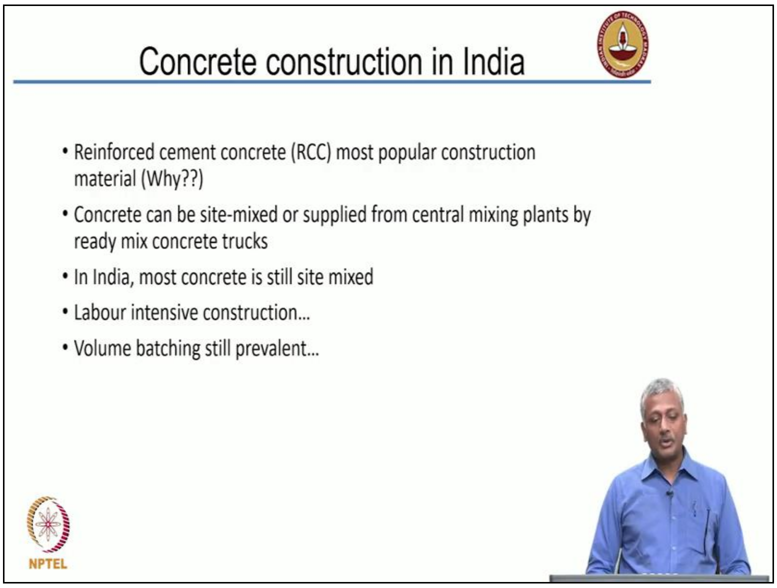

In India, reinforced cement concrete is the most popular construction material. When somebody asks us why this is the case, we would answer quite clearly that the economy will probably drive it. In most cases, the choice of construction materials depends on what is locally available what is economical. In India, reinforced concrete is a lot more economical as compared to steel.

To give us a comparative cost of materials your concrete, if we take a cubic meter of concrete that is nearly about 2500 kilogram, the cost is probably around 6000 rupees. Steel, on the other hand, usually we measure it in terms of tons; in tons the cost is almost about 50000 rupees per ton a ton is 1000 kilograms. So 1000 kilograms of steel cost we nearly 50000 rupees whereas 2500 kilograms of concrete costs are only about 6000 rupees.

So and this is top-of-the-line concrete. Suppose we can have the option of actually making concrete even cheaper than that. So concrete is a lot more economical as compared to steel. If we go to job sites, we will also realize that steel construction requires much skill; we need skilled labor to ensure that the steel segments are jointed together correctly with the welds, nuts, bolts, rivets, etc.

In concrete, we will see that the most basic of functions are going on at the job site we do not necessarily have people who are well trained, of course, I am not saying that it is a good thing we need to have people who are well trained to ensure that the supervision of the unskilled people is proper on the job site. But that does not happen in many of the job sites, and because of which your concrete quality turns out to be poor.

So concrete requires less skill as compared to steel to operate on a job site. We need less skill to work with the material; it is very easy to work with, it is easy to apply, and then it is economical, and these are the reasons why concrete is much highly preferred compared to steel. However, if we about the time taken for construction, steel construction happens much faster. Because all the steel construction components come from a fabrication in the factory, they come to the site, and all we need to do is assemble them correctly. In most cases, concrete would be made on the site, and we need to wait for some time for the concrete to gain strength; we will talk about that a little bit later. So in terms of time, steel construction is much faster.

So obviously, the overall cost of steel construction will be much higher than that of concrete construction. So, as a result, we have a preference for concrete. Now concrete can be supplied and mixed in many ways; it can be either site mixed, mix directly on the site, or be supplied from a central mixing plant.

At least most of us who live in the cities would have seen those Readymix concrete trucks; sometimes, they are called millers taking the concrete from the central mixing plants to the job site where the concrete is dispatched or delivered. So this is a common sight in most urban areas and even rural areas these days, which are in proximity with a good quality concrete plant. However, in India, most countries still site mix because that is an easy operation people are able to do it on their own on the side.

So why spend all the money to get a centralized mixing plant concrete even though it may be better in quality of course, that is something we will talk about a little later. In India, construction is labor-intensive, which is just got to do with how the economy works. In western countries, if we go to Germany or the US we will find that on the job site, there are skilled contractors, the skilled labor, not labor I will not call them laborers.

We have skilled workers who are operating machinery to make the structure possible. In India, we will find that there will be many laborers who work under a team of contractors who can deliver the material to the place and get the job done. However, there is a significant difference between the number of people employed on-site in a western construction site and an Indian construction site.

So just the way that the economy works, we have a large workforce, and then they need to be employed. And construction is one of the largest employers as far as India is concerned. After agriculture construction employs the most number of people. In India, of course, we use a lot of volume batching. Now I will talk about the benefits and disadvantages of volume batching later. But volume batching is where we take materials by volume, which is quite prevalent in residential construction.

We will see that people are simply mixing based upon measuring quantities by volume I will tell we later why that is not such a good thing to do. Anyway, in India, this is how concrete construction happens in residential job sites. When we go to infrastructure when we go to larger projects, we will find that there is a much better quality control people work to make the concrete mix design proper to ensure that the concrete will serve the needs of the infrastructure for many, many years.

In residential construction, we do not have that level of supervision from good-quality engineers. We have mainly contractors who carry out the work. They do not have the same level of scientific information as the engineers to understand what would happen if the concrete construction is not done correctly. Anyway, that is the status of construction in our country.

We have to do our bit as engineers to ensure that technical knowledge passes down to the last rung of people who are dealing with the material so that they can understand and apply it on-site.

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Now, of course, this is just an example of building in-plane concrete. We see these concrete blocks which have been laid here, and we see this. This is a concrete pavement that has been prepared as I said, concrete is excellent in compression, but it is poor in tension. So the limitations need to be overcome by optimizing the shape or providing reinforcement like steel. So if we can build with all arches and domes, we do not need any material to take care of the tension because, in arches and domes, the load is entirely transferred by compression. So in such cases, concrete could be quite helpful.

For example, let us go to the pantheon dome in Italy. This pantheon is composed of a dome made with waffle-like slabs of concrete, and all the members there are in compression, and there is absolutely no need for reinforcement there. So examples are where the plane concrete can be used, but it is quite difficult to construct with plane concrete.

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So that is why we always construct reinforced concrete where steel is embedded in the concrete, and together steel and concrete provide a composite action that takes care of both compression and tension. So here, for example, we have the formwork that is the wooden mould into which we place the steel reinforcement that is our reinforcement that is planes placed inside. So wooden formwork outside and then once the steel reinforcement has been wholly placed. We will pour the concrete into this mould.

Again here is the process of pouring the concrete from the back of a truck. We see that this is pouring the content in the concrete appears to be quite fluid. So it is essentially going to be flowing under the reinforcement. Then we will be subjecting it to processes like vibration or compaction to ensure that it properly envelops the reinforcement. Because if we have gaps between content and steel and a composite, they will not function together as a composite material; we will have individual functions that will not be the way to go about it.

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Now in most modern buildings, at least in the urban areas, we will see that people follow what is known as framed construction RCC framed construction. So here what we see that the columns, beams are coming on top of the slab; columns, beams, slabs are all made with reinforced concrete. So essentially, we make up a frame.

And as we talked about in the masonry lecture, we can then go about filling up this gap here, which is left behind between this beam between the columns of the and the beams. This gap can be filled by masonry. As I said today, in modern construction most common masonry infill that we use is lightweight concrete blocks such as autoclaved aerated concrete or foam concrete, and so on those can be used for infill walls.

So all we are doing is building up a frame with all the gaps we are plugging with masonry. It could be brick , so it does not have to be a concrete block.

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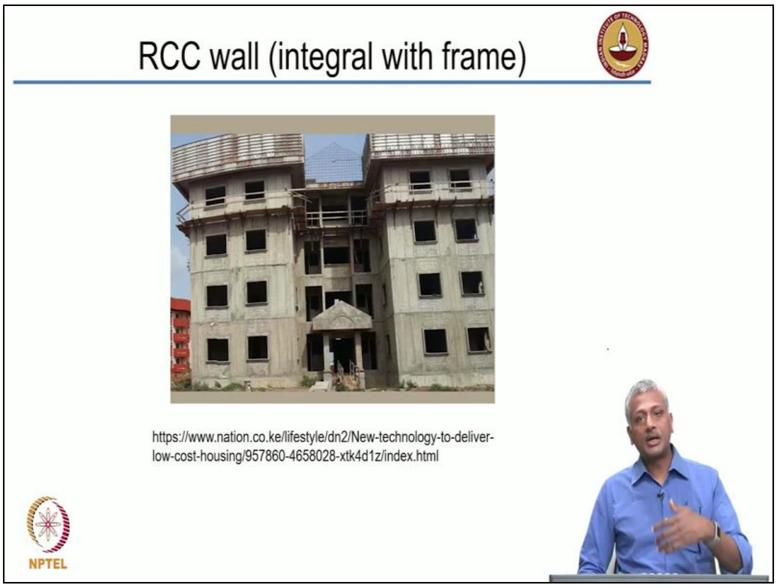

In some cases, if we come to a more modern type of construction, the wall itself is reinforced concrete. And many of fast track rapid housing construction projects will see that the wall is also reinforced concrete. So what happens is that the entire segment of the wall in the column is cast integrally, and it continues to move up. Our formwork which is here continues to move up as we are completing this construction.

So we do not leave behind any gaps; we construct the wall, along with the column, and the wall, also reinforced in this case.

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In some cases, we have what is called a tunnel form construction. We have a tunnel form which means that a formwork which is shaped like a tunnel, and then we cast concrete all around that formwork, including the walls and the top slab; everything is cast integrally. So that is called tunnel form construction. In many modern apartment buildings, we find that tunnel form concreting has become quite common.

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And of course, today, we cannot escape an urban setting without the use of precast concrete. Concrete is prefabricated and brought from factories and assembled on-site, just like what we do with steel construction. Especially with the construction of segmental bridges, what is done is each segment is cast in a factory and is brought to site and assembled on site.

So generally, what happens is a precast concrete comes to the site and is getting pre-stressed also; we will talk about pre-stressing towards the end of this chapter. So, for example, consider a string into which we put one bead, then we put the next bead and next bead, and so on, and we are tightening each bead against the next one. Similarly, what we are simply doing here is we have a concrete segment; we bring the next one and the next one, and so on. And then, we stitch them together with a very strong steel cable; we push them together to make one composite called pre-stressed concrete. We will talk about that a little bit later.

One of the common things that we observe in many of the multi-storied buildings these days is that they have large open spaces. They have huge open spaces available, enabling the creation of large office spaces or malls, for instance, and so on. We have large spacing between the columns; we have very large spacing, and on the top, we see no beams because the slab itself is functioning as a beam. So it is called a flat slab concept, again something that we will learn a little bit later in our curriculum when we take up reinforced concrete design courses. So pre-stressing precast concrete is all over the place today with respect to building construction and bridge construction.

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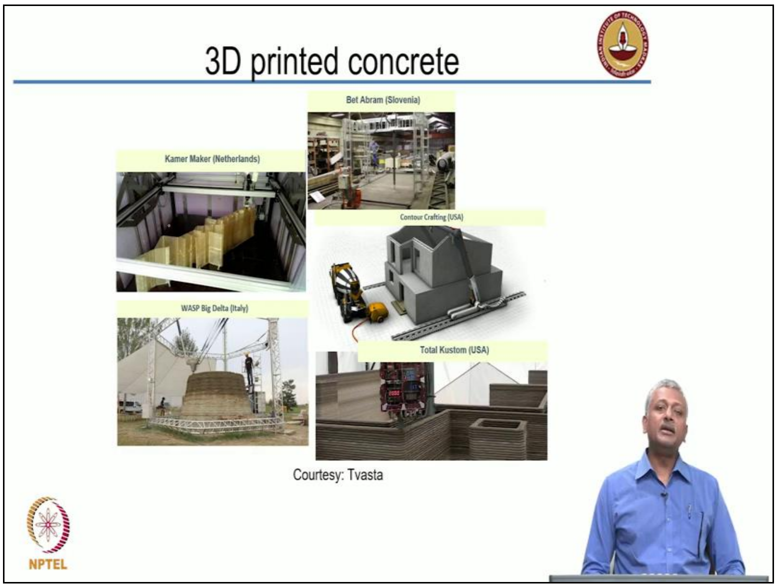

Of course, in the most modern of developments, people are talking about printing concrete now. I showed a picture earlier where the formwork had to be put in place. We need to define the shape of the concrete and then put the reinforcement and then place the concrete into it in a more or less liquid form. But what if we can print the concrete in the shape of the structure that we want, and that is what is being done with 3D printing.

Several different manufacturers worldwide have come up with printers that can print concrete, so what happens in this printing is that we do not need formwork anymore. So we do not need to spend time and money to assemble and disassemble formwork; instead of that, all we do is wherever we need the material exactly there we print our material.

Now, of course, 3D printing is not a new technology as when we look at other fields, for example, manufacturing or medical technologies in such cases, 3D printing has been used for quite some time to produce very complex components without actually having to create a mold or a die for them. So in construction, however, 3D printing is relatively new, although it has been in research for nearly ten years. Now but application wise people are talking about it only today for the last four or five years; there have been many applications with 3d printing worldwide.

However still, it is a technology that people are experimenting with. So all we are doing is placing layer by layer the concrete in the location that it is desired. So we do not need any formwork, so the structure supports itself and hardens and becomes firm.

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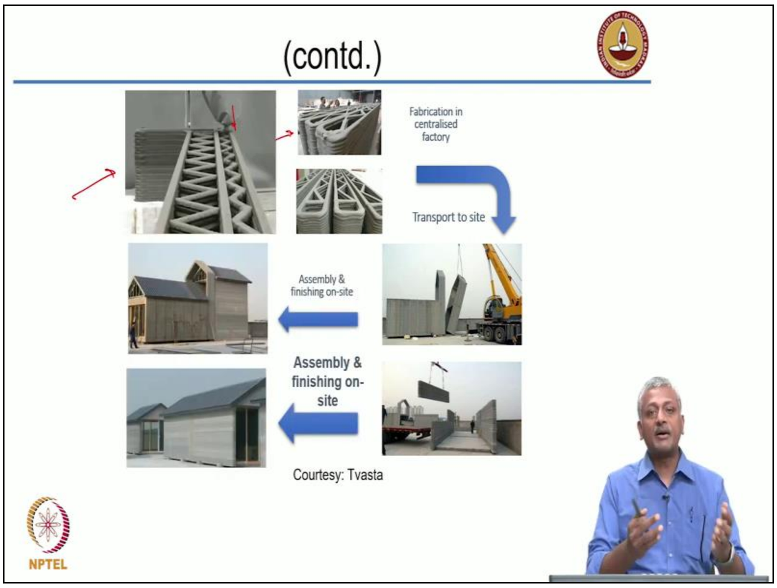

So again, to show we an example of how the 3D printing operation can be done. So on the top left, we find a centralized factory where the printing of these components is happening. We see here that this nozzle is depositing the concrete in the layers. So each layer is being deposited separately; once the layers are printed, and the entire wall segment is printed, they are stacked and then cured; the concrete has to be cured or sprayed with water until it gains strength.

So once it is done, we then transport it to the site and then assemble it almost like a masonry structure, so this is a prefabricated 3d printed concrete brought to the site and assembled. However, there are printers which we can actually take to the site and immediately do the construction there. For example, in rough terrains like hills and difficult to reach locations where our normal construction materials and workers cannot be sent, we could think about sending just material with the 3d printer, which can set up on the ground and build around it.

And people have been thinking about this process for building bases on the moon, so 3D printing has been thought of as a technology to build bases on the moon. So that is the kind of approach that people are looking at with respect to using 3D printing.

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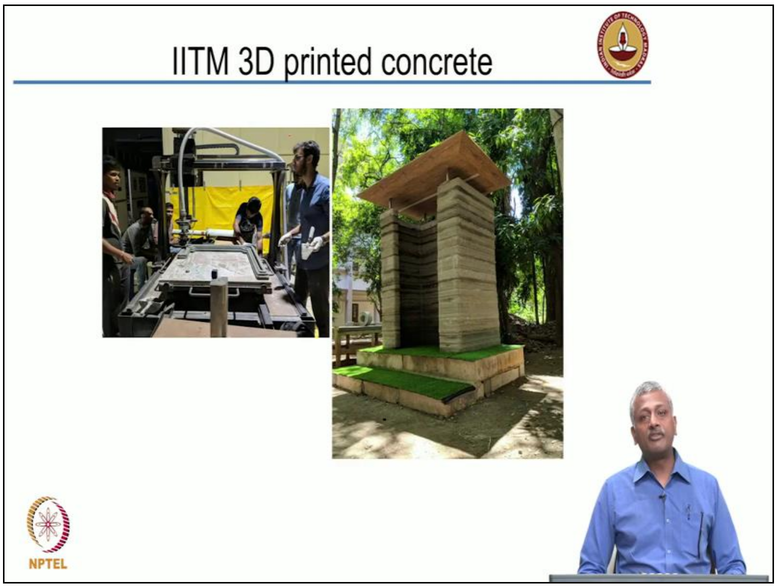

At IIT Madras, we have done a fair bit of 3D printing ourselves, and we have constructed this India's first 3d printed structure; this is just a very small room, but the idea was to print something of the size of a toilet. Subsequently, we printed a toilet and are in the process of printing actually a full-scale house that will be available on the campus of IIT Madras. I would welcome all of you to come and see the house that we printed entirely with 3D printed components.

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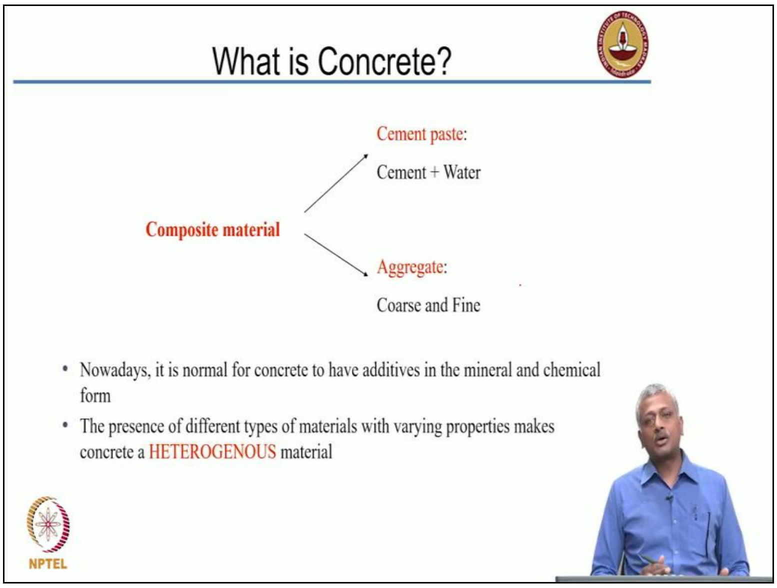

So having given this introduction as to how concrete technology is getting adapted and changed. Let us now go back to the basics and understand the different concrete-making materials? How is concrete prepared from these materials and the properties of concrete that make it so unique and easy to apply on the site. So first and foremost, we need to understand what concrete is composed of.

So if we think about concrete as a composite material, we can define two phases; one is our cement paste phase which is a mixture of cement and water. And then, we have the aggregate phase, which is composed of coarse and fine aggregate or stone and sand. If we go to the original definition of concrete, it will have cement, water, stone, and sand. If we made concrete with lime instead of cement, like in the past heritage structures, we would call it lime, water, stone, and sand that go into making concrete.

Now how is it different from a mortar? We do not have any stone; we only have sand, water, and cement or lime. So that is a mortar, but concrete is also having larger pieces of rock thrown in. Now we will come to why we need this kind of composite material in terms of the properties of each and every component and how it affects the overall properties of the concrete.

However, today it is not just about the four components that we have; we may get additives today that we need to add in the mineral or chemical form. Some minerals like extra powders are usually added to the concrete or sometimes some chemicals which are there for specific purposes we will talk about that later. They are added to the concrete to enhance the properties.

So because of all these inclusions inside the concrete, it is a highly heterogeneous material. In the chapter on steel, we will see how the steel looks very highly homogeneous on a macro level but on a micro level; because of the different phases present, there is some degree of heterogeneity. But in concrete, we can see this heterogeneity directly by our naked eye because the aggregates which we add in concrete are sometimes of the size of 20 millimeters or even more, whereas the paste which is having cement; the cement particles can be a few tens of microns or even smaller than 10 microns in size.

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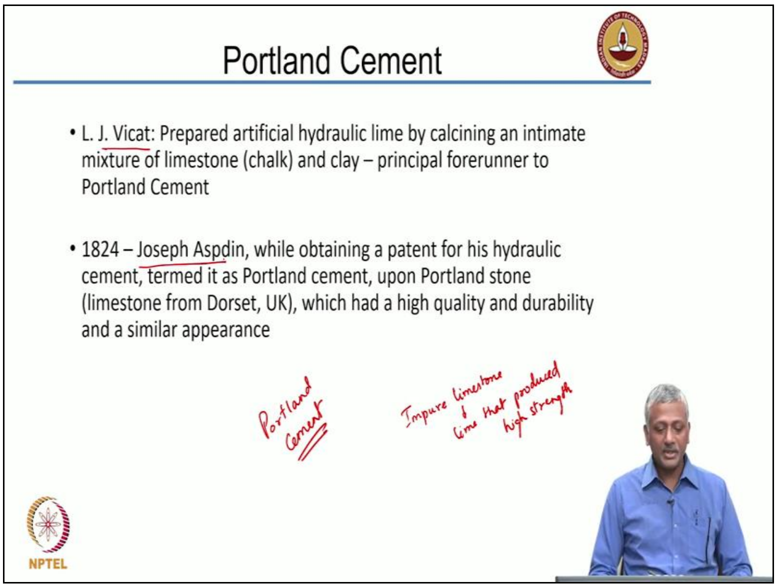

So what is cement? We discussed this in the stone, brick, and mortar chapter cement are nothing but binding material. It reacts with water and sets and hardens. Lime does the same thing; however, lime reacts with water; pure lime reacts with water to convert into calcium hydroxide and absorbs carbon dioxide from the atmosphere to convert to calcium carbonate and harden.

With time people found that when they started making lime with impure limestone, they used to get lime that produced high strength. So they found that this was because of the silica that was present as impurity and the alumina. So slowly, people started looking at burning impure limestone and producing different types of lime.

Later, scientists like L.J. Vicat prepared the first artificial hydraulic lime by calcining a mixture of limestone chalk and clay; this was mixed and then calcined or burnt together, and that gave the first sort of cement that we have. However, the actual cement that we know today is Portland cement. Today if we go to any market and buy a cement bag, it will be saying Portland cement.

Why did this name come about? It is because of this person Joseph Aspdin. In 1824 he obtained a patent for the cement that he manufactured. And what did he saw that the cement after it reacted with water produced a hardened material that resembled a limestone called Portland limestone in the city of Dorset in the United Kingdom. So he thought that it looked like that, so let me name it Portland cement.

So he took a patent and named it Portland cement. Now the power of this patent which ran out many years ago, is still such that we call cement as Portland cement everywhere we go. Today we do not necessarily have to call it Portland cement, but we still call it Portland cement that is an interesting thing. So the invention of cement is credited to Joseph Aspdin. However, in reality, many before him had produced similar types of cement.

Anyway, he got the patent, so his name is associated with the invention of cement. After him, his son took over the manufacture of cement and then produced the more modern type of cement as we know it. Over the years, cement technology has evolved; people have tried to produce cement in a much more modern kiln in operations. Because of that, we have a much more controlled quality of cement that we get in the market today.