Basic construction materials

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Lecture 01
Introduction to Construction Materials - Part 1

Hello everyone and welcome to this course on basic construction materials. Over the next 12 weeks or so I, Manu Santhanam and my colleague, Dr. Radhakrishna Pillai will take you through a journey that covers different construction materials that we use today. We will talk about the properties of the materials, their applications and how the choice of ingredients in specific combinations of materials makes a difference with respect to the long-term service life of such materials.

So, this course is intended to cover 12 weeks of content on different types of construction materials.

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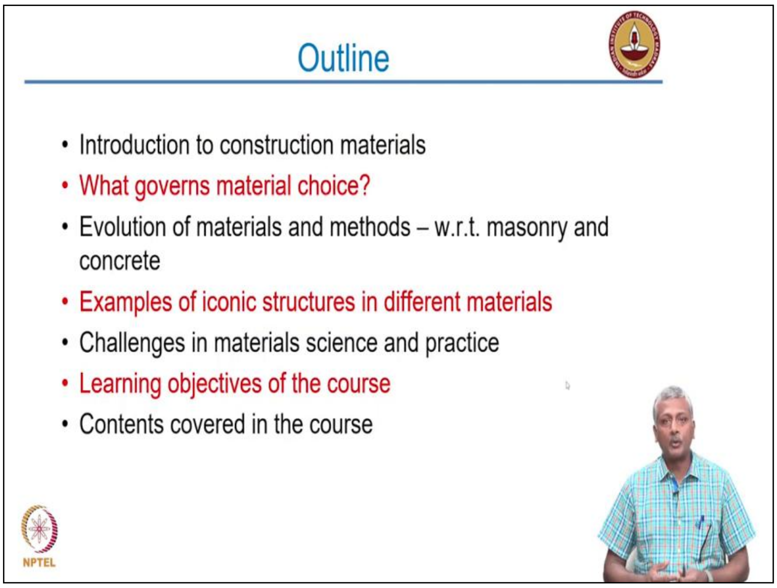

What I will provide in this lecture is primarily an outline of what construction materials are all about, what governs the choice of materials for a particular application, how have materials evolved over time from the periods of the Egyptian pyramids for instance. We had masonry applications in those days. Today we talk about reinforced concrete which is used in many different ways.

And I will also provide some examples of iconic structures from different time periods with respect to the use of different materials to produce these structures. I will conclude this introductory lecture by talking about the challenges in material science and practice. What is really the challenge that we face today with respect to the application of construction materials and practice?

And I will finally talk about the learning objectives that you have in this course and also the contents that we are going to be covering in this course.

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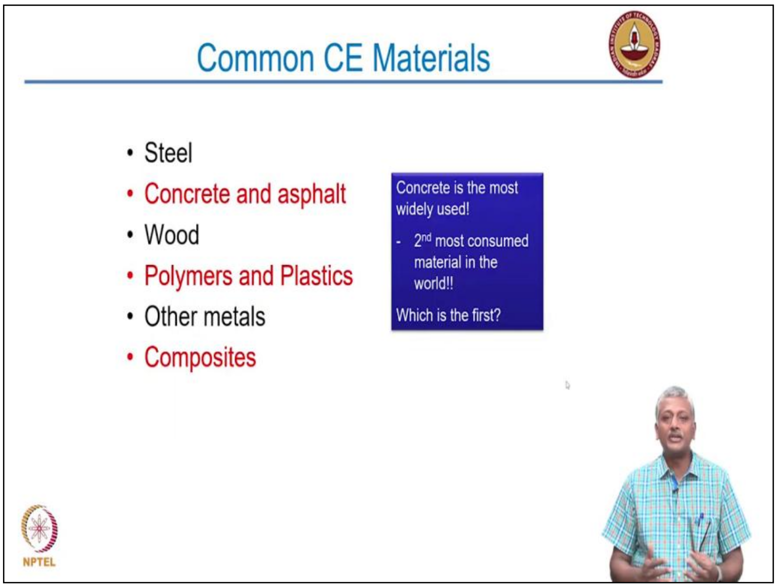

Let us begin with what are construction materials? Obviously these are materials used for construction and these cover a range of materials starting from steel, concrete and asphalt, wood, polymers and plastics. There are other metals that are used in construction and composites. Please note here that I have not included soil, truly speaking soil is also a construction material.

But then, we deal with soil entirely as a subject in geotechnical engineering. So I am not really touching upon that particularly here. And one of the aspects that we will focus strongly on this course is - the coverage will focus mainly on steel, cement, concrete and bituminous concrete or asphalt concrete. So, that is what will be the primary focus. We will also talk about the other aspects of other construction materials too.

Now of course, amongst these materials it turns out today that concrete is the most widely used construction material out of all. Of course if you don't consider soil as one of these materials because truly speaking the quantities of soil that we use for construction are probably exceeding anything else that we ever use. So, concrete is the second most consumed material in the world and I don’t know if you know which is the first most consumed material in the world.

I will leave that to you to guess for a minute or so. If you have not found the answer, it’s essentially water, because water is critical to our life on this planet Earth. And we consume the maximum quantity of water. Water is the material that is consumed in maximum quantities in this world. But, second to that is concrete. Can you imagine the impact that concrete will have on our day-to-day lives and on our environment. That is something we will also talk about towards the end of this chapter.

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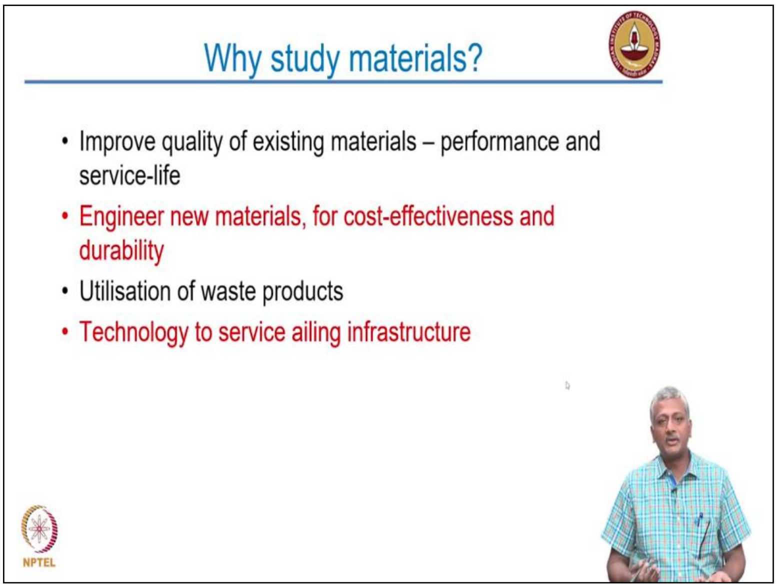

Why do we want to study materials? Because people have been using construction materials for ages now and buildings have withstood the test of time. Some buildings have stood for 1000 years, some for 100 years, some for 10 years and so on and so forth. So there is obviously a difference in the longevity of buildings. So, what we want to do by studying materials is that we want to improve the quality of the existing materials, which will impact the performance and service life of a structure.

The concepts of service life may be different depending upon the type of structures that we are talking about. If you are talking about a home, you want the home to be available for you until you pass away. So most typical human beings or at least the average family in India would tend to build their own house when the husband and wife are probably in their 40s or so. So you build your house or you buy a house in your 40s and you want the house to be good at least for 30 - 35 years, that is until your lifetime.

But then, when you are going to build a bridge across a river that is connecting two parts of the country together and it is forming a very important and integral part of the infrastructure of the country, in such cases you might think of actually designing the structure to last for 100-150 years. If you are building monuments like temples, like our forefathers did, they build several temples across the country and these temples have stood for 1000- 2000 years in some cases. That’s the impact that the structure and the importance of it has on the overall service life.

So, we want to study materials to improve the existing usage of materials that will affect the performance and service life of the structure. We also want to improve the cost effectiveness. Cost effectiveness implying benefit to cost ratio of materials. And we also want to increase the durability, that means how well the material responds to its environment.

Because of this, we want to study materials and develop and engineer new materials. We also want to utilize a lot of waste products that are generated by different industrial processes and this waste which otherwise would be dumped, sometimes find very useful applications in construction. So, utilization of waste is one of the major factors why we study materials. And of course we want to develop technologies to service the infrastructure that is ailing.

So if we understand what the deterioration mechanisms of materials in the buildings are, we can devise technologies to repair it. We can devise technologies or device alternative materials to repair the existing poor quality material that you find in the infrastructure. So, all these and possibly a lot more could be reasons why we want to study construction materials. That’s why this course essentially forms the most basic component of any civil engineering program.

You essentially start your civil engineering journey from here. You start studying about construction materials and then you talk about mechanics of materials, strength of materials, geotechnical engineering, geology and soil mechanics. Then you go towards concrete technology, design of reinforced concrete and so on and so forth. So you can branch off. And of course transportation materials like asphalt and bituminous concrete.

You essentially start from here and then you spread forward in your civil engineering program. So this course forms the most basic one and for a good reason; because essentially materials are at the background of all your understanding of structural behaviour.

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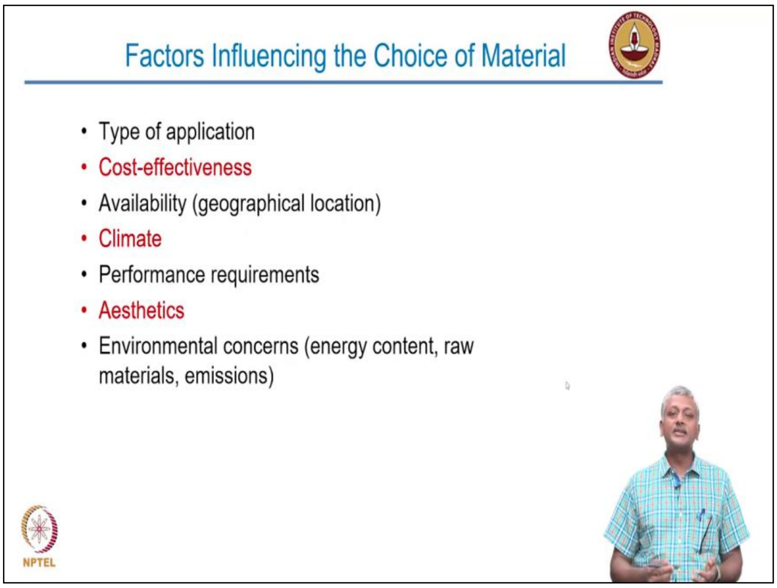

What are the factors that govern the choice of a material? If you are in a particular location, what would you think about before choosing a particular type of construction material for your building, for your house for instance? Of course it depends on the type of application. In some cases even though one material may appear a lot more cost effective as compared to another, I would think about using the other material because of the type of application.

For example, if I have to put up a petrol bunk in a matter of few days, I cannot rely on concrete or masonry because it will take a long time for the structure to gain strength and start being used. So I will go ahead and make it with steel. Steel construction is much faster, so I can actually execute the structure much faster.

The cost effectiveness obviously is important because, you would, given a range of materials to choose from, one of the factors that will affect your choice will obviously be the cost effectiveness. How inexpensive is the material to use and at the same time for a given cost what is the performance it can give me? So that's what the approach should be. Rather than looking at the initial cost of the materials, look at the performance that can be expected from this material for a given cost.

Availability is obviously very important. It is extremely important because the material has to be locally available, otherwise you need to transport it over long distances and that is not really a good thing to do. Because if you are transporting the material from long distances, it incurs a big cost, not just in terms of money but also in terms of the environmental pollution, because vehicles are transporting this material from very far off distances and then they are consuming petrol, emitting. All these are ancillary to your choice of materials from a far off location. So you want to choose materials that are mostly available in your location.

So, availability is one major factor that governs material choice and sometimes because of this availability issue, you may have to make do with poorer quality materials and design your structure in such a way that, that quality of the materials is accounted for. That's again, good quality engineering can take care of even bad quality materials, not bad but substandard quality materials.

Climate - You want to choose your materials that are apt with respect to the climate of your location. Now today, you may have seen several buildings in India adopting this glass facade type of approach. They have the building nicely covered up in glass, so it makes it look like a foreign building. But that's a very stupid move actually, why because glass essentially lets in more heat and when you let in more heat it's going to heat up our building. Most of our country is in the tropical region and here, the amount of heat can be tremendous, especially if you are in the south of India the heat can be tremendous. And if you are having glass facades, it's going to let in a lot more heat. And this heat, you want to drive away from the inside environment, so you will be spending a lot on air conditioning. So such buildings need to be heavily air conditioned and you will be wasting a lot of money and resources on the energy that you spend to cool the buildings. When all you could have done is, improved the ventilation characteristics and chosen materials that were apt for this tropical environment.

If you are living in the North Pole, you choose ice to construct your homes. Ice blocks are used there. Eskimos use ice blocks, why because that lets in maximum amount of light, ice is readily available, they do not have to go anywhere to look for it and on its own ice has a fairly strong ability to withstand the loads.

So, you have to base it on the climate in a particular location and the availability of the materials in a particular location.

Performance requirements - Now in some cases you want the structure to last for thousands of years. In such cases you choose materials that will not degrade within that period of time. So when stone and lime were considered to be the structural choice in the past, it was because no steel was being used in the structure.

Stone and lime are natural materials and they take a long time to degrade. Today we use concrete. Concrete also can take a very, very long time to degrade. So it can actually function for extremely long period of time but however, in modern structures we employ concrete in connection with steel reinforcement.

And steel obviously has a tendency to corrode; you can't stop that, it will corrode eventually. So you can only design a structure for as long as it takes for the steel to corrode. If you design a structure with plain concrete, it may last for a very long time just like your stone and lime did. So there is no problem with that. However when you start using steel, this service life of the structure is shortened because of the time to corrosion of the steel.

Aesthetics again could be a factor governing choice of a material. Some materials or some structures made with certain types of materials may look a lot more pleasing as compared to others.

And obviously environmental concerns can lead to the choice of material like energy content, raw materials and emissions. And this is the modern outlook. So this is how we want to look at the choice of materials. The modern outlook is to decide the material based upon the environmental concerns. What does it mean? This means that we choose materials which have the least amount of net carbon dioxide emissions, which consume the least energy to manufacture and to serve and which work for the longest period of time.

In other words we want to make a choice of sustainable materials. We want materials that are sustainable, that means we choose materials in such a way that we lead to a net sustainable ecosystem - low energy consumption, low amount of carbon dioxide emission, longevity of the structure. So this is the impact of study of materials that you get to decide what is the best way forward in a given structure.

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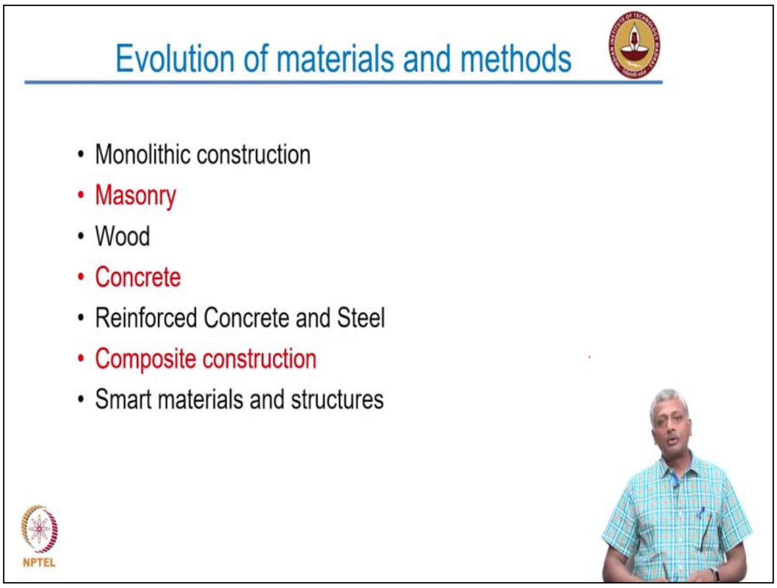

Now, how did materials evolve and essentially how did the construction methodology evolved? Both are actually connected. The choice of the material and the construction methodology often go hand in hand. And this is how the evolution actually occurred with respect to use of materials. Initially of course people were looking at monolithic construction, like the cave dwellers obviously carved out their dwellings inside large rocks. So those were monolithic structures. Even some of the shore temples that you see in Mahabalipuram are monolithic, they have been carved out of a single rock. So there is no question of instability there. Things are quite stable because the rock itself or the monolith has a very large mass. So shear mass basically leads to stability there.

Then from monolithic construction, we started moving towards masonry. And masonry essentially is nothing but putting blocks or components together and connecting them with a binding agent. That's what is masonry. So in the past, obviously we started with stone masonry and then brick evolved when people started understanding how to produce brick from clay and then stone and brick basically took a large part of the building history that we have recorded over the last maybe 5000 years. Stone and brick probably form the maximum used materials. In the last 200 to 300 years, we have started moving more towards concrete.

Of course in between I have left out wood. Wood has been an important construction material from the start. Obviously prehistoric man that lived in caves could also have easily built up a house out of wood, once they understood that wood had a very good strength on its own. And wood was obviously an integral component of the day to day lives of prehistoric men.

From concrete we moved on to reinforced concrete and steel, essentially looking at how to combine concrete and steel in the best possible manner to get a good composite action. That is the basis of reinforced concrete. And then of course we also started using steel buildings. We also started doing construction with steel itself.

In the modern era we moved towards composite construction, where we maximize the benefit out of the combination of two dissimilar type of materials. And then of course, today we are also talking about smart materials and structures. Materials and structures that respond to their environment and end up leading to a low energy, low CO2 emission strategy. So choose materials wisely, choose them in such a way as to lower the energy requirement for operational and maintenance cost of the buildings also.

Just to give an example of a smart material or smart component that you have in a structure, of course it is not truly a material characteristic there but if you have seen in some cases, they have these blinds on windows, venetian blinds. So the blinds basically alter their position based upon the direction of the sunlight. So, based upon the location of the sun in the sky, the blinds basically change their direction so as to let in light but at the same time minimize the amount of heat that gets into the building. This is called adaptive control and that can be brought about by the use of smart materials and structures.

Of course this is not a topic that we will talk about in this current course. We will cover the conventional construction materials.

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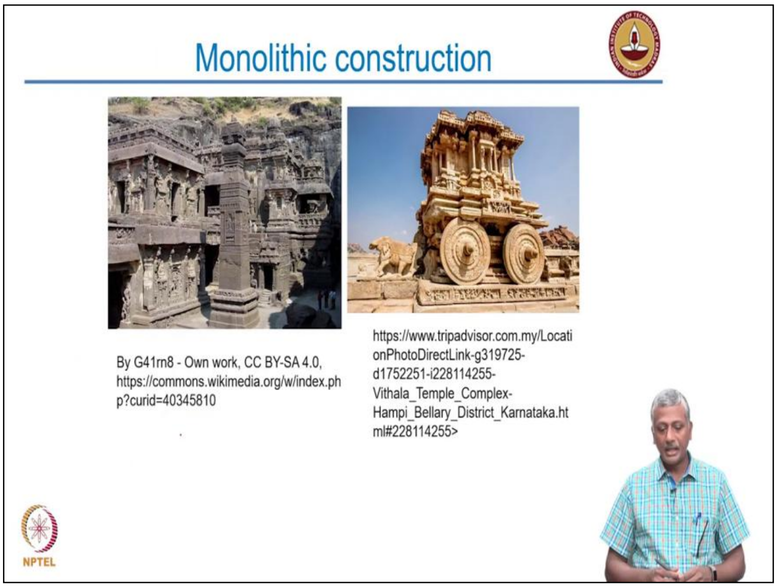

Monolithic constructions, of course in India there is lot of examples, there are several different temples and forts which have been carved out of single stone.

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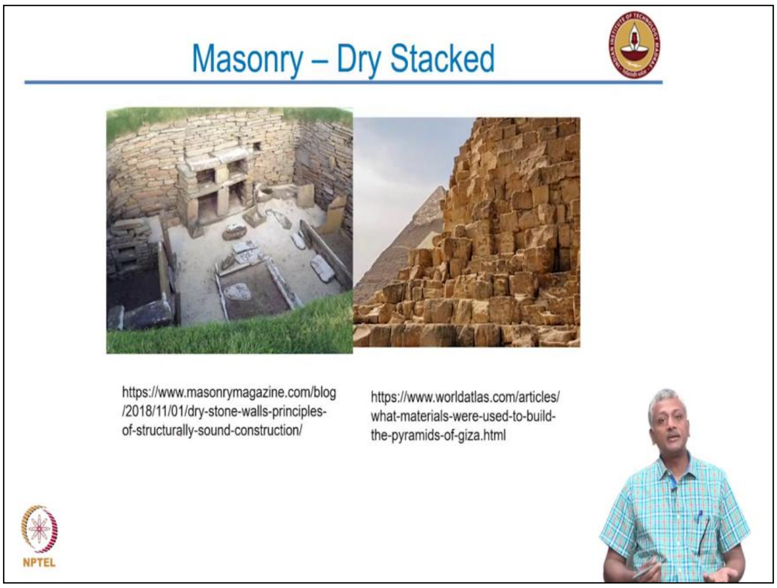

And then you have masonry in the past, when people did not think about using binder systems like binders or binding agents between the blocks. They dry stacked the masonry. Essentially large blocks of stone were dry stacked on top of each other like what you have in the pyramids. This is a pyramid, great pyramid of Egypt. Pyramids at Giza basically are dry stacked masonry. These were large blocks of stone that were kept on top of each other and the shape basically ensured that there was stability and the rocks would not fall.

Later people started realizing that you have to be superhuman to really lift these large blocks together or you had to waste a lot of human effort in trying to get these blocks together. So people started moving towards masonry and in masonry you have the advantage of using smaller blocks of stone or brick and connecting them with the binding agent like you have here, mortar basically which is connecting the bricks together.

Here you have stone blocks that have been connected again with mortar joints. So brick and stone masonry led to the use of smaller blocks of bricks and stones which were easy to put together. Workmen could handle them easily on the site and productivity improved significantly.

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People then started getting a lot more inventive with respect to masonry and thought, can we go back to the days where mortar was not used. See in most cases what happens is masonry blocks which are jointed by mortar, the time it takes for the wall construction depends on the time that it takes for the mortar to harden and start binding the blocks properly. So, what if we totally avoid the mortar by providing such interlocking joints? So what happens is these blocks basically fit into each other and they do not need any mortar to hold them together in place.

This is more like the lego that you played with or building blocks that you played with as kids. So, this is what essentially is interlocking block masonry. Later people realize you could produce masonry with concrete and that led to the formation of hollow concrete units. And later, the hollow cavities inside concrete blocks were then reinforced with steel.

So that now you could get a composite action out of the masonry wall, not just the compression load that will take in plane but also resistance to lateral forces because of the steel. So, we started utilizing materials and combinations of materials in such a way that they gave the maximum benefit.

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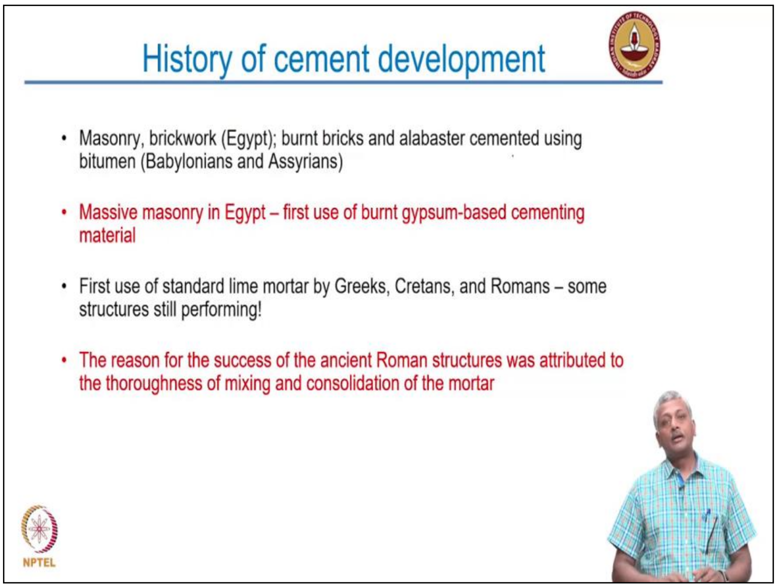

Now, on the one side masonry was getting developed and people were getting innovative with the use of masonry. On the other side the binding materials also were getting developed. Of course in the past, in the old masonry and brickwork, a lot of bricks and alabaster were cemented using bitumen in lot of the old structures in Egypt. Bitumen as you know, we also call it as asphalt, is also found in some naturally occurring pools around the world. And this bitumen is very sticky and it can make a very good glue. So bitumen was the binding agent in many of the old structures.

Then of course, burnt gypsum based cementing material was used in Egypt. So, when you burn gypsum or heat gypsum beyond 100 degree Celsius, what happens is, it converts to hemihydrate and then to anhydrite. Hemihydrate is commonly known as Plaster of Paris. When you mix water back with anhydrite or hemihydrates, it converts back to gypsum and starts getting some strength. So massive masonry in Egypt, there is some evidences of the use of burnt gypsum based binding materials.

So, from bitumen, people came to gypsum and then in the Greek period there was a first use of lime mortar. Lime mortar employs lime as a binding agent. Lime is basically calcium oxide, it reacts with water to form calcium hydroxide and that causes the mortar to set and then it hardens by transforming to calcium carbonate. A lot of these structures from the Greek and Roman periods were built with lime based materials and some of these structures are still performing. You still have satisfactory performance of many of these structures.

And again people have undertaken a vast study of all these roman structures and they understand that the effective use of materials and the thoroughness of the mixing and consolidation led to a very good property of the mortar in the roman structures.

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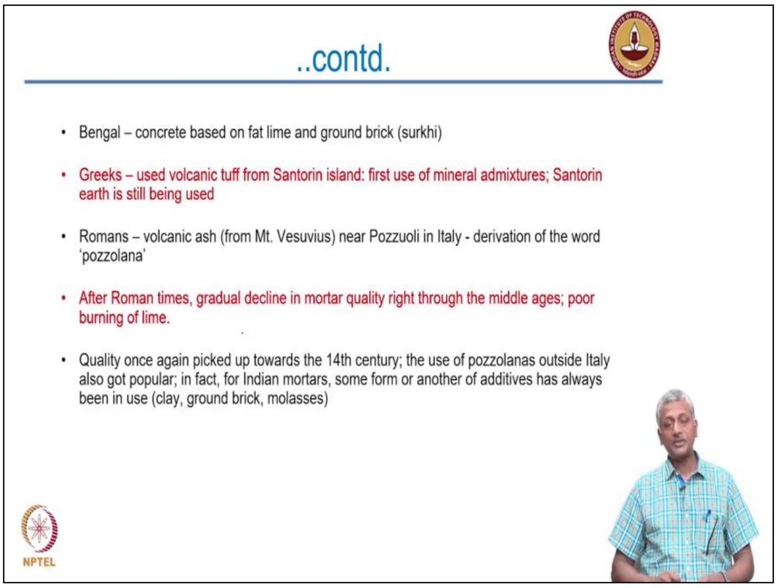

From bitumen to gypsum to lime and finally from lime we got to cement. Of course before we got to cement, people started experimenting with lime and adding all kinds of additives to improve the quality of the lime or to improve the quality of the mortar they get from mixing lime and sand. One of these was surkhi, which is basically ground brick mixed with lime. Greeks used volcanic ash, which is basically volcanic tough crushed to a powder, basically that was used for mixing with the lime.

Romans also used volcanic ash. The first use was historically recorded in a place near Pozzuoli in Italy. This was the ash that came out from the eruption of Mount Vesuvius. And this ash, because it was found in Pozzuoli, it started to be known as Pozzolana. Even today the term Pozzolana is quite well in use. When we talk about alternative cements in the market, you will see that there is something called Portland Pozzolana Cement, that means it has regular cement and it has an additive which is a pozzolanic material.

We will learn about this of course when we actually get to the chapter on cement and concrete. Now again, there are lot of examples of all kinds of additives that have been used inside lime mortars to improve its characteristics. Again a lot of these examples are from India also.

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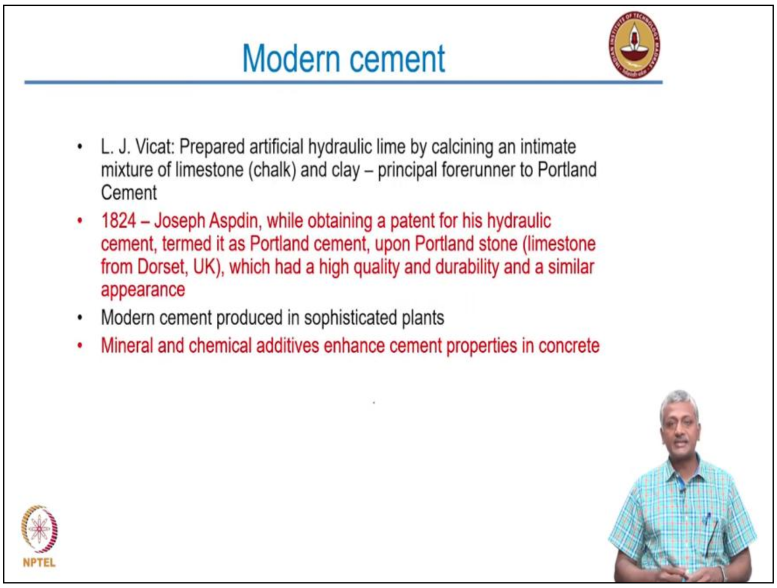

But, truly speaking the modern era really started with the advent of cement as a binding material. There were lot of scientists who did work with cement. First and foremost was L. J. Vicat. So he said that, ok I'm going to try this formulation out, I'm going to mix limestone and clay together and burn it. So to produce lime what they do? They just simply burn limestone. Then people started realizing that, if the limestone is not very pure and then burn it, it seems to be giving some very interesting properties in the mortar. What if now we take limestone and clay, add the impurity first and then burn it together? and that ended up producing cement-like substances.

Later a very talented and possibly business-minded Englishman named Joseph Aspdin patented this technology of burning limestone and clay together and said that the product that came out will be called as portland cement. He got a patent on it.

Since then cement which we use for construction today is called Portland cement. The patent was obtained in 1824, but we still talk about it as Portland cement. That is the power of the name. The patent is no longer valid but we still call it Portland. Now modern cement obviously is produced in sophisticated plants. We get a material that is free of variation, can perform very well in different kinds of environments.

So that's the impact of modern technology that has converted this material that was previously made by people who are not engineers, who are not scientists. But today it is properly engineered, it is properly manufactured just like any other commodity product. And we have not stopped at cement, we have actually gone to the use of mineral and chemical additives that enhance concrete properties. All these aspects you will learn a lot more when we actually get on with the course contents.

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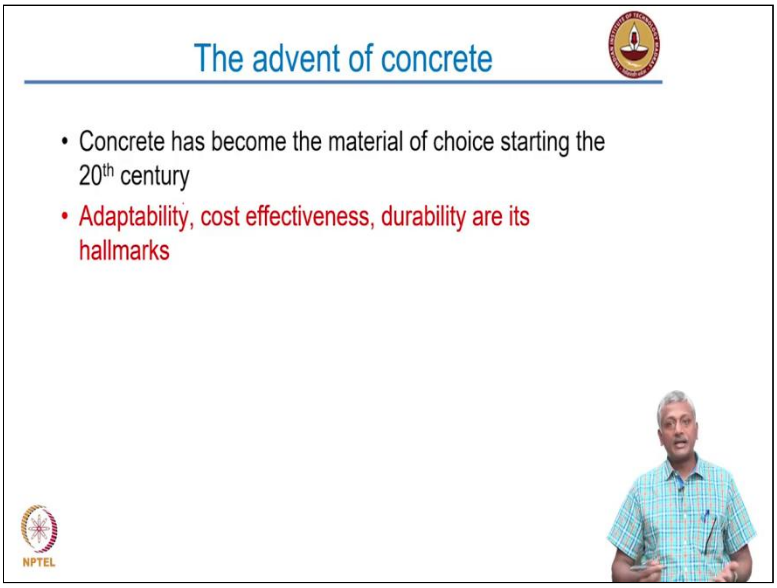

So, needless to say concrete has become the material of choice for the 20th century. Primarily because it is highly adaptable, it can be shaped into any kind of shape that you really want. It is cost effective, because the only costly component in concrete is actually the cement. The aggregate is not very expensive and because water is easily available, it is not really a problem. And of course, if concrete is designed properly, it will be durable and long lasting for a very very long time.

So these are the hallmarks of concrete and adaptability makes it a material of choice much over your stone. You can't really do the same adaptation with stone. You can't make stone into different shapes, it will take a lot of time and effort by workmen and artisans. We don't have that kind of time today in construction. For today's fast paced construction, concrete is probably the most suitable material.