Introduction to Civil Engineering Profession
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Lecture - 08
Construction Materials and Methods

All right hello everybody, so welcome to the session on Construction Materials and Methods. I am Manu Santhanam. I am working in the building technology and construction management division of that Department of Civil Engineering in an IIT, Madras. And I specialize in construction materials primarily concrete and my research is based on concrete technology. So, today I will give you a glimpse of what is out there in terms of construction materials and practices. Often times what we see is the evolution of materials deals with the way that we try to construct with these materials.

So, the kind of construction practices are driven by the kind of materials that we actually have ok. So, I will take you through a journey through a the use of different types of materials and where we are currently and where we are going from here alright.

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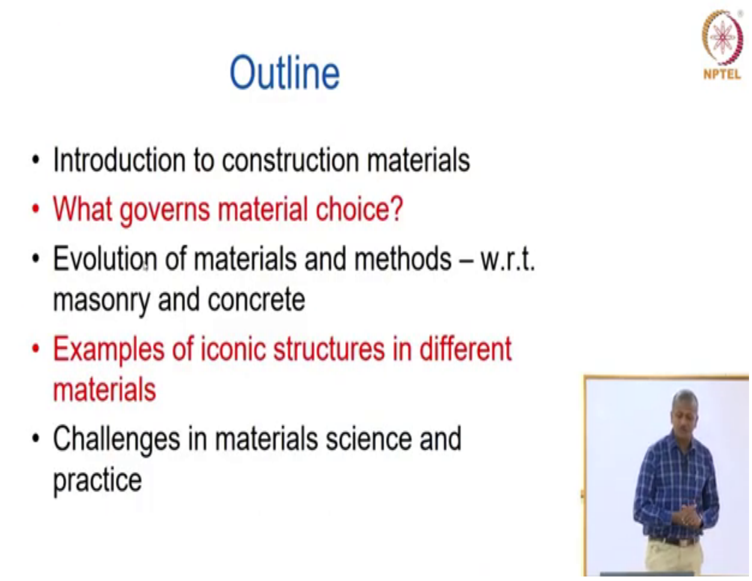

So, I will start with talking about why we want to study construction materials, what governs material choice, how do we actually decide what materials best for a particular situation. We will look at some historical evolution of materials and methods. I will specifically talk about masonry and concrete Because that is the most relevant in terms of materials for the Indian context that is why we use mostly masonry and concrete type buildings. We will look at some examples of iconic structures with different materials and look at some interesting aspects about the construction methodologies adopted in some of these structures. And finally, we will end with a the look at the challenges in material science and practice.

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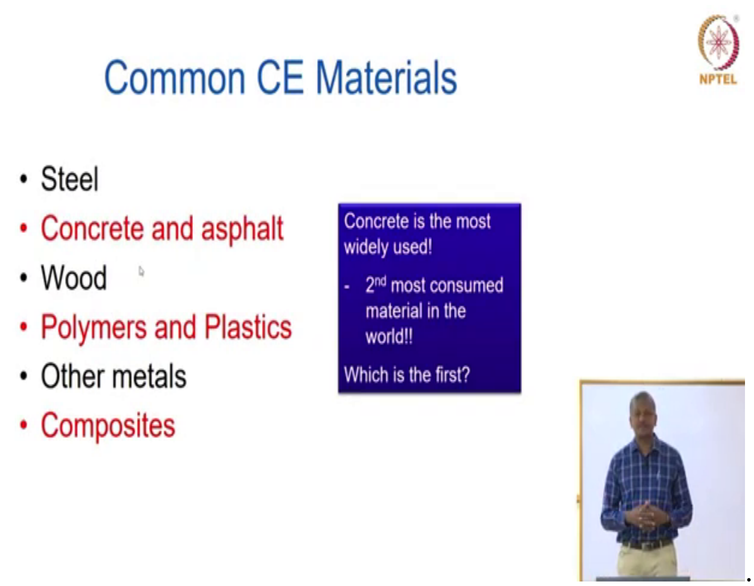

So, of course, you know very well that there are several different types of civil engineering materials that are available today. Common ones being steel, concrete and asphalt, wood, polymers and plastics; you have other metals like aluminum, copper which are also used in construction. Of course, today we are talking a lot about using composite materials which was earlier use in the aeronautical, mechanical engineering. Today we start using composite materials also in civil engineering.

So of course, you know very well from what you have seen around you, you was observed quiet a bet that concrete apparently looks to be the material that is most widely used right. In fact, it is a second most consumed material in the world after what is the first most consumed material?

Student: Brick iron soil.

Soil, well. So, if you consider soil is a construction material, yes we use a lot of soil in construction.

Student: (Refer Time: 02:35)

Somebody say the right answer in before.

Student: (Refer Time: 02:38)

Water.

Student: Water

Concrete is a material that is consumed in quantities which is second only to water. So, significantly large content of water is actually consumed for several things, of course including construction. But concrete is a second most consumed material apparently we are using about 25 billion tons of concrete every year 25 billion tons as per the last estimate. And it is only above to go up because we know that in countries like India in several African countries and several other Asian counties, there is a lot more work that needs to be done regarding development, infrastructure and that is where concrete is going to be used more and more.

So obviously, there is a heavy burdened that we have placing on the environment and these are some other aspects that we have look at towards the end when we look at the challenges as far as the material study is concerned alright.

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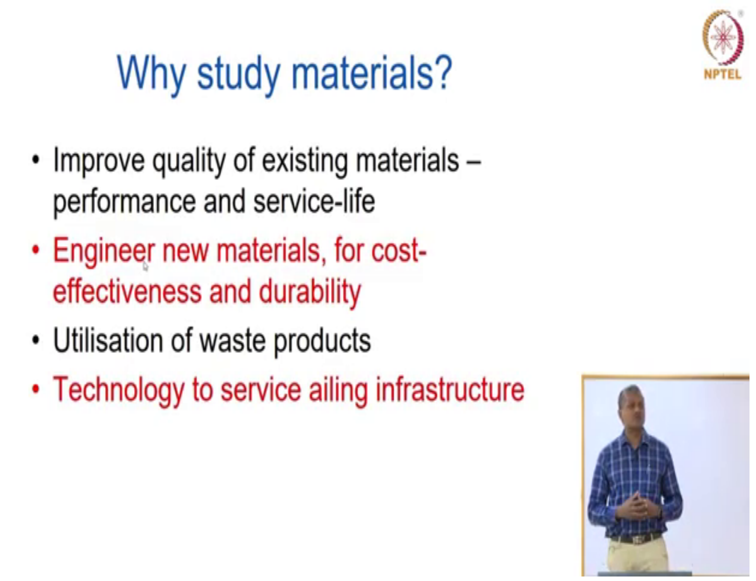

For now let us look at why do we want to study materials, I mean they are available let us just use them right. But there are several different aspects why we want to actually engage in a deeper understanding of material characteristics in order to make our construction more appropriate and more sustainable more durable in the long term. So, ideas to improve the quality of the existing materials and enhance the performance and service life. So, later when you learn other aspects of engineering, you learn about service life being one of the controlling factors which governs the choice of a given material or a construction product or a process right.

Service life essentially deals with how long is the material or the structure able to with stand it is given environment without losing it is quality, with which it is actually performing. The other aspect is we want to always look for new materials primarily looking at cost effectiveness and materials that are actually durable and long lasting. So, that is another aspect why we want to understand materials deeper from a scientific point of view.

Utilization of waste today is turning out to be a quiet a big challenge, because we have to extensively dispose a lot of waste that is generated from different types of industries. In many cases, we find that construction is a scenario where we can actually utilize many of these waste products. But not because we are just putting waste in the material excepted it to perform, but because a lot of the waste can actually end up being a value added resource to construction materials and projects.

So, waste utilization is another aspect why we want to study materials and understand the affect of these materials on the existing construction materials. And of course we have infrastructure which is ailing getting old we need to understand how materials degrade with respect to time. So, that they can decide on appropriate strategies for repairing rehabilitation with which we can prolong the service of these existing structures. You know you all travelled by trains and you have seen many of our railway bridges are on the verge of actually deteriorating to a state where they cannot be probably recovered any more.

So, because of that we need to understand how the material behaves with time and try to service the ailing infrastructures. So, that we can extend this service life of these can structure alright.

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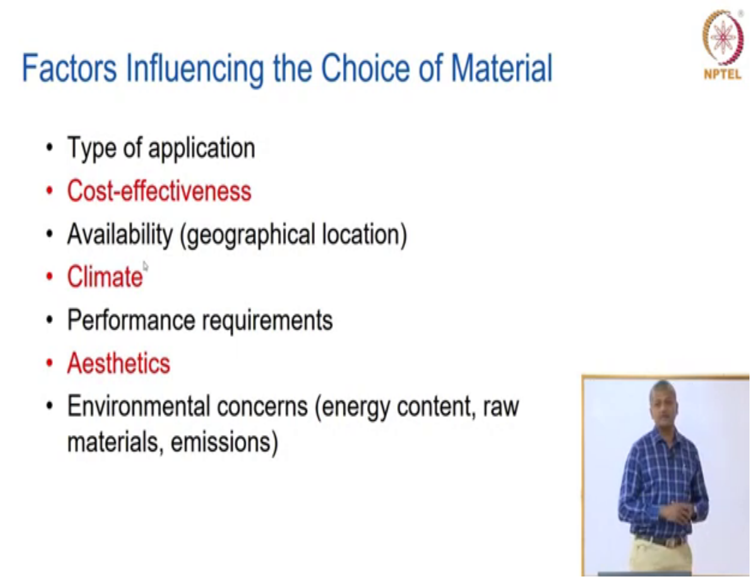

So, there are several factors that governed or influence the choice of materials right. First in for most of course, depending upon the type of application what exactly are you constructing, what material is locally available and available at a cost effective sort of a. So, cost should be low and the material should be available a plenty locally and that is probably the most important factors with respect to the choice of material.

Of course, in certain areas the climate will govern the choice of a material. For example, if you go to the Northern European country where very little day light is available most of the time, you could use glass as one of the major materials of construction because it allows in a lot more light. But unfortunately in India also we started copying the western use of glass and most of our IT buildings and structures are also come up with these glass resorts there completely enveloping the building. What is the problem with using glass in a climate like ours structure?

It brings in a lot more heat into the structure and because it does that we spend a lot more energy it trying to air condition the buildings. So, we are sort of losing the battle when we try to choose materials in technologies that are not really apt for an environment. So, climate is one of the deciding factors why we want to choose a particular material for a certain location. The other aspect obviously is a performance requirements what exactly do we want this material that they do right, what kind of engineering characteristics are expected from this type of a materials. So, that is the performance requirement.

Aesthetics again is an important factor; you obviously want to choose or builds structures that look good. And in many circumstances the same material may not look or give the ideal aesthetic qualities in different types of structures. And finally of course one thing which we have neglected so far, but we are beginning to realize that this is important are the environmental concerns about the use these materials like energy content, the raw material usage, depletion of natural resources and things like that and emissions that we have related to the production of the material itself. We will talk briefly about that towards the end of this lecture.

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So, let us look at how materials and methods have evolved over the years ok, This sort of is a historical process. But it is not probably entirely anchorite in the way that I have depicted the different materials and processes, but idea was to give you a comprehends of glimpse of what type of construction materials and processes are actually undertaken by engineers to build the types of structures.

So, you have Monolithic construction probably the oldest variety where people simply built out of carving rock right. So, the caves are the earliest example of a dwelling as for as human civilization is concerned and these caves were actually built into the existing mountains by simply drilling and knocking things down and making a space for yourself inside, so just to create a safe space to yourself right. Later on people realize that they had to work with smaller blocks of materials, so that they can actually construct in a lot more grander fashion. Because you can only do So much as far as monolithic construction is concerned, you cannot really go beyond a certain scale.

So, then they started looking at smaller blocks assembling these blocks in various types of shapes and sizes and that is what we call as masonry. Of course, along the same time wood was also quiet highly prevalented area where wood was available good quality wood for construction was available. And wood as a construction material probably dates back to as long as masonry is being used.

Later on we entered the era of concrete by people started realizing that you can actually optimize further the combinations of different types of materials to give you certain very interesting characteristics right. For example, in the fresh state concrete is flowable which makes it possible to casted in different types of shapes which is not possible with masonry all the time, which is not possible with monolithic construction also.

From concrete, we entered the era of reinforced concrete and steel with more and more steel being utilize in our buildings. We started realize in that we can actually do things to buildings which we could not envisage with the masonry or concrete. Primarily because we are utilizing the property of steel of it is high strength and ductility and with that we could actually start optimizing the usage of materials and builds structures that we are lot more cost effective, could take a lot more load and could perform exceedingly well in disaster such as earthquakes.

And then moving on from there we are encountering today several examples of composite construction and in the long term we are looking forward to the use of smart materials and sensing materials that can actually govern the performance of the structure as we live in it and adapt the environment to suit the needs of the inhabitant. So, these are smart materials structures probably the way to go forward in the future. But a bulk of our building constructions stock will still being concrete and steel and that is what we are primarily using today as a construction material in India.

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Now, let us show some examples here of monolithic construction, this is all to familiar for you the figure on the right. Can anybody tell me where that is from?

Student: Hampi.

Sorry.

Student: (Refer Time: 10:44)

Of course, it is says there it is from Hampi ok. It says on the slide it is from Hampi it is basically a chariot which is carved out of a single rock right. On the left you see another picture.

Student: Ellora

From Ellora, yeah you see that again from a single rock you have carved out an entire temple right.

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As you move forward towards masonry, the simplest examples of masonry are the Dry Stacked Masonry. So, you just take blocks and keep it on top of one another. And how is it is stable? Because of gravity; because of shear mass right. You use really massive components and as you go to the top of the structure, you keep on reducing the size of these components. Like the great pyramids of Egypt are essentially dry stacked line storm blocks that were kept on top of each other and ultimately resulted in a massive structure which even today is a fairly significant landmark in the world.

Moving on from dry stacked masonry, then people studied realizing to really achieve such feeds, you have to be super humans right. Lifting these blocks, I do not know if anybody reads asterisks in this in this room, you must have read asterisks in Cleopatra where they drinks this magic portion and lift all these blocks and build all these wonderful structures.

So, something like that must have happen to really make these you buckers lift all these blocks or they would have had very good engineering techniques, so lift this heavy blocks to get them placed one and top of each other right. But moving on people thought this was not really the best way to move forward. Let us look at some ways to join these blocks, so that they can work with smaller blocks if people will carry quiet easily and that is where the jointed masonry started being practice.

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And jointed masonry even today is practiced; only thing that is changing in jointed masonry is a type of cementing material used to bind these blocks together. So, in the past you have several other examples, I will come to that binding material part a little bit later. Today of course, we only think about cement has the only possibility as far as joining masonry blocks are concerned. So, these are some examples on the left, you have a brick masonry structure and the other right you have stone masonry structure. Both of these have very fine detailing work done with the joints and that gives a very nice appearance to the entire structure.

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Moving on from jointed masonry, you can actually get a lot more optimization with a speed of construction. Please remember when you are doing a jointing process in a masonry block; you are placing one layer of masonry. Then you have to actually place the cement mortar or lime mortar and top which is the binding material then put the next layer on. But you do not have you cannot keep doing this entire process in a single day, you need to wait for the material to harden otherwise the wall will become unstable and fall right.

So, because of that the use of water for joining the blocks is a process than actually slows down the construction work significantly ok. If you real thing about it, it slows down the construction work significantly. So, the way around it is to ensure that you do not have to actually put anymore mortar. But you can still get good stability by providing interlocking between your blocks and this is something you all know from your childhood days. You have played with lego other sorts of building blocks which you actually connect, because of the interlocking capabilities of these sort of blocks right.

And such blocks basically the interlocking blocks need you to have a construction which can be done much faster than what you would have in the case of a jointed masonry.

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From interlocking, people started getting the idea that you can strengthen masonry structures even better, when you have reinforcement put inside the structures. So, reinforcement ensures from the. So, the need for providing additional strength to masonry comes in when we actually look at the performance of masonry in disasters events like earthquakes. So, in earthquakes you can imagine that the structure actually has a motion that is moving along with a ground right. In such cases, just having a good strength in the axial direction is not going to a help. So, we need to start providing some degree of load carrying ability which can actually take the loads in the lateral direction. In such cases, proving reinforcement can go a long way in actually extending the load carrying ability of your masonry.

So, reinforcements in masonry became the next step in the development of masonry structures and where you could look at providing certain cavities within the masonry. Putting a reinforcement rod like an iron steel rod that we typically use with concrete and providing the reinforcement that provides the lateral resistance. So, reinforce masonry was a next step forward from your jointed masonry and interlocking masonry to provide additional load carrying abilities to your structure.

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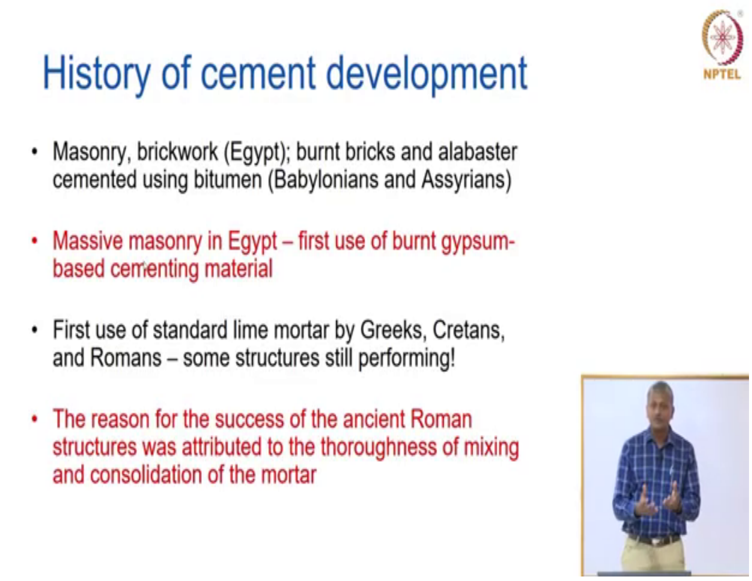

But coming back to the jointed part as I have saying the primary reason why people went for this was, because they discovered or they invented combinations of materials which could give very good binding characteristics which could join these pieces of masonry blocks together right and this binding characteristic is made possible because of use of different cementing materials. If you are go to the past structures in Egypt and in Greece, lot of the burnt bricks and alabaster were cemented using bitumen.

Now, today we know that bitumen is used to actually paved roads right. But the same material was earlier found in natural pools ok. You know the process of formation of bitumen right; it is formed from the process of distillation of your petroleum or crude oil. You get several products like gasoline kerosene all those kinds of things and what remains as a residuaries aluminum sorry asphalt right. This asphalt also occurs in naturally occurring pools around the world and people were actually able to extract this asphalt and use this as a binder to bind these masonry blocks together ok.

So, that became the first sort of binding material to start binding these masonry blocks. But later in Egypt people started using burnt gypsum based cementing material something that you would have done in school is to use plaster of Paris as a molding material right. When you mix plaster of Paris with water, what happens? It hardens because it converts to gypsum right. It is plaster of Paris is calcium Sulphate half H2O when you add water to it becomes calcium sulphate to H2O.

So, it causes hardening of this material and that again was a very popular binding material used in the past. Now only problem that gypsum is it is not highly resistant to moisture. When rain falls in gypsum, it will slowly erode away the gypsum and dissolve it away, because of which the binding properties may get reduced with respect to time. Later on of course, people started realizing that the best quality binding could be obtained by using lime, lime is basically your calcium oxide. And where is it obtained from where is lime obtained? From burning of

Student: Limestone

Limestone that is calcium carbonate. When you burn calcium carbonate at temperature is more than 800 degrees you lose the carbon dioxide, what remains if hand is your lime. When you react lime with water, what is it do?

Student: Calcium hydroxide.

It produces calcium hydroxide right and this calcium hydroxide again observes the CO 2 the atmosphere and converts to.

Student: Calcium carbonate.

Calcium carbonate so that is the lime cycle. We started off with calcium carbonate; we end off with calcium carbonate. So, that is basically again one of the technologies that people started looking at with a lot of interest. Because this had the potential now to actually do massive levels of construction because of the excellent binding properties you got with this line.

So again Roman structures, obviously have several of these structures are still standing and people have actually looked at the performance characteristics of this lime water and they find there is actually of a very high quality.

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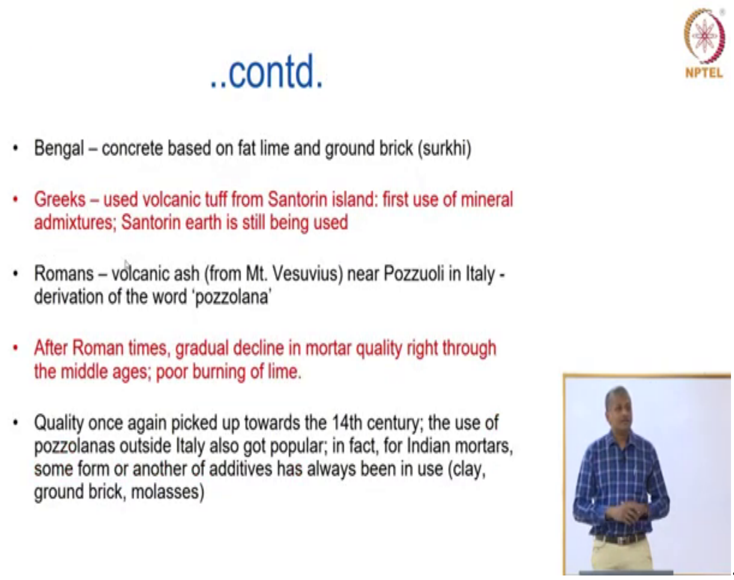

In India also, there are several evidences from the past, where lime was actually mixed with other additives like ground brick for instance. The brick itself when you grinded into a red powder, it enhances the properties when you actually mix it to make the lime water and that was one of the first uses of additive materials with the into the lime. Later on in Greece and in

Italy they started using volcanic ash and they saw that when you mix with lime, it gave much higher strength and durability properties ok. So, that is where the word pozzolana started coming into being and even today when you actually by cement that is a brand of cement which is called as Portland pozzolana cement. And this pozzolana PPC, this pozzolana is basically anything which is a reactive silica continent in it.

So, the earliest example was a use of volcanic ash and when you mix that with the lime, it started producing a chemistry which was not seen with plain lime kind of structures. Now of course, beyond that there is not too much of a development that took place until about the 19 century and the 19 century is when cement came into being.

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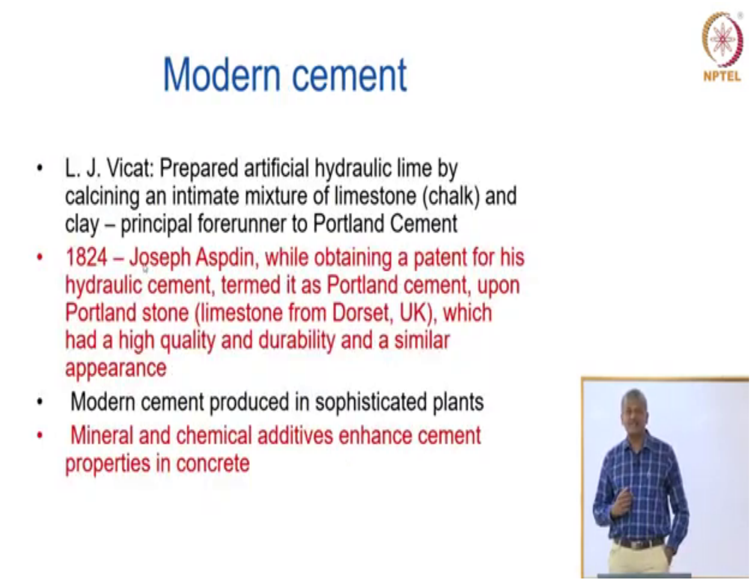

Cement basically has it is origins probably much before the 19 century. We have a great scientist one of them Vicat and Vicat is something that you will come across later when you actually do your lab class with cement. But that is not until the fifth semester.

So, basically Vicat essentially looked at some combinations of limestone which are the lot of impurities in the form of clay in it and he saw that when you burn this limestone in clay together, The resultant lime that you get is excellent with respect to it is binding characteristics. But later people realize it is not lime that you are getting, you are actually get something else you are getting cement. And the first person to realize this and understand the marketing potential was Joseph Aspdin. Although he was not the inventor per say of cement, but what he did was instead of calling at a lime, he called at as a cement ok. He just called it as cement but he gave it a special name called Portland cement.

So, what is saw was when this material that is obtained by mixing limestone and clay together when it reacts with water, it results in the formation of a hard rock like substance. And this rock was similar in appearance to a type of limestone that was found in Dorset in the United Kingdom. So, from that Joseph Aspdin gave it the name is Portland cement and this Portland name got stuck with people and people was still using it today, in spite of the patent have been obtained in 1824 in probably patent must have gone out 100 years ago may be.

The patent is no longer valid but we still call the cement as Portland cement, just like when you photocopy something you say that I am going to Xerox something. Xerox is not an English word; it is the name the company that manufactured the earliest photocopiers. But even today when you say you going to Xerox shop, but you go to I will challenge you to actually find a Xerox copy machine; you are probably finds some Japanese makes like Minolta or sharp or canon or something like that right.

So, that is the power of branding as far as cement is concerned the brand is Portland and even today in all bags of cement you see the name Portland, at least in India you see the name Portland everywhere being still use. So, modern cement is obviously produce in sophisticated plants. if you go to a cement plants you will see the kind of control they have on each and every process of manufacture, with which they are able to get a product that has very low degree of variability and that can be used to actually engineer the materials.

On the other hand if you go to a kiln where the lime is produced, many of you may have seen this while going by bus or train across rural areas. You see this lime kilns people are not really controlling the process well enough. They just take the limestone put it inside burn it to sometime and then take it out. They do not have a control on the time temperature or the pressure maintain it is of the kiln so on. As a result of which you do not get a product that is controlled with respect to it is characteristics, you may have something that is highly variable.

On the other hand. cement people have such control on the process that they can actually get a product that is very highly controlled with respect to it is performance. Of course, today we do not just use cement, we also use mineral and chemical additives and these enhance the properties the concrete that we make with this cement. And this is something you will learned a lot more with higher level courses in concrete alright.

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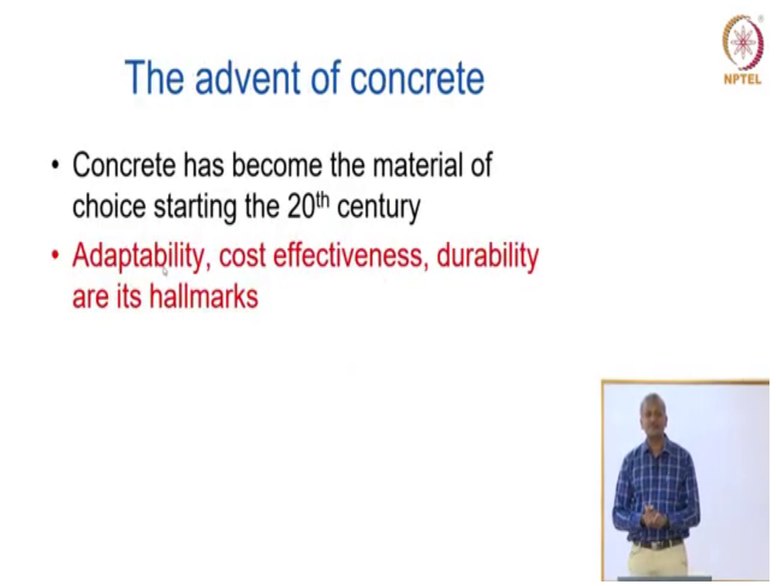

So, concrete itself has a material has been used for several years, I would say 1000 of years right. But people did not know that it was called concrete earlier concrete is just an English word, which means a mixture of different things; concrete means a mixture of different things. So, here obviously we are talking about mixing a binding material such as cement, we are mixing water we are mixing sand and we mixing stone to make the composite material which is otherwise called concrete.

And today we do not really have any other material which can have the level of adaptability cost effect effectiveness and durability as concrete, because of which concrete is still highly popular primarily. Of course, because of cost effectiveness you cannot really build structures with the same level of load carrying ability, as you can build with concrete in a reasonable degree of cost.

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So, people have built in plain concrete right, there are several examples of plain concrete structures. For example, this wall here which is retaining the soil and you have this derive on the right, which is again built with plain concrete. But there are obviously some limitations as far as building and plain concrete is concerned. Because concrete is a material is excellent in compression, but very poor in tension. What do you mean by compression and tension? Compression is when you are applying the load on to the structure or on to the material; tension is when you are pulling the structure apart.

So, concrete is not very good in tension and because of this you need to strengthen it right in tension and then strengthening in tension basically involves either using reinforcement like steel which is a very good material when it comes to tensile strength or using structures where you can optimize the shape. Like in the past people build with domes and arches. In such cases, you allow the load path in such a way that only compression comes on to the material, there is no tension at all in such cases.

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For example you may have seen pictures of these structures, the Pantheon Dome in Italy and the Saint Peters Basilica in Vatican City, which have some form of lime concrete used to create these massive slab structures on the top. These are basically dome shapes slabs and which have waffle like opening to reduce the overall weight and you have even a circle or opening in the end in the center to allow the light into the structure ok.

So, these are concrete structures, they were built with concrete; but not the concrete that we know today. They did not use cement, obviously because cement did not come it to being until the 19 century. This was built in the second century and of course St. Peter's basilica was in 17 century. So, they did not obviously use cement, they must of use lime with or without some additives to make the concrete which is basically mixing the lime with water sand and stone right. So, with the dome or an arch, you do not really get any tension. You only have compression, because of which the material is able to with stand quiet easily.

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But when you go towards other forms, when you go towards more rectangular forms that we are used to seeing in construction, you need to start putting steel to reinforce the concrete ok. Now you can see from this picture provided in the left, the typical scenario for reinforce concrete construction, you have the formwork which is the wooden part on the outside which provides the shape to the concrete structure. And then the reinforcement that is put inside the formwork and then you put concrete into this entire segment to ensure that the concrete completely envelops the steel right. Because if you leave steel exposed to the atmosphere what will happen?

Student: That will.

That will corrode, so concrete has to cover the steel and entirely envelop it. But you only provide steel wherever the structure needs resistance against tensile loading where there is only compression; you do not had to worry about it right where there is only compression, you do not had to worry about providing steel. You only provide steel where tension occurs in the reinforce concrete structure. So, reinforce concrete is given as a vast extent of possibilities which can define different types of shapes, different types of optimized uses and so on of to material combinations.

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This is a typical example of reinforce concrete building. So, frame construction is something that started happening, when people realize the potential of reinforce concrete. A frame construction simply means you built the vertical that is the columns and the horizontal members that is the beams right. You just build a frame out of the columns and the beams and then you infill the walls later, of course beams also implies that your having the floor slab built along with the beams.

So, frame is your column beam and the slabs which are the horizontal members and later you fill in the space between the columns is the wall and this wall can be filled up later. So, in this process what is different from a conventional masonry construction? In a conventional masonry the load is taken by the.

Student: Wall.

Wall right; load is taken by the walls. In the case of a reinforce concrete frame construction the load will be taken by the slab beam and column. The walls will be non functional with respect to load carrying ability. But they will be functional with respect to providing whether proofing, obviously because they are preventing the outer environment from completely entering inside.

So, you have the wall primarily as a separator of the building from the environment right. So, this gives you possibilities of using unconventional materials as far as the wall is concerned. And today if you go out to see real construction projects, you will see that the wall is now being build with concretes like light weight concrete or aerated concrete. Why is that interesting? Because if you put air inside concrete, if you make it highly porous the flow of heat and sound through concrete is increased or reduced?

Student: Reduced.

It is reduced right, because heat gets conducted much easily through a solid than through a porous material. So, introduced voids and gaps inside your concrete which makes the heap flow much reduced. And if you doing interior air conditioning, obviously it retains that coolness inside much better rather than losing out this coolness to the outside. So, you can use combinations of different types of materials which are providing these interesting functional characteristics inside the structure. Because, now you have completely eliminated the need to make walls very strong.

But only problem is again people realized that this is cutting down on the productivity, because you make the frame but the wall takes it is own time in getting hardened and then built up.

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So, because on that people started moving to the next stage that is building walls also with concrete with solid concrete and this increase the speed at which the construction could be done. Because now you can have a formwork system around the entire structure, you just fill up your concrete as soon as some level of hardening of the concrete happens you lift up this formwork and build the next level. And this way you can go from floor to floor much faster. And if you go to any of the high rise residential buildings that are being constructed in the city, you will see that this is the system that we adopt, where even the wall has a same concrete that goes on the column and the beam.

So, because not now you do not need to worry about other materials, you just need to speed up your project by using the same material throughout the structure. Of course, there is a disadvantage here that your walls are not going to be as efficient anymore as before right. Earlier with the frame construction you had the choice of choosing different types of materials for the wall, which could reduce the heat loading of the structure.

But here your building everything in concrete, so it is probably not a great idea. But then it is speeds up the construction extensively. And you can now produce or you can you finish buildings in a matter of a few months, where you earlier take more than a year or probably up to 2 years. The same level of building can be filled up or can be constructed in probably halfth time.

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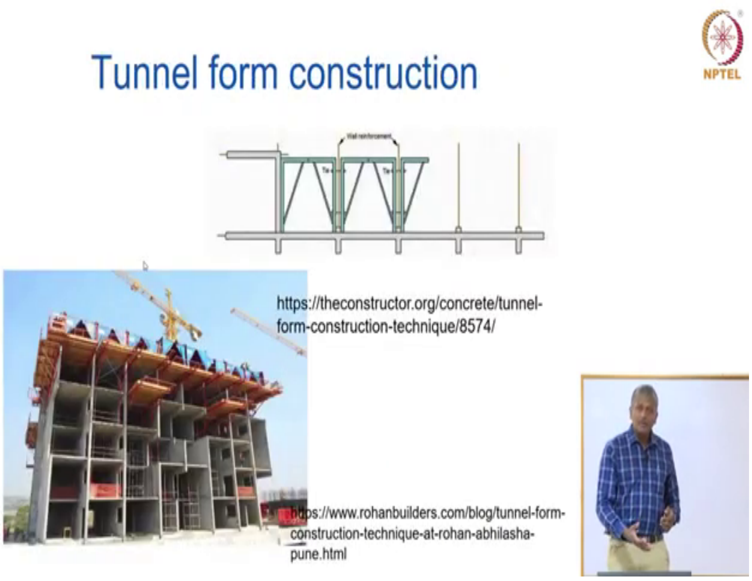

Moving on from this technology of using concrete walls you can now create almost entire segments of concrete, like entire room can be actually fabricated all at once and this is done by something like a tunnel form.

So, you see here as shown in this picture you have this, you have the tunnel form here. All you do is fill up the concrete into the walls and also into the slabs at the same time. So, concrete goes with the walls and the top slab with the same time and you simple buildup one level over the other, so that is called a tunnel form construction. Once again very popular means of building very fast especially with respect to higher rise buildings, for apartment buildings and so on right.

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Now, when you slow down your process because you need to marry steel and concrete, what to you can also do is try to look for methodologies by which you can strengthen in the concrete itself and make it respond in a positive way against tensile loads to. And this is being accomplished by the use of prestressed concrete ok. We will learn you will learn later about what prestressing is and how actually it increases load carrying capacity of concrete. But overall this prestress concrete belongs to a segment of concretes called as precast concrete.

Now what is precasting, that means without really assembling the concrete or shaping the concrete on the side. I already make the components of concrete in a factory, I bring them to the side and simply stitch them together right and that is called precast concrete. The advantage the obvious advantage I get from precast construction is that now I can control the quality a lot better and factory making these components. On site there are so many different people who can actually spoil the appearance right. The workmen need not be well trained because of which the final appearance of the structure could be spoil.

But I do not have that issue with the precast structure, where I build in components of the factory come to the site and simply assemble them stack them up connect them properly and so on. So, prestressed and precast concrete construction is actually responsible for a lot of our infrastructure construction today, including your Chennai metro rail and the figure on the right basically is a example of a Chennai metro rail construction where you have these pears and you have these precast segments there are taken up and put next to each other. All you do is simply put a steel through it and stretch this steel and press the concrete in compression. So, what are you doing here your applying a precompression to the concrete that is why it is called a prestressing, prestressing operation.

Now, when you use the same in slabs, you can get a structure like this which is shown on your left. But you have the column and the slab directly on top, there is no beams in this case. So, your strengthening the slab by prestressing it, so you do not need actually the slab to transfer the load to the beam any more. You can have the slab transfer the load directly onto the column. And what is the advantages like this? you get much higher floor area rooms right. You get lot more room in the floor which can help you put your falls sealing and have a much better efficiency with respect to your air conditioning.

So, a lot of advantages when they move from one material to the other, but the at the same time when we use the same material in different kinds of applications with different kinds of methodologies. We can actually totally open up a wide range of possibilities.

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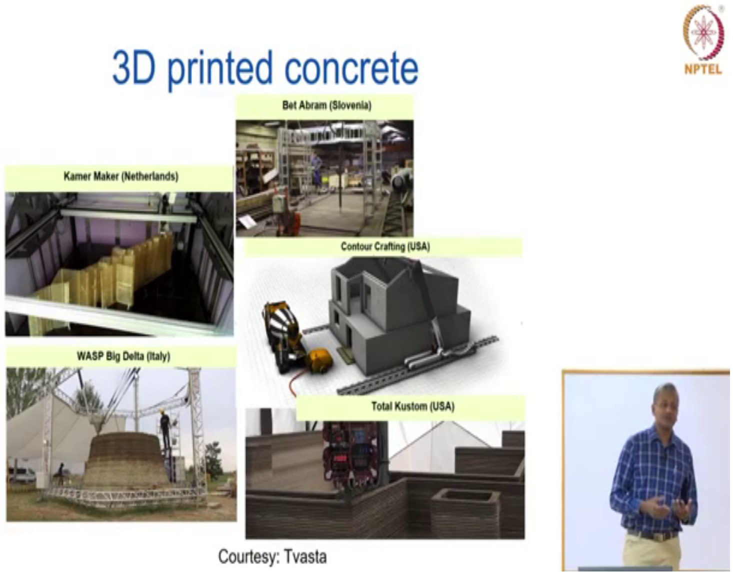

Now, today the limit of this possibility today is printing of the concrete itself. Now in manufacturing industry and in medical industry, a lot of the components on actually 3D printed. What you mean by that?

The deposition of the material is done layer by layer to build up the entire material right. So, these days even tends which they put to clear blocks inside your arteries, even those can be actually 3D printed to the most optimal ship desired and sent inside the arteries to remove the blocks. Similarly people who started realizing that lot of the machine tools, the common way of actually machining it is to go to the workshops start using these cutting machines to shape it and then use the filing machine to ensure that it gives the correct dimensions and so on and so forth.

But now what are you doing is instead of actually taking a large block in cutting, you are taking small layers and printing on top of the layers to build up the entire module. So, this aspect was taken up in construction also. Primarily from in the beginning the idea was what do we do when we encountered terrains where you cannot simply provide sufficient material for construction where conventional construction will not do like a free establish a base on the moon. Where do we take the materials to start constructing on the moon?

So, can we send an instrument out there with the required mix of concrete inside that which can simply go and start printing on the surface of the moon without having the need put the workers and carry a lot of material out there. So, that was the origin of this idea and people who started experimenting with this to a large extend. So, there are several different people who were actually doing 3D printing around the world, some examples have given here like the contour crafting operation there is total custom in US.

So, you can see what happens in this case is the concrete mix is spread inside the printer and the nozzles simply prints a layer of concrete and then deposits one more layer and one more layer and so on. So, what is the advantage here? The advantage here is in the pass when we have to make with concrete, you had to put formwork right. I showed you that in one of the previous pictures right, this formwork that you have on the site. Now it is estimated this formwork actually takes up nearly about 20 to 30 percent of the cost of your construction and nearly 60 percent of the time where it takes to actually build the concrete structure.

Why it is takes so long because, it has to be assembled and after the concrete has hardened it needs to be disassembled. Now that time can really eat up into the productivity of your entire project. So, that is why people think that 3D printing can provide a means of actually much faster construction projects. And so there are several attempts around the world where people have looked at 3D printing, there are some commercial successes also. People have actually produce smaller scale buildings and hotels with this and of course, there is one example of a Chinese company which does this 3D printing.

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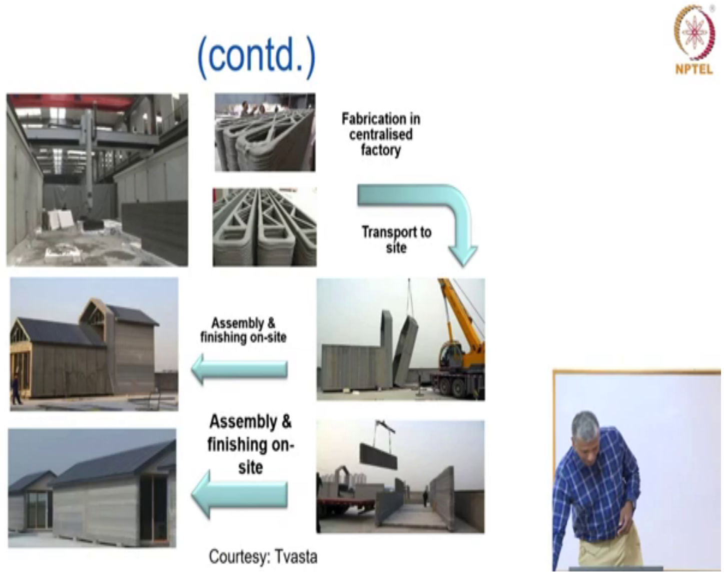

So, they prefabricate these 3D printed components in the, in the factory, you can see how this the arm of this printers moving and depositing concrete layer by layer and that is the finish structure on the right. Each and every wall is finished on the right and transportative site where it is basically simply connected together. The question is ok, what is the advantage of doing this when you as well do a precasting in the factory and then go and connect on the site. Again the advantages when you do the precast just you will have to use a formwork, here you are totally avoiding this formwork.

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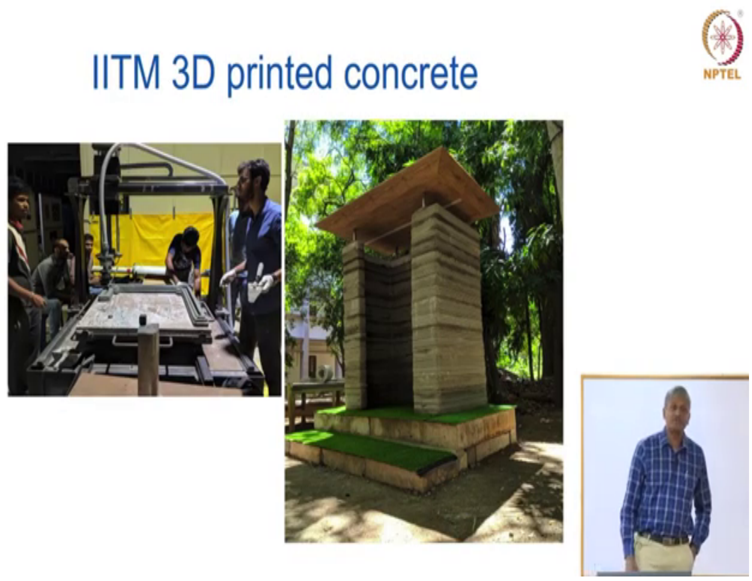

Of course in IIT Madras also we have done significant work on 3D printing. If you have visited the ground floor of the BSB, you can actually see the India's first 3D printed concrete structure. Which is basically a modular 3D print we did modules of 30 centimeters and then connected them using mortar.

So almost like connecting blocks, but with the printer that we had to print that this that is seen on the left here, we cannot build modules which were more than 30 centimeters. So, we had to build 30 centimeter modules and then connect them. Now we are actually producing another structure which is much larger than this and which can be printed almost up to height of about 1.5 meters without the need for connecting modules ok.

So, there is a lot more possibilities in this realm and definitely by the time you guys are done with your bachelor's degree; there will be a lot more construction on the world which is being accomplished by 3D printing of concrete.

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Of course I will just show you very quickly some iconic structures which show why these materials have been very popular. So, wood obviously it has been a popular construction material, it is got excellent tensile properties and because of that extreme efficient as the building material.

If you go to the western in countries like the US or Canada you will see often that people walk into the these large stores and by their own wood and construct their own house themselves. Because wood can be shaped and jointed quiet easily, if you build the bases of basics of carpentry and the joints are quiet strong wood is a excellent in tension, because of which you do not really need very sophisticated engineering to do wooden houses.

So, wood is still a very highly preferred material of construction those country. Only problem is of course, moisture and fire resistance and biological growth or some of the issues which can bring down this life of the wooden structure.

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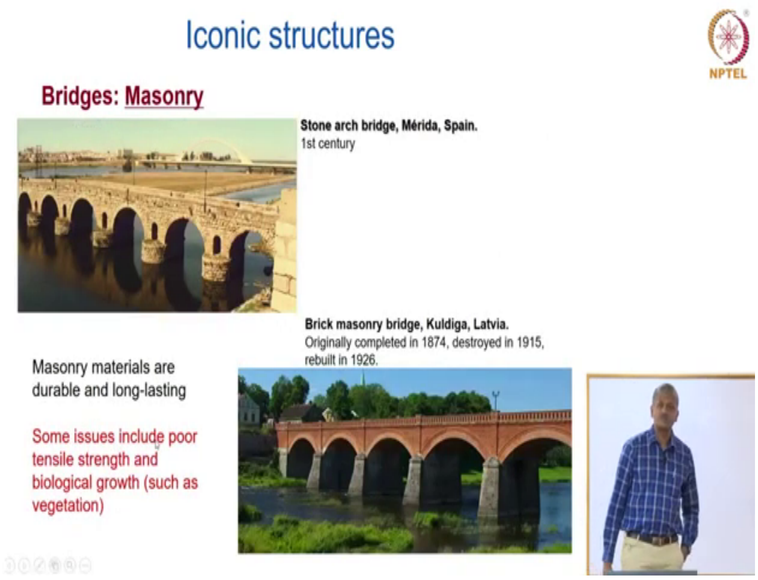

Then you have of course masonry, which is commonly seen in many of our bridges right. You see some examples of excellent masonry bridges from Europe. Of course, with masonry again poor tensile strength could be a factor that affects the usage and biological growth you would have seen in many masonry structures.

That I even plants and trees growing through the structure, because again you have porous mortar which is filling up this pace between the bricks and the brick itself is basically soil right it is derive from soil. So, if it observes moisture, obviously biological growth can take place within the brick also.

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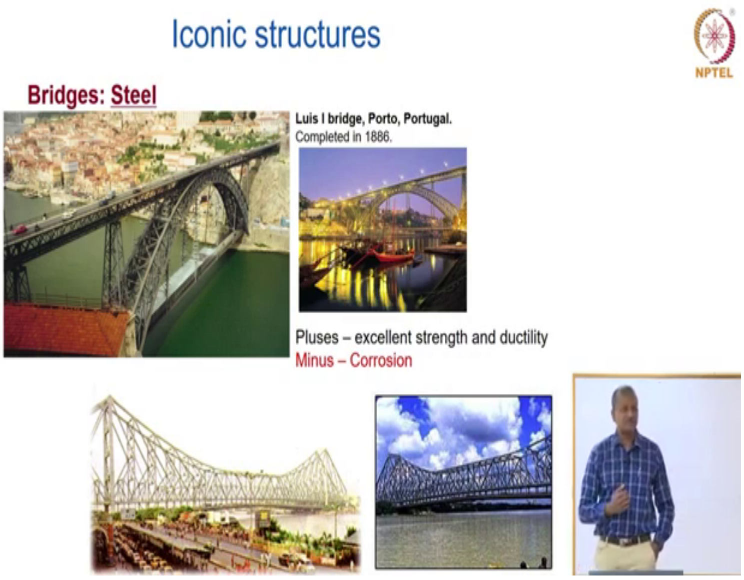

Bridges and steel most of our railway bridges are in steel, but lot of iconic bridges around the world are in steel, one of the bridges which is iconic as per as India is concerned as a one of the bottom. What is this?

Student: Howrah Bridge

The Howrah bridge right in Kolkata it is very popular bridge.

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The bridge on the top left is the Golden Gate Bridge and San Francisco again another popular iconic bridge right. And you have the Sydney Harbour Bridge on the bottom right it is again, you see that every time during new years when they put the fire crackers right.

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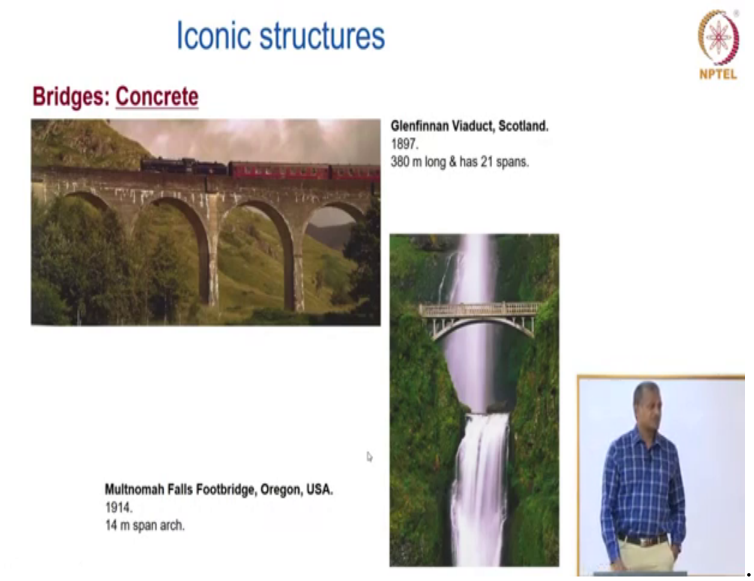

Concrete bridges again you see them all over the world the top left pictures from a very popular movie that you have see.

Student: Harry Potter

Harry Potter right this is basically the Glenfinnan viaduct in Scotland and then you have the Multnomah Falls footbridge in Oregon US. You can see the kind of difficulties they must have add an actually assembling this kind of a structure in that place.

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Then you have of course, Confederation Bridge in Canada.

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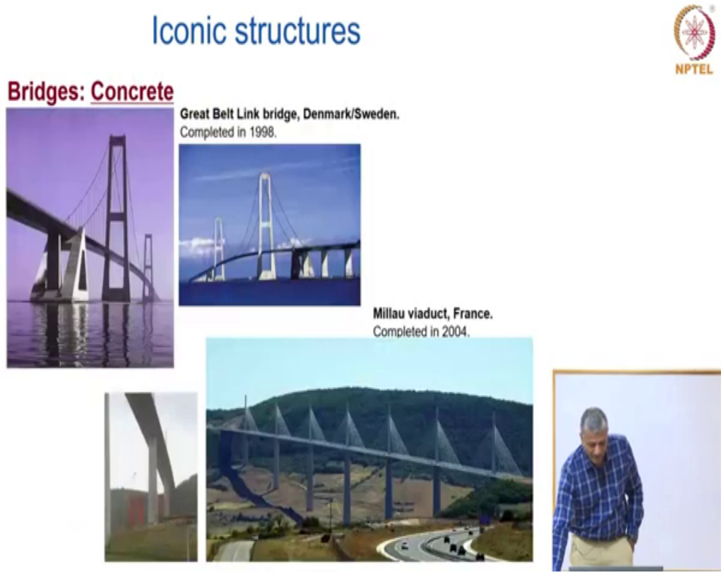

And you have the great link bridge in Denmark Sweden, which is actually an extensively long bridge. It also converts into a tunnel in between. So, the road basically goes on a bridge and gets into the tunnel and then comes out again in a bridge. The Millau viaduct in France again is a very popular structure that people often put in their representations.

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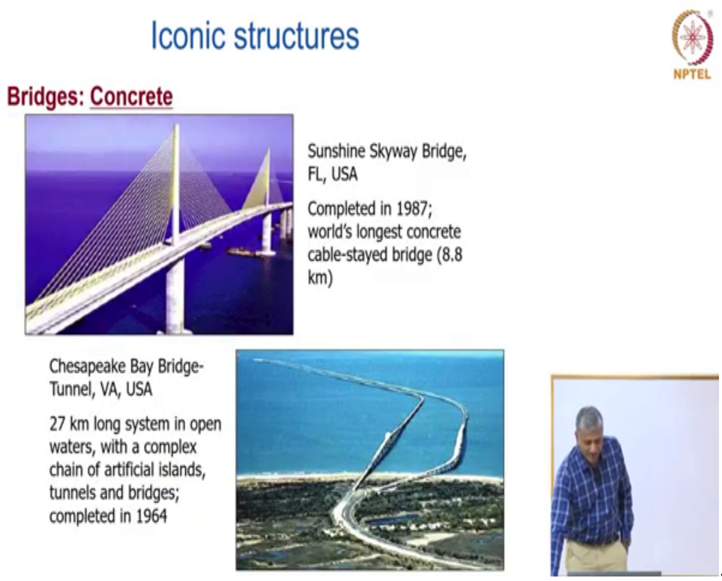

Again this is a more bridges from the US.

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Composite bridges, so again composites basically ensure that we can get the best out of two different materials by utilizing their strengths ok. For example, if you combine concrete and steel concrete is going to compression steel is going to in tension. So, you provide reinforce concrete which is an excellent composite material. But now we are not just stopping there we are also using other materials like fibre right. Fibre reinforce materials, fibres basically provide at a very small scale they provide excellent tensile resistance and because of which fibre reinforce structures have a much better potential of resisting. Dynamic loading like earthquake for instance and also can perform a lot better than non fibre reinforce structure.

For example here this is a storm water channel bridge in the US; you can see here glass fibre reinforced polymer deck which is used to actually construct this bridge. And these are basically shells of carbon fibre which are then filled with lightweight concrete to be uses grider. So, concrete strength there does not really matter as much because, the carbon fibre provides an excellent strength in the direction of bending and the concrete simply envelops this fibre and ensures that a proper matrices made. What is a naturally occurring composites structure that you are familiar with, naturally occurring composites structure yeah.

Wood is a naturally existing composites structure. Why do I say it is a composites structure, if you look in the structure of wood you have the fibres of cellulose which are embedded in the metrics of lignin ok. So, the fibres along this direction of the fibres, when you try to stretch wood it has excellent tensile characteristics ok. So, wood is a naturally existing composites structure.

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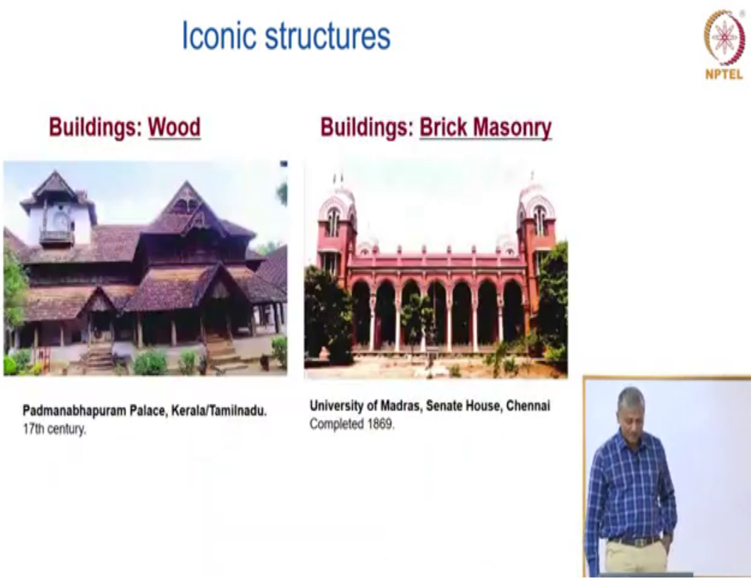

Of course wood has been uses several iconic buildings in India also like this Padmanabhapuram palace in Kerala and brick masonry of course is all over the place.

Especially with our heritage monuments that you see in Chennai a lot of brick masonry is used right.

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And stone masonry the best example of is of course Qutab Minar with concrete you have several examples around the world like the Petronas twin towers.

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Another interesting example obviously is the Burj Khalifa; Burj Khalifa is not entirely concrete the first 600 meters is in concrete the remaining 200 plus meters is in steel. And the interesting facid about this is that the 600 meters of concrete cause less than the 200 meters of steel. The 200 meters of steel on the top has no purpose with respect to people right. The 600 meters of concrete is where all the people are because up to 200 and something stories you have until that level ok. And this also has a very interesting record with respect to concrete technology; this is the highest level to which concrete was pumped from the ground.

So, concrete was mixed at the ground and pumped all the way up to 600 meters and delivered for the construction of the highest level of concrete in this building. But what happens when you start constructing these tall buildings. What is a governing factor is it stability any more or is it a strength of the stability.

Student: stability.

Stability against wind yeah, lateral loads when you start constructing tall you need to start thinking about designing against lateral loads. Not just wind even earthquake for instance you need to have essentially components of design built in which can take care of these loads. Another interesting aspect about Burj Khalifa, of course it came much after the downing of the twin towers in New York by Osama Bin Laden right. What happened there those structures were made with what material.

Student: steel.

Steel those were steel frame structures right, just like the one on the right that is sears tower in Chicago another iconic building. So, world trade center in the US in the in New York the twin tower were actually steel frame structure. So, when one floor gave way the rest of them simply collapsed. Progress of collapse is something that they did not have they did not actually design for in the World Trade Center buildings. But as far as Burj Khalifa is concerned even that has been take into account ok.

So if a progressive collapse happens, for example at this level here the structure may collapse, but it will stop collapsing at this point here you can see this massive raft that is being provided. So, that basically cuts off one segment of the building from the other and prevents the entire building to collapse right one top of one another, just like the World Trade Center trade. So, we adapt we learn from our past problems, of course nobody could have thought about an airline crashing into our building, that something totally unthinkable no nobody designing for that. But never the less we adapt and we learn from our past to try and build something different ok.

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So today of course, lot of glasses also being used in structures of glasses steel are popular choices with respect to your high profile structures.

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Even Guggenheim museum and Bilbao in Spain it is titanium clad steel and limestone which is combine together give this very interesting sort of an appearances.

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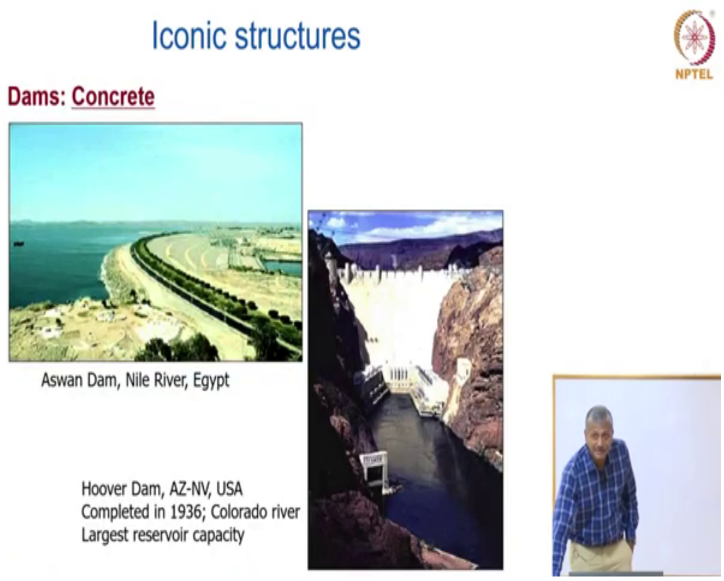

And of course, dams in concrete you see several hundreds of them all across the world.

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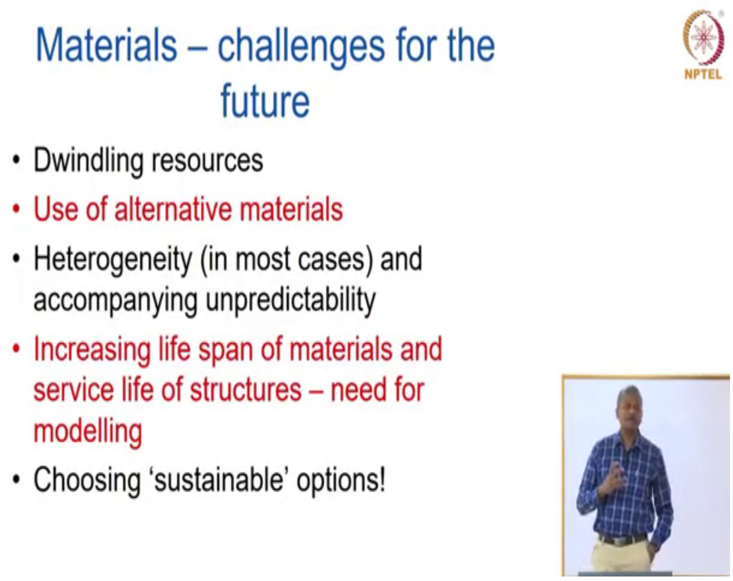

So, where are we going from here we have looked at how materials and construction practices evolved. How different materials led to various types of performance and functional characteristics and how we will limited by characteristics of one material to ensure that we could overcome that by choice of combinations of that material with one another one so on. So, what is the challenges that we have for the future one, primary challenges is that our resources are going down.

We have dwindling resources, especially if you think about cement which is the most commonly used binding material in the world. Manufacture of cement utilizes vast quantities of limestone from around the world and it is estimated that if we continued to produce cement in the same rate, will run out of those limestone results probably in 50 to 100 years. That means, they won’t be any cement beyond that and so people have started looking at alternatives to using cement in concrete.

So, alternative materials again is something that we need to wake up to the possibility of and start thinking about utilizing as much as possible. In most cases what happens is the construction materials are highly heterogeneous, because I am primarily talking here about concrete which is the most commonly used construction material. This heterogeneity leads to an accompanying unpredictability. We cannot really model these materials well enough and because of that we cannot predict how long they will with stand a particular set of loading and an environmental condition.

Steel on the other hand we are much more capable of understanding, because it behaves an very specific fashion. Steel components are factory produced when they come to the site all you need to do is connect them right. The characteristics of the steel at governed by how it is produced in the factory.

Concrete on the other hand a lot of it is applied or directly made on the site and because of which a lot of variability’s introduced into the formulation of concrete. Increasing life span of materials and service life of structures, generally says that there should be some aspects that we need to look at from point of your modeling these materials. Again I said that heterogeneity leads to difficulties in modeling, but then we need to model because we cannot keep on testing to ensure that the materials safe.

We can think about how to generate well excepted models which can be applied to the study of structures over the long term. And again choosing sustainable options is something that is becoming very important today, because we are using lot of resources we are using the lot of the energy. We need to choose technologies that can minimize on these ok. So, tomorrow when you become engineers you will start hearing of these terms more often.

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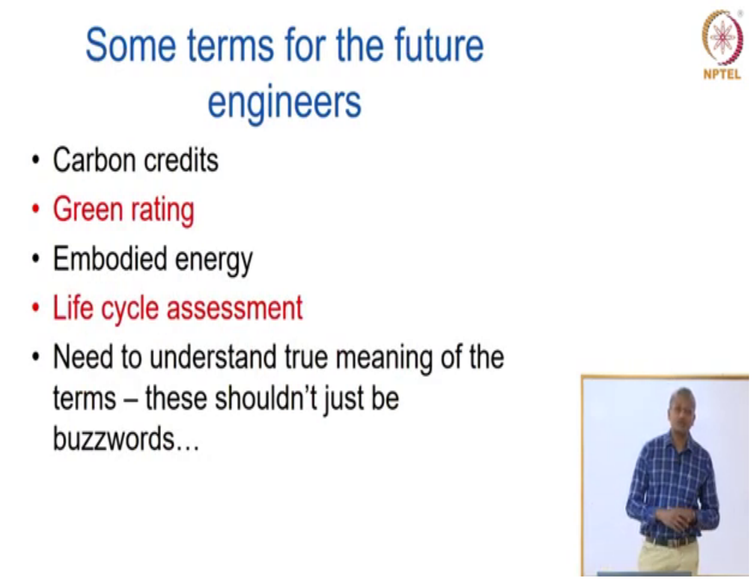

Carbon credits is one term that you will hear of quiet often, Green rating Embodied energy Life cycle assessment it is not no longer going to be strength durability workability.

No you will start thinking about how to make the technology in such a way that your carbon credits are obtained; you can reduce the embodied energy in the structure, get a green rating for your building and have numbers with respect to life cycle assessment. So, these cannot be just buzzwords they get the two meaning of these two really implement these in construction.

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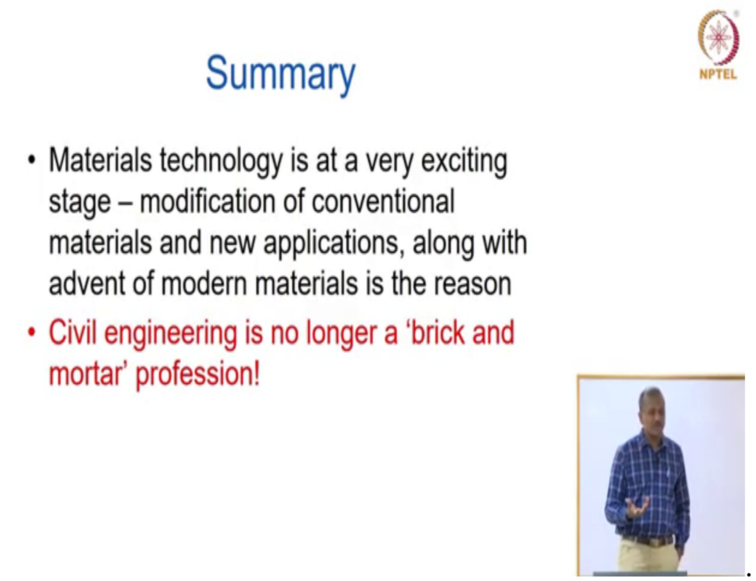

So, with that I would like to just end by saying that we are obviously had a very exciting stage with respect to the kind of applications. We have with conventional materials and with new materials coming in which can strengthen are understanding of existing construction technologies. People used to say mock civil engineering and say it is a brick and mortar profession, but the vast variety of materials and the construction process that we use clearly shows that civil engineering is no longer a brick and mortar profession.

So, thank you all for you are.