Basic Construction Materials
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Lecture – 3
Introduction to Construction Materials – Part 3

Hi, welcome to this NPTEL – MOOC course on basic construction materials. I am Radhakrishna Pillai. I will be co-instructing this course with professor Manu Santhanam. He has given one lecture before. Now, this is the second lecture.

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Before I get into the course material, let me briefly introduce our research group at IIT, Madras. We call it BTCM, which stands for building technology and construction management. And we specialize in the areas of building science, construction management, and construction materials. Construction materials focus on this course, and then we have five faculty members working in those areas.

We mainly work on cement, concrete, and steel reinforcement, another type of reinforcement, and so different types of construction materials used today. We work on those areas, and for more details on our division, you can look at or visit www.civil.iitm.ac.in

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Before I go into the course material, I would like to thank the people who really made my career, and this is professor David Trejo. I did my Masters and Ph.D. with him under his guidance. After joining IIT, Madras professor Ravindra Gettu and Manu Santhanam played a significant role in shaping or mentoring me etc. And also all my other teachers during my undergraduate studies and schooling I would like to thank all of them.

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And my students from BTCM division have helped us build one of the best laboratories on construction materials in India at BTCM, IIT, Madras. Thanks to all.

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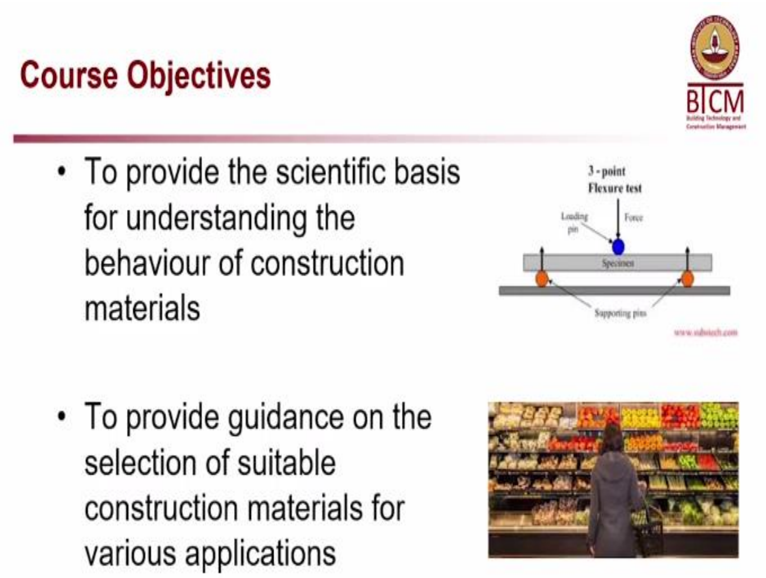

Now let us get into the course material. So what is the objective of this course? The main objectives are two that are

i) to provide the scientific basis for understanding the behavior of construction materials
ii) Moreover, provide you guidance on how to choose a suitable construction material for various applications okay.

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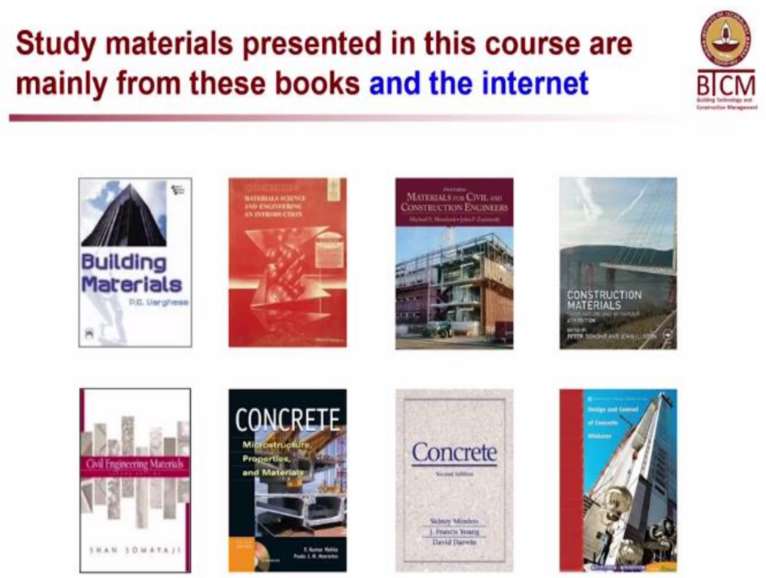

Now different study materials I have used for developing this course. These are different books that we used and much information you will see in this course from the internet and various internet sources. So it is not just following just one book, and you know a lot of information has been put together in this course material.

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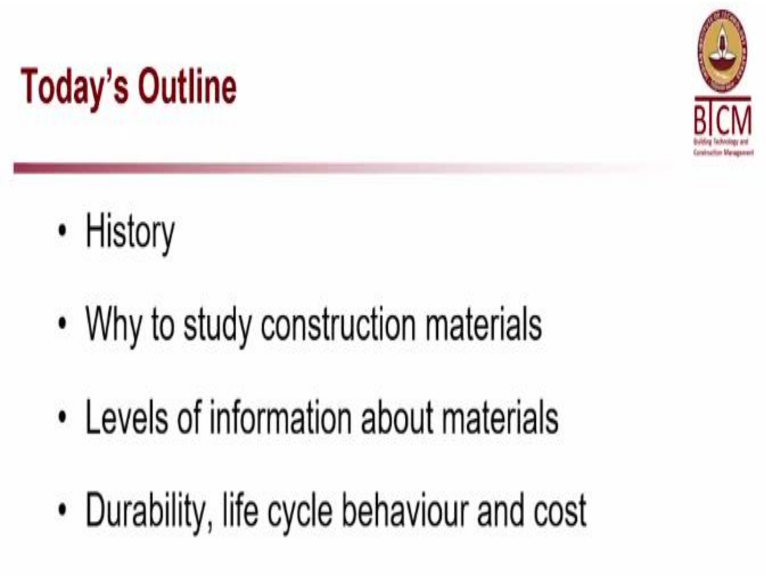

So for today's outline, we will look at

- the history of construction materials
- why do we study construction materials and their behavior
- what are the three different levels of information about various materials
- we will also talk about durability, life cycle behavior, life cycle cost, etc. of concession materials.

So this is for today's lecture.

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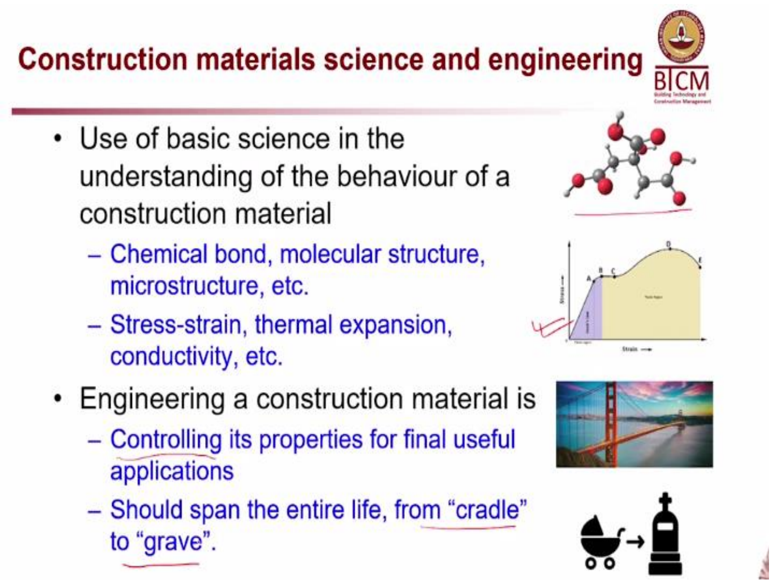

The science and engineering of construction material involves the use of basic science in the understanding of how a material will behave. That means we will even go into the chemical bond, molecular structure, microstructure, etc., of the material. It is like we look at chemical structure and how a material behaves when we talk about stress and strain behavior, which is also very important.

Once we know the stress-strain behavior or, let us say, thermal expansion or thermal conductivity, how the material behaves when applied either a mechanical load or an environmental load. Moreover, when a material is experiencing a mechanical or an environmental load and its behavior could differ depending on the type of applications or depending on the place where the material is used, etc.

How do we engineer a material so that it can withstand both the mechanical and environmental loading which is coming on to that? How do we engineer and that means engineering is a verb here and how can we control its properties so that the material is being used in the structures or material can withstand such loads while in service? When I say while in service, we should also think about it from the cradle to the grave concept.

That means when a material is unearthed or manufactured, or processed from the soil or ground through various manufacturing procedures. We put that into the structure and until that structure degrades or the life is over. We will probably dispose of the materials back into the Earth, so all that have to be considered while choosing a construction material.

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Now let us see some history of the construction materials. In the olden days, we used to make houses or buildings using timber, which is even practiced today in some places of the world depending on the timber's climatic conditions and availability. Similarly we use a lot of stone, even today we do that. Now the 20th century and onwards, we have started using cement concrete, asphalt concrete, steel, polymers, composites, glass, etc., various types of materials are in use in today's construction.

One question that comes is whether all these materials are better than the one in the past, maybe not, not always like there could be some properties that we enhance but some other properties might not be enhanced or it might be you know less. So, we have to see what is that property which we want or what are the properties which we want from a particular material system and the material in use can provide that or not?

For example, in some cases, strength may be essential. Some other properties like thermal conductivity may be more critical in some other cases. So we have to see when we talk about a material selection, all the properties have to be considered before we choose. Now material research can solve some of the problems, or if we have an issue, it can help develop new materials and technologies.

One example which I am saying here is let us think about clay. In the old homes, the people used to use clay, but it was probably not strong enough to make multi-story buildings. So we started making concrete, and then in the concrete itself, we started making the concrete with very high strength. For example, a few decades ago, if we think about concrete, we would probably talk about a block of concrete with a strength of 10 MPs or something around that.

Today, when we talk about concrete, we talk about M 30, M 40 even up to M 100 where M means Mix and number against it represents the strength in N/mm2, its characteristic strength. We will talk about that later. In terms of metals, if we talk about metals earlier, we used to have iron, and then people made cast iron. They found that cast iron is very brittle, so they made steel which is more ductile than the cast iron.

This evolution of these various metals evolved. Today, we have numerous types of metals available with various properties, which can cater to various industry requirements. So materials research is vital when we talk about even in civil engineering construction okay.

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Now, why do we need to know about the science and technology of material? Because the behavior of material systems depends on the properties at both macro and micro levels. So microstructure is very important and also the macro behavior. How the material systems are put together is also very important when we talk about a building's behavior, such as a bridge.

Now various information at different levels has to be brought together to give the foundation for materials technology needed for practice. Practice when I say a material like which is used let us say bridge we use steel and concrete to make the bridge if the bridge has to perform in a right way for a long period the properties of the steel has to be good, the properties of the concrete have to be good.

When they put together steel and concrete as a composite system, that system also has to perform very well and meet all the requirements. For this to achieve the material testing, how the material is processed, how it is handled and placed in the structure, and the basic science behind all these has to be very thoroughly understood. Now because of all these, training in science must be preceding the development of new and better materials.

We cannot make a new material without really understanding the science and fundamentals behind it. So, science is very important for application which is essentially the engineer okay.

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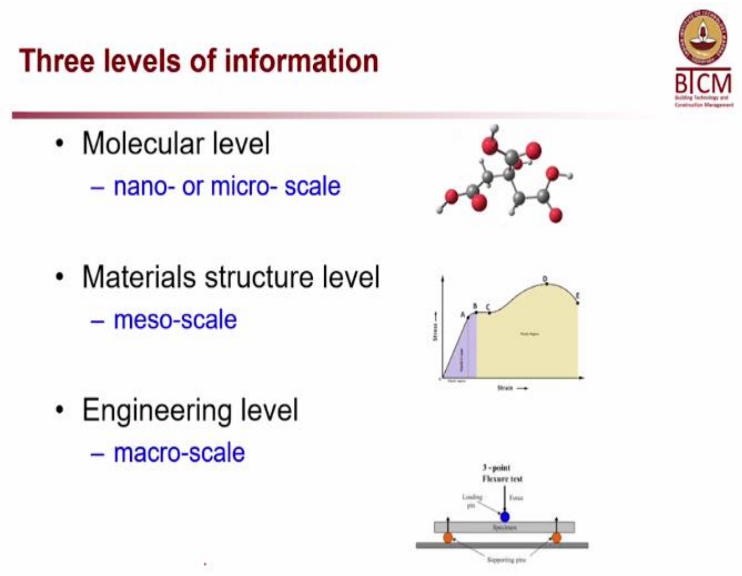

Now, what are the three levels of information? When we talk about materials, especially in construction, I am going to talk about three-level.

- One is the information available at the molecular level. We can say even nano or micro-level information.
- The next one is materials structure level information, not the engineering structure but the material structure level information we can say mesoscale.
- The engineering level information is slightly larger, which we are going to call it a macroscale.

When we talk about a particular material's stress-strain behavior, the material structure level information will be used, which will be termed as molecular level.

When we talk about a beam's behavior made out of a steel-concrete system, that is all about the engineering level.

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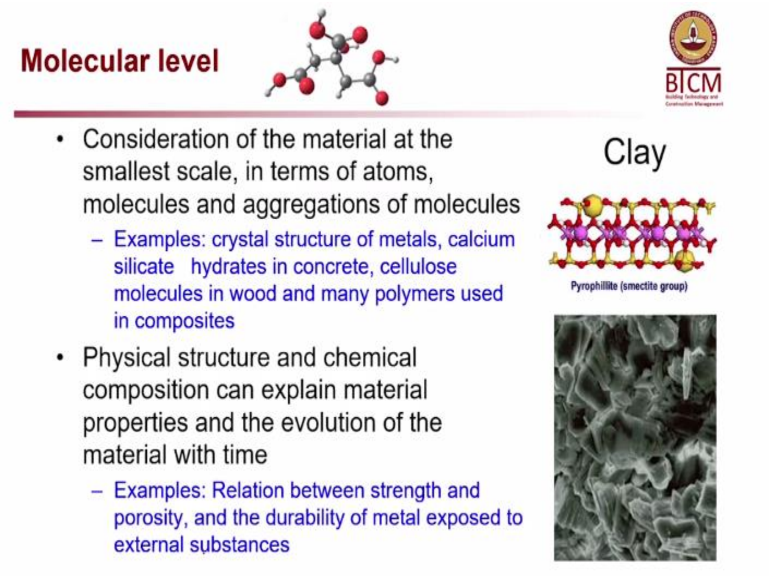

Now I will talk about one slide each on these three levels of information.
At the molecular level, we can see the sketches and images over there. We are talking about atomic bonds, and we are talking about lattice structure, the crystal structure of metals. So on the right side, we can see an example which I am showing for clay where we can see different layers. Clay materials typically are layer-type materials, and then when we look through a microscope, it will look like that is what is shown on the bottom right.

So other examples of this atomic level or molecular level information are the type of chemical complexes present. For example, in concrete, we have calcium silicate hydrate, which is the cement concrete system's binding agent. Moreover, when we talk about wood, we have cellulose molecules which are essentially a key player which influences the properties of wood and polymers, composites, etc.

Now the physical structure and chemical composition can explain material properties and the evolution of materials over a period of time. One such example is let us say we are talking about concrete and when concrete becomes hardened or it continues to react and from the day one after some days the properties will evolve, the strength will increase, the pore structure will get more refined. So, a lot of chemical reactions happen when we mix cement and water. Now how this strength, pore structure, etc. is changing over a period of time can be a piece of very good information to determine whether that particular concrete can be used for a particular application or not, especially if we want to talk about a structure which will last for 100 years of life.

We need to know that the quality of the material will be so good at the microstructure level. And based on that, we can say whether that structure will last for 100 years or not. So much science goes behind this.

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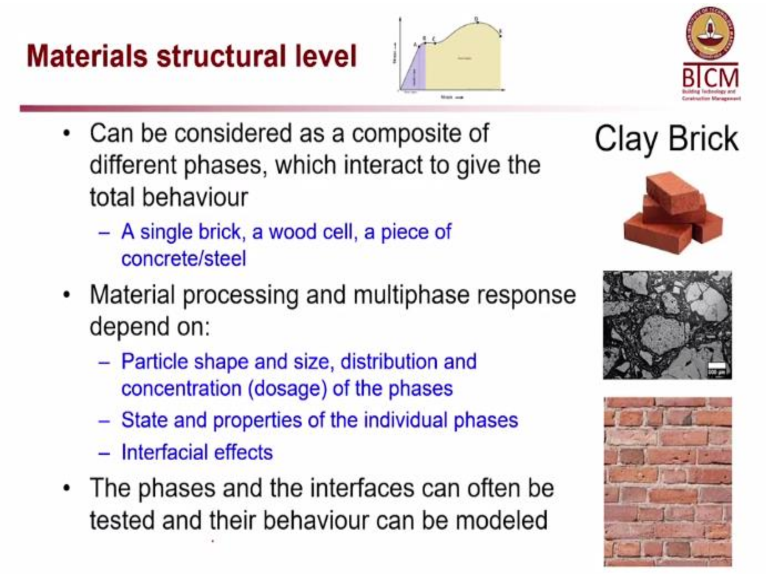

When we talk about material structure level, the second level of information I mentioned, it can be considered a composite of different phases that interact to give the total behavior. So picture on the right side, we can see a clay brick. So how the clay materials are initially and when they burn the clay? Like we know, we heat it, so there are a lot of chemical reactions which happen. And the final product or the hardened brick that we can look at how the microstructure of that is, how the different sand particles or clay particles they interact, they bind together all that we can look at and of course clay made in one place is may not be same as in another place or if we do not heat it properly you will not get the properties which we are desiring.

So there are a lot of chemical reactions involved in the making of clay and if we know the type of clay materials which are used and the type of processing like the heating treatment, etc. which are being used, I mean the entire clay break how they experience and how the reaction between various faces or various material elements within the clay system how they react, how they behave, how well they are bonded together all that can tell us what could be the strength of the brick and how that brick will behave. Whether it will behave in a very brittle manner or how much strength it will have, etc.

The third picture on the right side the bottom right corner we can see the interface, when we talk about a clay brick wall, we also have to worry about how the mortar between each brick binds the clay bricks together as a single wall unit.

All these interfaces, how the properties at the interfaces are also very important in addition to the interface between the various particles within the clay. Now these phases and interfaces can often be tested and then behavior can also be modeled.

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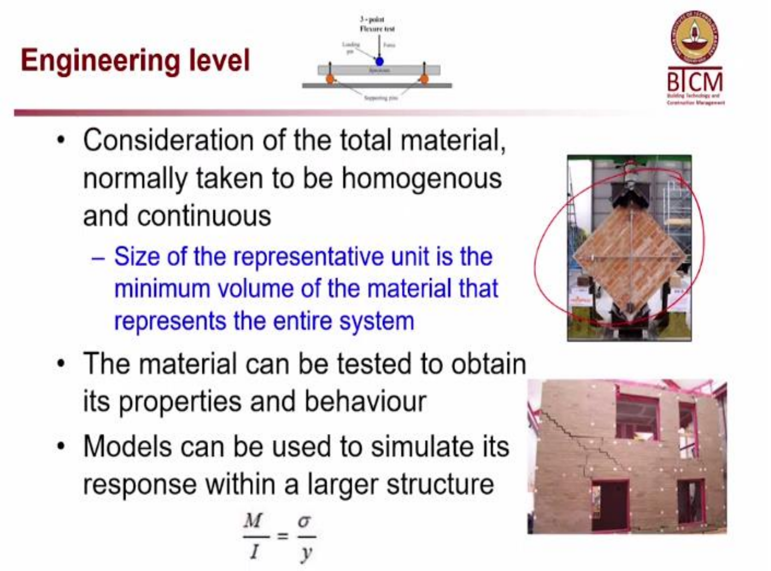

Now the third level which we talk about is called the engineering level. Taking an example of bricks here because that is what we have been talking so and probably we are more familiar with that also at this stage. Considering the total material normally taken to be homogeneous and continuous and when we talk about engineering level, we need to understand the size of a representative unit.

Now here the representative unit is not just one brick piece, but a small area of a brick wall where the brick used, the mortar which is used, all play a role in the behavior of that panel we see on the top right image here we can see that it is not just one brick which is being tested. So we make a panel of a brick and then apply some load on it and then see how that brick wall element or a representative unit of a brick wall is going to behave.

Once we understand the properties from this representative unit, we can actually even model as we see on the bottom right there is a testing done on a structure itself. So to see how the structure as a whole will behave, all these can be done and this is where we are talking about engineering level and such information is very useful in designing structures for various applications.

So, the point here is we have to understand how from the chemical structure level or very molecular level what type of material is used, how the different chemical and physical properties are and also at the macro level where we are talking about elements of size in meters, etc., where from nano to meter scale we are talking about different levels of information.

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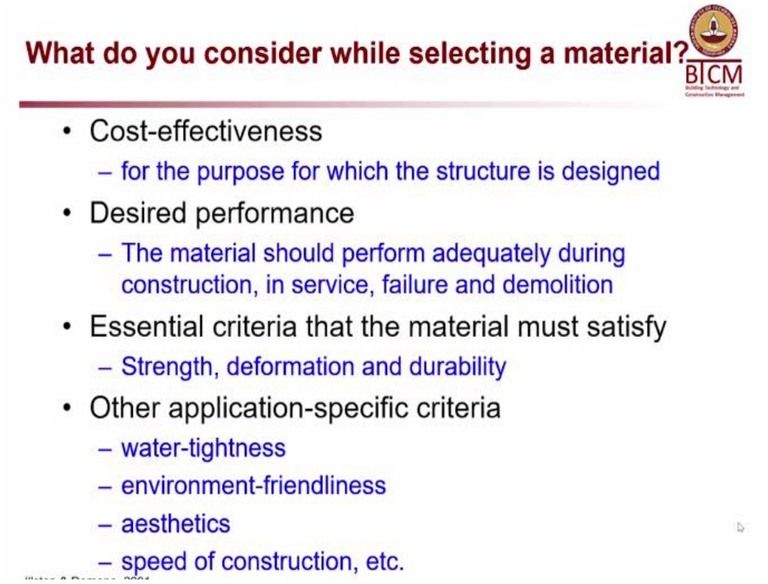

Now let us talk about what we have to consider while selecting a construction material. So one thing is cost-effectiveness. Then the desired performance for the entire life of the structure, then essential criteria that the material must satisfy from the beginning till the end of the structure's life, and then other application-specific criteria also we have to look at.

The cost-effectiveness for the purpose for which the structure is designed. For example, we can design a bridge considering different material options, its cost will depend on what type of material we are using. If it is a wooden bridge it might be a different cost, if we are talking about a concrete bridge or if we are talking about a steel bridge the cost will change significantly. So, we have to think about the structure's cost while we design the material systems cost has to be kept in mind.

Then the desired performance. When we talk about desired performance, the material should perform adequately during the construction, in the service period, and during the failure and demolition phase. So from the beginning till the end, that is from the cradle to the grave, so the structure should, or the material system should perform in the desired fashion for this entire life of the structure.

Now during this time, what are those essential criteria that the material must satisfy?

- We know that mechanical criteria, for example, strength it must satisfy the strength requirement. Otherwise, the structure will collapse
- It must satisfy the deformation requirements. Otherwise, there may be too much deflections. For example, if we are riding a car on a bridge, if there is much deflection, we would not feel comfortable sitting in that car, so we may not want to even go on that bridge. So deflection limit is significant to consider. We need to understand that it is coming from the deformation of the material. It is not the failure or breaking of the material into two pieces that is something to do with the strength criteria. When we talk about deformation, it is more of elastic behavior of the material
- Also, we have to think about the durability of the material system. How long will these strength and deformation criteria be met? Will it be the same as in the first year, in the 50th year, or even the 100th year? Whatever the design life requirement for that entire life period, we should have strength and deformation criteria. If it is met so, then we can say the system is durable.
- Now also, there are cases where other application-specific criteria have to be met. For example, if we are talking about a water tank, water tightness is significant along with the other three criteria strength, deformation, durability.
- The material which we use should be environment friendly. We cannot use a material that will cause or which will lead to a lot of carbon emissions or energy consumption. Nowadays, there is a trend for using recycled materials or material already mined from the Earth. Recycle the materials so that it does not lead to a significant amount of the carbon footprint of that process is going to be less
- Also, we have to think about aesthetics, how beautiful the structure looks? If we are talking about a house, we want our house to be looking very good, not like simple boxes put together.
- Also, the construction speed is very well associated or correlated with the money, so our construction cost. If something takes six months to construct and if option B will take one year to construct, so definitely we might go for the one that takes only six months to construct without compromising the quality. So we cannot pick an option where we can finish the work very fast, but with a compromise on the quality, So

without compromising the quality we should be able to provide, or we should be able to complete the construction as fast as possible.

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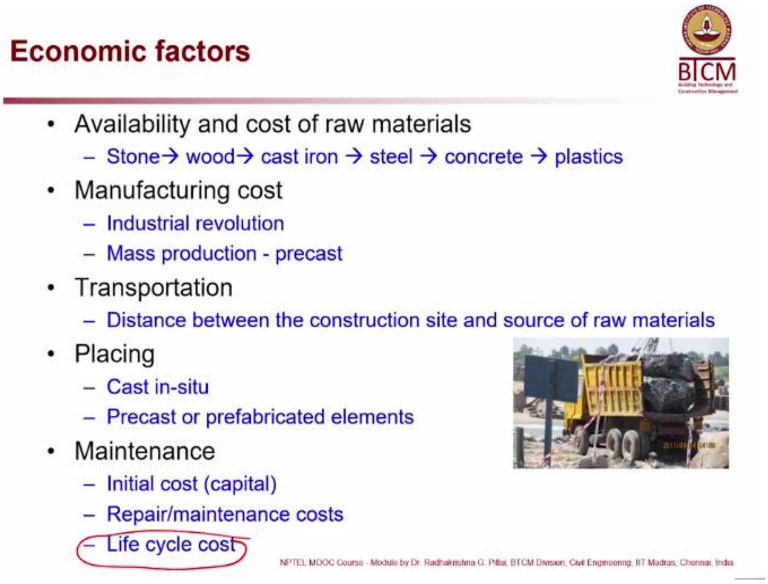

Now when we talk about economic factors, what are the factors which affect the cost of construction?

Definitely availability of raw materials is crucial. If we are talking about civil engineering construction, whatever material we talk about, we consume them in substantial quantities. So when we consume them in large quantities, we have to think about the unit cost, i.e., cost of the unit material and where we can get it from and like what is the impact of having that type of material, the availability of the material, the transportation cost of that material all this have to be thought about so that we can figure out which is the most less expensive option or an optimal option without compromising the quality of the construction. Now how can we reduce manufacturing costs?

Suppose we can design the systems by having a repetitive type of element or a similar element in number, such as brick. If we think about brick, if we are making every brick at the site, it will be very costly. However, if we make the brick offsite, it is already a manufactured product. We can order a large number, so the cost of individual brick comes down significantly. And another example of that is precast elements.

For example, let us talk about concrete structures. We can see the adoption of precast technology that means the elements are made in some other place in a factory environment

where the quality is also controlled very well and brought to the construction site and assembled at the construction site.
As the technology is picking up very fast nowadays and it is a need of the hour because there is a huge requirement for a significant construction in our country.

Sometimes precast may not be possible because we cannot transport the precast elements to the particular site. So in such cases, we might have to go with the cast-in-situ option, which means placing concrete or whatever material we use. So we have to see if precast is an option. If it is not possible, then we will have to go with cast-in-situ.

Especially if we can think about a design where multiple numbers of the same type of elements can design the structure in such a fashion, like a bridge structure, there are lot of beams used in bridges, and all those beams can be designed similarly. Moreover, in that case, we can have these beams made somewhere else, brought to the site, and then only we have to do is the assembly of that to make the bridge.

So that will reduce the cost by reducing the activities at the construction site. Time taken will be less, so effectively, our construction cost can significantly come down without really influencing or without adversely affecting the quality. Now also we have to think about maintenance. If a particular material we have selected requires frequent maintenance, then the cost might be more in the structure's life cycle.

So when we do cost comparison across materials, we have to look at the capital and the life cycle cost. Life cycle cost is something vital to think about, which has to be brought into many construction projects. The choice of materials affects the structure's life cycle cost rather than only looking at the construction cost okay.
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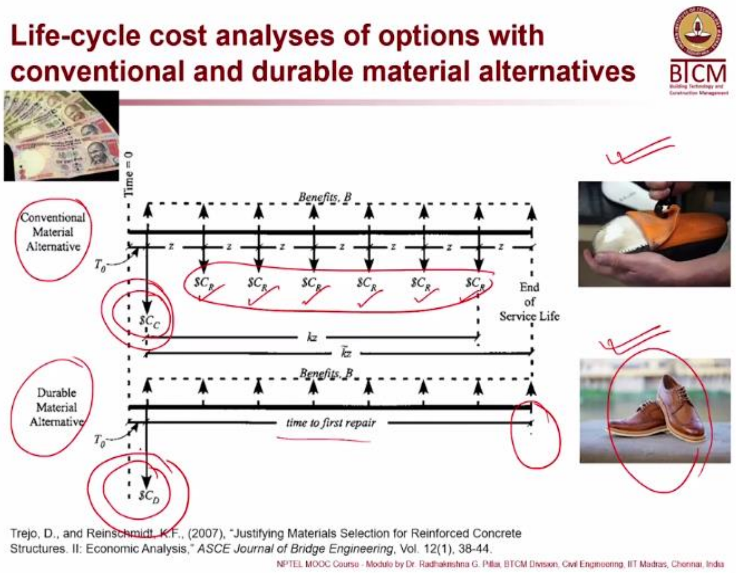

When we talk about life-cycle costs, Let us see an example that will help us understand what we are talking about. Here we have two options. One is a conventional material alternative and a durable material alternative. Now we think about an example of a pair of shoes, and we can see that the person has to repair the shoe very often in the first one. In the second option, I will say that this shoe is a very good quality shoe and we do not have to repair that very often.

Now, look at the top half of the graph where we have a dollar C_C or, say, construction cost with respect to conventional material. The subscript is for conventional material. And the bottom one is for durable material subscript d is for durable C_d. Now in the case of conventional material, there are 1, 2, 3, 4, 5, 6 times repair has to be done or for example, in case of a shoe if the shoe is not of good quality or we are roughly handling the shoes even same thing will be possible in the structures also, there could be cases where the structures experience severe exposure conditions, etc. so it can start corroding. So in the case of low-quality shoes or a shoe that cannot withstand the loads coming while we walk, we have to replace this. So at the time of replacement, we have to go to the shop and get the shoe repaired. Now when we do that process, we have to take a daily off to go to the shop to get that job done, to fix the shoe and then start using it again and on that day we cannot use that shoe and also we cannot do other work because we have to spend some time on repairing this.

A similar thing can happen in a structure also. When a structure undergoes repair, we cannot use that structure on that day or during that repair period. Let us imagine a bridge, and if there is work going on, we cannot use that, we have to close the bridge, which will affect many other things. Like in a shoe when we go to the shop, we cannot do other routine things. There are many direct and indirect costs coming into the picture. Here we are talking only about direct cost, which means we have to repair. So there is a repair cost associated with it, let us say that we have to repair the shoe for the first case every three months. In the second option if we go for this good quality shoe maybe we will have to pay a little bit more money, let us say we pay x amount of money extra, but if we do not have any repair, the first repair is coming here, I mean not even repair there because that is the end of life.

So we can have very long service, uninterrupted service. In the first case, we have to keep on repairing, so there are many interruptions of the shoes' service. In the second case, we can use the shoe for a long period of time without any problem. Which one should we prefer? We should prefer the durable option or the good quality shoe to use that shoe for a long time continuously. The same case for structures also.

If we can afford a little bit of extra payment, in the beginning, then if we can avoid all the intermediate repairs and time to first repair if we can increase that is always a better option, and this will reduce the life-cycle cost because in the first case the life cycle cost is the cost of construction plus all these repair costs that is what is life-cycle cost. In the second case, the life cycle cost is only this. That is it. There is no repair for the desired service life.

So when we look at these two options, we might find that going for a durable option may be a little more expensive initially. However, our life-cycle cost will be significantly less compared to a low-quality material in use.

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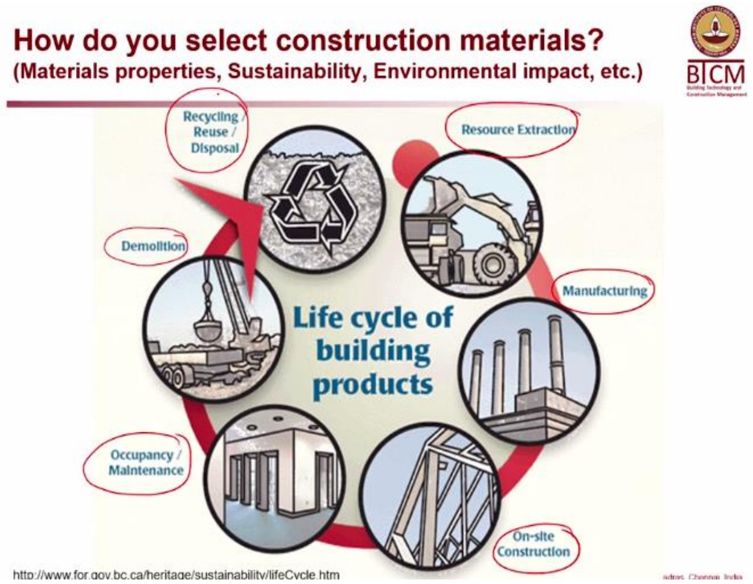

Now again some more things to consider while we select. Even though we have already discussed this, Let me show you this with this schematic diagram, so it is straightforward for you to understand.

When we talk about any material, we first mine it from the Earth. Let us say aggregate or cement, anything which we talk about construction is all coming from the Earth. There will be a mine we take the material from it and then manufacture that particular product.

For example, to make concrete, we need cement, make cement, use limestone, clay, etc., and then using aggregate, cement, etc., we make concrete. After that, we use that material at the site. During that time, what happens or when we use it and then during the occupancy of the material exposed to the external environment and the structural loading.

So both mechanical and environmental loading is important during the occupancy. Because of mechanical loading, the structure might start cracking, etc. During the environmental loading, it might have some chemical actions onto the structure, which might lead to some deterioration, which might eventually weaken the material, so it will also cause cracking, etc., or deteriorate.

So during the occupancy, we have to maintain the structure very well. If we do not maintain it, then it is not going to have a long life. So maintenance is also essential, but during that time, the material can degrade during the service. Eventually, we might reach a stage where we have to demolish the structure and build a new one. So at that process during that time, we can also think about recycling, reuse, or we have to dispose of the material.

If we can recycle or reuse some of the materials, it is an excellent sustainable option. If we have to dispose of it, we dispose back into the Earth and then done with it. So this is the life cycle of building products or building materials. Various materials we use end up in either recycling, reuse, or disposal of the material. So, choice of materials and how do we demolish all that should be thought through to maximize the reuse and recycling of material that is today's requirement.

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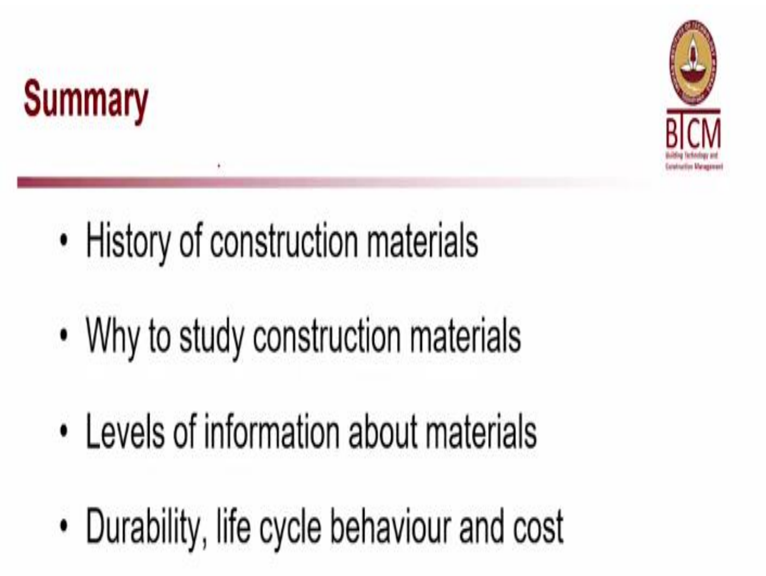

To summarize, we looked at the history of construction materials, why to study the construction materials, and looked at different levels of information about material from a microscopic level. Then, we looked at the materials structure level and then the third one on the engineering structure level. Then we also talked about life-cycle behavior, cost, durability, the whole life cycle of how a material behaves?

I mean, what are the various things to be considered while selecting a material? It is not only to select the material. We should not select a material based on only the initial performance, but we must think about the life cycle performance. So if we are designing a structure for 100 years, we should choose a material that will last for 100 years without much maintenance or minimal maintenance cost to reduce the life-cycle cost of the structure. I think with that we will stop today's lecture.

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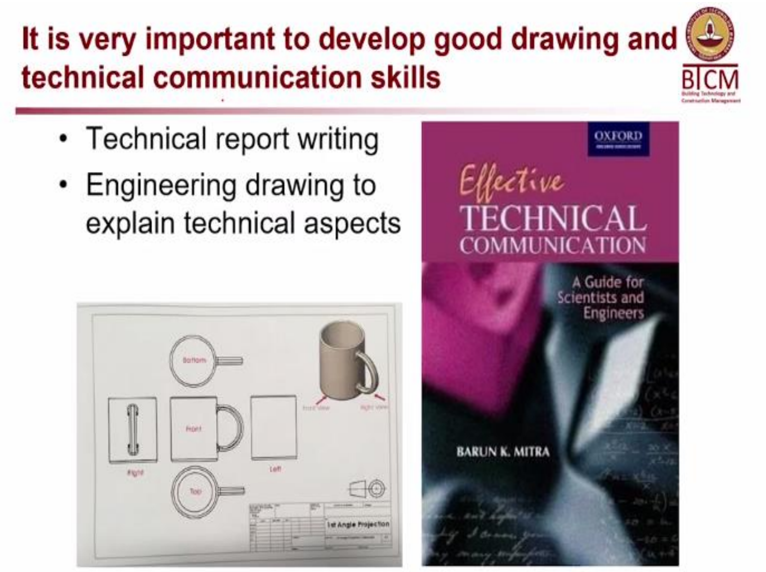

For the course material, so this is something essential. I thought I will put this in first day itself, which is on the importance of learning how to write technical reports okay or ability for technical communication and how to make sound engineering drawings okay. Look at this photograph a sketch of the coffee cup, how a cup you can make it 2D drawings.

I am also emphasizing this because it is vital to communicate our thoughts and ideas to other people. So we have to develop skills for preparing good engineering drawings to transfer the technical ideas to other people okay and also through writing we should be able to communicate. So both these are vital means for technical communication through writing and drawings.

Please focus on these two aspects that are very important when we think about along in a successful career. These are very important, so please put some effort into that, and this is a book which I found to be a very good book for this learning how to write technical reports. Thank you.