Basic construction materials
Prof. Manu Santhanam
Department of Civil Engineering
Indian Institute of Technology – Madras

Lecture 27
Cement and Concrete 2 - Part 1

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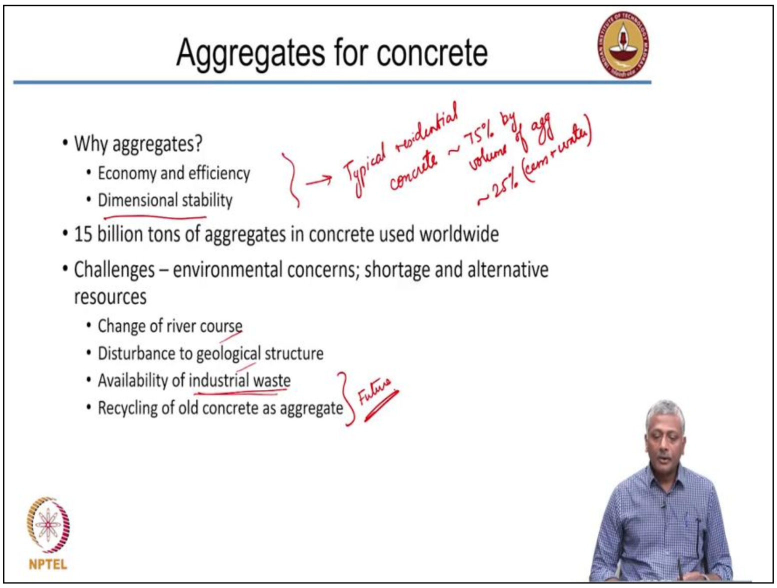

Hello everybody, welcome to next segment of our discussion on Cement and Concrete. In the last segment, we had an extensive look at cement, the types of cement, the properties of cement and what kind of tests we perform to assess the cement properties. In this segment, we will take a look at the aggregates, which are the other important ingredient of concrete.

First of all, in the past as you know, a lot of construction was done with stone. And there were obvious advantages for having done, doing construction with stone, in the kind of structures that were built in the past like Forts, Temples, monuments and so on, which required really starkly, kingly look. In such cases, the work with Exquisite blocks of stone, which were free of defects, which were really large blocks and they were placed one above the other, sometimes jointed, sometimes they were dry jointed. And ultimately the stability of the structure was governed primarily by the shear mass of these rocks.

Later of course as I discussed in the masonry chapter, we started using smaller and smaller stones that were easier to handle by the workmen on the site. Now, with concrete, you have an additional advantage that you did not have with stones. With stones, obviously the kind of shape that you can lend to the structure depends on the type of stone that you have and the extent of dimensional changes that can bring about the stone by working on it, cutting, tooling and so on and so forth.

Concrete has no such problems as long as they can have a form work that defines the shape. The Concrete can simply be filled into the form work and you have your necessary shape. Concrete can be shaped quite well. Now the question arises is, if concrete can be shaped so well and the primary ingredient that causes that to happen is the cement in water, why use aggregate at all? Why do we need stone and sand to fill up spaces inside the concrete?

The answer lies in my statement itself, filling up the space. So, obviously you need very large volume to be filled up with concrete to make a structural component possible. If you just made it with cement paste, you will have to use a lot of cement and that would be extremely expensive because in concrete the most expensive ingredient is the cement. So if you put a lot of cement in, your concrete becomes automatically, very expensive.

The second problem with cement paste is that with time the water drives off, leading to shrinkage of the cement paste and that will lead to cracking. Shrinkage is a very common phenomenon, especially when you look at soils like clays. In the wet season, you will find the ground to be very flashy and muddy and when the season changes to the dry season, you would see the ground starting to crack. And that is happening because all the water that is retained inside the clay has not been driven out by drying. The shrinkage is happening leaving behind the cracks. The same thing happened with cement paste. When you start putting the aggregates inside, that is sand and stone, that essentially restrains the change in volume. In other words, you have better dimensional stability, when you use aggregate.

Aggregate is absolutely important to make the concrete economical, efficient and also dimensionally stable. That’s the most important aspect of using aggregate. If you actually look at a typical residential concrete (the concrete that is typically used for building houses), you will see that it has nearly 75% by volume of aggregate. That means only 25% is cement plus water. So, a large fraction of your residential concrete, low grade concrete will typically be aggregate.

That’s because such concretes are typically low grades, low strength and they will have a lot of problem with shrinkage. So, more aggregate will prevent large amounts of drying shrinkage from happening. Aggregates are absolutely essential. Otherwise, the concrete will become very difficult to manage with respect to dimensions or with respect to the cost.

Now, we use large quantities of concrete. We’ve discussed it before in the introductory lecture that concrete is the second most consumed material in the world and for the quantity of concretes that’s used worldwide, the amount of aggregate that is required is well in excess of 15 billion tons. It is a staggering number, 15 billion tonnes and that’s just I’m talking about the aggregates required to make concrete. Apart from this, a lot of aggregate is used as base coarse material in pavements and slabs and Grade. We will talk about that when we actually get to the chapter on pavement.

So, there is a lot of Aggregates that are used for Railway ballast for instance, so all these applications involve the use of stone and you need stone everywhere. And because of these 15 billion tons is only a lower estimate of the amount of aggregate that is required. So, you probably need well in excess of 20 to 25 billion tons of aggregate, to satisfy construction needs across the world.

This means that we are extracting a lot of material from natural sources and that leads to a major challenge. There’ll be an environmental concern of depletion of natural resources. So, we are using more and more natural material to make artificial materials like concrete for serving our construction needs. So what happens to the land as a result?

Obviously there’s going to be major changes in the way that the land naturally behaves. In some instances, extra removal of material like sand and stone from the land has also been known to change the seismic effects that occur in that particular region because you have a natural rock formation and if you are trying to remove this rock for use in construction, you obviously, change the nature of the land itself. And that may lead to a change in the way that the land actually behaves.

You all know very well that rivers basically deposit the sand (very fine nice rounded granules of sand) in the silt that they carry it along with them. And very often what we do is, we go in and take the sand and use it for construction. That’s the river sand and we will talk more extensively about that later.

But what’s it going to do if we start removing excess of sand. Excess of sand, removal or dredging from the river beds has been known to change or alter the course of the rivers. That may lead to problems like flooding and so on. There are major environmental challenges dealing with the use of aggregate, but we cannot live without using aggregates.

So you can cause disturbance to geological structure, change the river course and that leads to a major environmental concern. But as I said, you cannot live without aggregate, so what you need to start doing is looking for sources that are other than natural sources. For example, there is a good potential of using material that comes in from Industrial waste. For example, many of the industries process material and leave behind tons of wastage. And this wastage, if you don’t utilise it in some effective way goes in landfills, which are again spoiling the quality of the land and also the quality of the scenery that you have around. So, all that wastes has a potential to be reutilised in construction. We should not lose that opportunity.

The other aspect is recycling of the old concrete aggregate. In a lot of cities, you will see demolition of old concrete structures happening. What do you think happens to the broken concrete? and the broken Steel?

The Steel that is retrieved from these reinforced concrete structures, obviously have a lot of value, that is, steel has good scrap value. You can get good price for it. But concrete on the other hand does not really have scrap value. So, what typically is done is, these guys who demolish it, simply go and dump it in some low lying areas as landfill. Again this is actually a wrong thing to do from the purpose of environment in mind. You can have some low lying areas that require upfilling but putting construction debris is possibly not the best way to do it.

What can you do with construction debris is set up processing plants that grind this debris into sizes of aggregate and then reuse it in new concrete. So there’s a lot of research today that is focused towards how best to utilise the broken demolition debris as aggregate in concrete.

So, this has to be the aspects that we need to look at in future. The future will depend on how well be we utilise the waste that is coming from industrial sources and the waste that is being obtained from demolished concrete, to be used as aggregate in construction.

Now, how do you classify aggregate?

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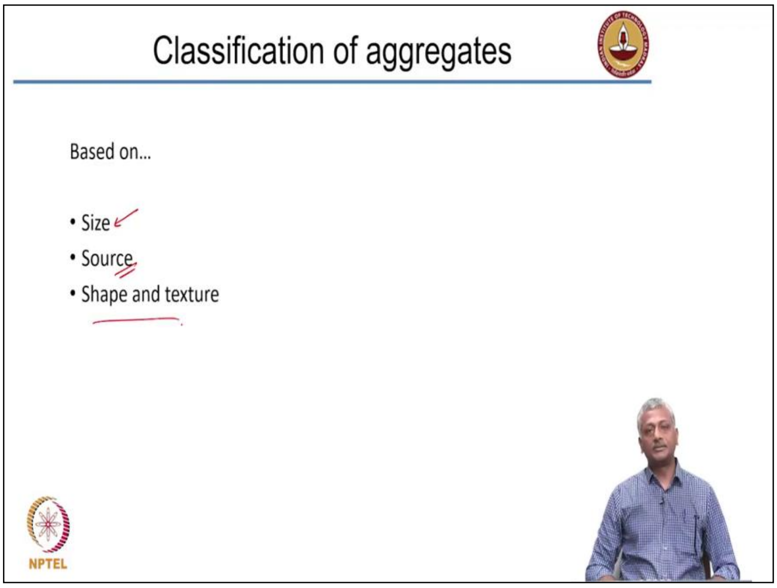

I said earlier that concrete is a mixture of cement paste and aggregate. Aggregate itself is composed of coarse and fine aggregate. Coarse means larger sized aggregate and fine means smaller sized aggregates. So, you can classify based on size.

You can classify based on source, whether it is a natural aggregate or a manufactured aggregate. Then you can have shape and texture, that is, round aggregate, angular aggregate, aggregate with a rough texture, aggregate with smooth texture. So, all that ultimately goes into affecting the properties of the concrete. Let’s look at how that actually happens.

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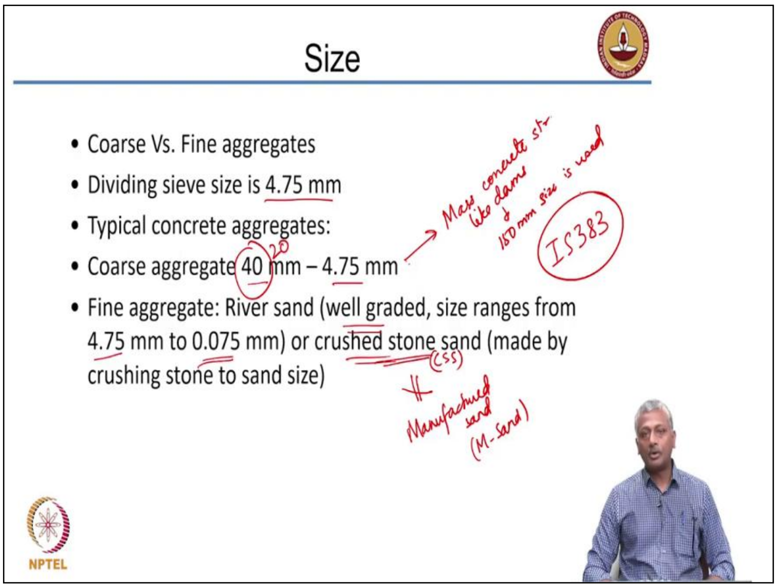

First of all based on Size, we define aggregate as coarse aggregate and fine aggregate. The dividing size essentially we consider in construction is nearly five millimetres, to be more precise 4.75 millimetres. Of course, this number is derived from the size of the sieves that were created in the old English System of units, that is the ancient system. Because of that, we have this vague 4.75 millimetres size.

Nevertheless, this is now become standard to classify any material that is above the size as coarse aggregate and any material below this size as fine aggregate. So, coarse aggregate typically are 40 mm to 4.75 mm. Of course, in very large mass concrete structures like dams, where we have very large chunks of concrete to be put and not necessarily much requirement of strength from it. In these cases, even 150 mm size aggregate is used. You can use 80 mm construction, 150 mm and so on.

But for general purpose construction, dealing with foundations and building superstructure, we will rarely go with more than 40 millimetres. In fact for the most part, we will actually even be going with only 20 millimetres. We will not go much more than 20 or 25 millimetres at the most. But you can use in some instances 40 millimetres also.

Fine aggregate on the other hand, as I said most commonly used fine aggregate around the world is River sand. River sand is generally well graded. That means its got a range of sizes from very fine to the coarse size. And the size range that you see in sand are ranging from

4.75 mm (the upper limit of sand) to 75 micrometre or 0.075 mm. So, this smaller sized particle can create some problems later in the concrete. I will talk about that later.

Or you can also obtain the fine aggregate by taking the stone and crushing it into a smaller size. You get, what is called, crushed stone sand. It is made by crushing stone to sand size. But please remember this crush stone sand is not equal to manufactured sand. Very often people use this interchangeably. But it is not technically correct to say that because crushed stone sand is still obtained from Natural stone and simply crushed to the right size.

Manufactured sand on the other hand is obtained from the source that is not natural, I will talk about that in just a minute and then processed to aggregate size. So, it’s a little bit different, manufactured sand as opposed to crushed stone sand. So, the correct terminology to use is crushed stone sand or CSS. Very often manufactured sand is given this terminology M-Sand. If you go to the market, people talk about river sand or M-Sand.

But what they are actually talking about is only the crushed stone sand that is used as a substitute to river sand. M-Sand is nothing to do with what I typically call as manufactured sand in the true sense of the term. To really get this distinction much more clearly, you need to read the standard IS 383. IS 383 is the standard for aggregates in concrete. It talks about size shape, texture, source and so on.

Based on that, you can figure out whether the material that you are using is fine aggregate based on river sand or crushed stone sand or manufactured sand.

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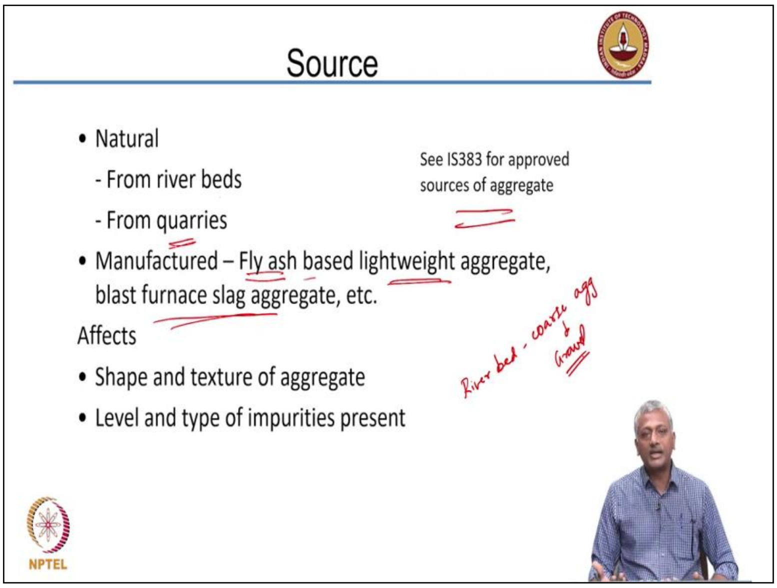

As I said that, the source can be from Natural Sources like riverbeds. You can collect the material from riverbeds or you can collect it from quarries. Stones are typically broken out from Quarries. Manufactured sand is actually the sand which is obtained from artificial sources, for example, if you take fly ash, if it is collected from thermal power plants, and you fuse the particles together to make an aggregate sized object, that becomes a Manufactured - fly ash aggregate. We call it fly ash based lightweight aggregate because mostly what happens if fly ash when you actually sinter it and fuse it, it becomes a lightweight aggregate. It is more or less like brick making actually. That's what you are doing with preparing fly ash-based aggregate instead of moulding into a brick based shape, what you are doing is simply rolling the particle so that they fuse together to become a rounded aggregates. And then you burn that at high temperature, sintering basically, to get your light weight aggregate.

The other possibility is using blast furnace slag. Many of you are aware of this blast furnace process, where Pig iron is obtained. We add limestone as a flux to reduce the temperature and that causes the calcium oxide in the limestone to combine with impurities in the iron ore in the form of silica and alumina and float on top of the iron as slag. And that slag, if you cool it, it becomes solid and then you crush it to aggregate size, it becomes a blast furnace slag aggregate.

You need to be aware of Natural sources and manufactured sources. And what happens as a result of these sources? One is, it affects the shape and texture. As you can rightly imagine, when you have a flowing water above the aggregate. So the aggregate you get from river beds will have a nice and rounded shape. Because of the weathering, the water has completely rounded the material. And secondly because of this constant action of the water, the surface texture will also be very smooth.

In a quarried aggregate, you are basically breaking large blocks of rock and crushing it into smaller sizes, so you will get angular aggregate. Generally, these angular aggregates will have a rough texture and that will affect the properties of the concrete. We will talk about how that happens later.

The level and type of impurities present are also governed by where you are getting this aggregate from. Very often when you have a quarry in between the deposits of rock, you may have deposit of organic material, you may have deposits of clay. So lot of the impurity that may come in along with the rock could be based on clay and organic material. Indeed, if you look at IS 383 for different sources of aggregate, it will tell you what to check for in terms of the materials that are not allowed to be used for aggregate in concrete.

The other thing you need to look at is also the fact that when you have river sand or when you collect aggregates from riverbeds, you need not just have sand, you can also get coarse aggregate from the riverbeds. So, when you get coarse sand from riverbed, that is called gravel. We typically call the coarse aggregate obtained from riverbeds as gravel. And they will be pebble type; they will be rounded and very smooth in texture.

In the case of a riverbed what will happen is, the kind of rock or the mineralogy of the rock that you get will be varied because this river basically carries all kinds of rocks with it. On the other hand, the rocks that you get from quarries will generally be of the same type. So if you are in a granite quarry, obviously you are not going to be finding the limestone. If you are in a quartzite quarry, you will not find sandstone. What I am saying is, in a quarried aggregate, you’re type of rock will be more or less uniform. But in river bed gravel, you can get a mixture of different types of rock.

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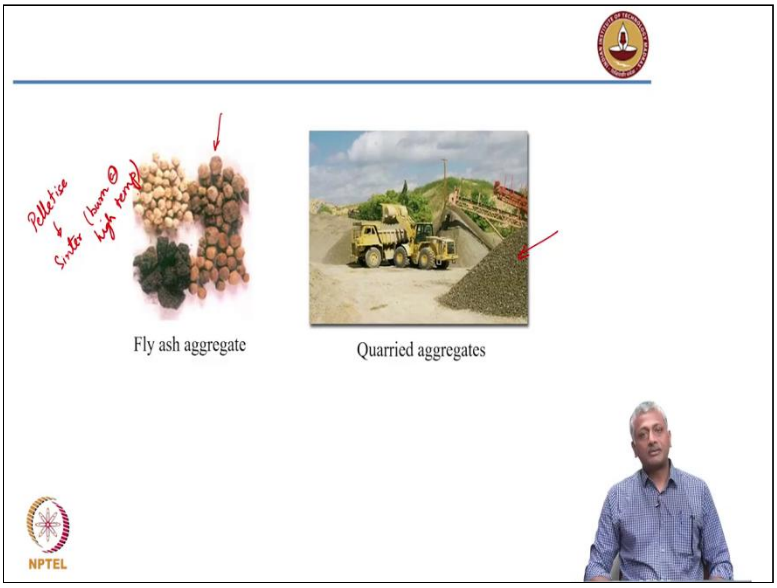

So, just giving you some example of quarried aggregates typically from the quarry, aggregates are broken down into smaller sizes and fractioned into different sizes and then stored as heaps. This is a fly ash aggregate and you can see how rounded it is. That is because the particles have been made to pelletized. So you basically have to pelletize the particles, make them into small pallets, and then sinter. That means burn at high temperature.

And that fuses the particles more or less like how it fuses a silica and Alumina in brick. Same ceramic bond formation takes place and then you get sintered flash aggregate, which is a good light weight aggregate.

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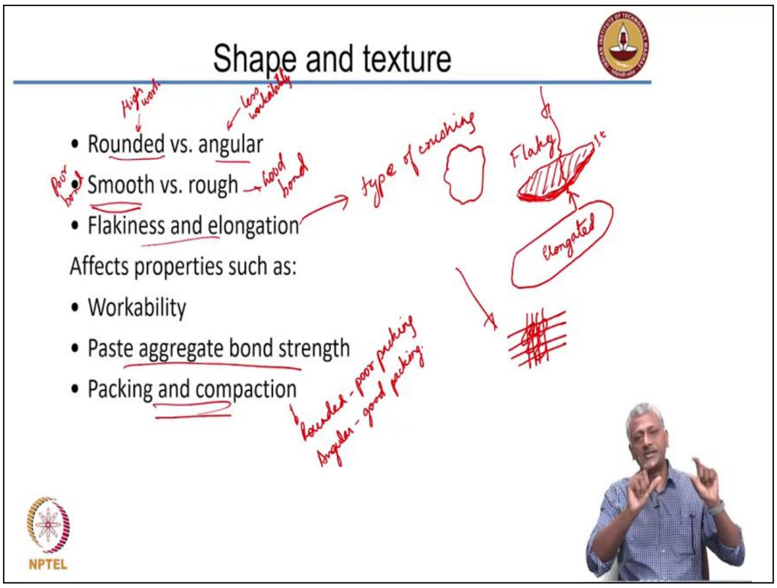

As I said, your shape and texture will determine the properties of concrete that you get with it. So, what are the different shapes? You have rounded shape, this is angular shape. The natural sources will give you rounded shape and whereas the natural quarried sources which are broken on to the smaller sizes will get the angular shape. Again the riverbed gravel will be both rounded and smooth, whereas the quarried aggregate will be angular and rough.

And what might happen depending upon the type of crushing that you use, the type of crushing of the quarried material may result in flaky and elongated aggregate. We typically expect the aggregates to be almost equi-dimensional. Even if it is quarried, the process of crushing should be such that we will get more or less equi-dimensional material.

But flaky material is when you have, so if I am taking an isometric view of the flaky aggregate, what I am trying to say is, its got a very large area on the surface, but the thickness it very less. It has got low thickness. That's a flaky aggregate. And obviously Elongated just means that we have a piece which is more or less like that. That's elongated aggregate.

And we want to avoid flaky and elongated material. Why do you think we want to avoid that? So, flaky material as I said has a very less thickness, small thickness. So what will happen is, when you are loading this concrete which has such flaky aggregate in it, if a crack has to go, it will go right through because this aggregate is going to be very weak. Flaky aggregate is going to be extremely very weak. So you don't want a flaky aggregate inside the material.

With elongated material what will happen is, now your concrete has to flow between reinforcing bars. So concrete is poured and it has to go between the gaps in the reinforcement. If you have elongated aggregate what will happen? It will sit on the gap and block it. So your concrete will not be able to flow through the reinforcement.

So, flaky and elongated aggregate have to be avoided in large quantities. Some amount of flakiness and elongation is acceptable. Again IS 383 give you the limits of what is acceptable from that perspective. So not only will this affect these aspects like strength and so on, they may also affect the workability. The use of different types of aggregate may affect workability. When you have a rounded aggregate, you will get a nice cohesive mixture. So, high workability when rounded aggregate is used. With angular, workability will be less. Workability simply is the ease with which you can work with the concrete. That means the consistency, or fluidity of the concrete. How easily it flows, that basically is one of the factors that govern workability. So we typically measure it as you will see later in terms of some methods that determine the fluidity or consistency of the concrete.

So, when you have rounded aggregate, you will get better workability. When angular aggregate is used, it gets lower workability.

The other aspect is the paste aggregate bond strength. I will talk about this in more detail somewhat later. Essentially the strength of concrete is truly only governed by the paste aggregate bond strength for normal aggregate. When you start using artificial lightweight aggregate, for instance, the aggregate strength also can be a determining factor. But in most normal concrete the aggregate or the rock is usually much stronger than the cement paste. As a result of which the bond between paste and aggregate really affects the strength of the material.

So, when you have a good bond, you get high strength. When you have a poor bond, you get low strength. Generally, a smooth aggregate will lead to a poor bond. You can clearly imagine that will be the case of rough aggregate leading to a good bond.

And as I said when you have a flaky and elongated material, it will also affect the strength and the ability to pass between reinforcement. Secondly, the packing and compaction will also get affected. So, in rounded aggregate, your compaction or packing will be poor whereas angular aggregate will give you good packing. Why is that?

Again you can readily imagine. Let us say you have a container and you put steel balls or glass marbles of a certain size into that container. So when these marbles occupy position, they will have lot of voids or gaps between them. The same thing you try to do with irregular pieces of stone, you will see that you will be able to fill in a larger volume of the container with the stone. So that's naturally because the angular material simply goes in the gaps quite easily whereas the rounded material is not able to do that.

Now, of course, it's not just the fact that it's rounded or angular that affects the packing, the other aspect that will affect the packing is also the distribution of particle sizes. What are the different sizes available? I will talk about that also in just a minute.

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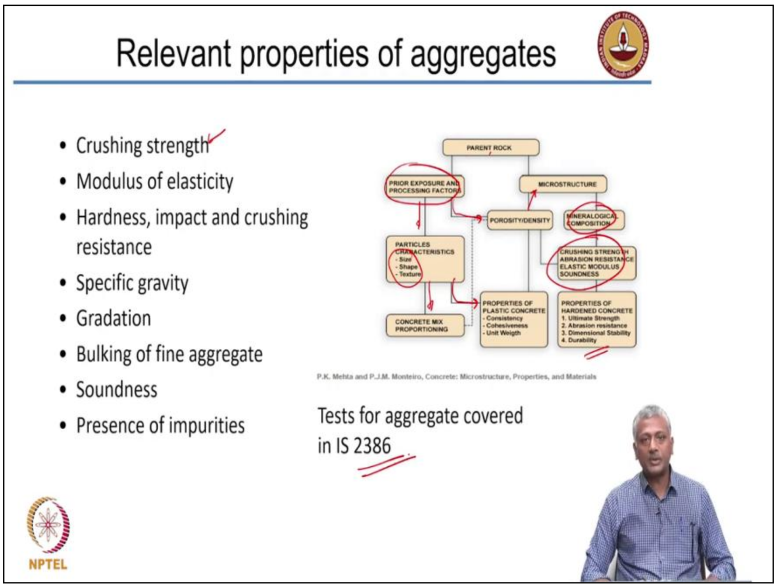

So what are the relevant properties of aggregates that need to be tested in order to qualify the aggregate is suitable to be used in concrete? One is of course the crushing strength of the aggregate. In most concretes, the crushing strength does not become a major factor. Nevertheless, this is something we need to have an idea of. The modulus of elasticity of aggregate is important. We will see why. The hardness impact in crushing resistance is important.

Specific gravity, the gradation that the range of a particle sizes that you have, the bulking of the fine aggregate (fine aggregate can absorb moisture and then increase its volume), the soundness of the aggregate, the ability to retain its volume in difficult circumstances and then the presence of impurities. We already talked about the fact in some cases, you can get impurities like organic matter or clay which may affect the quality of the material.

If you look at the parent rock, obviously the parent rock could be of different type, let us say, granite, limestone, quartzite, sandstone and so on. What happens is the parent rock has been subjected to some type of temperature and pressure type environment. And that once you start breaking it down, whether you have an igneous or sedimentary or metamorphic rock, the kind of crushing will produce different types of sizes shapes and textures of the aggregate.

So, we already talked about the fact that, that will affect the concrete mixture proportioning. And it will also affect the workability and the fresh properties of the concrete. On the other hand, the other aspect of aggregate that is important is its porosity or density. And that porosity or density is one of the components that describe the microstructure of the material. That means the structure at a microscopic level.

The microstructure also is determined by the mineralogical composition, that is, whether you have minerals of the type which are feldspar, quartz, plagioclase. And these are the different types of minerals that could be present within the rock. Those will also have interesting effects in terms of how it affects the properties of concrete like strength, abrasion resistance and soundness and so on.

Just to give you an example, if you take igneous rock, one the most popular igneous rock is granite. Now, the other igneous rock that is similar to granite but has much larger crystals is called pegmatite. Interestingly while the strength of both is more or less equal, the abrasion resistance of pegmatite is poor as compared to granite because the crystals are larger. So, what will happen is when you abrade this material, the crystals will get dislodged easily. Coarser grade materials have a poor abrasion resistance.

The formation of the material, the mineralogy of the material determines its properties and that will affect the properties of a concrete that you get, that's the ultimate strength, abrasion resistance, the durability and dimensional stability of the concrete. Let's take a look at these tests in little bit more detail, of course the test themselves are covered in Indian Standard IS 2386. Very important for you to go through the standard to understand, what are the different tests, as many of you will have actually laboratory classes also to talk about these tests.

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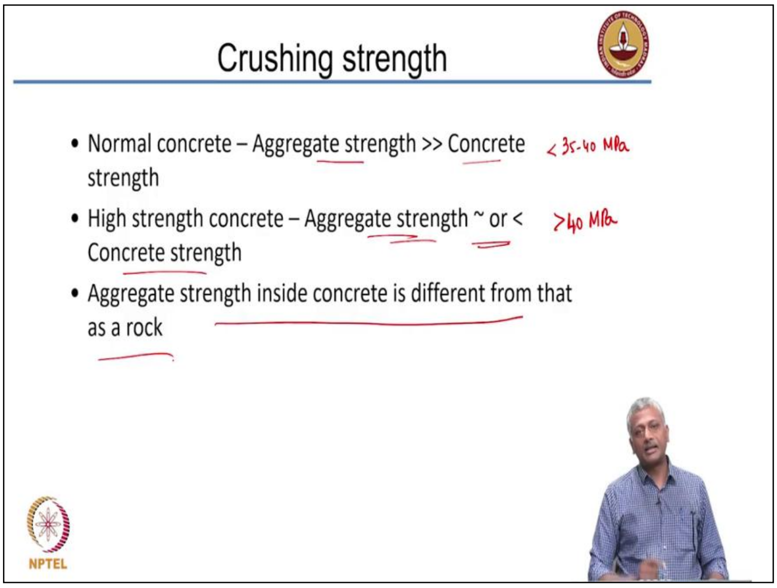

So, as I said, the crushing strength of the aggregate usually does not come into picture because for most normal concrete, the paste aggregate bond governs the strength. And in such cases, the aggregate strength is generally much greater than the concrete strength. Now, when you start going towards higher strengths in concrete or your strengthen the paste aggregate bond to a large extent, what then starts happening is, your aggregate strength becomes almost equal to your concrete strength. Or the concrete strength starts catching up with the aggregate strength.

So, once you break a normal concrete what will happen? Those of you, who do this experiment later will see that when you break the cubes of normal concrete of strength less than 35 to 40 Mega Pascal in compression, you see that the failure crack goes around the aggregate, indicating that the failure has started in the interface between the paste and the aggregate.

Whereas in high strength concrete, the interface is strong, so you'll see that the crack goes right through the aggregate. Does that mean the rock is of lower strength than the concrete? Possibly not, it's just the rock which is being cut to aggregate size or formed to aggregate size, may have a strength which is lower than that of the concrete. So, please remember, aggregate strength inside concrete is different from that as a rock.

So, if you take the aggregate as a cube, let us say, granite and test it, you get much higher strength than 100 - 150 Mega Pascal, because granite has that strength. But when you have aggregates of granite inside the concrete, even for strength as low as 60 Mega Pascal, you start seeing failure of the aggregate. That's because you have a lot of defective pieces inside. In a cube, you have a nice solid rock, but when you break down the aggregate, its weakness or its failure planes get exposed, as a result you will have a lower strength.

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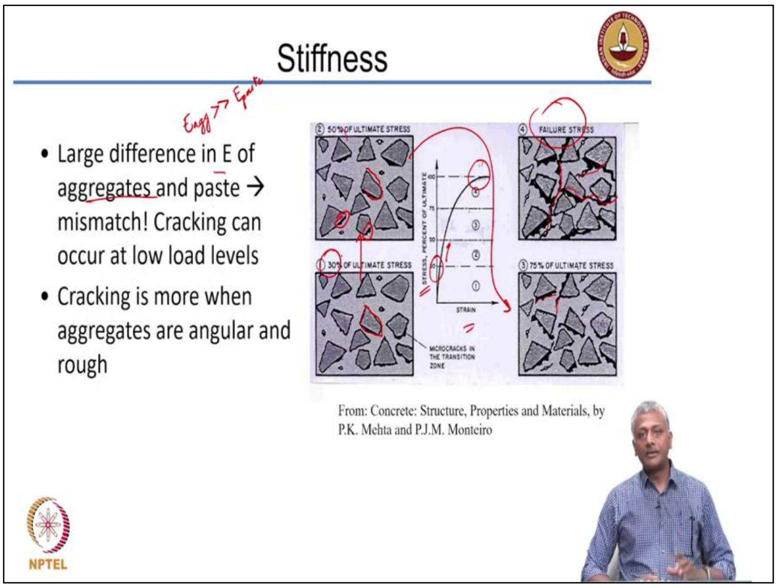

What about the stiffness of the aggregate and why is it important? Now, concrete is a composite material. Aggregates are embedded inside paste. And when you start loading the concrete, I already talked about the fact that stiffness of the aggregate or modulus of elasticity of the aggregate is generally much more than stiffness of the paste or modulus of elasticity of the paste. Again this is for normal concrete.

When you start strengthening the paste, in high strength concrete, it becomes more and more equal. It never becomes totally equal, but becomes more and more equal. So what will happen now is, when there is a large mismatch or one stiff material is there and other less material is there and when you start loading this, the load distribution will be such that the stiffer phase will get more load. That is, the aggregates will attract more loads. So the zone around the aggregate, of the paste which is attached to the aggregate will be experiencing very high stress levels as compared to the zone of paste which is away from the aggregate.

So, at very low levels itself, so here, for example, it is the standard the picture you see in many text books on concrete. If you plot the stress vs strain, even for stresses which are less than 30% of the breaking stress, you will start seeing that there are failures of the paste around the aggregate. Because the aggregate is attracted more load there.

As the load becomes higher, as the load level becomes more and more, I am sorry, this was 50% and this is 30%. the zone around the aggregate has cracking already. So, when you increase the load, the cracks around the aggregate become larger. We can see that the cracks around the aggregates become larger.

When you further increase the load to 75%, the crack that were around the aggregate have started going out to the paste, that is, into the paste.

And then, close to failure at the stock point here, what’s happening is, these cracks have started forming networks. If you start forming a crack network, it basically leads to a complete collapse of the concrete. So, the more mismatch between the modulus of the paste and the aggregate, the greater the initial cracking that you get. The lesser the mismatch, the lesser will be the initial cracking. So this will affect the overall load carrying capacity of the concrete itself.

And cracking is generally more when the aggregates are angular and rough, because then what will happen is, any movement to the paste also will be restricted by the bond between the paste and the aggregate. So when the aggregate are angular and rough, the cracking is going to be more as compared to rounded aggregate.