Advanced Topics in Science and Technology of Concrete
Prof. Mark Alexander
Concrete Materials & Structural Integrity Research Unit
University of Cape Town
Week - 03
Lecture - 16
Recycled Concrete Aggregates: Properties, Design, and Standards

Good day. It's a great pleasure for me to present this lecture today. My name is Mark Alexander from the University of Cape Town, and this was a joint collaborative project that we carried out with IIT Madras and the University of the Witwatersrand, Johannesburg. The title of my lecture is given there, Performance Approach for Design of Concrete Structures including with Recycled Concrete Aggregates and then as a second part, Current Standards and Limitations on the use of Recycled Concrete Aggregates. I want to acknowledge my co-workers or colleagues, Mr. Ichibade Amadie who does some of this work from the University of Cape Town, Rohit Prajapati from IIT Madras, and also Dr Emmanuel Leo who assisted with some of the presentation. So this is what I would like to cover in this lecture, essentially three main parts.

The first one will be an introduction to the importance and relevance of concrete, just again to put concrete in the international and into the total global scenario about where it fits in as a material. Then secondly to discuss something around performance-based approaches to the design and specification of concrete, in this case with recycled aggregate, the principles are the same but we'll see how they might be applied in the case of recycled aggregate. And then lastly there will be a closure and maybe something about the way forward. So we are well aware of the fact that concrete is both important and relevant in our context.

In fact it's the most commonly used construction material on the face of the planet. Without it modern life and civilisation would be completely unthinkable and it will remain that way into the foreseeable future. The challenge is how to use it properly and to try and reduce its environmental impact. Here we see an example of an old concrete structure, really more a kind of a stone structure from India which shows you just how durable this material can be. Concrete is after all a kind of an artificial stone.

This stone building has weathered extremely well and the challenge for us is can our concrete buildings weather like that over a long period of time. Then on the top right we see the

beautiful Lotus Temple in Delhi, a most magnificent structure which shows you the sort of just the way that concrete can be used in so many different ways and then below that is a building from Hyderabad where we see a very different concrete form in this construction institute in Hyderabad. Lovely examples of what we can do with this material. This is some other examples here. This is from our own home town on the left.

That's Cape Town with an iconic table mountain in the background and in the front you can see the construction about 15 years ago of the 2010 soccer World Cup stadium where the semi-final of the World Cup was played in 2010. That's a concrete structure. It's got a fabric roof which is not on yet obviously but without concrete this stadium could not have been built in order to accommodate the World Cup. And then we see on the right there another interesting structure with these curved panels showing again the versatility of the material and the highly aesthetic nature of the material when it's done well. But from that extreme to the other, the bottom right is a rural scene in this case in India showing how this material is being used by totally unsophisticated people in a very, very simple and rudimentary way without them understanding anything about the principles of this material.

Yet they're able to make something that can lay a path to a village and can be durable and help the people to walk on an all-weather surface instead of getting their feet wet and muddy in the rainy weather. So this is the remarkable aspect of this material, how versatile it is across a whole range of applications. It's also the developmental material par excellence. Without it the developing world will not be able to achieve the standards of living that it is hoping to achieve. On the other hand it's because we use this material in huge quantities that we have some of the issues that we have and are dealing with. For example the built environment sector alone comprises about 36% of global raw material use. Some estimates are even higher than that. So that is huge. It's huge. It's bigger than any other sector.

And concrete accounts for the vast majority of the materials usage in that sector. And you can see that in the diagram down to the bottom right where construction takes up about 34% of that total global raw material use. It's greater than all the others, even lumping all the others together is still not bigger than construction. So you can see how very large this particular aspect of things is. Now we also use it in huge quantities.

I mentioned other aspects of roads, monuments, dams, bridges, tunnels, houses. Here is the monument that has recently been built in India, this monumental statue and without concrete again that would have been impossible to build. And it was built in the short space of five or six years. Here is a road being built in South Africa and this is a high tech road. You can see for example the transfers reinforcement there.

But it's also being built with labour intensive construction. People are building this road rather than machines. And yet even then it is possible to produce a high quality structure in this road. Again versatility. Here is a dam also in South Africa.

It's actually a roller compacted dam that was built as part of a pumped storage scheme for electricity generation in our Drakensberg mountains. A very aesthetic dam actually, but vital to the energy infrastructure. And here is another example of precast bridge segments, precast in a factory type environment, more or less on the site and then assembled by being stitched together and post tensioned to form an elegant bridge structure for carrying a high speed railway. All of this would be impossible without the use of concrete. And lastly here is a tunnel, in this case carrying services.

Actually it's probably some kind of a construction tunnel and you can see the tunnel segments. They are also made out of concrete precast segments. It's also interesting to look at the sustainability of concrete. For example, embodied energy of concrete is significantly less than that of the other raw materials that we might use in construction. Clay bricks or steel.

And even the CO2 emissions, remarkably low. This is on the basis of a kilogram of concrete. Not of cement, but of concrete. Where again the CO2 emissions are less than the other materials. And the simple reason why concrete has such a high or large environmental impact is of course because we use it in such huge quantities. That's the reason why we have this issue that we have. But there are always, as we know, problems with the use of any material, concrete included. And premature deterioration is an issue. Here's a collapse of a bridge.

Looks very serious. I'm sure there would have been some loss of life there, which is very unfortunate. And loss of a very vital infrastructure link by way of this bridge. So this is a durability challenge. We also have this use of natural and non-renewable resources to manufacture cement in the aggregates. This prevents the drive to look at the possibility of

using recycled aggregates. Here's a quarry from which rock is produced, which could be used for cement or it could be used for aggregates depending on the nature of the rock. And of course in our case we do have this ability to use greater amounts of supplementary cementitious materials, which will go a long way to mitigate the environmental impacts of cement in concrete. We need to also use more amounts of recycled aggregates where we move towards a sort of circular construction cycle. Here we get construction. At the end of that maybe demolition.

After that discarded waste, which can then be brought back and used either as recycled coarse aggregate, or even in some cases hydrated cement powder, and that goes back into new construction. Now there's also a drive to try and prevent the amount of demolition that we do with our buildings, try and make them last longer, repurpose them and so on. But there's a substantial amount of demolition waste that we will have to deal with into the future. This is the circularity outline that the Globe Consensus has given us. This is an excellent initiative to try and really make an impact in the construction sector in changing practice, mindsets and technology moving forward to move towards a zero carbon type of situation.

Where we get the ideas of resilience, starting at the top right, environmental impacts, the circular economy, safety and durability. All of these things are important in the construction sector. Sustainable construction then draws from proper design, execution and maintenance, renewal of the building or whatever, the materials and then societal aspects as well. All of these are needed if we're going to think holistically about the problem that we're dealing with. So what we need is functional, durable and resource efficient concrete including the use of recycled aggregates where this is possible.

If we consider the population growth scenarios in Africa and India, then we can see the reason why we need to take this situation seriously. Here is a diagram giving us the prediction of urban world population, the global trends. You can see that Asia is growing, although it will start to peak about now. Europe is in relative terms shrinking. Likewise, Latin America and the Caribbean will more or less hold their own.

North America will also be reducing in relative terms and Africa will be growing quite substantially. Now in terms of the population growth in Africa of urban population, in the space of 30 years it's expected to go from 40 to 56 percent. If you take into account the actual

increase in the population that is expected, of course this is literally millions and millions of people that will be moving into the cities. Likewise in India, the same story, millions and millions of people will be moving into the cities.

New cities will have to be built. Existing cities will have to be expanded. We will have to repurpose our buildings and we'll have to do this in a very sensitive way as far as the environment is concerned. We also need to think a little bit about the social value of infrastructure. In other words, what does that bridge mean to me? What about that pipeline that is buried under the ground? All of which are made with concrete. How important are those to my life, to the life of my community, the place that I work, the place that I worship, the place that I recreate and so on? Well, the answer to that is a very important one.

If we value our infrastructure, we'll look after it. We'll take care of it. We'll make sure that we can get the most out of it. We will not abuse it or neglect it. We will maintain it and we will take a long-term view of that infrastructure so we can get the best out of it in every way.

So this question of the social value of infrastructure is really very important and these questions will increasingly dominate into the future. Now let's have a quick look at the global scenario around waste generation and recycling. These numbers you get from the literature and indeed you may get different numbers if you look at a different source, but the kind of numbers that we give here are as follows. The global C&D or construction and demolition waste, maybe we should call it a resource generation, is around 3 billion tonnes per year according to that reference given there. On the other hand, the global aggregate demand for 2024, in other words something of a projected demand, is around 62 billion tonnes.

So the global C&D resource from that waste is only a fraction, roughly one-twentieth or so of the demand. So clearly even if we use our C&D and produce aggregates out of it, it's not going to solve the aggregate problem in total. There will still be huge amounts of other aggregates that are needed and this is another issue that should occupy our minds. So here is a building under demolition. Once that is demolished you can see the large amounts of reinforcing steel.

Well, not such large amounts but you can see the presence there which complicates the demolition process in a certain way. And from that we want to of course try and take that

material, use it no longer as a waste but as a resource. And here you can see some recycled concrete aggregate, you can see the sort of adhered mortar that is sticking onto the surface of those particles which can be treated in different ways and another lecture has dealt with that issue. But this can then be used as a further resource either in new concrete or indeed even in other forms of construction such as maybe road bases or hard standings or things like that. Now if we look at the question of the recovery rate of the C&D waste that we produce, this is a rather interesting graph so let me quickly look through it.

If we take India and we look at the C&D waste generation versus the recovery rate, you can see that India has about 716, this would be in million tons, generated C&D waste on an annual basis but only 1% is being used. So there is a huge possibility to reuse in India. In Africa, which is where I come from, we have around 4.5 million tons generated, very very much smaller than India but we are at about 19% or so of recovery rate.

Good day. It's a great pleasure for me to present this lecture today. My name is Mark Alexander from the University of Cape Town, and this was a joint collaborative project that we carried out with IIT Madras and the University of the Dvadas Ron Johannesburg. The title of my lecture is given there, Performance Approach for Design of Concrete Structures including with Recycled Concrete Aggregates and then as a second part, Current Standards and Limitations on the Use of Recycled Concrete Aggregates. I want to acknowledge my co-workers or colleagues, Mr Ichibade Omadie who does some of this work from the University of Cape Town, Rohit Prajapati from IIT Madras, and also Dr Emmanuel Leo who assisted with some of the presentation. So this is what I would like to cover in this lecture, essentially three main parts.

The first one will be an introduction to the importance and relevance of concrete, just again to put concrete in the international and into the total global scenario about where it fits in as a material. Then secondly to discuss something around performance-based approaches to the design and specification of concrete, in this case with recycled aggregate, the principles are the same but we'll see how they might be applied in the case of recycled aggregate. And then lastly there will be a closure and maybe something about the way forward. So we are well aware of the fact that concrete is both important and relevant in our context.

In fact it's the most commonly used construction material on the face of the planet. Without it modern life and civilisation would be completely unthinkable and it will remain that way into the foreseeable future. The challenge is how to use it properly and to try and reduce its environmental impact. Here we see an example of an old concrete structure, really more a kind of a stone structure from India which shows you just how durable this material can be. Concrete is, after all, a kind of an artificial stone.

This stone building has weathered extremely well and the challenge for us is can our concrete buildings weather like that over a long period of time. Then on the top right we see the beautiful Lotus Temple in Delhi, a most magnificent structure which shows you the sort of just the way that concrete can be used in so many different ways and then below that is a building from Hyderabad where we see a very different concrete form in this construction institute in Hyderabad. Lovely examples of what we can do with this material. This is some other examples here. This is from our own home town on the left.

That's Cape Town with an iconic table mountain in the background and in the front you can see the construction about 15 years ago of the 2010 soccer World Cup stadium where the semi-final of the World Cup was played in 2010. That's a concrete structure. It's got a fabric roof which is not on yet obviously but without concrete this stadium could not have been built in order to accommodate the World Cup. And then we see on the right there another interesting structure with these curved panels showing again the versatility of the material and the highly aesthetic nature of the material when it's done well. But from that extreme to the other, the bottom right is a rural scene in this case in India showing how this material is being used by totally unsophisticated people in a very, very simple and rudimentary way without them understanding anything about the principles of this material.

Yet they're able to make something that can lay a path to a village and can be durable and help the people to walk on an all-weather surface instead of getting their feet wet and muddy in the rainy weather. So this is the remarkable aspect of this material, how versatile it is across a whole range of applications. It's also the developmental material par excellence. Without it the developing world will not be able to achieve the standards of living that it is hoping to achieve. On the other hand it's because we use this material in huge quantities that we have some of the issues that we have and are dealing with.

For example the built environment sector alone comprises about 36% of global raw material use. Some estimates are even higher than that. So that is huge. It's huge. It's bigger than any other sector.

And concrete accounts for the vast majority of the materials usage in that sector. And you can see that in the diagram down to the bottom right where construction takes up about 34% of that total global raw material use. It's greater than all the others, even lumping all the others together is still not bigger than construction. So you can see how very large this particular aspect of things is. Now we also use it in huge quantities.

I mentioned other aspects of roads, monuments, dams, bridges, tunnels, houses. Here is the monument that has recently been built in India, this monumental statue and without concrete again that would have been impossible to build. And it was built in the short space of five or six years. Here is a road being built in South Africa and this is a high tech road. You can see for example the transfers reinforcement there.

But it's also being built with labor intensive construction. People are building this road rather than machines. And yet even then it is possible to produce a high quality structure in this road. Again versatility. Here is a dam also in South Africa.

It's actually a roller compacted dam that was built as part of a pumped storage scheme for electricity generation in our Drakensberg mountains. A very aesthetic dam actually, but vital to the energy infrastructure. And here is another example of precast bridge segments, precast in a factory type environment, more or less on the site and then assembled by being stitched together and post tensioned to form an elegant bridge structure for carrying a high speed railway. All of this would be impossible without the use of concrete. And lastly here is a tunnel, in this case carrying services.

Actually it's probably some kind of a construction tunnel and you can see the tunnel segments. They are also made out of concrete precast segments. It's also interesting to look at the sustainability of concrete. For example, embodied energy of concrete is significantly less than that of the other raw materials that we might use in construction. Clay bricks or steel.

And even the CO2 emissions, remarkably low. This is on the basis of a kilogram of concrete. Not of cement, but of concrete. Where again the CO2 emissions are less than the other materials. And the simple reason why concrete has such a high or large environmental impact is of course because we use it in such huge quantities.

That's the reason why we have this issue that we have. But there are always, as we know, problems with the use of any material, concrete included. And premature deterioration is an issue. Here's a collapse of a bridge.

Looks very serious. I'm sure there would have been some loss of life there, which is very unfortunate. And loss of a very vital infrastructure link by way of this

bridge. Here's a building, a multi-story building, has collapsed.

Again, loss of life, loss of infrastructure. Very unfortunate. And there are many such examples. Here is another one, a residential building I would imagine. So we need to understand more about the behavior of concrete and that's the point of this lecture. It's a durable material, yes, but we need to understand the conditions under which it operates and then we can design it to behave better under those conditions. So what do we want from our concrete?

Here's a little diagram on the left. We want durable concrete. It's important to us. It's important for the life cycle of our structures. We want concrete that is fire resistant, not that it's going to burn. Concrete doesn't burn. But we want it to maintain its strength in the fire. We want concrete that is resistant to the penetration of aggressive agents such as water, chlorides, sulfates, and so on. We want concrete that is resistant to freeze-thaw attack, especially if it's going to be exposed to cold environments.

We want concrete that is resistant to chemical attack, acid attack. And we want concrete that is resistant to biological attack, in other words, the growth of algae and other biological materials on its surface. And then lastly, we want concrete that is resistant to impact and abrasion. In other words, it's going to last a long time and it's going to perform well in the environment. And then of course, we also want concrete that is sustainable, which is the point of this lecture.

We want concrete that is going to minimize the environmental impact of its manufacture and its use. And in that way, we are moving towards what we might call green concrete or sustainable concrete. And of course, the way that we're going to achieve that is through the use of recycled materials. And that's what we're going to talk about a little bit more today.

But before we get to that, just a little bit of a background on the global consensus. This is something that is being promoted quite strongly now, the global consensus for sustainable construction. It's an initiative that has been promoted by some of the international agencies such as the International Energy Agency, the International Institute for Sustainable Development, the United Nations, the International Institute for Sustainable Development, the United Nations Environment Programme, and the International Labour Organization.

And they have come together to try and promote sustainable construction as a way of reducing the environmental impact of our construction activities. And in that way, to try and move towards a more sustainable construction sector. And they have set out a whole lot of principles and practices that they would like to see implemented in the construction sector.

And this is a very good initiative. And if we look at some of the key principles, they talk about using resource efficient materials and minimizing waste, using energy efficient building materials and practices, reducing greenhouse gas emissions, and promoting the use of renewable energy, minimizing water consumption, and protecting water resources, and promoting biodiversity and ecosystem services, and promoting social equity and economic development.

So these are very important principles. And they are very important for the construction sector. And they are very important for the future of the construction sector. And so, I think that's a very important initiative that we should all be supporting.

And then, I think, one of the key principles is that we need to be looking at the life cycle of our buildings and our infrastructure. And so, if we're going to be looking at the life cycle of our buildings and our infrastructure, then we need to be looking at the life cycle of our materials as well.

And so, we need to be looking at how we produce our materials, how we use them in construction, and then how we dispose of them at the end of their life. And so, if we're going to be looking at the life cycle of our materials, then we need to be thinking about things like recycled aggregates, where we move towards a sort of circular construction cycle.

Here we get construction. At the end of that maybe demolition. After that discarded waste, which can then be brought back and used either as recycled coarse aggregate, or even in some cases hydrated cement powder, and that goes back into new construction. Now there's also a drive to try and prevent the amount of demolition that we do with our buildings, try and make them last longer, repurpose them and so on. But there's a substantial amount of demolition waste that we will have to deal with into the future.

This is the circularity outline that the Globe Consensus has given us. This is an excellent initiative to try and really make an impact in the construction sector in changing practice, mindsets and technology moving forward to move towards a zero carbon type of situation. Where we get the ideas of resilience, starting at the top right, environmental impacts, the circular economy, safety and durability. All of these things are important in the construction sector. Sustainable construction then draws from proper design, execution and maintenance, renewal of the building or whatever, the materials and then societal aspects as well. All of these are needed if we're going to think holistically about the problem that we're dealing with. So what we need is functional, durable and resource efficient concrete including the use of recycled aggregates where this is possible.

If we consider the population growth scenarios in Africa and India, then we can see the reason why we need to take this situation seriously. Here is a diagram giving us the prediction of urban world population, the global trends. You can see that Asia is growing, although it will start to peak about now. Europe is in relative terms shrinking. Likewise, Latin America and the Caribbean will more or less hold their own.

North America will also be reducing in relative terms and Africa will be growing quite substantially. Now in terms of the population growth in Africa of urban population, in the space of 30 years it's expected to go from 40 to 56 percent. If you take into account the actual increase in the population that is expected, of course this is literally millions and millions of

people that will be moving into the cities. Likewise in India, the same story, millions and millions of people will be moving into the cities.

New cities will have to be built. Existing cities will have to be expanded. We will have to repurpose our buildings and we'll have to do this in a very sensitive way as far as the environment is concerned. We also need to think a little bit about the social value of infrastructure. In other words, what does that bridge mean to me? What about that pipeline that is buried under the ground? All of which are made with concrete. How important are those to my life, to the life of my community, the place that I work, the place that I worship, the place that I recreate and so on? Well, the answer to that is a very important one.

If we value our infrastructure, we'll look after it. We'll take care of it. We'll make sure that we can get the most out of it. We will not abuse it or neglect it. We will maintain it and we will take a long-term view of that infrastructure so we can get the best out of it in every way.

So this question of the social value of infrastructure is really very important and these questions will increasingly dominate into the future. Now let's have a quick look at the global scenario around waste generation and recycling. These numbers you get from the literature and indeed you may get different numbers if you look at a different source, but these are the ones that we've taken here.

So you can see that in the total amount of solid waste that we produce, nearly 2 billion tons. Now that's of the order of a quarter of the total amount of solid waste that we produce. Construction and demolition waste, much of which is concrete, is estimated to be about 500 to 600 million tons per year. Now a very small percentage of that, you can see 5 to 10 percent, is recycled and the majority of it goes into landfill.

Now that's a very sad situation because as we will see in a minute, there's a lot of value in that waste that we are just throwing away. So what's the big problem? Well, in Europe and in the US where there are very good studies on the question, you can see that the bulk of the waste that we produce in construction is indeed concrete and masonry, about 30 to 40 percent.

The next largest component is asphalt, 20 to 25 percent, and then the rest is made up of metals, wood, glass, and other materials. So you can see here the problem that we're dealing

with. And so if we're going to look at recycling, we're going to be concentrating mostly on concrete and masonry and to a lesser extent on asphalt. But it's not only the volume of waste that is a problem.

It's also the composition of that waste. If we look at the composition of construction waste, you can see that the bulk of it is concrete, about 60 percent, followed by asphalt, 15 to 20 percent, and then there are metals, glass, and other materials. So you can see here again the problem that we're dealing with.

And so if we're going to be looking at recycling, we're going to be concentrating mostly on concrete and masonry and to a lesser extent on asphalt. But it's not only the volume of waste that is a problem. It's also the composition of that waste.

If we look at the composition of construction waste, you can see that the bulk of it is concrete, about 60 percent, followed by asphalt, 15 to 20 percent, and then there are metals, glass, and other materials. So you can see here again the problem that we're dealing with. So why don't we recycle more? Why is this the case? Well, there are a number of reasons for this. One of the main reasons is that recycling is simply not economically viable in many cases. It's cheaper to just throw the waste away and start again with new materials. And so we need to find ways to make recycling more economically viable. And one of the ways that we can do this is by creating markets for recycled materials. So if we can create a demand for recycled materials, then the economics of recycling will start to make more sense.

And so this is something that governments can do, for example, by introducing regulations that require the use of recycled materials in construction. Another reason why we don't recycle more is because there are often technical barriers to recycling. So for example, it can be difficult to separate different materials from each other, or it can be difficult to remove contaminants from recycled materials. And so we need to find ways to overcome these technical barriers. And then finally, there can also be social and cultural barriers to recycling. So for example, people may not be aware of the benefits of recycling, or they may not be willing to change their behavior in order to recycle more. And so we need to find ways to overcome these social and cultural barriers as well.

Now, despite these challenges, there are also many opportunities to increase recycling in the construction sector. And so what I want to do now is to talk about some of these opportunities in more detail. And then you can see the other countries. China dominates as it often does, again huge opportunities for reuse of that material. When you get into more of the developed world like here, you can see that here the recovery rates in fact approach those of the generation rates and indeed in countries like Holland or the Netherlands, I think it is pretty much 100% which is very meritorious. So what we can see here is that there is a huge disparity between what we produce and what we use which simply means that we are taking a valuable resource and in a way throwing it away, putting it into landfills which is no longer sustainable. This is a problem that we have to address. So this raises the questions of standards and norms.

These are important in a construction context because in general we construct to standards and norms. We have codes of practice, we have specifications, we have standard test methods and these are important because they mean or they allow us to construct within a certain framework which gives us some guarantee of safety and efficiency of our construction. But it also raises the issue of performance-based approaches because in many cases these new challenges that we face are not covered by the existing standards and norms and we cannot maybe wait for them to be changed to move forward. So let's think a bit about the approaches to design of concrete and specification as well. We have two primary ways of looking at it in the prescriptive way or in a performance way.

The current approach is of course prescriptive and in terms of mixed design of concrete this means that the water cement ratios is prescribed, the cement content often, the cement type and many other things are prescribed and essentially it's a recipe. So all the contractor has to do is to pick up the recipe and do what it tells him or her to do. So there's no room for innovation, there's no room for optimization, there's no room for rational design and it may not even do the job as we realized very often in this approach. So performance-based approaches to design and specification is the alternative and I would argue the better way to go. It's based on the performance criteria that we set for our material.

So for example, if we're dealing with concrete we might say well we want the concrete to have a certain strength after a certain number of days. Or we might say we want the concrete to be resistant to frost or we might say we want the concrete to be durable in a certain

environment. Whatever it might be, these are the performance criteria that we set and then we design the mix of concrete in order to achieve those performance criteria.

And the advantage of this approach is that it gives us more flexibility, it gives us more opportunity to innovate, it gives us more opportunity to optimize the performance of our materials. So let's just think a bit about how we might apply this approach in the case of recycled aggregates. Well, if we're going to be using recycled aggregates in our concrete, then we need to think about what are the performance criteria that we're going to set for that concrete. And so some of the things that we might consider are the compressive strength of the concrete, the tensile strength, the flexural strength, the durability of the concrete, and so on. And then we need to think about how we're going to design the mix of concrete in order to achieve those performance criteria. And so one of the things that we might do is to adjust the mix design parameters in order to compensate for the use of recycled aggregates.

So for example, if we're going to be using recycled aggregates, then we might need to adjust the water cement ratio in order to achieve the desired strength of the concrete. Or we might need to adjust the cement content or the type of cement that we're using in order to achieve the desired strength of the concrete. And so these are some of the things that we might consider when we're designing the mix of concrete with recycled aggregates.

And then another thing that we might do is to use supplementary cementitious materials in order to improve the performance of the concrete. So for example, we might use fly ash or slag or silica fume or some other supplementary cementitious material in order to improve the durability of the concrete or to improve the strength of the concrete. And so these are some of the things that we might consider when we're designing the mix of concrete with recycled aggregates.

And then finally, we need to think about how we're going to test the performance of the concrete in order to verify that it meets the desired performance criteria. And so some of the tests that we might do are tests of the compressive strength, tests of the tensile strength, tests of the flexural strength, tests of the durability, and so on. And so these are some of the things that we might consider when we're designing the mix of concrete with recycled aggregates.

So that's just a brief overview of some of the things that we might consider when we're using recycled aggregates in our concrete. And then let's move on now to think a bit about the current standards and limitations on the use of recycled aggregates. So the current standards and limitations on the use of recycled aggregates are based on the prescriptive approach to design and specification.

And so what this means is that the standards specify certain requirements that the recycled aggregates must meet in order to be used in concrete. And so some of the requirements that the standards might specify are requirements on the grading of the aggregates, requirements on the cleanliness of the aggregates, requirements on the strength of the aggregates, and so on. And so these are some of the requirements that the standards might specify in order to ensure that the recycled aggregates meet the desired performance criteria.

And then the standards might also specify certain limitations on the use of recycled aggregates in concrete. And so some of the limitations that the standards might specify are limitations on the maximum percentage of recycled aggregates that can be used in concrete, limitations on the types of structures that the concrete can be used in, limitations on the exposure conditions that the concrete can be used in, and so on. And so these are some of the limitations that the standards might specify in order to ensure that the recycled aggregates are used in a safe and effective manner.

So that's just a brief overview of some of the current standards and limitations on the use of recycled aggregates. And so in conclusion, I think that there are many opportunities to increase recycling in the construction sector, and so if we're going to be successful in addressing the challenges that we face, then we need to find ways to overcome these challenges, and so I think that by using a performance-based approach to design and specification, we can overcome these challenges, and so I think that's a very important step forward. Thank you very much.