

ERDC EL
Moderator: Courtney Chambers
November 12, 2014
12:59 am CT

Courtney Chambers: Okay, at this time I'd like to give you today's speaker sharing, The Alkali-Aggregate Reactions in Concrete: Mechanisms, Testing, Mitigation and Occurrence in Army Corps of Engineers Navigation Structures.

Dr. Robert Moser is a Research Civil Engineer in the Concrete and Materials Branch at the Geotechnicals and Structures Laboratory at the U.S. Army Engineer Research and Development Center in Vicksburg, Mississippi. In his position he leads the Materials Diagnostics and Forensics Group of the Concrete and Materials Branch. He conducts research in a variety of areas focused on the development of new materials and material systems with the goal of improving the performance and durability of military and civil infrastructure systems. Robert is an active member of the American Concrete Institute, National Association of Corrosion Engineers, and American Ceramic Society. Robert also serves in a joint appointment as an Adjunct Professor of Civil Engineering and Mechanical Engineering at Mississippi State University where he teaches courses on concrete material science and infrastructure durability. More about Dr. Moser can be found in his bio with the presentation and recording of today's meeting on DOTS Web page for your reference.

We're very happy to have you sharing with us today Robert, and at this time I'm going to switch over to your presentation and give you the presenter rights, and we'll enter listen-only mode and then you can begin.

Operator: All participants are now in listen-only mode.

Robert Moser: Okay, can you hear me Courtney?

Courtney Chambers: We can Robert, yes.

Robert Moser: Okay. Well thanks a lot for the introduction and thanks everyone for tuning in. So I put together a briefing that gives a brief overview of all the things that we think about when we think of alkali-aggregate reactions in concrete. We have a limited time duration and we could talk about this all day, but I'm going to try to cover the high points of how AAR occurs and some of the different types of AAR that are out there.

We'll talk a little bit about test methods, and then finish up on mitigation. And then throughout this I'll give a few examples of the occurrence of AAR in structures. So I'll go, next slide here.

So just a quick outline. We'll give an introduction to AAR. We're going to cover both alkali silica reaction and alkali carbonate reaction in this briefing. And we'll give a little detail of the mechanisms; how these things actually work in our concretes, and that will actually tie in well to how we can mitigate them when we're trying to eliminate some of the sources for these mechanisms to actually occur.

Then we'll talk about some of the damage that can actually occur. I'll go over test methods. We're going to focus specifically or more so on test methods to support new construction, and evaluation of aggregates and aggregate matrix combinations.

But I'll also touch on evaluation of AAR in existing structures, especially to look at residual expansion. It's just there's not a lot of standardized techniques to actually do that and discuss.

We'll talk a little bit about guidance, and then I'll finish up on mitigation. And so if you all have any questions, feel free to type them in the Chat window and I'll try to address them as we go through the talk. Otherwise we can address them at the end of the talk. And if we don't have enough time to do that like Courtney said, I'll get back with you, you know, via email or we can set up a time to talk on the phone.

All right so when we think about alkali-aggregate reactions or AAR, they're generally divided into two different types. We have alkali carbonate reactions or ACR, and then alkali silica reactions or ASR. And ASR is generally much more - at least it occurs much more frequently in our structures than ACR. But there are specific regions of the country, and many of them where the Corps operates extensively where ACR is a concern. And so from ACI's 116 terminology document, the definition for ACR is pretty self-explanatory. It is what it sounds like it is, it's a reaction between alkali, primarily sodium and potassium that are present in Portland cement paste. These can be contributed by the paste itself, by the Portland cement, and we'll talk about that in more detail. But they can also be contributed from other sources, especially if our structures are exposed to de-icing salts or waters that have high alkali content like sea water. So it's a reaction between those alkalis and certain carbonate rocks, primarily with a specific combination of calcite and dolomite, along with some clays. And we'll talk about that in some more detail. And the result of that reaction is an internal chemical - internal production of a material which is actually hydrophilic. It imbibes water and it results in expansion and cracking of concrete and service.

Now alkali silica reaction is a little bit different. Rather than being a reaction with carbonate minerals present in our rocks, it's actually a reaction with siliceous minerals. In particular, siliceous minerals that are poorly ordered or poorly crystalline.

So things like strained quartz, volcanic glasses; just poorly crystalline materials that are present in some of our aggregate sources. And so these will react with alkalis that are again contributed by Portland cement or by external sources, leading to the formation of a reaction product within the concrete, within the aggregates, the mortar fraction and the paste fraction of the concrete that will lead to cracking of the concrete in service. And that reaction is much more probable than in ACR.

So we're going to focus a lot of our time today on ASR and we'll touch some on ACR, partly because of course ASR occurs much more frequently, but also ACR is I would say, much less well understood than ASR as well.

So starting off here on ASR, ASR affects all types of structures, especially structures that are exposed to moist environments. So if we think about let's say a commercial office building where the members are - they live in a nice HVAC environment, we can have a reactive aggregate, but we generally don't see a lot of issues with ASR. But bridges and pavements and dams; anything that is exposed to the elements is susceptible to ASR if we have a reactive aggregate and we have sufficient alkali source. And this has been known to cause distress in thousands of concrete structures across North America. Many in Europe, Canada, and Asia as well.

ASR was first discovered in the 1930s. It was discovered by Thomas Stanton who worked for The California State Division of Highways, I guess the equivalent of CalTrans nowadays. You can see a picture of Thomas Stanton there on the slides standing next to a wall that's affected by ASR. He was one of the first people to ever note ASR and to actually start some research to see why this was occurring in their structures.

So if we go back to how ASR occurs, ASR again is a reaction between alkali hydroxyls. And so if we think about things like hydroxyl groups with the OH minus that you can see there on the slide, which is always going to be present in our concrete because the PH of the pore space in our concrete is extremely high. So the PH is on the order of say 13 to 13-1/2, so there's lots of hydroxyl groups floating around. The PH is high. And then we also have a sufficient source of alkalis like sodium and potassium. Those are being contributed by the cement - supplementary cementitious materials, and de-icing salts or sea water, if the structure is exposed to those. So those are always going to be present. So it's a reaction between those and siliceous minerals found in some aggregates. And we'll talk about what those are.

So this reaction product that forms is extremely hydrophilic, meaning that it likes water. And when that water is actually available it will hydrate and result in the formation of an expansive gel inside of a concrete. And we all know, concrete is good in compression but it's weak in brittle in tension. And so the formation of that expansive gel will lead to cracking and spalling and delamination and other types of deterioration of the structure. I'll show some examples of that later.

But again in general, we need an alkali hydroxyl source. We need some type of reactive silica, and we need some type of moisture present in order to have ASR.

Okay, so first the reactive siliceous component which needs to be present in our aggregates - and so one interesting thing here is that we could have aggregates with, you know, very similar chemical compositions, but the most important thing is their mineralogy. So is the material highly ordered and highly crystalline meaning that it's going to be relatively inert and it can survive well in acidic environments and alkaline environments and not react?

Or is it something that is highly disordered and very vulnerable to reactions when exposed to an alkaline solution.

So one example we think about all the time is comparing between opal and quartz. Quartz is extremely stable, extremely crystalline, and silicone dioxide.

If we look at opal, opal from a chemical composition standpoint is similar to quartz, but mineralogically it's extremely different. It has a much more disordered structure. And when we expose it to an aggressive solution like we have in concrete; a very alkaline solution, it can break down those bonds and form an alkali silica gel.

And so you can see that reflected in the plot up there on the right. These are results from a very rapid test, ASTM C289 which is - we call that the quick chemical test. Not too many people use that test other than some quarries.

But it's basically we're taking an aggregate sample, we crush it down to a fine powder, we expose it to a very strong alkaline solution; a one molar sodium hydroxide solution at 80 degrees Celsius, and then we just look at the amount of silica that dissolves off of that aggregate. And we know that if we get more dissolved silica that means that that aggregate is more reactive.

And so we can compare between say a quartz sand which is extremely non-reactive; very ordered, very crystalline material. And then as we go up to things like volcanic glasses, chalcedonies and opals, we see that that dissolves silica increases significantly, and that's generally proportional to the expansion and the degree of deterioration that would result from ASR if you were using that aggregate.

All right, so then we need alkalis. And our primary source of alkalis in most cases - this is from the Portland cement itself. So if we think about the different materials that we use to make Portland cement, we need a source for silicon, and we need a source for calcium. So our calcium is coming from limestone and things.

And our silicon may be coming from clays, and we're also getting aluminum and iron. But along with that we're also getting alkali. So we're getting sodium and potassium and other alkalis, and so that's being incorporated into the Portland cement and that's going into our concrete and participating in things like ASR.

And that alkali content will vary significantly, depending on your cement source. So we have locally available sources, let's say here in Mississippi that are low alkali content. Maybe .25 or so percent alkali equivalent.

But we can look at other places and say one cement that we source from Maine specifically for ASR testing which has a 1.25% alkali equivalent. And you can see that if you look at your mill certificate or any testing results for your cements that you're using.

So generally our cements that are less than .6% alkali equivalent or you'll probably see it on the mill certificate, it will say Na₂O EQ for equivalent. If it's less than .6% you have a low alkali cement. If it's between .6 and .9%, you have a moderate alkali cement. And if you have greater than .9% you have a high alkali cement.

Another source that can contribute alkalis is from other cementing materials. And in particular, supplementary cementitious materials, so things like fly ashes or slags. And generally you're more impure SCMs like fly ash and slag

will contribute more alkalis than your pure SCMs like silica fume and metakaolin. So, that can be another source.

Some chemical admixtures can also contribute alkalis. Most of the typical chemical admixtures that we use, air trainers and super plasticizers don't really contribute alkalis. But if you get into, corrosion inhibitors or maybe even accelerators, they can contribute alkalis into your system.

Some aggregates can contribute alkalis, but the other major source of alkalis that we have is from external sources. So structures that are exposure to sea water, sea water has a high concentration of alkalis. And then many common de-icing chemicals also are good sources for alkalis.

So if we think about air-field pavements and highways, they can also have sources of alkalis from de-icing chemicals.

And then finally we need some source of moisture. So this is just showing the effect of relative humidity on four different aggregates. And we have expansion on the Y axis versus relative humidity on the X axis. These are four very reactive aggregates - historically reactive aggregates.

And you can see that if the relative humidity gets below about 80% in his case that basically your expansion goes away. So there's not enough moisture in there to drive ASR and cause expansion and damage.

So we could - let's say we take an aggregate that's extremely reactive, but they're using it for concrete in New Mexico, that structure will perform fine. But if we drop that aggregate over here to Vicksburg, Mississippi and we built concrete with it where the relative humidity is 80% plus almost all the time

that concrete would deteriorate rapidly. So relative humidity is an important consideration too.

So just to summarize again, we need reactive silica with some reactive mineral components present in our aggregate. And we need sufficient alkalis where those alkalis are typically coming from the cement itself from de-icing salts or supplementary cementitious materials. And then we need sufficient moisture for ASR to occur.

All right, and so what does ASR actually do to my structure? So it's expansive, leads to cracking. Here on the left you can see cracking in an airfield pavement. This large crack is actually because this is in an area of the pavement that actually isn't confined.

And so it's being dragged along by the concrete that is confined and it's expanding on this airfield.

So we've got a large crack here. You can also see map cracking. This is extremely severe; extremely, extremely severe ASR. A little bit atypical, but a good textbook case scenario.

And we can see a little bit here on the bottom figure on the bottom left. You can see some map cracking there. In general, in this case because we're looking at an airfield, there's really no directionality of stress because when there's nothing driving on it and it's unloaded, it's in a fairly uniform stress state. And so we're not seeing oriented cracks.

Now if we saw this, let's say in a prestressed structure, let's say a precast concrete bridge girder where we've got some longitudinal pre-compression

force, those cracks are actually going to align with that and they're going to be parallel to the pre-stressing direction.

So sometimes they'll be oriented and sometimes they won't, depending on what the stress state is within the concrete.

On the right you can see here, this is a bridge bent, actually from Texas. Texas has quite a few issues with reactive aggregates. You can see the map cracking there. You can actually see in the cracks and adjacent to the cracks it looks like they're moist, and that's from the exudation of the ASR gel which is very rich in moisture.

You can see on the top portion here where we've got this pier coming up off the bent, and we've got some spalling and some exposed reinforcements.

And so the other thing you can think here is we could have combined durability reactions. So we have ASR which is causing cracking, but now those cracks are providing a quick pathway for other things into the concrete and cause problems.

So if we're in a freeze/thaw environment we could have water getting in there freezing and causing spalling and delamination. If we're in an environment that's exposed to chloride - that's a super highway for chloride to get into your structure and cause corrosion issues in embedded reinforcement.

So oftentimes this ASR will be combined with other types of deterioration if there is an aggressive exposure on that structure.

Looking at a USACE civil works structure, this is David Terry Lock and Dam in photos I took a couple of years ago in Little Rock District. The photo here

on the right, you can see some fairly significant ASR here in the (trunion) region on these dam piers.

You can see the exudation of some ASR gel that's also mixed with some products of efflorescence, mostly calcium carbonate.

Oftentimes those occur together because we have the exudation of moisture that also carries along calcium with it and will precipitate out. But also as the ASR gel exudes from the concrete, it can actually carbonate by reactions with CO₂ in the atmosphere and form something very similar to a typical efflorescence product.

In the bottom right - or actually bottom left picture you can see the extensiveness of those cracks. They've actually gone in and done some repairs to limit the availability of moisture within those cracks and try to prevent the concrete from actually ruffling.

And some more recent photos - we actually got these on some concrete samples from Lock and Dam 18, Rock Island District. And here you can see some fairly extensive deterioration. We have some map cracking and a lot of efflorescence with ASR gel and calcium carbonate.

And also in the bottom right you can see some microscope image from some petrographic analyses we performed on that concrete. And you can see micro cracks forming here in the mortar fraction. They're actually going through the aggregate. And you can also see inside of those cracks, they're in-filled with an ASR gel product.

So that's the ASR gel migrating through these cracks, imbibing water, expanding and leading to more cracks in expansion.

All right, so that's a little bit about ASR, and so we also want to talk a little bit about ACR. And so ACR again occurs much less frequently, and it's a very different mechanism than when we typically think about ASR.

So ACR was first discovered in 1957 in Ontario, Canada. They have quite a few issues with ACR. Here in the U.S. the largest occurrence that we see of ACR is primarily in aggregates that are sourced from the Western side of the Appalachian Mountains, so Tennessee, Kentucky, Ohio; they have sources of ACR reactive aggregates.

It's also found in Central Europe. In China they have quite a few issues with ACR. And these reactions occur in a very different fashion.

So when we think about ASR we're looking for specific minerals that are ASR reactive. When we think about ACR we're looking at a specific combination of minerals that when present in our aggregates, can make them ACR reactive.

And so generally we think of a calcite to dolomite ratio of approximately one to one. And we can determine that through x-ray diffraction techniques. And then we also need some clays or insoluble residue, and that's generally needed at about five to 25% by mass. And we also need a specific microstructure to be there.

So we have calcite and dolomite but they have to have grains that are specific shapes and specific sizes in order to create an aggregate that's ACR reactive.

And so in general the ACR deterioration process results in a chemical alteration of rhombohedral dolomite crystals that are present in these

aggregates, and ultimately leads to a similar type of deterioration that we see with ASR, with expansion and cracking of the concrete.

So one example that we have of that within the Corps; probably the best example and the one that most people know about is Chickamauga Lock and Dam, probably one of the most AAR in general affected structures that we have in the Corps has both ACR and ASR. And they're doing a lot of - I think a lot of great work trying to monitor that structure and keep it going. Do repairs and saw cut joints and things when needed.

Another recent ACR example that we worked on was at Tinker Air Force Base. We do a lot of work for the Air Force to support their needs for concrete analysis.

And they actually had some interesting issues with a moderate amount of ASR, but mostly ACR. And so here you can see some microscope images on the bottom from our petrographic analysis of their concrete. And you can see some of the coarse aggregate, especially here in the picture on the left - bottom left where you have a darker reaction rim around the perimeter of the aggregate and some internal micro fracturing.

If you look at the image on the bottom right we can see some similar deterioration with internal micro fracturing of the aggregates. And we have cracks actually extending from those coarse aggregates into the concrete.

So it looks a little bit different than severe ASR deterioration. So one thing that we always want to do when we see this type of deterioration is to confirm that those aggregates are actually ACR susceptible.

And so we would break out these coarse aggregate, crush them down into a powder, run x-ray diffraction on them to confirm that they have the correct composition that would make them ACR reactive.

All right so if I have this, what are the ramifications in my structure? That's the big thing that we're concerned about or should be concerned about.

And they can be fairly benign; not a big concern, just something that you probably wish that you would retire before you had to deal with it. It can be very severe.

So the first of course is things that are related to expansion. And so if we have an unconfined structure and there's no issues with expansion, really all we're worried about is the - maintaining the appropriate mechanical properties of the concrete.

But if we have something like - let's say like a navigation lock where we have all these moving mechanical components, we've got valves and mooring bits and gates, and all of these need to work for this structure to actually function.

When we have this expansion, especially if we have differential expansion in different areas of the structure, we can get misalignment and binding of mechanical systems. And we can get differential expansion by a lot of different reasons, especially if we have different amounts of relative humidity or moisture exposure in different areas of the structure.

Confinement - just by the overburden, let's say, of a massive concrete lock wall can also change or minimize expansion. So that's a big issue.

Also, failure of joints and closure of joints so that they can't perform adequately to relieve stresses from thermal expansion and contraction. That's also another issue that can occur.

If we have some confinement we could also induce internal stresses within the concrete because the concrete has nowhere to go. There are some examples of that occurring in USACE civil work structures.

Probably the best examples that you can see is in airfields. So let's say we have a taxiway between two large airfields. That taxiway is expanding and it's being confined by the airfields on each side, you're going to build up significant compressive stresses inside of that, and maybe even cause it to buckle or spall at the joints.

So that can be another issue which can be of course relieved if you saw cut open those joints or monitor for the buildup of those stresses. And then when we think about how AAR actually influences the mechanical properties of our concrete.

And in general if we have a small amount of AAR, it really has a very negligible effect on strength and stiffness. It actually in some cases, can actually be beneficial because we're infilling a lot of the pores. We're infilling some pre-existing micro cracks with a solid ASR gel or ACR gel.

However if we get to cases which are extremely severe like most of the cases that I showed in the examples, those can lead to significant reductions in strength and stiffness due to internal cracking within the concrete.

Now even with severe AAR if they're not significant, but if we look at some extremely severe AAR which we don't have some - don't have as many issues

in the Corps, but there are quite a few examples in the Bureau of Reclamation structures where they have up to half of the compressive strength of what they originally had due to AAR, so it can be significant.

All right, so I wanted to move in and talk a little bit about how we actually test for AAR. This is primarily going to focus on new construction, but will also touch a little bit on how we can evaluate existing structures.

And beginning just with ASR - so here you can see listed all of the different test methods that are out there. These are all ASTM standard test methods for ASR.

And I've highlighted in green the ones that are currently used by most organizations and are recommended in UFGS.

So we start off with ASTM C295 which is our petrographic examination of aggregates for concrete. And then we have two standards - C289 and C227. These are really historical standards. There's not hardly anybody even uses these anymore.

C289 some quarries use. C227 is used very infrequently, and I would say it's probably used more by people who aren't familiar with some of the newer test methods that are out there.

The most frequently test method is ASTM C1260 which we typically call the accelerated mortar bar test. This is done only on mortars.

Then we have ASTM C1567 which is basically the same thing as C1260, but it focuses on mitigation. And then we have ASTM C1293 which is actually

our concrete prism test. So it's the only ASR test that's standardized for use in concrete samples.

So first our petrographic analysis - so here we want to look at the aggregate and see, based on its mineralogical composition, is it inherently ASR reactive or not.

And this is described in detail in our EM-2000, so it looks for reactive components like opal, Chalcedony, glassy igneous components, Cristobalite and strained quartz.

And so if these are present in your aggregates at the percentages noted here on the slide, we would reject that aggregate, assuming that it is ASR reactive.

So we generally do these based on a visual examination. We can do quantitative x-ray diffraction to look at the mineralogy, and refractive index petrographic microscopy to identify amorphous phases.

And so I put some results in here. These are for a couple of aggregates that we use. On the top we have a very non-reactive limestone and you can see its x-ray diffraction pattern there on the left, and composition on the right.

So it's primarily calcite and dolomite. They're not at one to one ratios and they don't - there's no clays present in this aggregate. It's actually the material that we use as our non-reactive control aggregate for all of our laboratory testing.

And then on the bottom we can see an x-ray diffraction pattern which is significantly different. And so this is a - one of the most highly reactive aggregates that we know about. It's almost basically a pure opal.

And so this is the optimal combination of reactive components. We have tridymite and cristobalite and other even amorphous components. And so this is a highly reactive aggregate. And these can be easily evidenced using x-ray diffraction.

But by far the most common way that we would evaluate ASR is with actually measuring expansion caused by ASR. And so the most common test for that is accelerated mortar bar test or AMBT, that's ASTM C1260. And so we make a mortar sample to test the aggregate's reactivity. We can test fine aggregates, and we can crush down coarse aggregates to a fine aggregate gradation.

We produce these mortar bars. They're exposed to a one normal or one mole per liter sodium hydroxide solution at 80 degrees Celsius. And we measure expansion for 14 days.

And you can see here, if we see after that 14 day duration an expansion greater than .2%, we deem that material as to be reactive. If it's between .1% and .2% it's potentially reactive and will require some additional testing.

And if it's less than .1% we consider that aggregate to be innocuous, so it's non-reactive. And this is the primary test that's recommended in UFGS and most DOT specifications.

So just to show you some example results, this for 11 different aggregates. These are all natural aggregate sources. And you can see the wide array of reactivity that you can get.

So we move from something like this bottom orange and green curve which are extremely non-reactive, to something like the purple curve up at the top, which after 14 days we almost get 1% expansion. That is an aggregate from near Albuquerque, New Mexico. It's basically the most reactive natural aggregate source that's ever been tested.

So you can see a wide array of reactivity, depending on where your aggregates are sourced from.

Some additional test methods - we can also use the accelerated mortar bar test to evaluate the effectiveness of mitigation of ASR, and that's covered under ASTM C1567. It's basically the same exact procedure as C1260, but there's some additional guidance in there related to proportioning of your mortar and acceptance of the expansion levels when we're using supplementary cementitious materials.

And then the other test which is used frequently and is also specified in UFGS' concrete prism test or ASTM C1293, and this is the only real standard test that's used in the U.S. that actually can test concrete.

So we can test both coarse and fine aggregate gradations which is an important thing to consider, especially if you find that you have a reactive coarse aggregate in your ASTM C1260. It may not actually perform the same way in 1293.

All right, and so we make concrete prisms to evaluate aggregate reactivity. You can see an example of one of those prisms here on the right. They are three by three by 11 and a quarter inch prisms.

Rather than exposing the samples to an external alkali source like we do in the accelerated mortar bar test, we're actually adding alkalis as sodium hydroxide internally to the mix water, and we're boosting the alkali loading internally in the concrete to 1.25% by weight of cement.

And then we store those at 100% relative to humidity and 38 degrees Celsius. So the big drawback of this test is it takes so long.

The accelerated mortar bar test takes between 14 and 28 days. ASTM C1293, the concrete prism test can take up to two years. One year if you're just testing an aggregate; two years recommended if you're looking at mitigation using supplementary cementitious materials.

And then based on the results of this test, if our expansion is greater than .04% we deem that as potentially reactive. And if it's less than .04%, the aggregate source or aggregate matrix combination is deemed to be non-reactive.

And this is generally considered to be the best predictor of field performance out of all of our standard test methods.

So here you can see some results from the concrete prism test. This is from a very highly reactive aggregate from near El Paso, Texas that's used in quite a few studies. And you can see we have our control - the black line here at the top, which expands almost .5%.

And then as we incorporate supplementary cementitious materials, here we're working with fly ash and metakaolin. Metakaolin is extremely effective at mitigating ASR. And we can see a significant reduction in expansion to even almost acceptable levels with the addition of 8% to 15% metakaolin.

All right, so those are all test methods that we would use for evaluating aggregates for new construction. But of course within the Corps and many other agencies that have interest in aging infrastructure, we also want to think about what is the residual expansion in an existing structure?

And this is something where there really are no standard test methods, but we can rely on some of our standard test methods and use some of the conditions that they impose in order to evaluate what additional expansion I might be able to anticipate in my structure.

And so we do that in a couple of different ways. I usually recommend doing it both ways simultaneously because they both provide some interesting and useful information.

So the first is we could take cores from that structure, put gage studs on the end of them and expose them to an environment that's like ASTM C1260. So expose them to a very aggressive environment with basically an infinite source of alkali, and then we just monitor expansion.

And so this really represents a worst case scenario of, if over the rest of the service life of this structure I had an infinite supply of alkalis and an infinite supply of moisture, how much additional reactive material is there in my concrete that hasn't reacted already? So that's a worst case scenario.

The other test which does take a little bit longer like I mentioned, but gives you actually a more realistic view of what the residual expansion is, is to take cores and test them according to the ASTM C1293 exposure.

So rather than giving an infinite source of moisture and external alkalis, we're just maintaining a high moisture content and we're using the internal alkalis

within the concrete to drive expansion. And so that's general a more realistic expansion measurement for a structure.

And so what we're trying to get at is the figure down here on the bottom left. So if I look at expansion versus time, we're going to have an initiation period. Then we're going to ramp up and have expansion. And eventually we're going to react all of that reactive material that's present in your aggregate within the concrete. Then you're going to go into a dormant stage.

And so what we want to do is see where we are in that lifecycle. And that information can be useful in predicting what I need to do in the future in anticipating what additional deterioration is going to happen in the structure.

All right, I'm not going to go into too much detail on ACR test methods. There are not nearly as many ACR test methods out there, and I would say we really don't even understand probably how well we're evaluating ACR with many of these.

But of course we could use C295 which is our petrographic examination of aggregates for concrete to see whether that aggregate is inherently susceptible to ACR. That's an important thing to consider.

Another test which is fairly effective and is used frequently is ASTM C586 which is typically referred to as the rock cylinder method. And so we take a core out of the actual rock formation, machine the ends, expose that to an alkali solution and just measure expansion of the rock itself. That's a fairly useful test for looking at ACR susceptibility.

There is another test, ASTM C1105 which is the length change of concrete due to alkali carbonate rock reaction. This is a very similar test to ASTM C1293, the concrete prism test for ASR.

But the conditions are somewhat different, and there are some issues with actually interpreting the results from C1105, especially if you have an aggregate source where you may be getting the combined effects of ACR and ASR. And the expansion limits are very different. We could go into a long discussion on 1105. There are relatively few ACR test methods out there that are very well proven.

So if we look at our DOD guidance that's present in the UFGS, and this will actually vary depending on which guide spec you're looking at. Airfields will be different than just typical cast in place concrete than mass concrete.

But in general, DOD guidance is actually more strict than what we see in most ASTMs.

So our ASTM limit was .1% for a non-reactive aggregate. In UFGS our limit is .08%. So if we read this, fine and coarse aggregates must show expansion less than .08% at 16 days after casting, so 14 days after exposure to the alkali solution.

If expansion is greater than that we have to reject the aggregate or we do some additional testing according to ASTM C1567 to look at mitigation. And that would be using supplementary cementitious materials.

And it also states that the aggregates must not possess properties or constituents that are known to be reactive, if we look at our petrographic analysis by ASTM C295. So that's really what governs us.

All right and so I wanted to finish up on a little bit of how we can actually mitigate ASR or AAR in general. So we'll start off with ASR because that's more prevalent.

The first thing that we think about right, is we need reactive silica to have ASR. And so we can avoid a reactive aggregate either by doing this accelerated testing. We do primarily ASTM C1260 if we have to because it's a longer, more expensive test, we do ASTM C1293.

We can also do selective quarrying of areas that are known to be non-reactive, or use known sources that are historically known to be non-reactive.

And I would caution, this known sources thing is useful, but I would caution that you really have to be careful, because we say a known source that is historically non-reactive, it's historically non-reactive with a historic cement or a historic fly ash and a historic mixture proportion.

So as your concretes are changing and your cements are changing, their interaction with the aggregate is changing too. So that's something to think about.

Next we have to think about the alkalis. So we can limit our alkali content by using a low alkali Portland cement with an alkali equivalent or NA 20 equivalent less than 0.6%.

We also want to ensure that the alkali content in the concrete itself is low, generally less than five pounds per cubic yard. That's something that a lot of people don't think about. We can use a low alkali cement and put in 800 pounds per cubic yard of cement and get the same actual alkali loading as

using say a high alkali cement at 450 pounds per cubic yard. So we have to think about the total alkali loading.

Supplementary cementitious materials like I mentioned, can contribute alkalis, but oftentimes, especially if we're using a higher quality SCM like a class F fly ash metakaolin a silica fume, they'll actually reduce the alkali loading and they'll also actually alter the microstructure to help bind the alkalis that are being contributed by the Portland cement, so they can't actually participate in as great of a degree in ASR.

And then we can limit the availability of moisture, so that could be done in some ways just through design of the structure itself. So if we think about let's say a bridge deck; does the bridge deck have adequate drainage? Does water pond on it; anything that's going to provide moisture can help drive ASR.

And then we can do other things that will help to reduce the permeability of the concrete through mixture proportioning, using a low water to cement ratio. We can use supplementary cementitious materials to reduce the permeability, and we can also use good curing practices to minimize early age cracking, shrinkage cracking which provides rapid access for let's say, de-icing salts to get into the concrete.

So oftentimes we're looking at a combination of all of these approaches. Let's say using a low alkali cement, using an aggregate which has as low of a reactivity as possible, and then using supplementary cementitious materials to try to mitigate any remaining expansion.

I would say out of all the options here that SCMs or supplementary cementitious materials are the most effective and have been demonstrated over the long-term to be the most effective method to mitigate ASR.

The most effective mitigators are primarily Class F fly ash and metakaolin, probably followed by silica fume. And then our least effective SCMs for mitigating ASR are Class C fly ash and slag. That's primarily because they typically have a higher alkali content and they also bring a lot of calcium into the system versus those other SCMs which are lower in calcium.

And these help with ASR in quite a few different ways. One by reducing the permeability. So most SCMs will react with calcium hydroxide in your concrete in the presence of moisture to form calcium silicate hydrate which a gel like binding phase in your concrete, and that will help to fill up pores.

It will help to densify the matrix and reduce your permeability. So it will reduce the availability of moisture within the concrete.

And then the formation of the CSH phase with the use of supplementary cementitious materials actually forms this new phase that has additional sites for binding of those alkalis. So they act like a sponge and really any external alkalis that are floating around in the concrete are actually bound into this supplementary CSH. And so they no longer become available to participate in things like ASR. So SCMs are very effective.

There are a lot of other things out there. There are companies that sell lithium based admixtures to mitigate ASR. But really proven over the long-term is the use of supplementary cementitious materials.

So you can see a few examples here. This again is with fly ash and metakaolin under the accelerated mortar bar test or ASTM C1260. This is using that very reactive aggregate from El Paso.

So we have expansion of the control material of approximately .7% at 14 days; around .82% at 28 days, an extremely active aggregate. And as we incorporate fly ash and metakaolin we can bring that down to a level that's actually acceptable or nearly acceptable, depending on what your limit state is.

So even with one of the most reactive natural aggregate sources that we know about, we can incorporate some SCMs and mitigate that expansion.

All right and finally I just wanted to cover a little bit on mitigation of ACR. Mitigation of ACR is challenging. It's almost impossible. The best thing that you can do is avoid the reactive aggregate.

ACR does not require a high alkali content, so even using a low alkali cement really has no influence on ACR because it works very different from ASR. So in ASR the alkalis that we're using were actually being bound into the reaction product so they can't participate in ASR any further.

In the case of ACR, those alkalis are actually recycled back into the system. So they're going to keep going in and reacting any reactive material in your aggregate until it's all completed. So it's very difficult to mitigate with either using a low alkali cement or SCMs.

So really the best thing we can do is use a non-reactive aggregate. Reducing the maximum size of the aggregate has also been shown to reduce the influence of ACR. And then blending of no more than a 20% of a reactive

aggregate or an ACR reactive aggregate with a non-reactive aggregate has also been shown to be effective. And that's also discussed in UFGS.

So just to summarize briefly, AAR including ASR and ACR are important considerations for concrete durability. They occur throughout the Corps.

We think about these things and many other agencies, local DOTs think about AAR all the time.

So for both of these reactions we need a reactive aggregate with reactive mineral components or a combination of minerals. We also need moisture and we need alkalis.

We know that ASR occurs much more frequently than ACR. There's lots of test methods that are out there for all of these AAR mechanisms. They all have their benefits and their tradeoffs. So some of them are useful for say rapidly evaluating an aggregate, but they may be as effective at looking at something that's marginally reactive in the long-term.

Some of them can only be used on fine aggregates, not coarse aggregates. Some of them can't be used for mitigation. So you really have to use the test that fits your needs.

We know ASR can be mitigated by reducing permeability using SCMs; using low alkali cements, chemical admixtures, but we know that ACR is very difficult to mitigate. And one of the best things that we can do there is to understand the reactivity of our aggregates initially versus trying to fix things later.

So that's what I have put together. I thank you all very much for tuning in and I'd be glad to take any questions that you have. And you've got my email address here, so if you'd like to shoot me an email, I'd be glad to talk there or we can set up a time to talk on the phone. So, thank you very much.

Courtney Chambers: Excellent, thank you Robert. I'm going to return our participants to interactive mode.

Operator: All participants are now in interactive talk mode.

Courtney Chambers: So at this time you're free to unmute your phone line and ask your questions. Or again, you can use the Chat feature in the lower right-hand corner of your screen.

Okay, I received one question privately asking, what are some good methods to treat ASR in existing structures.

Robert Moser: Okay, that's a good question. So I would say it depends on what type of structure it is. So if it's - let's say it's - if it's a dam you have big massive concrete elements that are experiencing ASR.

And so some of the things that are currently being developed to mitigate ASR in existing structures are largely focused on pavements and so they're for thinconcrete elements. So they're using things like sealers to minimize the intrusion of moisture.

There's also examples where people have tried to use lithium based admixtures which have some mixed results. But in a thinner element you can actually make some - you can get some benefit out of those. So you apply let's say, a lithium admixture to the surface or you vacuum infiltrate your

concrete with a lithium based admixture, and it can help to in a minimal way, to mitigate ASR.

But when we think about a massive concrete element, nothing you're really going to apply to the surface is going to penetrate all the way through that concrete in any meaningful way.

And so historically for those massive elements we - if we can deal with the ramifications of ASR, we deal with them. So if a joint closes and it starts to build up stresses in the concrete, then we cut that joint open using like a diamond wire saw or something.

So we could either relieve that by cutting open the joints. Another way that that could be done is by helping to confine the concrete. If we have a moderately reactive aggregate providing expansion by pre-stressing or post-tensioning the concrete, it can help to minimize expansion.

Generally if we put say 500 to 1000 psi of post tensioning force in the concrete, you can significantly minimize expansion. Rather than expanding the concrete it forces the gel to migrate throughout the concrete and find pores.

And that's generally been pretty effective, but it's very expensive. And on a massive concrete structure, to think that you have to, you know, triaxially confine the concrete to mitigate expansion can be expensive.

But that's really the only ways out there for existing structure to try to reduce the effects of ASR.

Courtney Chambers: Great, thanks Rob. Any other questions this afternoon?

Robert Moser: I think the only other question - I got a question in my Chat box from (Ed Brown) who's in Florida where their geology is mostly locally available limestone aggregates or carbonate aggregates.

Really you know, there's little to no issues with at least your coarse aggregates. Your fine aggregates, if they're straight quartz are relatively pure as well, not ASR reactive. And they're not ACR reactive because they're mostly calcium carbonate. They're mostly calcite. Really not much dolomite, at least if you're looking at like pleistocene limestone.

If you've go say in North Florida that could probably be different, but most of the Florida aggregates that I'm familiar with don't really have many issues.

Courtney Chambers: Okay, thanks Rob. If you all noticed I posted the link in the Chat box where you can - I'm not sure if can click on it or copy it if you can. If not, write it down, but that's the link where we post our DOTS presentations and the PDF of today's presentation will be loaded there shortly after the meeting today along with the recording within the week will be posted there.

Any other questions? Well you were a wealth of information Robert. Thank you very much for sharing with us today.

Robert Moser: Thanks Courtney. Thanks everyone.

Courtney Chambers: Yes, you've already shared your contact information and such, but any other final comments before we wrap up Rob?

Robert Moser: I appreciate it. If you have any questions just shoot me an email and we'd be glad to talk or help. And my office number is 601-634-3261.

Courtney Chambers: Okay, great. Thank you very much Robert. And thanks to all of you who have shared the names of those of you calling in a group. If you haven't done that please go ahead and do so.

And just a reminder, if you listened in today and would like a PDH, shoot me your full name and affiliation and I can email that to you. And I've received number of them already. Thank you all very much.

And thanks for participating today and please watch for upcoming announcements for our next meeting from (Cynthia Banks) here at ERDC. Thank you all very much. Have a good afternoon.

END