Ultra-High Performance Concrete for Prefabricated Bridge Element Connections
Webinar 1 – Introduction to UHPC
Transcript from Webinar

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Ladies and gentlemen, thank you for standing by. Welcome to the Introduction to Ultra-High Performance Concrete for Prefabricated Bridge Element conference call. Today's conference is being recorded. At this time all participants are in a listen only mode. If you should require assistance during the call, please press star and then zero. I would knowledge the conference to your host, Jag. Please go ahead.

Thank you. Welcome to the webinar series and Ultra-High Performance Concrete for Prefabricated Bridge Element Connections. I am Jag and I will be our moderator for today's session. With me in the background is Tim Luttrell, my cohost for the session. Today's webinar is the first of the UHPC webinars we will be hosting between now and August 2017 to provide interested agencies and private entities with information on UHPC uses, benefits, and lessons learned. We have an exciting line up of topics and speakers for you, but before we dive into today's call, I will tell you a little bit more and cover administrative items. The first is a set of poll questions that will help us learn about the demographic of the participant make up for today's call. As a reminder, for those of you calling in, please mute your speakers and we will launch the first set of poll questions here.

Everybody will get a few minutes to complete the poll questions before we close them.

[pause]

It looks like we are getting a good response rate. We will leave it open for a few more seconds before it closes. Okay. Thank you for your participation. At this point, what I would like to say is if we have multiple people in the room that are not registered within the NHI system and if you want a PDH certificate at the end of the webinar today, please insert your name and email address in the chat box so we can capture your information and send you a certificate by email once the webinar is done. You can do that at any time during the webinar. Also we believe the line open at the end of the webinar for about 30 minutes or so, so we can capture all of your information. For those who have not registered, if you are in the room, multiple parties are multiple people are attending, please use the chat box to put in your name and email address for the certificate if you would like one. Also the chat box that you see there is a good medium for communication with the presenters in terms of asking questions.

So I would say please use the chat box, typing in questions as we go through the webinar. This webinar is the first in a series of six that will introduce the ultra-high performance concrete innovation as part of today's presentation. The focus of today's webinar is on defining Ultra-High Performance Concrete, its composition, mechanical properties, durability, cost, applications, and ways to make Ultra-High Performance Concrete. Today's webinar will last 90 minutes. The first 60 minutes are allocated to speakers and the last 30 minutes are for questions. Again, use the chat pod to your questions as we go through today's webinar because that is the only means of communication with the presenters today. We will be unable to take questions via phone call.

At the end of the presentation, the formal presentation session, the speakers will be back on as a technical panel to answer any questions that you posed in the chat pod. For today's webinar, we have two experts and two presenters. The first presenter will be Mark Leonard and the second will be Ben Graybeal. The transition between the two presenters will be handled by them as they go through their presentation.

Some information about Mark is he is a structural engineer on the FHWA Research Center Technical Services Team. He provides technical services training and reviews services for highway structure design and preservation. He began in 2012 and has 28 years as of experience as a structural engineer and at the D.O.T., including 12 years as a state bridge engineer. He is a registered professional engineer in the state of Colorado and is a graduate of the University of Notre Dame with a bachelor of science in civil engineering. Mark is also an FHWA innovation lead.

The second presenter for today is the technical subject matter expert Ben Graybeal. Ben is the team leader for bridge engineering research in the FHWA office of infrastructure research. He also leads FHWA's structural concrete research efforts. Ben's expertise includes bridge engineering, concrete materials, and forensic investigation. In terms of today's webinar, he will be presenting the bulk of the introductory materials regarding UHPC. He has a wealth of experience with UHPC having been the leader in the HPC community when FHWA began research on this topic in 2001. But before we get to the Ben, I want to send the presentation over to Mark first. Mark will give you an overview of the UHPC innovation.

Thank you, Jag. As Jag mentioned, today's webinar is made possible by FHWA's Every Day Counts initiative. In 2011, FHWA started the initiative to promote innovative technologies to help us build roads and bridges better, faster, and smarter. Since 2011, there have been four two-year rounds of Every Day Counts. With each of these rounds that you see here, FHWA has promoted 10 to 15 different innovative technologies or processes.

For Every Day Counts 1, the bridge-engineering-specific innovation was prefabricated bridge elements and systems. Prefabricated bridge elements and systems were promoted to decrease on-site construction time and to improve the durability and quality of bridges. Prefabricated bridge elements were also included in round 2 as a part of accelerated construction, and the focus was on accelerating on-site construction time.

The structural engineering innovation for rounds 3 and 4 of Every Day Counts is Ultra-High Performance Concrete. It is an extension of rounds 1 and 2 because Ultra-High Performance Concrete is being promoted as a means to improve the connections of prefabricated bridge elements. The purpose of the Every Day Counts deployment of Ultra-High Performance Concrete is to promote the use of Ultra-High Performance Concrete to improve the connections of prefabricated bridge elements. Ultra-High Performance Concrete can be used in, and improve the strength, simplicity, and durability of, those connections.

The goal is by the end of Every Day Counts or bridge designers, construction personnel, and materials engineers across the country, to have an understanding of what Ultra-High Performance Concrete is, the benefits to using it for connecting prefabricated bridge elements, and where more information can be obtained.

When Every Day Counts 3 started in 2015, there were 12 highway agencies in the country that had used Ultra-High Performance Concrete and there were about 52 bridges where Ultra-High Performance Concrete had been used in their construction. Over the 2-year period of Every Day Counts 3, that is from 2015 through 2016, 8 additional highway agencies used Ultra-High Performance Concrete for the first time and 28 additional bridges were built using Ultra-High Performance Concrete. So now, as of August of last year, there are 20 highway agencies that have used Ultra-High Performance Concrete, and there have been 80 bridges in the country that have been constructed using Ultra-High Performance Concrete in some form. The New York State D.O.T. has the most experience with Ultra-High Performance Concrete, as you can see looking at the map there. There are a lot of dots around New York and over half the bridges, half of the 80 bridges in the country that have used Ultra-High Performance Concrete are located in the State of New York.

Looking north, you can see that Canada is also a frequent user of Ultra-High Performance Concrete. Canada has around 80 bridges that have used Ultra-High Performance Concrete in some form. FHWA continues to promote this increasing familiarity with Ultra-High Performance Concrete through Every Day Counts providing technical assistance, workshops, webinars, peer exchanges, and presentations. In this workshop or this webinar today, the first of six, is part of this effort.

We will speak a little bit about workshops. To date, there have been 18 highway agencies that have hosted workshops, and if your State agency would be interested in hosting a workshop, get a hold of me. My contact information is given at the beginning and will be given again at the end of this webinar. FHWA is working with Leidos and with Parsons Brinkerhoff to bring the workshops and webinars to you and it is good to have the consultant team on board to help host the webinar today—and again, if you are a State that is interested in hosting a workshop, we can get that to you in the future—the purpose of these webinars is to share a subset of the most important information from the workshops.

We can reach a wider audience with the webinars. Also, the webinars, which you will see in the webinars 2 through 6, we have guest speakers that do not attend the workshops. So that is an extra feature we get through the, hosting these webinars, we get to reach a larger audience and we get to have guest speakers.

FHWA, let me say one more time, is also available to provide technical assistance. As Jag mentioned, I am the coordinator, so if you have a questions, if there is any assistance FHWA can bring you, be sure to contact me. Ben Graybeal who is with the Turner Fairbank Highway Research laboratory is the FHWA technical expert.

With that, I will turn it over to Ben Graybeal.

Thank you, Mark. Thank you for that introduction. Glad you are all here and glad you could sign in to hear this webinar. We are kicking off this webinar series where we are going to learn a lot about UHPC. This first webinar is obviously an introduction to UHPC, sort of a broader picture of what UHPC is and how you might want to use it. As we go deeper into the series throughout the successions, we will get more depth of information and more viewpoints about UHPC and how it can be used and deployed successfully, how it can help you solve challenges you might have in highway infrastructure.

I work for the Federal Highway Research Center. I have been here for almost 2 decades and have been involved with research, development, and deployment of UHPC for about 16 years. So, I have a good length of service on this particular topic. [I've been involved in] a lot of papers, a lot of articles, a lot of research reports. I am pretty well known in UHPC, and I suspect some of you have heard me talk about this topic. We do have some resources before getting into the meat of the matter here.

There is a file sharing pod including downloadable reports, PDFs of the slides for this webinar, the series announcement for all the webinars, and all that information is in the file sharing download pod, so feel free to grab some of that. The UHPC highway report is something that has been published in 2013. It includes a lot of the history of concrete and a lot of research that has been done to that point. It is a good resource of information if you want to know the back story of Ultra-High Performance Concrete.

Another great resource is the website for my research group for Ultra-High Performance Concrete. The simplest way to get there is to just to open a search engine and type FHWA space UHPC. It should be the top when it comes up on your search. That will take you into the site. It includes basic information on UHPC and access to a lot of the different reports and deliverables that we have produced over time.

Mark, a minute ago, you showed a map that showed a little like this, but I want to talk about it also. This map is also accessible via that website. This is an interactive map that tells you something about all the different deployed instances of UHPC on bridges across the United States and Canada. These are bridges that are open to traffic and completed. They are not projects that are hoped to happen in the future. These are all done. At this point, there are more than 130 of them and what you can do, go to the next slide here, if you can see them, grab some information about each one.

They are not just flat. If you click on the dots, you can get information. The one I am showing right now was one of the first bridges constructed in the U.S. using UHPC with prefabricated bridge elements. It was constructed in 2009 by New York State D.O.T. It's 8 years old and still performing well. You can see, you dive into this map and get more details and get some pictures on some of these bridges, so it is a pretty cool feature some might want to try out.

What is Ultra-High Performance Concrete? I suspect a lot of you have heard of UHPC and some may have even used it but what is it really? The way I like to explain Ultra-High Performance Concrete is that it is really a combination of lots of advancements that have happened in the field of concrete. In the past 40, 50, even 60 years, there have been continuous advancements. Concrete is infinitely malleable. They are 70 different ways we can advance it and make it better. With UHPC, we took a lot of the advancement and put them together in one package. I am showing on the screen some of the different advancements that go into making concrete a UHPC. Fiber reinforcement is one; it has been around for a long time and is an integral part of UHPC. Particle packing theory as well—you need to have the particles packed together tightly. You need to have the material almost flow without having to add extra water. That comes from the particle packing theory. Super plasticizers are very important—particularly the most recent are very important to making UHPC behave the way you want to today. Finally I will mention supplementary cementitious materials. It is a Portland Cement base material. They do help a lot in making UHPC have the properties that you want it to have.

The American concrete it's just the committee on UHPC. Those familiar with ACI, they have a lot of committees and the ACI 239 committee I am a member of has come up with a definition of Ultra-High Performance Concrete and it is shown on the screen. As you read it, you probably think that does not say very much. It is a nebulous definition. There is a compressor strength number in there, but beyond that it just sort of defined the other things. That is true. UHPC is a little hard to explain exactly what it is. For those of us well-versed in it, we sort of know it when we see it. We know it has these properties, advanced properties, but putting the hard numbers to it is sometimes difficult, so there is discussion about what actually constitutes a UHPC. From Federal Highway's standpoint, we put some extra numbers to it because we know it is important, because our sector is one of the heavier users of this class of material.

The definition on the screen talks about the fact this is a Portland-based concrete with a water-to-cement ratio less than 0.25 that has a lot of fiber reinforcement and a compressive strength of almost 22 KSI. Probably most importantly, it has a sustained post-cracking tensile strength more than about 720 psi or five MPa, and I will talk more detail that some of the numbers—there's a lot of different details to going to making a UHPC.

Talking in more general terms, if someone said to you what is UHPC, there are a few ways to describe it to help them understand. One way to think of it is it is a highly durable strain hardening concrete. The high durability is self-explanatory. We want it to be durable, and UHPCs are very durable. Strain hardening, I bet some of you think of it in terms of steel, a property that steel exhibits after yields and eventually gets into a strained hardening stage. We sort of adopted this term for UHPC because it gives a good description of the tensile behavior of a UHPC. Basically once UHPC gets out of the elastic behavior, once it begins cracking, it begins in elastically deforming, as opposed to conventional concrete which just loses its capacity, UHPC has fibers that will stitch across the cracks and allow the UHPC to continue to carry tensile forces even after cracking. You will have a progressive cracking with more and more and more cracking while the UHPC can continue to carry tensile load. It is a high-end fiber reinforced concrete.

Another way to think about UHPC is as reinforced concrete. We are pretty familiar about reinforced concrete. You build a cage of steel and cast concrete around it and you have a reinforced concrete structural element. Imagine if you took that element and shrunk it down. Imagine if you took the rebar and concrete and reduced the order of magnitude of the sizes of all those constituents to a much smaller scale, so instead of rebar you have steel fibers and instead of being measured in foot lengths, they might be measured in millimeter lengths. If you scale down the whole thing and put lots of steel fibers and make that into the concrete, you can create a mesh that creates a micro reinforced concrete, so that is another way to think about UHPC. The last way is the most nebulous. It is a resilient cementitious composite. It is more resilient than what we expect of concrete. Its properties are much better and it made just a resilient material that meets the demands of whatever you choose to use it for.

Now that we know about what UHPC is, let's talk about where you can get it or how available it is. There are proprietary versions of UHPC that are available in the market. You could look through a supplier and obtain some UHPC from them.

It's just like you might obtain a prepackaged grout you might use in some applications or a repair material you might use. You can also purchase UHPC. In this way, a private company has developed a robust material and they're supplying it to you. You are buying it from them and they're taking on some liability to make sure the product will work for you. On the other side, I am showing a nonproprietary version. I am showing an executive summary of a report where I hired Dr. Kay Willie to develop a nonproprietary mix design. There a lot of these designs out there, and a lot of academics are working on developing mix designs that are basically UHPC. Just like you develop conventional concrete mix, you can also develop a UHPC mix design. To give you a sense of what is in a UHPC, there is not one definition of what constituents make up a UHPC but what I am showing on the screen is an example mix design from some work that was done in Germany by Teichmann and Schmidt. And for those who are materials folks, you can say that is a lot of cement and you add on top of that a lot of silica fume and that is true. The way these mixed designs are put together, you do tend to have a lot of Portland cement and a lot of silica fume. You tend to also have sand. There is frequently very little if any course aggregate. It is a very fine mix. Some might say a sort of pasty, but that is the way you put together UHPC, so when you add in the steel fibers, in this case over 300 pounds per cubic yard of steel fibers, you would know that is a lot of steel fibers.

These fibers can be short, small, but they can be very, very effective at stitching together the material. You will also notice there are a lot of super plasticizers used given that we have water cement ratios that are commonly in the 0.18 to 0.20 range, which have as much as we might have within normal concrete mix design. Given the very low water amounts, we need to use a good amount of super plasticizers to make the system work, and then you can finally see the water content there. The water cement ratio is quite low.

On the next slide I have another mix design. This comes out of the report I mentioned at the University of Connecticut. In this case, there is some fly ash in there, but it's a pretty similar design. This has steel fibers in a lower content, but in general this is the kind of thing you might see from a UHPC mix design.

Let’s talk about the fiber reinforcement. Steel fibers are most commonly used in UHPC, particularly in a UHPC you're using for a structural application. If you do not use steel fibers and you use some sort of plastic fiber, you will end up with a low stiffness fiber, and that does not bond the material together as well across those cracks that form and eventually want to surpass the cracking strength in the UHPC. Steel fibers are stiffer, and they bond very well into the matrix, so they end up giving you good structural performance. If you have a structural application where you want to use UHPC, in all likelihood you will use steel fiber reinforcement. I am showing on the screen some fibers that is a common fiber size for UHPC. These are 0.20 mm in diameter and they are about a half inch long. These are really small fibers. Imagine as a best case scenario that you have a quarter inch of fiber on either side of a crack. But the matrix is fine enough that the cement tissue matrix of the UHPC is fine enough that it can grab onto the fiber in a very short distance and still provide good tensile resistance across any crack.

Costs, people always like to ask me questions about cost. I will start out by saying they are expensive. The primary reason for the expense is the constituents that go into UHPCs are expensive. If you are putting more than 200 pounds of steel fibers into a cubic yard, those do not come for free. The cost of UHPCs can be high. I am showing on the screen here the cost of some other things that are somewhat similar to UHPCs, at least in ways that UHPCs are being used most commonly today across the United States.

It is not uncommon for State agencies to purchase Portland cement grout or repair mortars. Sometimes they might use epoxy grout, and those materials can be pretty expenses per cubic yard, but people do not usually think about them per cubic yard. People purchase them in smaller quantities and do not think about them as multiplying it out to how many dollars is it going to be per cubic yard of this material.

UHPCs fall in the middle of the number you are seeing. They are expensive if you compare them to a ready mix or what a pre-caster might incur when they make concrete. UHPC is a lot more expensive than that. But compared to some of these other specialty materials, the price is pretty similar. At the bottom I show the constituents, rock constituents. If you developed your next design, you probably would be at least in $800 per cubic yard just in terms of purchasing the cement, sand, silica fume, water, flash, steel fibers. If you did other things, you're probably at least $800 and not including the proportioning, R&D, making it robust, quality control, all those sorts of things. Just to give you a sense of the cost of UHPC.

Let's talk about the material properties of UHPC. People often think of UHPC and think that is the really strong concrete. We also think of compressive strength. It is an important part of its behavior. It is a little hard to use this from structural design standpoint because it strength is often in the upper 20s of KSI sometimes even up into the mid-30s. So the definition is to put the compressor strength level at about 22 KSI, but I have seen UHPCs in the upper 30s, so it is extremely strong in compression. But what do you do with that from a design standpoint? That is an open question. I am showing the stress response for UHPC on the solid black line. This particular cylinder on the right side of the screen popped out at about four, and just for comparison, there is a six KSI conventional shown by the dotted line. You can see the UHPC has a higher stiffness and elasticity and a much higher compressive strength, four times higher. It is more of a linear behavior, too. It does not bend over, and does not take the parabolic form that we normally think of for concrete in terms of compressive strain response. It is more of a linear response until it gets to the peak and goes over.

People are also asking about the maturity of the concrete or how fast you can gain strength. That is what I am showing on this plot. We have compression strength of the Y axis and days after mixing on the x-axis. In this case, I am showing three different scenarios. They are all the same mix design. We have one single UHPC, but that UHPC was cured in three different ways. The green line shows the UHPC that was mixed and cured at 50°F. The blue line was cured at 73°F. The red line was cured at 105°F. We have different strength. This is not surprising. It has a lot of super plasticizer in it that acts as a retarder during the early ages. You get sort of a dormant period at the beginning and then the reaction kicks off. We see the same thing in conventional concrete. Once the reaction starts to happen with UHPC, it can happen very quickly. You can see we put extra heat to it and the reaction can almost be a vertical line where you're going from almost no strength up to around 12, 14 KSI within just a few hours.

Again, if you are in a colder situation down to 50 Fahrenheit for instance, it does take longer to get to that strength. Eventually the materials will reach about the same strength level. Is a cascade of chemical reaction that happens within a Portland cement base material and eventually those reactions all do occur but it is a temperature base. The more temperature you input, the warmer your ambient environment, the faster those reactions will occur.

Tensile behavior is where things get interesting. Conventional concrete and tension, we normally think it is elastic until it cracks, then after it cracks it is done. We do not count on the tensile resistance any further after the cracking happens. With UHPC, we are in a different scenario. We have elastic behavior, and this particular UHPC has a tensile strength or cracking strength of a little more than one KSI in a curve I am showing you here. After it cracks, what you get is progressive cracking. There are enough fibers bridging any one crack that it can carry the load that was previously carried by the cementitious matrix before it cracked. We have a sustained tensile resistance that will last out beyond 6000 micro strain. Earlier when I mentioned the strain hardening response, this is the sort of thing I am talking about, where after we get into that inelastic regime, it continues to be able to carry tensile load. This changes how your structural elements will behave when composed of UHPC. It makes it fundamentally different than conventional concrete elements.

I am showing on this slide stress-strain responses for five different trends. They were all tested in tension, direct tensile loading, all of them had 2 percent steel fiber reinforcement, and were tested before they reach their full compressive strength. They were in the 13 to 16 KSI compressive strength range when the tests were run. You can see these materials all behaved pretty similarly and all had some tensile resistance after cracking. Four out of the five had a very similar response and the green one dropped off a little sooner in this particular test just to give you a sense on how some different UHPCs behave in tension. I talked a good bit about fiber reinforcement so far, it is very important. On the earlier slides, I will back up and show you again, these were all 2 percent steel fiber reinforcements. If we add in more reinforcement but otherwise keep everything the same, you can get better response in attention from the UHPC. Fiber is expensive but you can get better performance, and you have to decide whether you want to pay for the performance. But fibers do certainly impact the tensile response of the UHPC as I am showing here with some 4.0-4.5% fibers, you can enhance the performance of the UHPC. I do not want to go too deep on the slide but I do want to point out a very important thing about fiber reinforced concrete. That is that fibers in concrete are basically one-dimensional little sticks that are interspersed throughout the cementitious matrix.

If those are randomly distributed throughout the concrete, that is a good situation. If those are all, if they all for whatever reason sank to the bottom of the concrete or if they are all aligned in one particular direction, that is not as good a situation. So when you are using fiber reinforced concrete, you need to keep in mind that fiber dispersion and fiber orientation matter. These sorts of materials can display anisotropic behavior, so they have different mechanical properties in different directions. You need to keep this in mind. It’s certainly not insurmountable, but it needs to be considered.

This screen shows the stress-strain response as a series of tensile test that were completed on UHPC—the same UHPC, the same slab of UHPC, but it was cast in a way that forced the fibers to align in one direction. Not 100 percent, but they had a tendency to be aligned along the direction of flow, which happens with UHPCs. We cut out different pieces and tested that indirect tension. We got different responses depending on which orientation we're using, and that is anisotropic behavior, so you can see this kind of thing with high-end fiber reinforcement, which is what UHPC is, and it does matter but it can be handled.

A little more about tensile behavior: cracking from a structural standpoint. You may see cracks in the UHPC, or you may not. I say it that way because what I am showing the right side of screen is a picture of a microscopic crack. In the upper right, you see a 0.1 mm, a pretty small distance, and you can see how much smaller that crack is than 0.1 mm. The structural cracking was the end UHPC, they may be externally small. Even though you cracked a section, cracks are so small that they are on the order of the disturbances that exist inherently in conventional concrete, uncracked conventional concrete. I point this out to give you a sense of the sort of behavior when you get this micro-reinforced concrete with all the steel fibers holding it together.

Another material behavior to be aware of is interfacing, to give it as a cold joint. You have existing conventional concrete, you prepared the surface, you roughened it somehow, and you will cast some UHPC against the surface. How well does a UHPC bond to a concrete substrate? What we have done is tested in a few ways from a bending perspective, which is shown in the upper left. We have also tested direct tension. I don't want to go into the details, but what we found is different UHPCs are different, but in a general sense, trenches combined to a conventional concrete at approximately the level of the tensile strength of the conventional concrete. So conventional concrete might normally have tensile strength in the 250 to 350 PSI range. UHPCs can bond to conventional concrete at about the same range. That is the best you can do, and that's shown by the picture in the upper right. That was a bending test where instead of failing at the interface, we ended up seeing it fail in conventional concrete about half an inch away from the interface.

Shrinkage matters. For concrete, we know Portland concrete shrinks. The mix design, just like with conventional concrete, will determine how much it shrinks. In UHPCs much of the shrinkage is called "autonomous shrinkage," which is due to chemical circuits that happens within UHPC. Trenches do not have a lot of extra water. It gets used up in a chemical reaction. For trenches you will see some shrinkage. Some materials drink less, like you can see the red line there. This is shrinkage after a setting; in this particular case, it was drinking around 200 micro strain, some other materials shrink more up to 800 micro strain. Certainly you could have trenches that use less than this, but you could have some that use a lot more. It does depend on your mix design. Shrinkage is important; it does matter, and trenches will exhibit shrinking. I would like to show you this picture because it is pretty cool. For those not familiar, looking at a wharf that is at low tide during the picture. It is a U.S. Army Corps of Engineers test facility for concrete up in the Bay of Fundy North of Maine and they have tides that submerge that wharf every day. Twice a day. You can see the people there standing on the wharf looking at the concrete assessments. Strap concrete to this wharf and see how it lasts. There are pieces of UHPC that have been strapped to this wharf for 15 years now.

They are still there and performing well. Lots of pieces of concrete that appear might only last a year or two, and they are just gone. Is a very aggressive environment with saltwater, freezing, and thawing twice a day, it is not a nice place to be most of the time. Probably some nice days in the summer like they are showing here. But UHPC has been shown to perform really well in this sort of aggressive environment. Why is that? One of the primary reasons is because UHPC is far less permeable than conventional concrete. I do not want you to get bogged down in the numbers, but if you look at the exponents, you can see conventional concrete, the number is 10 to the minus 11 in terms of diffusion coefficient. For high-performance concrete, it is 10 to the minus 12, which is one magnitude better. You go another order of magnitude better than that when you get to UHPC. UHPC is about two orders of magnitude less permeable than what we have for conventional concrete and one order of magnitude less permeable than high-performance concrete. It is basically really hard for the water to get in, and if water cannot get in, then the things that water carries like salt, they also cannot get in and that means the concrete will be much more resilient in terms of durability. Here are a few more durability plots. The one on the left is rapid chloride test and the one on the right is freeze-thaw testing. Do not get stuck in the details. Just realized that for the rapid chloride, those numbers are all low. The top of the plot goes up to 1,000. If you look at the 56 day numbers, for materials shown there, they are all 500 or less so very good rapid chloride numbers.

You can see that all materials are right around 100, so basically they kept their dynamic elasticity throughout the testing, and normally the test is only run for 300 cycles. What you're seeing on the screen is that they were run for 600 cycles for most of them. Very good performance from the standardized durability test.

One last test to talk about is one you will hear a good bit more about the this series. This is a bond of UHPC or rebar into the UHPC. This is critical to prefabricated systems and how the UHPC performs when you have rebars embedded into the UHPC. We are doing a lot of testing on this. The picture on the left is showing you some rebar lapse slice where we have the UHPC element shown in this case in sort of a brownish color. In a tension configuration, there are bars below holding it down in a bar in the center that we are testing by pulling up on that bar. We want to see if we embed that bar a very short distance what kind of stress can we develop in the bar. What we found is that in very short embedment, we can actually develop the bar well beyond its yield strength. The rule of thumb is whatever the number size of the bar is, you need to embed at least that many inches. That is a very short distance as compared to conventional concrete. There is a lot of design guidance that has been published on this topic and certainly much more than I will explain here in the few minutes I am spending on this. The take-home message here is when you micro reinforce the concrete, you can create passive reinforcement around the rebar, and that can basically stop the rebar from splitting the concrete and pulling out of the concrete nearly as quickly as it would in a conventional concrete. Some ballpark properties on UHPC - compressive strength is pretty high in the 20s generally up to the mid-30s of KSI. The modulus of elasticity is twice what we have for conventional concrete. A good thing tensile capacity usually is about one KSI. The interface bond can bond very well to conventional concrete, and it is a lot less permeable than conventional concrete. Good freeze thaw and rebar bond is eight times your bar diameter in terms of delivering you'll strength in that bar.

Let’s change gears a little bit. Let's talk about what's UHPC looks like and how you might use it. This is a picture in a central mixer in a precast. UHPC can be mixed a lot of different cards and mixers. This is a large central mixer. Fibers are being poured in and dispersed in the UHPC matrix. Portland cement, sand, all those parts have already been mixed to sort of be a paste like consistency. The fibers are generally added at the end.

The mixing continues until the fibers are dispersed throughout the UHPC mix. This is mixing probably 3 cubic yards in a large mixer. That is not the only way you can mix UHPC. You can mix it in almost any concrete mixer. The energy put into it defines how much time it takes to complete the mixing and how warm the UHPC gets during the process. This is a case where the UHPC is mixed in a ready-mix. Trucks of the dry constituents were added to the truck and it is a drama mixer. It took about 45 minutes. The UHPC turned into the fluid type of UHPC that we would expect. It can be mixed into this sort of mixer as well. These mixers here are more the kind commonly seen on projects where UHPC is being used in connections between prefabricated elements. We have two half yard, half cubic yard mixers. They will be used in series where one is being loaded with the dry constituents while the other one is mixing and getting ready to discharge. You'll makes the back-and-forth or use them in sequence, so every 5 to 10 minutes you have another batch of a half cubic yard of material ready to be put into some wheelbarrows, driven out onto your breach site, and placed into the connections. That is a common way.

Another similar mixer is this one. It is more of a mortar mixer, but it performs the same way. You mix the UHPC and discharge it into some buggies and take it out onto wherever you needed to be.

The way you cast UHPC, this is a picture showing UHPC being cast out of the back of a ready mix truck. That case with a mixed in the ready mix truck and they were able to take the truck to the form work. They are casting a structural component here. This is a case where the ready mix truck is putting it into a trough and the toughest milling it out onto a plate-like element so you can see that UHPC flowing out of the side of the trough. This is a picture that is more common in terms of when you use UHPC between prefabricated elements. This is a great video except I cannot show it to you here in this format today so you will just get the first screenshot of it . There is a wheelbarrow full of UHPC being ported to connection. You can see the rebar sticking out of the components into the void and the UHPC will fill the void and be topped off with a top form.

Here is a picture of a location where we have deck panels and a hunch connection so you can see that's there and those studs are being surrounded by the UHPC. That UHPC is flowing down into the space between two deck panels and will flow underneath into a hidden connection between the deck panels and the supporting steel girders. A cool video, but I cannot show you in this format here today.

Just a few words about structural design with UHPC in terms of the broader picture, if you wanted to design a full bridge made out of UHPC or a building using UHPC columns and beams, how could you do that? Some parts of the world have advanced that far. In France and in Switzerland, they have developed full-fledged UHPC structural design specifications. Those are available. I have copies of them here on my desk. The French, for instance, as a supplement to the European code—and that is when I am showing there on top in the picture—tells you what a UHPC is, what test you need to run, how to design it from structural standpoint, and also how to construct it. The Swiss have a somewhat similar document that's a little simpler and more of a first principles document, but again it tells you how to design with UHPC. The Canadians are doing a similar process, developing materials, design documents, and then I will start structural design documents. In the U.S. we are just getting started on this.

Last week, March 2, 2017, I spoke to the concrete committee and told them that at Federal Highways, we are embarking on a process to write a structural design guide in the AASHTO format, and we expect in about 2 years we will have a draft ready for review. The process is getting started here in the U.S. I want to point out this is a document that is in the download pod and is titled "Design and Construction of UHPC Field Cast Connections." It tells you what UHPC is, gives you examples of connections, and provides structural design guidance, so it is produced by the Federal Highway that provides a code and commentary similar to what you see in the AASHTO guidance documents. It tells you how to design connections between prefabricated elements using UHPC in the connections. It also gives you guidance on construction quality assurance and gives good information on deployment. This is good information, and I would encourage you to download it from the file share and take a look.

One last thing I want to talk about is structural testing. There has been a lot of structural testing done, and this will be one slide to whet your appetite a little bit. This one is to precast deck panels or portions of deck panels on either side and in the center that gray area is a UHPC connection where we have a 6 inch wide connection and a noncontact splicing bar. They are number five bars with no hooks or heads. These are just straight bars embedded into the UHPC, and we saw very good performance. This ran through millions and millions of cycles. We had a leak test going and you can see water. We have done larger structural tests of girders, deck panels, lots of different things have been tested in the world of UHPC in the last decade or so, so it is a pretty exciting area. With that I will ask Jag to do another question.

Thank you, Ben. That is a very information packed, great presentation so far. Do not go too far. We are coming right back after these poll questions. I would appreciate if the participants can chime in with their experiences with UHPC . As we prepare implementation products, we would like to know more about your experiences. I will give you all 30 to 45 seconds to complete this before we close it.

[pause]

As you are filling it out, just a reminder, I am seeing some really nice strong, good questions coming from the chat pod. I encourage you to continue submitting them. We have a little over 37 minutes or so left with the Q&A today. We will try to get to some of these questions and those we cannot constantly we will have FAQs at some point to answer many of these questions. I think we are coming to an end to this poll. Thank you for participating in it. Back to you, Ben, to finish out.

Thank you for those answers. That is very helpful for us to get a sense of the knowledge of our audience. We have about 10 minutes left and I will give you a few more details on some different things, talk about appointments of UHPC. This is the Mars Hill bridge in Iowa in 2006, the first bridge structure constructed in the United States with UHPC. It spans 110 feet. I am showing you on this slide the traditional Iowa 45 inch bolt T pretensions elements on the left. On the right, this is how to modify the cross-section in order to use UHPC more efficiently. They made it narrower and shallower and spent a longer distance. That comes from the advanced mechanical properties that you get out of that UHPC. This bridge was constructed 11 years ago and has been in service ever since. You find yourself in the county, you should go and take a look. Here is a more structurally optimized shape called the pie girder looking like the Greek letter pie. You can see the deck as part of the structure and it is only a 4 inch thick jack, and the webs are only 3 inches thick.

It is more optimized to make use of the properties you get out of the UHPC. This is in Buchanan County Iowa. There are three girder side-by-side for the main span of this particular bridge. UHPC has been used for bridge decks and not as the connections before the deck panels themselves. The concept here is that you can use the UHPC and you do not have to have a uniform depth of bridge deck. It's a waffle slab design. You eliminate about 30 percent of the material that you do not really need. So it is ribbed into directions and it is made with some reinforcement that runs along the ribs, and the bridge deck is placed and connected together. In this case, UHPC was used for the field cast connections as well.

Here is the footbridge. Footbridge designers are getting very excited about UHPC. This is a channel structure, and in the right you can see what it looks like. This is a free spent structure with the main span spanning 250 feet. It has a span-to-depth of 42, which is quite a shallow structure. This post-tension structure, it is in Marseille, France, connecting this castle you see with a new modern museum. I will show it to you here in the next slide. This is basically a museum of European civilization and culture.

Here is another footbridge constructed in 2002 in South Korea for the soccer World Cup. You can see in the inset that it also uses a pie type shape. There are six elements that together make this arch structure. Here's the first road bridge constructed using UHPC in southern France. This bridge is sort of like I-girders connected by a UHPC plate on top. It was constructed more than 15 years ago, 16 years at this point.

Here is the largest deployment of UHPC in North America to date. This is the Pulaski Skyway in Newark, New Jersey, and it is undergoing a major rehab right now. Part of that is replacing the entire deck with deck panels and UHPC connections. You can see the Manhattan skyline in the background. This is a 3.5 mile long bridge with four lanes and also acceleration and deceleration and ramps and things like that. There is .5 miles of bridge using deck panels and UHPC, and that means there are a lot of deck panels and a lot of UHPC. Construction has been going on for years and it continues and hopefully will be done in the near future. Thousands and thousands of cubic yards of UHPC have been used on this project.

Here is a project from last summer, Franklin Avenue Bridge in Minneapolis, Minnesota that was redecked in the course of less than four months using precast panels and UHPC connections. I will show you what that looked like before they poured the UHPC. As you can see, the deck panels are in place and the inset shows rebar sticking out the space that would be filled by the UHPC. You have these relatively small connections and straight lengths of bar, but that UHPC can develop those bars in a very short distance, and that makes the construction very efficient. The fabricators like it because it is simple to fabricate something with a straight bar sticking out the side of the form. The construction guys like it because it is easy to assemble the pieces, because you do not have a lot of conflicts. This project was completed while the University of Minnesota was out of session during the summer months, so between the end of the semester the start of the fall semester they pulled the whole deck off and put it back on using deck panels and UHPC connections.

There are a few other concepts where UHPC can be used. One is for piles. Some of these have been manufactured and driven. Iowa again has been a leader in this particular technology. UHPC is being considered for seismic retrofit, so you might have a bridge whose substructure was not in a seismic region until the seismic region was redefined and became a seismic area. In that case maybe you do not have enough lap splice on your bars. You could do jacketing or different ways you could try to rehab that substructure, but one way would be to take off the conventional concrete around the bars and replace it with UHPC. Remember, what we can do with UHPC is short the development length instead of adding extra concrete and still jackets. You could just surround bars in UHPC and they would be fully developed. It is pretty interesting as a concept for connections and substructures.

This is a case where we had a deteriorated pier of the columns. I will show here that the columns right at the top—what we have is a 12 inch tall piece of UHPC that was cast, so instead of exposing a large portion of the column to connect the pieces together with field-cast concrete or use some expensive complex connectors, what you do is fill a volume with UHPC and splice the bars. Pretty interesting concept that was deployed in upstate New York a couple of years ago.

You can also use it for link slabs. There are a lot of situations where you have leaking joints, deteriorated superstructures because of the leaking joints, and strip seals that require a lot of maintenance. The idea is to use a structural material, but use it in a way that will not attract a lot of structural load to take advantage of the durability of the properties you get out of it. When the strip seal is removed and UHPC has been used, you have to tie together the deck a little bit. You have to change the bearing condition so you do not drive a lot of displacement into the deck where the UHPC is. You want to rotate about that point and not rotate about the bottom of the girders. It can be done, and New York has a played with a bunch of these and is having good success with getting better durability out of the system than they were getting out of some of the strip seals.

Another concept for UHPC is girder rehab. In some parts of the country there are a lot of steel beams that are in pretty aggressive environments under leaking joints, and you can see some ugly pictures there. This is also New York State D.O.T. The idea is to suitcase the end of the beam in UHPC. You take off the deteriorated stela, put on studs, cast the UHPC around it, and get the performance out of the beam without having to replace the beam.

Here is a project that was just completed a few months ago in Florida with adjacent boxes with deteriorated joints using hydro-demolition to take out the concrete around the leaking connections between the boxes. They filled it in with UHPC, and that is a picture you see on the right. They are expecting some pretty good performance out of this. It was finished in fall 2016, so we are getting to the first year. With this one, it's a pretty good concept, and there were a lot of adjacent boxes that could use some TLC, so it is a good idea.

Talking about UHPC for bridge deck rehabilitation, here is a bridge in Switzerland that was starting to have problems. It was about 45 years old when they started to see deterioration of the deck. As you can see on the inset, we have a pretty thin deck, and it will not be easy to replace. They took off the cover, the conventional concrete cover, and replaced it with UHPC. It was a strengthening with UHPC and also a hardening of sorts from a durability standpoint. They took off some concrete that was more susceptible to degradation and replaced it with a very durable concrete.

On the next slide you can see this is a bridge in a scenic but tight location. It is between a mountain and a lake, and at the far end of the bridge, it goes into a tunnel into a mountain. Replacing this bridge would be expensive, and there was not a lot of room to do a replacement in kind, so using UHPC was a pretty good solution.

The Swiss have deployed dozens of those sorts of bridge deck rehabs using UHPC. In the U.S., we are just getting started on this. Last May, they deployed dozens of those sorts of bridge deck rehabs using UHPC. In the U.S., we are just getting started on this. Last May 1, deployment of this concept happened in the U.S. near Brandon, Iowa. Here you can see the UHPC being spread out on a bridge deck that was starting to deteriorate, so Iowa D.O.T. and Buchanan County Iowa joined together to try out this new concept using UHPC to rehab a bridge deck, so you get many more years' worth of performance without having to fully replace the existing deck.

With that, I will say again, what is UHPC? What I hope we have learned is that it is a resilient composite, but also that it is a capable solution for today's challenges and tomorrow's opportunities. There are a lot of things you can do with UHPC, and we will see, time will tell which of these applications turn out to be the perfect application. We know that using it for connections between prefabricated elements works very well. A lot of owners are really latching onto that, but I am sure there are a lot of other places we can use UHPC as well.

Thank you, Ben. That actually concludes the formal presentation part. Thank you very much, Ben and Mark for a great presentation, and the audience for asking those nice questions and this is the time to get into the interactive session.

You asked questions in the chat pod and the experts will answer them. But before we do that, I do have another poll question. The reason for collecting all this information through the poll questions is to help FHWA's understanding of the community a little better in term of addressing needs, so I appreciate if you could answer this as well. I will give you a minute or so to respond. As you do that, we will begin our Q&A session. We would take the questions as they came in. I will be moderating that. At some point, I will close the poll question, but Mark, Leonard, and Ben will answer the questions. The first one I see, from Ohio, asks if the initial cost of your UHPC is higher than the conventional concrete, then at what point is UHPC better in lieu of conventional concrete in terms of breakeven?

So this is not a situation where you would say try to just use less UHPC to make the same element because as you saw from the cost, if UHPC costs 10 times more or even more than that of conventional concrete, you cannot build a bridge girder using 10 times less concrete. That does not work. You could certainly use 30 percent less maybe. The cost is not just 30 percent more. So when using UHPC, you have to think about some other bigger picture things like what is going to be the lifecycle cost benefit of using UHPC. Things like if I can span a longer distance with the same depth member, is that going to allow me to eliminate a substructure? And if I eliminated substructure, is that going to save me a lot of money? Things like, if I replaced this project with, if I put a UHPC overlay on this project, even though I am using an expensive material, if I can get another two decades out of this project without having to fully replace it, that could save a lot of money. So you have to consider the bigger picture. You cannot just look at the cost of the material and make a decision.

Great. Thank you, Ben. That is a very good answer. The second question I have again, I think this is to you, Ben, is corrosion a problem with steel fibers in UHPC?

Any steel fiber that is exposed, sticking out of the UHPC, it could corrode. Generally the fibers in UHPC are not stainless steel. They would be even more expensive if they were stainless steel so generally the fibers are regular corrode steel. If fiber is exposed then it could corrode. Generally they are inside the UHPC, so then you have that low permeability material protecting the fibers so that you do not run into corrosion problems.

Great. The next question—either you or Mark can take it or both—is related to the shear capacity, so this is a design-related question here. What is the shear capacity of UHPC connection? Mark, do you want to go first, or Ben?

Either one. Shear capacity is a function of your tensile strength of your concrete. You think of a shear capacity as a strength property in itself. It is a combination of both compression and tension, so as you increase your tensile capacity of your concrete, you increase sheer capacity of it. As far as quantifying it, what would be appropriate design parameters? I am not familiar with that. Saying it again, as your tensile capacity goes up, your shear capacity goes up. I am thinking I have heard that there are some agencies or some research that has been done with designed and built UHPC beams or girders, and they have minimized or even removed all the sheer reinforcement and let the Ultra-High Performance Concrete and the girder web carry their tensile stresses.

That is correct. The bridge I mentioned, the first one constructed in the U.S. in 2006 in Iowa, that bridge does not have any stirrups. The UHPC carries out the shear forces and does it through its tensile strength. If you think of shear, you can rotate it. If you think of it, you can rotate it and it becomes a tension and compression sort of element. So the UHPC needs to have enough tensile and compressive strength, and if your web area is large enough and your tensile strength in the UHPC is large enough that you can carry the shear demand, so yes, that has been done.

Great. Thank you both. Another question for both of you here is, and you can take it in sequence or maybe reverse, can you explain how durability is impacted by saltwater?

As I said earlier, the trick here is that if your material is basically impermeable, then the salt that might be carried by that liquid does not get in. So if water has a very hard time penetrating UHPC, the salt is not getting in, which means your salt is not accelerating the corrosion of any embedded steel reinforcement. So whether it is water or saltwater, it does not really matter if the water cannot get in.

I think that is fair. It goes back to the basic properties you had mentioned for the UHPC. Mark, maybe this is for you. How can you get access to those cool videos that have been mentioned? Will they be on the website?

They are not on the website right now. We are getting them out to the public or people through our workshops. But that is a good question to ask. And we should get those on our website so I will look into getting that done in the next couple of months. Watching those videos, it really does tell you a lot and give you a feel for how the material places. Repeating myself, if you are State sponsors a workshop, we show videos in the workshop and in the next couple of months here, we will look to see how he get those videos up on our websites.

Thank you. The next question, maybe Ben to you, is about connecting new concrete to existing hardened concrete. Usually it requires the body material to ensure or enhance the bond strength. Is this required for UHPC? If not, what enables UHPC to get the bond? I suppose there is a criteria for sheer strength of the bond, it is 250 PSI here.

Yes, it is true that commonly with conventional concrete you might use some sort of bonding agent to help the secondary cast material bond to your initial substrate concrete. With UHPC, you can do that. What we have found is that wetting the surface of the substrate concrete is helpful. Using water as a bonding agent, you don't have to do much. The general terminology is saturated surface dry, so you want the substrate concrete to be wet but you do not want pounding water. That helps the UHPC bond to the substrate concrete because if you do not have that, the substrate concrete socks some of the water out of the UHPC and you end up with a bit of a weaker layer than you would otherwise have. So you can get good bond either way, but using water as a bonding agent can be helpful. The reason UHPC bonds really well, or one of the primary reasons, is because it is a very fine material, so it fills into all those nooks and crannies and, assuming that you have a good roughing surface on your substrates, the UHPC can really get into the concrete, so you have good chemical and physical bond to give you an overall good bond strength.

Great. I think there are a lot questions here and I am trying to get to some of them. Another question I have is related to the mixing. I think there are a lot of fibers used, and district 9 is asking, and they actually are commenting, their observation is, is this common? I guess you can expand.

I am aware of that particular instance. I would not say it is common. UHPCs are all often so consolidating and when you have a self-consolidated concrete, it is pretty fluid. If you made it too fluid something went wrong with the mixing somehow, too much water was used, too much super plasticizer, somehow there was too much water in there, it would become to fluid and then the fibers would start to sink. Remember, steel is heavier than a cementitious matrix. As long as you have a thick like molasses mixture that flows well but sort of is thick, the fibers do not sink very much if at all. If you get something thinner like water, the fibers will start to sink. That is a bit of an extreme example, but I suspect that is probably what happens. Quality control in the field is very important. You really need to have control of your mix just like with conventional concrete. How we do some tests also gives an indication of the sort of consistency of the concrete, that it has been produced and delivered right. You need to do something similar with UHPC.

Great. Quick answer on this one. Can UHPC be used as a rapid set material?

Not really. If you really rapid set, like you need strength within three hours, it will not do that, at least to date no one has developed a UHPC that can make that happen.

A good question related to nonproprietary mixes. Regarding the not proprietary mixes, what is the availability of steel fiber around the country?

About Buy-America, you are asking a Federal Highway guy and I would definitively say yes, it does apply. Steel fibers are made of steel and there are fiber manufacturers that make fibers that are relevant to UHPC in the United States. If you are developing a nonproprietary mix, you need to get in touch with some of those fiber suppliers and work with them to make sure that whatever fibers they are producing, they can document they are produced in the U.S. and they work within your mixed design.

Mark do you have something regarding that?

No, I do not. Well, actually FHWA—I will say in 2014 I believe it was, 2013, 2014—put out a memorandum that advertised, made clear that there was a domestic supply of steel fiber, and if you can, find that memorandum on FWA case website.

That is a good point, Mark. Great. I think there is a question from Cindy on the long-term performance in different climates and temperatures. I will say we will defer that the next webinar. That doesn't talk about long-term performance. I am going to take another question from somebody here on I think it is again Cindy. She asks how does the workability of UHPC compare to other types of concrete.

UHPCs are so consolidating. It is to the point of almost being self-leveling. Now, if you cut, this works really well for prefabricated system connections because you are often filling in tight spaces and often have connectors that are rebar, so it works very well there. If you are using a UHPC for something like an overlay on a project, we all know projects are not flat. So having something that is self-leveling is not going to be very helpful, and it will end up at the low corner of the bridge deck. In those cases you need to change the viscosity of the UHPC. You need to add some sort of viscosity modifying mixture or agent or somehow you need a change to the mix design, a chemical change that will make it more of a material that flows when vibrated and that stands up when it is not.

Okay. I think there is one more question and I'll take a couple of…we may have to wrap this up, but there are some really good questions coming through. There's questions that are not answered, we will be sure to answer them and either send them email or put them up on the website. There's a question related to design. Do you have to factor in shrinkage for large element design?

Of course, the answer is yes, you would if you have a constraint situation. You would think of it as the same as you would consider shrinkage with conventional concrete. The shrinkage that Ben was showing you is comparable to conventional concrete, although the sugars with Ultra-High Performance Concrete tends to happen very early during the curing process because it is autogenous shrinkage instead of trying shrinkage. So you have a constraint condition and that becomes a factor. Just to give you what to look at, so if you have a precast member, generally they are not constrained during curing, and so shrinkage would not be so much of a factor there. With our connections, we do have constraint. The fact we have shrinkage with that, that is a consideration, so there you go to experience.

There have been a number of bridges—we were seeing well over 50 bridges—I am assuming where Ultra-High Performance Concrete has been used to connect deck panels, and as far as having problems with the shrinkage and those that have panel connections, that is one of the most demanding situations, incidentally. As far as having outstanding problems with shrinkage in this connection, States like New York have not necessarily been noticing that. You have kind of a small volume of concrete for these connections. That may be a significant factor there. But remember what Ben said, it is a function of your mix design, so when you are characterizing your mix, you may want to see how the shrinkage looked.

Very good. Great. I will ask the last question in the interest of time here. And then will wrap up. Do we know the best fiber percentage yet? I know you showed the proportions there.

Well, as a rule of thumb, most commonly 2 percent by volume is used, but sometimes it is a little more and sometimes a little less. It depends on the efficiency of your particular fiber type and your matrix. So all these different sorts of knobs, you have to turn all these different knobs to get your mix design to deliver the sort of performance you want. There is not a single magic solution. Rule of thumb is usually around 2 percent.

It is the mix design issue. There is one question critical to answer here is can we apply adjustments to the rheology properties of UHPC in the field?

Yes. That is commonly done if you're mixing in the field, if it is a day that is getting warmer, you're going to get more evaporation of your water during the mixing process, your materials might be hot at the start of the mixing so you might need to add a little more super plasticizer or a little more water. Basically what happens is you have a range of what is acceptable. And you might start out at the low end of the range, and as you progress through the day you might have to change a little bit. You might change some water for ice; there's things you can do in the field to make it have the right characteristics.

Terrific. With that I think we have to close the Q&A session. There are more questions coming up please keep those coming. We definitely want to get to those. I would say that a great source to get more information, Ben pointed to the resources available in the file share, particularly the state-of-the-art reports, and he pointed out a couple of more publications. In this webinar series, we will have opportunities for Q&A with experts. Of course there is the FHWA website that he pointed out also that has tools and Mark, hopefully we can get those videos up there as well.

There are some tools there, reports, and other pieces of good information on UHPC available at the FHWA website, which I assume will continue to be developed and more information will put out there. So I do want to remind people about the PDH certificates. I see people are typing in their email information and also names so we can get those certificates out to you. Before you leave, I have one last poll question. It is a rating of this seminar. If you would be kind enough to take time and let us know how we did today, I also want to take this opportunity to thank both of the speakers, Mark and Ben, thank you for putting the time and to get this done, you did a great job. There was a lot of information that you presented here.

I will give everybody another 30 seconds and then I will go to close where it will make some important announcements about the next webinar coming up.

I will end the pole questions now.

Our upcoming webinar for next month is on April 4. Will have the second webinar of our series coming up. We might announce a little change in time but please watch out, no decisions have been made yet. It might be one hour later to capture some more of the audience, but hold your time and space until the announcement comes out. Everybody who participated in today's webinar will get an email reminder. We will also make an announcement to other industry avenues regarding the next webinar and those subsequent to that. In the next webinar, we will have D.O.T. speakers from New York State D.O.T. and Iowa D.O.T. from the consulting world talk about their experiences with using UHPC in PBE superstructures and long-term performance.

That is again, April 4, and I again want to think our speakers today. Their contact information is provided here. This seminar is recorded. A recording of this webinar will be made available on FHWA's website as well as through the information links that will send out to the participants from today's webinar. Again, the contact information for Mark and Ben is here. Please feel free to reach out to either of them if you have any questions about UHPC. With that, I think everybody for participating and making this a good event. Mark and Ben, again, thanks to you. With that, we conclude this webinar and hope to see you next month.

Thank you.