Event ID: 3214844

Event Started: 5/9/2017 12:51:30 PM ET

Please stand by for real time captions. Ladies and gentlemen thank you for standing by. Welcome to the structural design detailing and specifying UHPC for prefabricated bridge element connections conference call. At this time all participants are and listen-only mode. Later we will conduct a question-and-answer session, and instructions will be given at that time. If you require assistance during the call press star zero. I'll now turn the conference over to your host, Jag Mallela. Go ahead.

Welcome to the webinar series on ultra-high-performance concrete or UHPC for prefabricated bridge element connections, which is an Every Day Counts focus innovation. I am Jag Mallela, with WSB USA, formerly known as WSB Parsons Brinkerhoff. I will be your moderator today. With me, in the background helping with the session is Eric Perry my cohost with Leidos.

Today is one in the series of six UHPS webinars that FHWA will be conducting until August 2017. The purpose of the webinars is to provide interested agencies and private entities with information on UHPC user benefits and lessons learned. I have two administrative items before we dive into the presentation part today and a few poll questions.

The first is a reminder for presenters today to mute your lines if you are not speaking because the participants are in listen-only mode. The second announcement is for the participants. For those of you who wished to obtain a certificate for professional development hours, there will be an opportunity at the very end of the webinar to type in your name and email address into a PDH registration card. We will leave the line opened after the webinar concludes for a few moments to facilitate the entry of names and email addresses, and if you do so we will be sure to send out certificates for those of you who request PDH certificates.

At this time before we jump in would like to administer a poll question. The first question is basically helping us learn more about the demographic in the audience. If you would please take a minute to fill this out I will end it and we can return back to the presentation.

[Event is being polled.]

Okay, I will end the poll at this point. So as all of you who have joined us today know, today's presentation is entitled "Structural Design: Detailing and Specifying UHPC for Prefabricated Bridge Element Connections." The focus of today's presentation is on design and detailing criteria for field casting connections, design of key connection types, identification of ways to specifying UHPC, and discussing resources for handling proprietary products related to UHPC. By the end of the webinar we hope you will understand the importance of pre-construction mockups, identify key submittal requirements, and lessons learned. Today's webinar will last 90 minutes with the first 60 minutes allocated or the speakers and within the remainder of the 30 minutes we have 20 minutes roughly for question-and-answer and the last few minutes for closing and for resource identification that will be beneficial to the audience.

At the end of all of the presentations, the Q and A session will include a guest panelist and presenters to engage in a discussion of the questions that the audience has on today's presentation or on UHPC topics in general. All audience members are encouraged to type in questions into the chat pod at the left of your screen and the presenters will answer them in sequence during the question-and-answer session after the formal part of the presentation.

For today's presentation we have four presenters with us, four experts on UHPC. The first presenter is Mark Leonard followed by Andy Foden, Sri Sritharan, and Dan Enser. Mark Leonard—I will introduce each of them now—Mark Leonard is a structural engineer on FHWA structural center team. Mark provides technical assistance and training and review services in areas of highway structure design, maintenance, preservation, and inspection. He began his employment in 2012 and has 28 years of experience as a structural engineer for the Colorado Department of Transportation, including 12 as a state bridge engineer. Mark 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 the FHWA EDC UHPC Innovations Deployment Team Leader, so he is one of the two go-to people for the Every Day Counts initiative related to UHPC.

The second presenter is Andy Foden, who is a senior bridge design evaluation and technology manager at WSP USA. Dr. Foden's career has primarily focused on bridge technology, high performance materials, and advanced bridge assessment and management systems. As an active American Concrete Institute member, he's currently working with the ACI Committee 239 developing design guidance and standards for UHPC. For WSB USA, Dr. Foden has overseen the placement over 1 million pre-cast panels connected with UHPC. Dr. Foden is also the lead instructor for the current FHWA workshop on new HPC connection.

The next speaker is Sri Sritharan, who is the Wilkinson Chair Professor of Engineering at Iowa State University. He's engaged in UHPC research for nearly 15 years, and has actively participated in UHPC bridge design projects in Iowa, from the Nation's first bridge to the most recent overlay project.

The last speaker today is Dan Enser, who is with HNTB Corporation, where he's worked for the last 20 years in design construction and management. While working there he has been involved in either the design, construction, or management of bridge, wall, and tunnel structures of various types, from typical steel or prestressed concrete bridges to complex curved, arched, or long-span beam truss segmental and cast-in-place concrete box bridges. His experience includes delivering projects with design-bid-build, design-build, and CNGC methods. Most recently and relevant to today's discussion, Dan has been HNTB's project manager for the design and construction services for the Hennepin County during the during the Franklin Bridge restoration project, which he will discuss in today's presentation.

I will turn it over to Mark Leonard to start the formal part of the presentation.

Thank you, Jag. Today's webinar is made possible by FHWA Every Day Counts initiative. Before we get to our main presentation, I want to say just a few words about FHWA's deployment of UHPC through EDC. This initiative started in 2011 to promote innovations that will help us build roads and bridges better, faster, and smarter. Focusing on bridges, Every Day Counts 1, which started in 2011, the innovation for bridges was using prefabricated bridge elements and systems to help us build more durable bridges and decrease on-site construction time, was the focus. In Every Day Counts 2, the innovation for bridges was accelerated bridge construction, which included prefabricated bridge elements and systems.

For Every Day Counts 3 and 4, that started in 2015, the bridge engineering innovation is Ultra High Performance Concrete Connections, and so Every Day Counts 3 and 4 is really a continuation of 1 and 2 with a focus on prefabricated bridge elements, but using or looking for ways to use Ultra High Performance Concrete to improve the use of prefabricated bridge elements.

So, the purpose of the deployment of UHPC through Every Day Counts is to promote the use of Ultra High Performance Concrete in ways that can help us improve the strength, simplicity, and durability of prefabricated bridge elements.

So when Every Day Counts 3 started in January 2015, there were 13 agencies that reported they had used Ultra High Performance Concrete—at least on a pilot project, and some agencies on a routine basis. Again, in January 2015 there were 13 agencies that had used Ultra High Performance Concrete on highway projects or bridges, and then two years later with the beginning of Every Day Counts 4, there were 9 additional agencies that had used Ultra High Performance Concrete. In a period of 24 months, there were 9 additional agencies that had used Ultra High Performance Concrete connections on bridges. Right now where we are at is there are 14 agencies that have a goal to—preferably by the end of Every Day Counts 4, two years from now—to have used Ultra High Performance Concrete connections.

Taking a broader look at the deployment or use of Ultra High Performance Concrete in North America, here you see a map that shows all of the projects. They've all used Ultra High Performance Concrete in some form on their bridges. We are over 80 projects in the United States, or let me say 80 bridges in the United States were Ultra High Performance Concrete has been used in some form. About half of those jobs are in the state of New York. New York State DOT is one of the most frequent highway agency that uses Ultra High Performance Concrete. Iowa and Pennsylvania have also used ultrahigh performance several times, in fact about 9 or 10 projects for Iowa and Pennsylvania. You'll notice in Canada they have used Ultra High Performance Concrete frequently, and they have over 80 jobs in Canada as well.

You can access this map. It is available online. It is an interactive map by clicking on the dots you can get more information on each of these projects and I'd encourage you to do it. Rather than give you a big long web address, and if you look in the right hands corner of the slide, you can do an Internet search on "FHWA UHPC interactive map," it should bring up this interactive map for your use.

So, through Every Day Counts, FHWA is continuing supporting this growing familiarity with Ultra High Performance Concrete by providing technical assistance, workshops, webinars, facilitating exchange of information between state agencies, and providing presentations. Today's webinar is an example of this. It is one of the webinars that is being provided through Every Day Counts for Ultra High Performance Concrete.

We're also providing workshops. Right now there are 20 state agencies that have held ultrahigh performance workshops or have been scheduled to hold a workshop. If your state agency is interested in welding in Ultra High Performance Concrete workshop get a hold of me and we can hold a workshop in your state. The webinar series that we are having this year is an extension of the workshops, and by an extension what I mean is a lot of the key information from the workshops will be presented in the webinar. But the webinar has an advantage of having a guest speaker with each webinar representing state DOT, academia, and contractors and consultants. I am so thankful to have our guest speakers that we have today. I will turn it over to Jack and will get to our main presentation.

Thank you Mark for that excellent EDC UHPC overview. I have another set of questions here on the experiences of our audience regarding UHPC. I encourage you to submit your responses to this poll. It is open at this point. As you do that, I have a couple quick announcements. The first one is please do not forget as you are listening in on today's presentation to type in your questions in the chart pod, and also if you would like a PDH certificate, please do not forget to stick around until the end of the webinar, and both of those things if you can. Keep in mind to provide questions and stick around if you need a certificate we would be thankful for that. That will help our presenters line up their responses to the questions. Thank you for participating in the poll. I see the answers are trickling out a little bit here and I will end the poll right now, and we will return back to the presentation. Our first or next presenter is Andy Foden. So Andy, whenever you're ready.

Good afternoon everyone. I will now provide a brief overview of the guidance on design, detailing, and specification from the FWHA Technote on the design of field-cast for UHPC connections.

UHPC is a Portland-cement based hydraulic concrete that, like other concretes, requires water to complete the hydration and development of its hardened property. Like ordinary concrete it is castable. Unlike normal concrete, it is typically self-consolidating. However what distinguishes it most from normal concrete is its ultra-high durability and strain-hardening properties. In other words, it has an ability to be loaded into a flat crack and continue to carry more loud and further to form until ultimate failure. This property known as ductility provides early or advanced warning of overload, allowing you to investigate before a catastrophic failure.

UHPC has a high compressive strength and high Young's modulus for stiffness and has significant tensile strength due to the steel fibers. It bonds extremely well to conventional concrete and has exceptional durability due to its low permeability and prevents substances from entering the matrix. The durability properties measured with standard ASTM test methods indicates durability properties an order of magnitude superior to HPC. It also exhibits strain hardening behavior. Let's put some numbers to the performance properties.

The compressive strength ranges from 18 through 35 KSI dry with modulus from 6000 to 8000 KSI. The tensile capacity is from .9 up to 1.5 KSI. The bond strength is 600 PSI, which is greater to or equal to the rupture of the modulus of a 6500 PS dry concrete. A low permeability is evidence of the rapid fluoride test from 20 through 360 and dynamic modulus of 95%.

FHWA has a very specific definition as it relates to transportation related projects. It is slightly different than the definition used by other agencies. I will read through the definition and highlight a couple of things that are very critical to using the UHPC as stated in the FHWA Technote and the design equation. "UHPX is a cementitious composite material composed of an optimized gradation of granular constituents, a water-to-cementitious materials ratio less than 0.25, and a high percentage of discontinuous internal fiber reinforcement. The mechanical properties of UHPC include compressive strength greater than 21.7 KSI or 150 mega pascals, and sustained post-cracking tensile strength greater than .72 KSI, or 5 mega pascals."

The most important difference in the FHWA definition is the requirement for fibers and a minimum post-tensile crack strength, which are very important for mechanical properties that are required in bridges. This will become more obvious as we get into the use of the technology.

FHWA's guidelines for design of the UHPC connections are given by the October 2014 Technote "Design and Construction of Field-Cast UHPC Connections." This document can be found in the file share section of this webcast for download.

The design guidance we will discuss is given on pages 11 through 16. The guidelines address: reinforcing steel details for splicing and developing reinforcing steel and connections, using closure pours for concrete elements of thin precast deck panels, shear connections between girders and precast deck panels, and connections between substructure of using rebar and grouted ducks. The guidelines also provide mechanical and physical properties of UHPC for use in design.

This is a detail of a connection between precast deck panels that has been designed for UHPC. It shows the advantage of using UHPC for connections between pre-cast deck panels. This connection is transverse to the length of the bridge. Notice the short splicing length with straight bars. The rebar details are simple and uncongested. When conventional concrete is used for the closure pour, loops are required or other means for developing the rebar, or you need a wider joint. This increases congestion and splice length and increases the width of the opening.

What is the guidance for developing length of splices using UHPC in the FHWA 2014 guidelines? For number 4 to number 9 rebar with yield a stress less than 75 KSI, as long as you have a fiber content of 2% in our UHPC, the development length is 8db. This compares to a minimum development length of 24db for conventional concrete. The minimum cover needs to be at least 3db. If the side cover is 2-3db, then the 8 db is increased to 10 db. The minimum splice length is .75 in development length, and the clear spacing between the two bars and the noncontact lap splice needs to be at least 2db to allow enough room for the UHPC with the fibers to surround the rebar, and as large as the splice length of 6DB, but not greater based on test results. The bar spacing also needs to be at least 1.5 times the fiber length.

Although the 28 day compressive length of UHPC is over 20 KSI, the guidance on development length is based on 14 KSI to permit the early application of construction lengths. Generally 14 KSI is the strength of UHPC when you start getting the kind of mechanical performance that you want. UHPC is pretty green under 10 KSI.

The LRFD design specification such as 10-10-1-3 requires shear studs to extend at least 2 inches above the bottom of the deck. When using UHPC and the FHWA 2014 guidelines, the shear studs can be shortened to 3 inches below the deck rebar, but no more than 3 inches. This minimizes interferences and simplifies construction. The steel plate details shown here were used for research to simulate the top flange of a steel girder.

How do you design and detail these connections? The design of a sheer friction interface needs to the following requirements of LRFD 5.8.4, and the design of the shear connectors including their numbers and connections to the girder, should follow the requirements of 6.10.10. But if the distance between the shear connectors and the deck rebar is less than 3 inches, and the cyclic shear stresses are less than 150 psi, and the factored maximum shear stresses are less than 750 psi, then the reinforcement requirements of 5.8.4. can be waived for shear planes within the UHPC, and the shear connection projecting into the deck requirement of 2 inches and 6.10.10 can also be waived. Note that New York State has been using this criteria since 2014.

Let's take a closer look at another type of PVE connection, ducted substructure connections. These connections are typically between a pier cap and a column, or between a column and a footing. What is the guidance for ducted substructure connections using UHPC in the FHWA 2014 guidelines? For number 8 through number 11 rebar with a yield strength less than 75 KSI, and with a steel fiber content of 2% in the UHPC, the embedment length is 8db. The ducts must be corrugated galvanized steel with a minimum inside diameter of 4db. Debonding is necessary to avoid strained concentration in the precast concrete adjacent to the component interface on seismic loading.

The bar clear spacing between 1.5 of the fiber lengths and splice length as per the 2014 Technote. It is applicable for number 8 and 11 bars, and can be used for uncoated, epoxy coated, and stainless steel or any bar without any additional modifications. In additions to the guidance provided on the previous slide for development of the rebar within the UHPC, we must also consider non-UHPC failure modes. First is the mechanical failure of the conventional concrete and the second is the pullout of the duct itself from the conventional concrete.

The equation shown here is from the Caltrans report on the next generation of bridge column for accelerated bridge construction in high seismic zones.

When detailing UHPC connections, it’s important to consider all tolerances and provide details that have flexibility to accommodate these tolerances. For example, when considering the transverse connection detail where we want the minimum lap length between number 5 bars of 5.9 inches, you need to account for tolerance in bar placement, panel placement, panel size, etc. There are also tolerances of other items on the bridge that can could into play, such as placement of shear studs within the pocket—particularly important if studs are installed before the panel us placed. You need to detail and maintain a minimum clearance around the rebar, studs, and any precast concrete of at least 1.5 times the fiber length after accounting for these tolerances.

Here we see a panel being installed. By having tight concrete tolerances, setup systems seem to be going well. With UHPC connections, the simplicity of the details allow for more play between all the components, reducing likelihood of interferences in the field.

UHPC is available in premixed manufacture, similar to packaged conventional grout, or it is can be developed from their constituent materials. Mix design guidance is available in the FHWA publication FHWA-HRT-13-100, which was developed by Dr. Willie at the University of Connecticut. Other academics have also developed local and nonproprietary mixes.

There are three ways to specify UHPC: A prescription spec detail of the mixed design, a product specs specifies one or more products and the contractor must use, and a performance spec that does not specify any particular product, just performance criteria. Most DOTs have not developed the expertise to prescribe the mix design, although many states are looking into it. A product’s specific specification is often used for an agency's initial project, but performance specifications are the preferred option, as I will discuss on the following slides.

By specifying a specific proprietary product, or perhaps a list of proprietary products, you have a very clear idea of what you will obtain because you are requiring a contractor to use a proven mix design. A proprietary UHPC supplier also brings experience and technical support to both the owner and the contractor, therefore the agency does not need to thoroughly specify or verify all of the necessary UHPC characteristics. Product specification is an appropriate approach on the first project especially where it's designated as an experimental feature.

To help ensure competition in the selection of materials, the Code of Federal Regulations has requirements for using proprietary products on Federal-aid projects. 23 CFR 635.411 provides four alternatives for using a proprietary product on a Federal-aid project. Of these four alternatives, the first two have been used the most frequently by DOTs for deploying UHPC. Agencies have often used the experimental feature option to specify a specific UHPC product for their initial project, as I discussed in the previous slide. For a competitive bidding option, agencies have typically used a performance specification, as I will discuss on the next slide. We discuss these options in more detail in the EDC UHPC workshop. Additional information on all four options can be obtained by contacting Federal Highways.

The last method of specifying UHPC performance is performance specification. As noted previously in the introduction to the various methods of specifying UHPC materials, a performance specification is the preferred option. It specifies the final desired outcome that leaves the door open for any product or material that could meet the performance requirements, whether it is proprietary or nonproprietary. This helps ensure competition in the marketplace and may even stimulate innovation. It also is not limited to single use situations like the various circumstances under which sole-sourcing can be supplied, so it is the best long-term solution. However, a performance specification generally requires a little more effort from an owner than a product or prescription spec. First, it requires the owner to specify the performance through standardized accepted measures that the construction industry can readily meet. It also requires the owner to verify if the provided materials meets the performance requirements, which could require increased effort if nonproprietary or if new on the market products are proposed.

Finally, the key specification section that should be included in most UHPC specs, whether prescription, product, or performance, are shown on this slide. Keep in mind not all of these key specifications will necessarily go under a UHPC-specific specification section. While some jurisdictions like Iowa and the District of Columbia use special provisions that are independent of the standard specs, allowing them to include multiple types of work in the special provision, others like New York, New Jersey, and Washington state use special provisions that integrate with the standard specifications their numbering system.

Now I will turn it back over to Jag.

Thank you, Andy. Sri, you are up next.

Thank you Jag. So for my part of the presentation I will spend a minute or so discussing some of the experiences and primarily on the test we have conducted in the past on the UHPC connections.

Here is a quick outline I will use. Some of the work that we have done and talk about UHPC research very briefly that we have performed at Iowa State University, and we will talk about the bridge deck and connections, the connection tests, and continue with the standards development.

I think many of you know the state of Iowa has used UHPC in a multitude of ways, and that has been successful because there's a strong partnership between the Iowa DOT, the Iowa Highway Research Board which funds the research projects, Iowa State University and also FHWA have us as a partner, but most importantly we also got a pre-cast fabricator, contractors and material suppliers as partners as well. Looking back at the various projects that we have worked as a team, certainly all of the projects led to a lighter member if they choose to use UHPC for members, and definitely accomplished the connections.

But most important the reason to use UHPC is durability properties. If you were to look (NC stands for normal concrete) for the normal concrete on this slide, I have compared the normal concrete with UHPC for different durability properties, and you can see—and you can see where and the location of the label that the HPC is here. So it's important to realize as you specify UHPC for projects like Andy discussed, make sure that the UHPC durability properties are also emphasized if that is a key element for you.

Looking at the various research projects that we have completed, we certainly have done a lot of materials tests, compression test, and we still do a series of tensile tests to study improved behavior of UHPC. We worked with the Iowa DOT and other partners to design the first UHPC girder bridge with a multi-girder, we have developed a pipe based on UHPC that we can see deployed in a bridge project that has successfully performed. We successfully performed 3 tests as well as the last lab test, and lastly we have done a waffle deck bridge where the connection is similar to what we are talking about today. We have also invested quite a bit in the understanding of the bonding between UHPC and normal concrete. We have been created composite bridge decks as well.

In the context of bridge deck options, Andy talked about connections, and I will emphasize that you could certainly use precast deck panels as shown here, or you could choose a UHPC waffle deck and that is something we have designed with Iowa DOT and deployed on a bridge, or lately what we have been working on an overlay options where you can have a precast deck below with a thin layer of UHPC on top with the connection established in the field. In all three cases the connections we have been talking about are applicable.

Let me focus on just the connection a little bit. For the waffle deck bridge, that we have constructed, we did a test to understand the behavior of the waffle deck as the lines were connected. Today I will focus on mainly the connection performance. On this particular side there is a waffle deck with three different connections. One is a connection that you would expect between panel to panel on top of a girder. That is what you are seeing here. The second connection is also a load connection, which is typically appropriate for an exterior girder where you would have pocketed connections overhanging, and that's what you are seeing here. So you would have at least one or two u-bars coming into the connection.

The second probably is the most critical connection and that is panel to panel. That is shown here on the bottom, and all three connections have been designed in this particular bridge and then we tested.

Here is a test unit set up. In the light blue shows that UHPC joints. We picked 2 UHPC waffle decks, connected them with an exterior and internal girder as we can see here to establish our test set up. So the girders are regular concrete and the UHPC connections were made using UHPC mix.

Details of all three connections are shown here. The top showing the long connection, and this is the transfer connection between the panel on top of the girder, here's the pocket, and then you can see how we constructed with the connection using UHPC.

This shows the test set up. The one on the top shows how the setup looks with the displacement transfusers and strain gauges. The picture on the right shows the setup for applying the load. We applied the load either in the center of the panel to evaluate the panel performance or at the center of the joint to evaluate the joint performance. In total we performed nine tests and I've some references if you're interested in learning more. But I want to focus more on the joint test and what we've observed. There were four tests done. The first was the service load test on the joint. From the transverse joint the load was applied to the center of the joint. We applied 28 kps, that is 1.75 load factor to have a real load of 16 kps. At that point we did expect micro cracking in the joint. Then we did a fatigue test on the joint and we applied one million cycles at 28 kps. Then, in test four, basically we applied an overload. So, it used three times the service load to overload the system to reach 48 kps. Then we eventually performed an ultimate load test with 155; in fact, the project was 160kps, but we stopped at 155 because the girder was experiencing noticeable cracks.

This shows typical test data that we collected. The load was applied in a cyclic manner, and in this particular case the load went up to 28 kps, and you can see the maximum strain we were seeing was about 150 micro strains. In this particular connection we used number eight rebar with the eight times the bar diameter that Andy was talking about that in terms of providing adequate cover.

If you look at the joint and service load test, 28 kips was the maximum we applied, the peak displacement was very negligible, and the maximum peak strain in the joint was 180 micro strains, so that's less than 10% of the yield strain. The maximum strain in a panel was even smaller, and there was a crack which was less than 0.002. If you focus on the figure on the left side, I would emphasize these systems can be sufficiently modeled and predict the performance. We did have a model to predict the performance, and we did expect cracks to form in this particular case. There was a hairline crack formed and we observed that in the test. Then we performed a fatigue test and we applied one million cycles. During the fatigue test, we observed no new cracking.

There are three lines used with three different colors used here because they were in the sensor data. So the red shows the 1 kip data, the blue shows the 28kip, but I want you to focus on the green line which shows the fatigue damage. Here we are looking at the gain in displacement, you can see there is a small gain, and it is pretty insignificant. The micro strain increased gradually over time and again that increase is pretty small.

This last figure shows the crack width opening, and crack widths are remaining constant, which confirms why the strain grows and the displacement remains the same.

This one shows the test we performed after 168,000 cycles during the fatigue testing, and 333,875 cycles, and at the end of the 1 million cycles. You can see the responses pretty much remain the same, confirming the damage to the system was pretty insignificant.

The overload test we mentioned, we applied 48 kips. This was decided based on a number of things. The basic number was decided based on that being three times the load factor, because we weren't sure to apply higher loads on the system at this point.

Fatigue displacement increased about .05 inches. Peak strain on the joint went from 180 to 325, so still you're looking at a very small strain. The maximum strain measured on the panel reinforcement was 175, and the maximum measured crack was .003.

The last test performed was increasing the load significantly until we see extensive damage to the system. The interesting thing is we applied the load close to 155 kips as we mentioned earlier, some of which came from the cracks that developed in the girder, and on the right side you can see the significant amount of cracks on the connection, so basically you're looking at the underside of the connection. So this is the joint region here, and this is the waffle deck, and a significant hairline crack developed at this point. As I said, this is almost 10 times the service loaded that we applied in the system.

So to conclude, the panel to panel transverse joints may experience hairline cracks on the underside of the deck under service conditions. This will not necessarily develop in all cases, but the possibilities you can evaluate up front and know that that is the case or not the case. The cracks widths will remain relatively small, and they are not expected to widen due to fatigue load from service load increases. The dowel bar stresses were small and provided anchorage links that are more than sufficient. The bar size as mentioned could be reduced because we registered a small strain. And Iowa DOT and the projects they followed afterwards did use, I believe, number 7 bar instead of number 8.

Larger cracks may form if the boundary conditions of the decks are altered. I presented the results based on our conditions, it was duplicating what I think a span bridge would do, and if you see the boundary conditions, obviously you could change the crack width if the crack is going to form. I would monitor and evaluate what you should expect from the applied service loads.

The last thing to mention is we have been working on some of the basic stuff to help contribute to the standards development of full UHPC from the materials characterization as well as the design of members. The documents that have been made available to you provide some of the information in terms of what we have done with UHPC waffle deck, and how sections could be designed using UHPC.

With that I will turn it over to Dan.

Thank you for the opportunity to present the Franklin Avenue Bridge Rehab Project. Here is an elevation of Franklin Avenue bridge. It is a historic, 1,050-foot-long, five-span, open-span concrete deck arc over the Mississippi River. Here is a view looking down on the project site. On the bottom of the screen there is a five-leg intersection. Due to traffic patterns at this end of the bridge, the bridge deck was widened by 10 feet to accommodate four lanes of traffic and a shared use path on each side of the bridge.

The project is located in Minneapolis, Minnesota, just downstream of the University of Minnesota. The main project team has delivered this project. Hennepin County is the owner, HNTP Corporation, Kramer North America is the contractor, and Minnesota DOT state aid office also helped with projects. There were many other sub consultants and supporting staff that completed the inspections, concrete surface repairs, and environmental aspects of the project.

A little bit about the project: it was essentially two projects, a restoration project, and then replacing the deck and the cap beams. Today we will focus on super-structure replacement, which consisted of accelerated bridge methods, precast elements, and innovative materials, including ultrahigh performance concrete, premixed polymer concrete, and PTFE stainless steel sliding joints.

Project schedule. We started in 2015. In 2015, it was mainly concrete restoration and pre-casting deck panels leading up to the accelerated bridge construction and the close down in 2016. We continued concrete restoration in 2016 and we are finishing it up this year.

A little bit about the ABC design details. This is a picture of the original bridge construction back in 1923. It was built around an existing truss, which could be a form of ABC. It resulted in two lines of independent arch ribs, which had a large effect on the approach to closing the bridge to replace the deck and cap beams versus a partial-width construction method. Once the decision was made to close the bridge everyone understood the work needed to be completed quickly with the ABC methods.

The short closure was accomplished with pre-cast elements. Here are the deck panels. They are 14 inches thick, they are reinforced, and they did not have prestressing or post tensioning. Here is a layout of the deck panels. They are essentially tinker toys, if you will. When placing the new panels on the existing bridge, not everything fits up correctly. We had to adjust panel geometry to remain within tolerances by shifting the red colored panels and adjusting the length of the blue panels. The lesson learned here is to understand the as-built geometry and determine whether the designer will account for the survey and the precast elements, or if the contractor will be responsible for the survey and making adjustments in the shop drawing stage.

The deck panels were joined with the UHPC design per the Tech Manual that was previously described here in the presentation. One of the design goals was to reduce the locations for possible water intrusion, thereby limiting the number of expansion joints. The original bridge had 15 expansion joints and we changed it to 6, of which only 4 are actually on the bridge itself. Multiple span arch is susceptible to high thermal induced forces due to inherent restraint. Design feature is to release the translation and rotational restraints between the deck and the cap beam. The red circles are where the joints are now after the rehab.

To make the reduction expansion joints reality, we had to develop a sliding plate joint to reduce the bending in the spandrels and the arch rib and to create a release between the deck and the cap beams. Stainless steel and PTFE pads reduced friction and allowed the deck to slide over the spandrel caps, and here's the cap here, if you can see my arrow. Here’s the deck panel here, here’s the sliding plates, and here’s the cap beam. This is the stainless steel plate in the bottom of the deck panel showing over here, and here is the PTFE surface it's riding on to slide over. Note the cap beams are only 2 foot 6 wide. The narrow construction joints allowed by the use of UHPC made ABC possible. Without UHPC the joints would have been wider than the cap beam, resulting in much more false work and time to construct the project. This is a view of the fixed joint above the piers. Note the deck panels were set on shim packs, and the UHPC flowed under the panels to complete the joint.

Here is the expansion joint with a sliding plate joint used in a drop panel fashioned without the expansion joint assembly to fit in.

ABC preparation. The ABC timeframe is limited to 116 days. This means considerable planning and preparation is required prior to closure. The preparation involved fabrication of the majority of the precast structural components, prepping the existing by saw cutting longitudinally, and temporarily supporting existing utilities and wireline with false works. All of this planning and preparation was completed with regularly scheduled ABC planning meetings that we start a year before we actually closed down the bridge.

On the screen here, this is the casting yard where they cast all the deck panels and below here is the piers with the precast cap beams waiting to be installed.

Now let's get into the actual construction. The bridge was closed on May 8. The contractor approached each span as an individual project with many operations occurring simultaneously. The bridge was opened September 1, just prior to the start of the fall semester for the University of Minnesota students. Here is the view of the new cap beam with the deck panels installed, you can see the bars between the deck panels with the with the longitudinal joints, which would be filled up with UHPC. Here's a view of the deck panels and the longitudinal UHPC joints. Note the bars for the inner barrier were cast with the deck panel.

Here's a view of the transverse UHPC joint above a cap beam. Here's a view of the UHPC forming system, which we will talk about little more in a little bit.

Now we have 350 individual panels sitting on new cap beams that need to be connected, which is accomplished by using UHPC. UHPC operations were set up with two active mixers that in total would mix in place 350 yd^3 of UHPC for the second-largest application in the United States at the time.

We used a Ductal JS 1000 mix. We did a product specification, so we made a request for public interest finding for the proprietary items, which was approved, and our specifications require the use of Ductal JS 1000.

Here the mixed proportions for the UHPC: 2500 pounds of premix, 124 pounds of water, 33.6 pounds of super plasticizers, and 45 pounds of steel fiber.

As many of you know, UHPC forming requires very tight forms to prevent leakage. Not quite watertight, but very close. Likewise, the formwork must provide access to prep the joints. The contractor developed a formwork design by applying information gained from other UHPC placements in Chicago and Iowa, and they added their own twist to the means and methods. These scanning tools are very important to the team. In this case the Walor system is held in place by stay-in-place threaded GRFP rods.

Here is a view of the joints showing the top form. We had a top form right here and went back down into the deck panel to hold it down. UHPC joint preparation is very important. UHPC placement best practices include establishing a supersaturated dry condition on the existing roughened concrete surface. Obtaining the SSD condition proved critical in having a sealed joint between the existing concrete and the UHPC. Hennepin County was very focused on obtaining the best joint possible, and the contractor understand that the SSD condition was a must. They developed a process of using soaker hoses overnight prior to placement to get the concrete saturated. During the placement, the location that appeared to be drying were touched up with a hand sprayer.

The self-leveling nature of the UHPC required the use of top forms and chimneys to facilitate completely filling in the joints. At the high-end of the joint the chimneys were placed and then filled to keep positive head pressure to fill eight spaces as the air migrated out of the joint. The chimneys in our case were simply 5 gallon buckets attached to a plywood base with a three-inch diameter hole through each. A lesson learned for us was to rock the chimneys to make sure that they were full. We had several instances at first where a crust would form on the top of the UHPC in the buckets, so while they looked full they were not. So we had somebody walking around constantly rocking those chimneys.

This QC was provided by the supplier of the UHPC, and Hennepin County completed QA. Both documented the temperature, timing, quantity, drop loaded table results, and compressive strengths. Here is a sample of the daily log.

Here are the facts of the UNPC placement.

[brief pause due to failed connection]

We batched about 35 batches a day. The contractor was running four buggies to deliver the UHPC. A bay of longitudinal joints —about 168 feet per bay—with a 7-inch joint took about an hour and a half, and for slightly smaller joints it took about 1.2 hours. The transverse joints which were between 66 and 76 feet long, took longer at an hour and a half to pour.

Lessons learned for UHPC. We learned to always overpour one quarter of an inch. Going to the next slide, this joint seems OK. We just got done pouring and it seems okay; however, upon further review, the top of the UHPC had trapped air, and here is a view of what we found there. We found it very important to overpour and come back and grind later.

More lessons learned. We had differences between our QA tests and the QC tests performed by the supplier. While all of the results met requirements, there was a difference, and when we looked further, we believe it was because the supplier's QC firm was grinding the cylinders to one thousandth of an inch and the QA cylinders were ground to two-thousandths of an inch.

Mixed temperature plays a very important role, and our lesson learned was to be sure the contractor provides ice to the water to keep the mix temperatures below 80°F at the mixer. We also recommend adding language about construction equipment so the contractor understands the requirements associated with moving equipment and buggies over the joint. On a fast-paced project, this can impact the contractor's pour sequence and schedule; i.e., he needs to lay out his sequence so that he can get to all of the joints without driving over the fresh ones.

We all know about the rapid strength gain and high compressive strength of UHPC, which is witnessed in the representative plot. We can see that by 14 days, the compressive strength of 24 ksi is achieved. More interesting is the initial gain by the JS 1000 mix. We found over the first 24 hours the UHPC had minimal strength gain, and, in fact 24 hours later the mix was still semi-plastic in the joints. However by 36 hours the UHPC had set and was well on its way to strength gain. The slow set time influenced the placing plan as we did not desire to drive across still-setting joints. The pour workability was much temperature dependent; too hot, and the mix wouldn't flow, so ice was used to chill the water in the mixer. A lesson learned was to have the UHPC placement plan that addresses access to joints without driving on previously placed joints and addresses the temperature requirements of the UHPC mix.

Contractors should also think about the pouring sequence ahead of the UHPC placement to avoid crossing joints and reducing the potential for cracking of the joints. We recommend adding language requiring a pouring sequence submittal. We also learned that cold joints between UHPC placements should be roughened to avoid a smooth joint for water intrusion.

SSD is a must for achieving our bond. Think about how SSD is obtained and maintained with the presented form work prior to and during placement. The reason we overpour to 1/4 inches is to expose air pockets and any other anomalies uncovered during grinding. We noticed there was entrapped air and in some places there were divots present in the ground UHPC. We recommend that the team that does the UHPC mixing and placement, that scanning tours be added to the project to educate the team. Test pours and mockup panels are also recommended for the team to gain experience on precast elements and UHPC before doing the work under a short closure.

That is a view of the completed bridge. So thank you all. I will turn it back over to Jag.

Thank you Dan. Very good presentation there and very important lessons learned at the end. We will now move to our question and answer segment, but before then I have or would like to bring up a poll here. It is kind of an open-ended poll basically asking a question about the types of guidance that will be helpful to the audience, that you would like to see that would help you implement your UHPC connections more in the field in terms of design and detailing your connections. It's an open-ended question and it requires a statement or a sentence from you in terms of the type of guidance. What kind of details and connections and design details would be helpful for you for your UHPC connection.

As you type those questions I will start the question-and-answer portion and will have all the presenters today answer some questions. The audience is encouraged to submit questions in the chat pod on the left side. In addition to the four presenters today, we also have Ben Graybeal to join us as well to answer any UHPC questions. Ben Graybeal—a real quick introduction—is the team leader for bridge engineering research in the FHWA office of infrastructure research and also one of the nation’s most prolific UHPC researchers and research program managers. He has a wealth of experience with UHPC having been a leader in the UHPC community since FHWA began its work in 2001.

As I said please go ahead and type in your questions and as you type them out, we will start moderating them as they come in. Our first question here is from Stephen, and he asks is the 24-hour lag in the setup of the UHPC a universal characteristic, or was that due to how it the UHPCD in Minnesota was batched? Ben, if you could weigh in on that first and then we'll open it up to other presenters.

I'd be happy to answer it. So Stephen I guess I wouldn't say it's a universal characteristic, but it is a characteristic that comes along with the type of mix design that you generally have with UHPC. With UHPCs, there is usually a large amount of super plasticizer, at least as compared to conventional concrete, and that acts to some extent as a retarder in the mix. It is needed because you have such a low water-to-cement ratio, but the retardation of the mix means you have a dormant period before the chemical reaction starts and your mechanical property development gets underway. It wouldn't necessarily be 24 hours. You could use accelerators, and in an environment where you had more heat, you could help the reaction to begin happening more quickly. In some mix designs it could be six or eight hours before you start to see a mechanical property development, and with other mix designs or with very cold temperatures, it might be longer than 24 hours until the property development starts.

Great thank you Ben. The next question is from Cindy. I think this is a comment on the presentation that Dan presented. Cindy said the 3 inch diameter hole for forms seem to defeat the purpose of high impermeability. Your response Daniel.

I'm not quite sure if I understand. The reference to 3 inch diameter hole was for the 5 gallon bucket for the chimneys. We had a 3 inch diameter hole in the top form where the chimney would set. So essentially the UHPC would fill up in the chimney and there was a 3 inch hole in the top form to keep the top form under a head pressure to work out the air bubbles.

Yes that could be it. Cindy if you feel like that clarifies it, great, if not please type or post a follow-up question to that. While you do that, the next question is what other products were considered for the deck closure pours on the Franklin Street bridge.

I think we just went right to UHPC. With 2.6 cap beams, we knew there weren't many other products out there that we could get needed. We looked at several different scenarios of where that joint would be, but more from an ABC perspective, being able to set down a panel on the cap beam and cut the crane loose to go to other things because the crane is on a critical path, we felt we needed that joint on the cap beam, and so we had to back into the UHPC.

So the project conditions dictated the selection, and it was pretty narrow from the get-go.

Yes we were narrow to start with.

Next question is from Thomas Wilson. Again, to you Dan, did you perform a cost comparison between UHPC and HPC or NC.

No we did not in the joint. Again, the project dictated going to such a narrow joint that we went right to UHPC.

Your previous answer answered that and the next question is perhaps for Dan and maybe others if you want to jump in. In a general way here, was there a certain timeframe in which you began grinding the UHPC joints? Did you have issues with joints that had reached a higher strength? I'm guessing for the grinding portions this is something you can comment on Dan and Andy from your projects.

Yes absolutely. It was one of our concerns going into it and I believe we even had some spec language warning the contractor to get out there and grind these before they got to the high-strength. We found they were able to grind joints with just a simple walk behind grinder without any problem. So that was I guess a lesson learned.

Was that an experience, Andy from your perspective on any grinding jobs, that you have had grinding is not an issue?

I certainly agree with what Dan said, that it's very important that you grind the joints and Once they get to the 14 ksi they have enough strength they can take HL 93 loading, so you can put heavy equipment on there and do your grinding. So as soon as you get your 14 KSI, that's the best time to do it. I have seen joints that were left unground for six months and eight months, and now they're up there at 28KSI and yes you can still grind them, but it's a heck of a lot easier if you do it while it's at 14 KSI than when it's at 28 or 30 ksi.

Thank you Andy. I will skip to this question. Since the UHPC has high stiffness compared to the panels, wouldn't that cause a relative rotation and crack at the joints? This is an interesting design related question. So perhaps Sri first, and then both of you can tackle that question.

I certainly appreciate the question. It is certain that the E value goes up, but within that panel I am not seeing a high or a lot difference between the two. Both are rotating and so this particular case, I'm imagining the transverse direction joint… Basically the deflection would be the panel from panel to girder and in the test we did not certainly see this is a problem. and we did apply the load directly to the panel so I think the questions is fair but I don't think it will cause significant difference in the structure. Ben?

This question has come up periodically because the stiffness of the UHPC is about twice that of conventional concrete, but it's still much closer to conventional concrete than it is to, say, steel, and we combine concrete and steel together frequently in structures. So the stiffness is a little higher in the connections, but the connections are relatively small compared to the overall bridge deck, if we're talking about a bridge deck. So in the testing that has been done, and in the field deployments that have been done, there have not been any issues that have cropped up around this sort of localized stiffness issue and the potential that that could somehow cause strain concentration. It just has not been seen, so I don't think it's an issue.

That's a very astute comparison. So the next question is from M Hayes. After grinding the surface where there still fibers exposed—I guess it's a general question not just related to this project but perhaps stand and Mark Andy come into this one—

We did not see many fibers exposed. My belief is that as your flowing it in, it's kind of flowing in horizontal and aligning the fibers. We did not see a lot of exposed fibers. We went at over it with an overlay as well.

[Indiscernible - multiple speakers]

I will jump in here as well. On other projects I've been involved in, grinding often does expose some fibers, so your grinding machine will grind off the cementitious matrix, but then it will leave behind some steel fibers that are still bonded into the matrix that's left behind. So yes, you could have a bit of a hairy surface on your deck. Now, it depends on what you're going to do next whether that matters. The exposed fibers will corrode pretty quickly; they are usually around .2 mm in diameter so they're very small fibers. Those pieces that stick out will corrode off and disappear, and might cause a little bit of brown staining on the surface. Other than that, they don't cause any trouble. If you're putting some sort of overlay over it, it will bury them anyway so it does not matter.

That is good thank you. The next question is I think Cindy again. Were the form ties through the joint removed or where they left in place?

For our situation in Iowa, we used carbon fiber so essentially we were not worried about corrosion. We just ground them off or cut them off at the surface of the UHPC.

Okay, so how about any other situations any other comments from anyone on the panel.

I typically see them left in place.

Excellent. I guess the last question we have right now is from PennDOT. What is the minimum bottom cover for UHPC? Ben?

That is tricky. I guess this question is asking about the cover requirements in related to the ??? spec for durability reasons. So UHPC is a much more durable, so you can get by with less cover and still have plenty of good performance. However, I guess it depends on where the question is coming from. Cover matters also from the standpoint of, the UHPC has to flow around the bar in order to encase the bar. When you're doing with these connections often what you're doing is using UPHC as is a castable confinement, and that confinement is what allows the rebar development lengths to be shorter and thus the connections to be much smaller. So from that standpoint you do need a cover of at least a certain number of bar diameters in order to achieve the short development lengths that you want with UHPC. You can find that in the design guidance that we have put out there.

For that reason you cannot go down to say a half an inch cover on the UHPC on the bottom of the connection because you needs more UHPC that that just to encapsulate the bar.

To add to that, for typical deck panel connection, you're going to be governed by the cover requirements of the precast concrete and not necessarily the UHPC.

Yes. Good point.

I think there is one question here from Philip, and I skipped it, I apologize. It's related to the physics of the project. The strength of 150 mega Pascals, was it based on field-cured cylinders, or was it the laboratory mix design?

The 21.7 is what we reported in the GS 1000 data that we had. Definitely from our field-cured cylinders during the actual project we exceeded that. I think we're up at like 28,000 on some of the cylinders.

OK we are coming up to the end I may have to cut this off but these are good questions here. The last one I will read out is from Brandon. Are there any UHPC-specific requirements in high or low temperatures that are different from concrete. Ben?

I will answer that quickly. It is concrete so there are high and low temperature requirements for conventional concrete, and since UHPC is a Portland cement-based material, you would have similar requirements. On the high side UHPC, it's best to be at 80 Fahrenheit or below, the actual UHPC mix temperature, at 80 Fahrenheit or below, at the time when you're placing it, and that's because if you get it too hot, it starts to lose water and gets stiff. On the cold side, you obviously don't want it to freeze. Again, it's a Portland cement reaction with water, and so you need to keep it above freezing until a sufficient portion of that reaction has happened that you gain the mechanical properties that you need.

Great thank you. With that we will wrap up. Thank you for submitting your questions to the presenters and thank you to the panelists for answering them. I want to close this presentation with a few announcements here. The first one is about the UHPC resources that have been alluded to by our speakers. If you go to the file share pod on your screen at the bottom, you will see variety of resources that you can actually download. There's a design guide that Sri referred to for the UHPC panel waffle deck system, there is the entire slide deck from today there, and there is a webinar flyer with all of the six webinars listed and dates also downloadable from the file share. There is another document on structural connections of UHPC waffle bridge deck in there and the UHPC state of the art report from 2013, that I think Andy mentioned at the beginning. It's a very nice report that synthesizes information from several hundreds of articles out there on UHPC up until that point in 2013 on various aspects of UPHC, from material to construction to placement and testing. The design and construction of UHPC construction, the Federal Highway Administration technote, is also downloadable from the file share. I encourage everyone to take a look at those documents and see if anything takes their interest and download them. As I mentioned earlier, the state of the art report is also in the file share, and you can also download it. In addition FHWA has a wealth of resources they keep updating on their website.

The one that is shown here can be Googled with the operative word FHWA UHPC. This is the Federal Highways research resources website which has all of the latest and greatest information that FHWA has on that topic. You can Google FHWA UHPC and the first hit is this website. Incidentally, the second hit on a Google search is the FHWA EDC UHPC resource page, which gives you information about the workshops and webinars and resources that we have on this topic. I highly encourage the audience to go to those sites to get more information.

We are almost at the end so I will administer our last poll for today, which is an evaluation, and if you would not mind taking a few minutes to let us know how you received the information today, that would be helpful for us in fine-tuning our contents for upcoming webinars. I will leave this open for a few seconds to get through this. Once we are done, I will end the poll and also announce at the end of a webinar the PDH registration page, so please stick around for those who want that PDH. Do not type in your email and name in the chat box. There's a special data entry pod I will bring up at the end and that's where we need to do that.

Thank you for participating in the evaluation, and I will go back to the presentation with a couple more important reminders. The first one is our next webinar, which is on construction inspection and quality assurance for UHPC connections, where we do a longitudinal section analysis of a real world project from a designer, owner, and contractor perspective. That's scheduled for June 6. Please tune in to that one. And last but not least, all questions related to FHWA's EDC UHPC implementation efforts should be directed to Mark Leonard, and this is his email and contact information shown on the slide here, and this slide deck can also be downloaded as a PDF from the file share, as well as Ben Graybeal's phone number and contact email. Please direct any questions you have on UHPC to the Federal Highway point person dealing with that.

That concludes our presentation for today. Thank you for attending and thank you to all of the presenters and panelist for participating as well. Those who did not want the PDH certificate can disconnect. For those seeking PDH certificates, I will bring up the certificate pod, and you can start typing in your email address and name and address here. I apologize if you did that in the chat pod, but this is the place you can type in your email address and name as it should appear on the certificate so we can capture that accurately. We'll also try and gather those in the chat pod from those that have already done that. I still encourage you to enter it again here.

This pod will be open for several minutes after we close today until we do not see any more entries. So do not try to rush you have plenty of time to enter your information

Thank you everyone for participating and that is the end of our webinar today.

Thank you.

[Event concluded]