ABC-UTC October 2021 Research Seminar: Service Life Design Guidance for UHPC Link Slabs		
#	Questions	Responses
	Design	
1	When retrofitting multi-lane bridges, how does one handle the vibrations from the adjacent lanes that are still open to traffic?	This would be similar to any other application. In the two times we have worked in this situation, we did not see adverse affects from the adjacent traffic lanes.
2	Are you utilizing small diameter rebar to increase the flexibility of the link slab connections with the adjacent concrete deck?	We are using No. 5 bars to match the connection into the bridge deck. We are primarily counting on the geometry to provide appropriate flexibility, but small diameter bars do help with the connection.
3	What is the behavior of UHPC under different conditions?	This was addressed to some extent in the webinar slides. We can provide some additional information for other applications if you contact us directly. We have tested continuous joints, repairs, and many small-scale applications using UHPC.
4	Do you have any available reference calculations for link slabs?	These will be part of the materials submitted with the project final deliverables. There are examples in some of the references at the end of the presentation slides.
5	Can you provide access to link slab design guidance, Code of Practice, or other guidelines?	Some useful items include the ABC Guide Specification (https://www.trb.org/Publications/Blurbs/180078.aspx); Appendix F of Aktan, H., Attanayake, U., and Ulku, E. (2008). Combining Link Slab, Deck Sliding over Backwall, and Revising Bearings, RC-1514, Michigan Department of Transportation, Lansing, MI; Caner, A. and Zia, P. (1998). Behavior and Design of Link Slabs for Jointless Bridge Decks, PCI Journal, 43(3):68–80; and Caner, A., Dogan, E., and Zia, P. (2002). Seismic Performance of Multisimple-Span Bridges Retrofitted with Link Slabs, Journal of Bridge Engineering, 7(2):85–93. These items have some design examples of typical link slabs. New York DOT also has some guidance for UHPC link slabs.

6	Do you have any recommendations or observations for the use of normal-strength (4-6 ksi) concrete in link slabs?	Normal-strength concrete link slabs can work well if designed properly. I would call it more difficult to do for retrofit because of how much concrete would need to be removed. There is the potential for cracking and faster deterioration when using normal-strength concrete. They should be designed with appropriate methods.
	Research	
7	Do you have plans to research in-service link slabs and their performance?	Yes, we are working with the Oklahoma DOT on a potential implementation project that would include performance monitoring in place.
8	Were there comparisons to typical link slab details using standard cast-in-place concrete with f'c around 4 to 5 ksi?	We did compare UHPC link slabs to conventional concrete link slabs, but not with exactly typical details due to the limitations on size in our lab. The specimens we constructed utilized typical concrete, but did not have the same dimensions as a typical conventional link slab.
9	What ADTT (Average Daily Truck Traffic) and ADT (Average Daily Traffic), salting, and Vehicle Loads are used for projections of link slab performance?	It depends on the individual bridge. Loads would match design criteria considered for that bridge. Guidance for some of these items is provided in the Service Life Guide Specification.
10	What are the desired characteristics of UHPC for link slabs?	In general, compressive strength of 22 ksi, post-cracking tensile strength greater than 0.72 ksi, flow 8-9 inches, and high durability are the desired characteristics of UHPC link slabs. For this application, the tension strength, bond strength, and durability are important considerations.
	Questions during Seminar	
11	Has the feasibility of debonding materials other than a synthetic sheet gasket (e.g., building paper) been considered?	We have not considered other materials as we wanted to match the material used in a specific application. Other materials have been examined in previous research, such as roofing paper.

12	How is Service Life Design different from ASD (Allowable Stress Design) or WSD (Working Stress Design)?	Service life design is focused on selecting items intended to extend the life of a bridge rather than just designing it to achieve satisfactory strength to ensure life safety. The bridge would still have to be designed for strength and serviceability requirements. ASD and WSD are methods focused on strength.
13	Does UHPC require additional cooling (similar to mass concrete)?	It may be necessary to control UHPC temperature during mixing to ensure adequate workability. This is typically done by replacing some mixing water with ice. It is not typical to need cooling during curing.
14	How do you seal the interface between the link slab and the bridge deck?	UHPC is typically considered to bond sufficiently with base concrete to create a watertight seal. However, typical crack/joint sealing materials can be used if necessary.
15	What work have you done to establish the rotation and forces that link slabs should be designed for? Other than what is in the literature?	We have not done any work in this area and have considered only items available in the literature.
16	There are questions related to what rotation and what forces that link slabs should be designed for. Did you do any numerical work to verify the suggested design provisions that are in the literature?	We did not do any numerical analysis and only used items suggested in the literature.
17	Can you provide more information on why restraining the lateral movement at the bearings can cause serviceability issues in the link slabs?	Fixed bearings have been shown to lead to restraint and additional bending in the link slab. Some references that may be useful on this topic are El-Safty, A. (1994). Behavior of Jointless Bridge Decks. PhD thesis, North Carolina State University, Raleigh, NC; Caner, A. and Zia, P. (1998). Behavior and Design of Link Slabs for Jointless Bridge Decks. PCI Journal, 43(3):68–80; Okeil, A. and El-Safty, A. (2005). Partial Continuity in Bridge Girders with Jointless Decks. Practice Periodical on Structural Design and Construction, 10(4):229–238; and Ulku, E., Attanayake, U., and Aktan, H. (2009). Jointless Bridge Deck with Link Slabs Design for Durability. Transportation Research Record: Journal of the Transportation Research Board, 1(2131):68–78.

18	In reference to Slide 21 - improper bearings: My state DOT does not currently use link slabs as detailed here. We use a lot of simply-supported prestressed girders with fixed (pinned) shoes on each end, with integral abutments, and the deck is continuous over intermediate bents. Our standard detail for the slab over intermediate piers is empirical and just includes additional deck reinforcing. With fixed shoes at all bearings, would link slabs be an appropriate solution to provide better deck detailing and performance, or are expansion shoes a requirement for link slabs?	I have seen various support conditions used in the literature and previous practice. From what I have seen, it is my understanding that using expansion bearings for both beams at the location of the link slab is the best way to go. Fixed bearings can lead to additional bending in the link slab, but this can be accounted for. Some references that may be useful on this topic are El-Safty, A. (1994). Behavior of Jointless Bridge Decks. PhD thesis, North Carolina State University, Raleigh, NC; Caner, A. and Zia, P. (1998). Behavior and Design of Link Slabs for Jointless Bridge Decks. PCI Journal, 43(3):68–80; Okeil, A. and El-Safty, A. (2005). Partial Continuity in Bridge Girders with Jointless Decks. Practice Periodical on Structural Design and Construction, 10(4):229–238; and Ulku, E., Attanayake, U., and Aktan, H. (2009). Jointless Bridge Deck with Link Slabs Design for Durability. Transportation Research Record: Journal of the Transportation Research Board, 1(2131):68–78.
19	In the 1990s, ECC (Engineered Cementitious Composite) link slabs where constructed with success. Have you reviewed ECC as a better solution to cracking issues?	We have not reviewed this specifically. If I understand the question correctly, these should have similar behavior to the UHPC link slabs discussed in this presentation and could be a viable option.
20	Have you seen any studies on UHPC sleeper slab joints?	We have not seen anything on this topic specifically.
21	Are the presenters aware of any UHPC link slab deployments in high seismic areas of the U.S.?	None of the implementations we have identified were conducted in high seismic areas of the U.S. A potentially useful reference on general link slabs in seismic areas is Caner, A., Dogan, E., and Zia, P. (2002). Seismic Performance of Multisimple-Span Bridges Retrofitted with Link Slabs. Journal of Bridge Engineering, 7(2):85–93.

22	Around Slide 25 showing the freeze-thaw specimen, was it stated that "The majority of damage of these specimens was in the base concrete"? The close-up picture of the base concrete appears to show damage within the substrate course aggregate and at the substrate course aggregate-cement paste interface. Can you discuss this further? Since UHPC has 50% higher CTE (Coefficient of Thermal Expansion) and 100% higher E (Modulus of Elasticity) than the substrate concrete, is there a concern for in-service conditions of extreme thermal cycling?	There was substantial damage in the conventional concrete portion of the composite specimens. This damage began as small cracks that widened and led to spalling as the testing continued. There was some spalling at the paste to aggregate interface and some through the aggregates. The difference in thermal expansion and modulus of elasticity can be a concern relative to thermal cycling. The specimens without fibers cracked transverse to the bond which was likely due to the difference in these properties. We did not see that sort of issue for any specimens with steel fibers.
23	I have a question about the impact of the link slab on the overall behavior of the bridge. The idea of the expansion joint is to allow the expansion/contraction of the superstructure in order to avoid any extra stresses that would be generated if the superstructure was restrained longitudinally. My question is: what is the real purpose of the link slab; is it to restrain the longitudinal displacement of the superstructure, and therefore use the link slab as a structural element that would withstand the stresses generated by the longitudinal restrain, OR, the link slab would play the exact role of the expansion joint by allowing the longitudinal deformations of the superstructure?	The link slab is intended to reduce the amount of joints in a bridge while still maintaining simple span behavior. There would still need to be provision for expansion and contraction of the structure. The link slabs are intended to transmit longitudinal forces between spans such that the deformation could be taken up at a reduced number of expansion joints.
24	If the link slab withstands the stresses induced by the temperature and shrinkage, and since the link slab is stiffer than the deck slab because of the material used, is there any risk to see a modification of the static scheme of the bridge and see some generation of extra forces, stresses, and extra longitudinal bearing reactions induced by the longitudinal restrain of the link slab that would impact the design of the foundations of the bridge?	I have seen nothing to indicate that additional forces would result on the foundations from thermal and shrinkage stresses transmitted through the link slabs.
25	In reference to Slide 48: When do you anticipate the training materials to be available?	Completion is anticipated in the first quarter of 2022.

26	Are link slabs applicable in cold weather conditions, e.g., Minnesota or Wisconsin regions?	Yes.
27	In terms of the design, how do we consider the link slab in our models? Do we consider them as nonlinear longitudinal links that will be defined as working in tension/compression only?	The idea is that they act like a hinge that can transfer longitudinal force but there is some bending in the element that is dependent on stiffess and beam bearing conditions. There is some discussion of different possibilities in the literature including a longitudinal link acting in tension/compression and as a beam element with stiffness that accounts for any cracking. In general the method is to design the beams on each side as simply supported and then design the link slab using induced rotations.
28	How does the link slab accommodate thermal movement due to expansion and contraction?	The link slab would transmit the thermal movement between spans to expansion joints located within the bridge.
29	Are there any good design examples in addition to the NYSDOT (New York State Department of Transportation) MathCad design example?	I am not aware of any other good design examples yet for UHPC link slabs. There will be some useful information in our final deliverables for this project. Appendix F of Aktan, H., Attanayake, U., and Ulku, E. (2008). Combining Link Slab, Deck Sliding over Backwall, and Revising Bearings, RC-1514, Michigan Department of Transportation, Lansing, MI; Caner, A. and Zia, P. (1998). Behavior and Design of Link Slabs for Jointless Bridge Decks. PCI Journal, 43(3):68–80; and Caner, A., Dogan, E., and Zia, P. (2002). Seismic Performance of Multisimple-Span Bridges Retrofitted with Link Slabs. Journal of Bridge Engineering, 7(2):85–93 have some design examples of typical link slabs.
30	Has using cementitious material with sufficient tensile strength to eliminate debonding entirely been considered?	To my knowledge this has not been considered.
31	Is the bond breaker considered compressible, and is the wheel load designed to span the bond breaker length and not just the opening gap?	The bond breaker is very thin and is considered to transmit vertical loads into the slab below. Only the opening gap would need to be spanned.

32	Did the UHPC design use micro or macro fibers? In consideration of Buy America requirements, are there any domestic producers for these fibers, as many are from overseas?	The UHPC design used steel microfibers, 13 mm long and 0.2 mm in diameter. There are domestic producers of these or similar fibers. One domestic producer is Hiper Fiber LLC out of Michigan.
33	Do contractors need to be trained for placing UHPC link slabs?	Link slabs themselves are similar enough to other construction that contractors would probably only need specific training on using UHPC. This includes forming, mixing, and placing the material.
34	Are there written specifications for construction of UHPC link slabs?	NYDOT has a UHPC material specification (https://www.dot.ny.gov/spec-repository-us/557.66010116.pdf), and at least North Carolina, New York, and Virginia include link slab design in their bridge manuals or standard specifications, but I am not aware of a specific UHPC link slab construction specification.
35	During freeze-thaw cycles, how would the link slab behave without crushing the existing bridge slabs?	It is similar to any other type of connections of dissimilar materials. There is a possiblity of differential deformation that could be problematic, but in general UHPC produces a strong bond that allows both materials to act as a unit.
36	With the high modulus of elasticity of UHPC, do you see link slabs as flexible elements?	Yes, link slabs can act as flexible elements if the thickness of the link slab and debonded region is designed properly to account for the larger inherent stiffness of the UHPC. This is one reason UHPC link slabs are usually only partial depth compared to the total deck thickness.
37	Are link slabs applicable for transit loading, e.g., light rail or AREMA (American Railway Engineering and Maintenance-of-Way Association) loading?	I do not have sufficient experience in this area to say for sure, but I would think this would be possible if designed correctly.

38	Some states allow for only one of the bearings at link slabs to be expansion bearings, where the other bearing is a fixed bearing. I have always designed for both to be expansion to allow for the rotation in the slab. Do you have any opinion on this detail, and will you be running any tests simulating this to evaluate the performance?	We do not intend to run any tests to examine the performance of these details. I have seen various support conditions used in the literature and previous practice. From what I have seen, it is my understanding that using expansion bearings for both beams at the location of the link slab is the best way to go. Fixed bearings can lead to additional bending in the link slab. Some references that may be useful on this topic are El-Safty, A. (1994). Behavior of Jointless Bridge Decks. PhD thesis, North Carolina State University, Raleigh, NC; Caner, A. and Zia, P. (1998). Behavior and Design of Link Slabs for Jointless Bridge Decks. PCI Journal, 43(3):68–80; Okeil, A. and El-Safty, A. (2005). Partial Continuity in Bridge Girders with Jointless Decks. Practice Periodical on Structural Design and Construction, 10(4):229–238; and Ulku, E., Attanayake, U., and Aktan, H. (2009). Jointless Bridge Deck with Link Slabs Design for Durability. Transportation Research Record: Journal of the Transportation Research Board, 1(2131):68–78.