IBT/ABC-UTC December 2023 Steel Bridge Rehabilitation Using UHPC to Repair Corroded Beam Ends

#	Questions	Responses
		Please note that these responses are those of the Presenter and are not endorsed by the IBT/ABC-UTC.
	General	
1	Are there limits or thresholds for beam-end corrosion that possibly render this UHPC retrofit structurally undesirable?	There needs to be sufficient sound steel in the repair area to affix the welded shear connectors.
2	Can this material be used as a preventative measure for steel beam end corrosion?	In theory yes. This has been discussed, but not implemented. Work on this including a life cycle cost estimate is ongoing at the University of Connecticut.
3	In using this method of repair - what is to be done with the bridge bearings under the repaired beams?	In most cases, the bearings are not replaced, since we are typically just repairing one or two beam ends per pier (gutterline girders). Bearing replacement would require jacking of the girder, which is one aspect of the repair that we were trying to avoid.
4	Was any consideration given to eliminating the deck joints as part of the repair to minimize future corrosion?	Yes, however this would require replacement of bearings as the link slabs change the thermal movement characteristics of the bridge.
5	Would this be a useful application for Steel Box Beam Caps by filling the inside of the box beam?	UHPC is most appropriate for compression elements. In most cases, the bottom of a box bent would be a tension element. The upcoming AASHTO guide specification for UHPC will address the material properties of UHPC. In theory, a design could be developed using a strain compatibility approach.
6	How do you measure the amount of section loss? Will this dictate the length and the thickness of the UHPC repair area?	There are various ways to measure loss. Calipers, D-meters, straight edges. UConn did include very sophisticated means of measuring losses using structured light 3D scanning, although this may not be practical for everyday maintenance repairs. A precise measure of section loss is not required as we do not design the repair assuming residual capacity of the beam, we just need to know there is enough web to attach the studs.
7	Is there a percent of section loss that precludes the effectiveness of this method of repair?	There needs to be sufficient material to attach the welded studs. We have not seen a case where this was not possible.
8	It looks like the UHPC block in the test is partial, and the block in the field is full. Please comment on whether or not the block needs to have full contact in between the flanges.	You do not need to have full contact with the top flange as long as you can transfer the bearing reaction to the adjacent web. Both full height and partial height repairs have been implemented in the field.
9	When the repair was implemented, did you repair only the beam ends that exhibited excessive section loss by corrosion, or did you repair all beam ends?	Just the corroded ends. This is typically the fascia and the first interior beam. You could in theory do them all as a preventative measure, but this is not normally required. The degree of section loss on repaired beams in the field did vary greatly.
10	The study appears to be focused on the webs and shear, but would it be possible to perform the same type of repair for corroded flanges of steel girders, and did you study the impact on bending?	CTDOT has a project in construction that includes strengthening of a compression flange at a pier. The research did not study the combined effect of shear and bending.
11	Would it be possible to use a high compressive strength concrete (10 ksi for instance) instead of UHPC for the repair of the steel web?	The tension resistance of UHPC with the steel fibers plays a significant role in this repair. The flowability of UHPC and the ultra-low permeability are other benefits. 10 ksi design would require significant amounts of reinforcing steel. UHPC does not need reinforcing. Studies during Phase II of the research showed lower strengths did not work and resulted in concrete failure rather than stud failure.
12	Does the UHPC encasement stop the propagation of corrosion along the web of the steel beam?	Yes. This is an added benefit of this type of repair.
13	Are the properties of UHPC similar to regular concrete?	No. Benefits include: High compressive strength, ductile post-cracking tensile strength, flowability, and ultra-low permeability.
14	Please comment on the adhesion of UHPC to existing steel and existing concrete compared to standard concrete.	UHPC does not have any appreciable increase in bond strength when compared to normal concrete. This is why studs are used in the repair.
15	Similar corrosion can be found on connections of floor beams to main girders at railway TPGs (Through Plate Girder). Can the same concept be used for reinforcement of floor beams to main girders?	We do not see why it would not work.
16	For structures that require bearing replacement, but bearing or jacking stiffeners are insufficient, can the repair be executed first and the UHPC block be used as the jacking stiffener?	Yes, this should work well. Texas DOT used UHPC encasement on diaphragms to enable jacking, this work is published.
17	Does the UHPC repair require a coating? If yes, what type?	No. UHPC has very low permeability. Coatings are not required.
18	What are the components of the UHPC material.	Please refer to the FHWA UHPC website for more information. https://highways.dot.gov/research/structures/ultra-high-performance-concrete/ultra-high-performance-concrete

Design

19	Are there any concerns with the difference in material properties between the UHPC and steel for this construction type?	The design is similar to any composite design. Transformed section and a strain compatibility approach can be applied. We believe that the soon to be published AASHTO Guide Specification for UHPC will cover this.
20	How does this repair affect the load rating for shear of the repaired member?	The repair is based on restoring the full shear capacity of the beam end. The rating could be run assuming the beam is undamaged.
21	What considerations or details are used to account for skew? And how do you work around end diaphragms?	The only issue with skew is the installation of the studs. The UConn study included using threaded rods in place of the studs. It does work, though the research is limited. Therefore, the hole can be drilled through the obtuse side of the web to facilitate the treaded rod installation. In addition, traditional welding methods rather than a stud gun can be used for the acute corner. One of the great properties of UHPC is that it can be poured around unusual geometries.
22	Does Connecticut DOT have standard UHPC specifications for this type of construction?	Connecticut DOT has developed a special provision specification for the repairs.

Construction

23	Please comment on the general availably and sourcing of UHPC.	UHPC use is gaining popularity. There are now several approved suppliers in the US. Contractor familiarity is gaining with every UHPC project.
24	How many providers, or approved installers, are there for UHPC in Connecticut?	There are multiple suppliers in the market now. For this type of repair, the contractors are performing the installation. This approach has worked well. We do recommend a test pour so the contractor can prove a successful installation and correct any issues. The number of UHPC suppliers available has led to CTDOT switching to a performance based specification.
25	Are certifications required for installation personnel regarding this type of construction?	No. We do recommend that a representative from the UHPC supplier be on site or train the crew in the mixing and placement of the material. We do recommend a test pour so the contractor can prove a successful installation and correct any issues. It is critical that the material testing lab that will be doing the cylinder breaks has the equipment and expertise required for UHPC. UHPC cylinders cannot be capped, they need end grinding.
26	If the deck is not replaced, how do you place and remove the forms for pouring the UHPC in such tight confinement, particularly adjacent to the backwalls?	The contractors have come up with different solutions for forming. We typically allow them to core through the deck to facilitate placement and simplify forming. Several methods of forming were shown In the presentation. We have considered allowing the contractor to core through the deck and top flange to simplify the forming even more.
27	Please comment on how to cast the UHPC to ensure contact with the underside of the top steel beam flange.	In theory, contact is not required. The design is based on transferring the total shear from the UHPC to the girder web below the top flange. If full contact is desired, casting can be done from the top of the deck and the UHPC can be poured until the deck core hole is filled.
28	How do you determine the number of studs that need to be used for the repair?	It is a function of the bearing reaction and the capacity of the studs. The design guide covers this.
29	Does the UHPC "replace" the corroded web of a steel girder in terms of the shear strength or is the shear strength provided by the composite section of steel/UHPC?	We generally neglect the capacity of the web (conservative assumption). One design approach is to design the studs for only the live load impacts while the other is for the full shear capacity neglecting all steel.
30	Please comment on whether it is necessary to add studs to the stiffeners to make the whole steel section works together with the UHPC?	Studs can be placed on the web or the stiffeners.
31	How did you take into account the amount of corrosion when modeling the interface between the substrate and the UHPC in the Finite Element Method software?	The Finite Element Method models did simulate section loss. However the bond between the web and the UHPC was not considered. To be conservative, only the force transfer through the studs was used.
32	In lieu of welding shear studs to the web, would drilling holes thru the web and inserting threaded rods through both sides with nuts (two against web and two at opposite ends) be an option?	This was studied and found to be an acceptable option to welded studs. It is important to note, this approach has substantially less research and results in larger differential displacements between the web and the UHPC block so it is not an exact trade off.
33	By adding studs, did you have issues with reduction in fatigue strength?	The fatigue stresses at beam ends are so small that fatigue is not an issue.
34	Was loading removed from the bearing area prior to casting of end repair and then reloaded? Was the design loading capacity of the repair only for Live Load?	Dead load was not removed, since one of the goals of the repair is to avoid jacking. The design is for both dead and live load (conservative), although the design guide does provide multiple options such as designing for live load only.

35	Are the shear studs welded outside of the limits of the corroded web so that the load path bypasses the corroded web and is transferred to the bearings through the UHPC?	Yes
36	What is the function of the studs structurally? How do they participating in the load path - especially if they are welded to the corroded web with advanced section loss?	They are welded to sound or nearly sound steel. The studs transfer the bearing reaction from the UHPC to the girder web and/or stiffeners.
37	Have the stresses in UHPC and girder flanges been monitored/analyzed through Finite Element Analysis investigation?	Yes. Both FEA and field strain gaging were used.
38	Please explain how the installation of UHPC restores the full dead load and live load capacity and is able to remove the locked in dead load stress in the steel portion of the beam?	There is no simple way to answer this. Please refer to the research report cited in the presentation. Without jacking, only the live load is carried thought the studs and UHPC block. If jacking is used at a different time (for example if bearings are replaced later on) the repair could handle both dead and live loads.
39	Is the repair designed for full DL+LL reaction despite not jacking to transfer the dead load during the repair?	Yes. We conservatively design for both.
40	What surface preparation of the steel is required prior to pouring the UHPC?	Blast cleaning is recommended.
41	Is the 18 ksi compressive strength easy to achieve, or are there any special considerations? Is it correct that no vibration of the mix is necessary during installation?	There are several UHPC mixes in the market that can easily achieve this strength. Vibration is not required and should not be used as it can cause the steel fibers to settle to the bottom of the pour.
42	If drilling from the deck through the top flange, what would be a minimum diameter core size to pour the UHPC material?	The material is very flowable and the aggregate is very small. The only issue is the steel fibers. A hole as small as two inches would most likely work. There are limitations discussed in the guidelines based on the fiber length.
43	What were the lane closure requirements, particularly for the full height repair, and are extended closures required to minimize local live load effects at beam ends during the curing?	Lane closures are only required if the installation of the UHPC is from the top down. Live load vibration was studied. The test samples were vibrated to study the effect of live load on the repair during curing. There were no issues. Lanes were closed only over the areas that were being cast based on standard maintenance of traffic procedures, no extended closures were needed.
44	How do you ensure that the UHPC fully fills the forms up to the bottom of the top flange?	We recommend a test pour (mock-up). The material is very flowable. This has not proven to be an issue.

Service Life

45	Comment on the potential for deterioration of this type of UHPC repair over time?	UHPC has been shown to have superior durability, much better than normal concrete. The presence of the steel fibers has shown to have no impact on durability. Phase II of this research included accelerated corrosion testing. Apart from coloring on the surface of the UHPC, there was no loss in capacity.
46	Questions: 1) Do you see potential for extending this application to: a) railway bridges, b) seismic applications?; 2) Regarding durability, is the UHPC prone to failure due to vibration cycles during bridge operation?; 3) What is the expected life of these repairs?	Responses: 1a. Yes 1b. There are other research projects that have investigated the use of UHPC for siesmic applications. 2. This was studied. The test samples were vibrated to study the effect of live load on the repair during curing. There were no issues. 3. The repair should last the life of the bridge.
47	Have there been long term deterioration issues for partial height UHPC beam end repairs at the interface of the steel and concrete?	This was studied. Samples were exposed to severe corrosion conditions and faired well. We do recommend sloping the top of the UHPC and painting the steel along the edges of the repair. Sealing the interface joint with sealant has also been considered and silicone was used for this in the field applications.
48	Have there been subsequent inspections to see how the repairs are performing over time?	Yes. There were no problems noted.
49	What is the typical life of this repair and is it possible the retrofit could spall and delaminate due to exposure to deicing salts?	Research has shown that UHPC is extremely durable. Much better than normal concrete. From the accelerated corrosion tests completed in phase II of the research and from other studies on UHPC, spalling was not seen and is not anticipated.

Cost

50	How does the cost of UHPC compare to the cost of standard concrete?	The unit costs are very high due to the high labor to material ratio. The majority of the cost is the labor to clean the steel, prep the area, form the pour and place the UHPC. This adds up to a lot of cost compared to a small quantity of material. Therefore, unit cost estimating is not recommended. Estimates should be based on labor and equipment, with a small amount for materials (say $2000 per CY). Most repairs have a fraction of a cubic yard of UHPC, so this is not a major component of the overall cost.
51	What is the estimated cost and time saved compared with traditional repair methods?	It depends on the traditional repair methods. If calculations are run on a bolted repair, the number of bolts can get very large, driving up the cost. If jacking is required for the repair, that cost can get very high depending on the situation. We have seen traditional costs for beam-end repairs exceed $40,000 per beam end. The UHPC repairs should be less than $10,000 per beam end. In certain cases, even less.
52	What is the construction cost comparison for this UHPC repair method vs welded/bolted steel plates?	See response above
53	What were the cost for repairs/per beam for weathering steel?	We do not have exact numbers. The cost for weathering steel would be similar to the cost for painted steel. See response above.
54	Approximately what quantity of UHPC was required per beam end?	It depends on the depth of the girder. The UHPC section is approximately 12"x12" (6" thick on each side of the web). For a 48" deep beam, that would equate to 4 cf or 0.15 cy.