J. P. Binard

UHPC: A game-changing material for PCI bridge producers

- With the increasing availability of nonproprietary versions of ultra-high-performance concrete (UHPC), using UHPC to advance the precast concrete bridge industry is becoming more of a reality.
- Cost savings in other areas of bridge construction because of UHPC could offset the higher cost of the UHPC itself.
- Dura Technology in Malaysia provides an example of how U.S. precast concrete producers could make UHPC work for them.

The segmental box-girder bridge at Batu 6 in Gerik Perak, Malaysia, is not an ordinary concrete bridge. It is made with ultra-high-performance concrete (UHPC). Projects and publications throughout the world have highlighted UHPC and its various applications in bridges, buildings, and other sectors for about 15 years.[1] Numerous research activities in the United States by the Federal Highway Administration's (FHWA's) Turner-Fairbank Highway Research Center, headed by FHWA Bridge Engineering Research Team leader Benjamin Graybeal, have investigated components and connections for the bridge industry.[2,3] The results of these tests have been implemented successfully in a variety of projects throughout the United States.

Aside from smaller FHWA-subsidized pilot projects, UHPC has not been considered a viable option for precast concrete components in the United States. Although there are plenty of perceived obstacles, such as cost, to marketing UHPC in the United States, Dura Technology is producing large components fabricated from UHPC for use in a variety of bridges throughout Malaysia. Dura Technology uses a facility solely focused on UHPC and directly competes with conventional structural solutions. The process developed for mixing, delivery, and quality control are designed for UHPC. Dura Technology founder and chief executive officer Yen Lei Voo's energy, accomplishments, and enthusiasm for this subject during a presentation at the 2016 PCI Convention and National Bridge Conference in

PCI's TechnoQuest trip to Dura Technology in Malaysia

From left, John Lawler, Mason Lampton, J. P. Binard, Yen Lei Voo, Jim Fabinski, and William Nickas stand on the UTC Perak footbridge in Ipoh, Malaysia, during their TechnoQuest trip. Courtesy of PCI.

As a result of Dura Technology founder and chief executive officer Yen Lei Voo's presentation about ultra-high-performance concrete (UHPC) at the 2016 PCI Convention and National Bridge Conference in Nashville, Tenn., a trip to Malaysia was organized. In September 2016, members and staff from PCI and representatives from six countries on behalf of the *fib* (International Federation for Structural Concrete) Task Group 6.5, Precast Concrete Bridges, met with Voo, toured the Dura Technology facility, and saw some completed bridges.

Everyone was eager to see something new and nonexistent in their own countries as it pertains to bridge products. The facility is fully developed to cast products out of a nonproprietary UHPC, developed by Dura Technology using local materials, and has specialized means and methods.

Rows of completed product are stored downline in tight increments to maximize the available space at the Dura Technology facility in Ipoh, Malaysia. Courtesy of J. P. Binard.

The Dura Technology factory is a small facility relative to most U.S. bridge producer facilities, but well organized and clean. It bore the appearance of a laboratory, which is not surprising as that is how it started for Voo and his team more than a decade ago as they developed their mixture proportions. Molds were centrally located under a covered building and serviced by an overhead crane. Rows of completed components were stored downline in tight increments to maximize the available space. The components sat on small blocks of UHPC that serve as dunnage; punching shear resistance as well as the bearing strength of this material are phenomenal, whereby the blocks were minute relative to the wood or concrete dunnage for common products. On the day of our arrival, a segmented concrete U beam was prepared for casting with the forms secured and reinforcement present to accommodate horizontal shear requirements for a conventional cast-in-place concrete deck at the jobsite.

After a brief tour of the facility, the mixing process and fiber delivery at the batch plant were observed, followed by testing, dispensing of the UHPC into a bucket from the mixer, and arrival at the form. At this point, the placement and casting were no different from a self-consolidating concrete (SCC) placement at producer facilities in the United States. External vibration is carefully orchestrated after filling the molds to a desired elevation. Internal vibration is not recommended, as the steel fibers prohibit doing this safely where the steel fibers may fling about or get jammed in the equip-

Nashville, Tenn., led to a PCI-organized TechnoQuest trip to his fabrication facility in Ipoh, Malaysia.

Background

UHPC is a fiber-reinforced, portland cement–based product with high compressive strength and reliable tensile properties. It can be described as a composite material like concrete with a water–cementitious material ratio *w/cm* from about 0.17 to 0.25; a high volume of small steel fibers, which allow a strain hardening response; and with sand as the largest particle size (that is, it has no coarse aggregate). The use of UHPC in the United States had previously been stalled due to the domination of proprietary, prebagged UHPC products and the lack of domestic steel fibers. Recently, other preblended products and domestic fibers have become available. Research sponsored by the FHWA on nonproment and the alignment of the fibers could be affected. The rheology of the mixture was fascinating as the fibers migrated with the mixture up the webs of the piece, similar to coarse aggregate. The U beam was topped off from the bucket carried by the overhead crane and then covered for an initial cure.

The means and methods closely mimicked those of SCC. The tightness of the forms, necessary and appropriate moisture controls of the constituent materials, a heavy reliance on chemicals to aide in the rheology, and limited vibration to avoid segregation (settling of the steel fibers in this case) were evident. The main nuance to this entire process, which differs from any conventional concrete casting, is dispensing the fibers into a material with such a low water–cementitious material ratio *w/cm*. The material is essentially designed to desiccate; therefore, the chemicals may form an "elephant" skin, a moniker to describe a thick, gray cover that may form atop the liquid material due to lack of movement. Furthermore, improper dispersion of the fibers or "balling" can significantly affect the performance of the material. No hindrance to production at the Dura Technology factory was observed due to either of these phenomena.


A segmented concrete U beam is prepared for casting with the forms secured and reinforcement present to accommodate horizontal shear requirements for a conventional cast-in-place concrete deck at the at the Dura Technology facility in Ipoh, Malaysia. Courtesy of J. P. Binard.

The philosophy of mixing and placement at Dura Technology centers around a standard of care and respect for the material. From a production standpoint, one may envision that such a low *w/cm* may require laboratory technicians in white coats with pipets and sophisticated instrumentation in all facets. Perhaps in a laboratory with a low volume, this may be required; however, in the field it is rather more of simply an attention to detail. The kiln-dried sand commonly used for glass making is stored in super sacks to prevent ingress of moisture and to ensure the driest possible dry ingredients. The cement temperatures are monitored closely to allow for the best flowability and working time. The addition of ice and admixtures are all timed and staged with precision for the most repetitive results. Fibers are added at a constant rate and folded meticulously for the required amount of time for proper dispersion, orientation in the completed piece, and consistent results.

The group from PCI observed bridges composed of UHPC components as well as the fabricator's facility during casting. The limits of what could and should be done with UHPC were learned as well as removing the limits in thinking of what can and will be done with UHPC. Moreover, what is being done today was seen and experienced. Rather than some far-reaching future concept, UHPC is being used today in daily fabrication in Ipoh, Malaysia. Dura Technology has successfully completed more than 70 bridges, including structures with high average daily traffic. Dura Technology boasts of the longest simple span with UHPC in the world as well as the longest bridge. These feats are not epic or heroic. They stem from using a well-researched material in practical applications to be more competitive than other material solutions.

prietary UHPC mixture proportions and properties in 2013 quelled some of the perceived impediments to the widespread implementation of this material.[4]

The most commonly stated impediment to using UHPC in larger applications has been material cost, which has been significantly higher than the cost of the typical concrete used in bridge structures. Using UHPC for various components within structures has long been a goal to improve the longevity of infrastructure. For example, UHPC has proved vital in addressing a challenge of precast concrete construction for bridges: the connections. In precast concrete bridges that use UHPC for the connections, the parent concrete cracks prior to the UHPC.[2,3] Therefore, the cost of UHPC is offset because of its performance.

Manufacturing a precast concrete bridge component with prebagged material is not common and is ineffi-

The segmental box-girder bridge at Batu 6 in Gerik Perak, Malaysia, is made with ultra-high-performance concrete and has a 328 ft (100 m) long span. Courtesy of Dura Technology.

cient. With the increasing availability of nonproprietary versions of UHPC, using UHPC to advance the precast concrete industry is becoming more of a reality. Increased market share may become more viable when UHPC components are applied as an overall bridge solution. A typical prestressed bridge girder cast with UHPC instead of high-performance concrete (HPC) is not cost effective. However, a modified section that uses 40% to 50% less material with less-congested reinforcement and can be used on longer spans with the same depth can become an attractive alternative to a steel equivalent. With less material, superstructure weights are lower, thereby reducing foundation costs. Crane capacities that are required onsite are diminished, and pick point limitations are similar to those of steel beams. Perhaps using UHPC to manufacture other bridge components, which may be combined to reduce the overall structure weight, can further result in greater efficiency and use of the material. Automating precast, prestressed concrete construction to new levels with less, or perhaps no, manual labor may also be possible.

Ultra-high-performance concrete connections are tested in the laboratory at the Turner-Fairbank Highway Research Center In McLean, Va. Courtesy of Ben Graybeal, Federal Highway Administration.

UHPC: A game-changing material

Several challenges and limitations pertaining to precast, prestressed concrete components are diminished or eliminated by using UHPC.

Clear cover and crack control

Serviceability requirements in precast, prestressed concrete components for bridges often govern the design. As a result, reinforcement is often added to control the growth of cracks. The durability models, alternatively, lead to greater cover of the reinforcement, thereby leading to more reinforcement to reduce the spacing and widths of possible cracks. A design with 3 in. (75 mm) of clear cover requires reduced spacing of nonprestressed reinforcement relative to 2 in. (50 mm) of clear cover in a similar design. Compare this with a possible clear cover requirement of only ¾ in. (19 mm) for UHPC. It is compelling that the nonprestressed reinforcement, or prestressing strand, is more effective, as the distance to the surface is as close as can be imagined. This leads to the largest lever arm and potentially uses the tensile strength of the UHPC in flexure. Furthermore, and perhaps the greatest consideration, reinforcement to serve as crack control is completely unnecessary because it is already embodied in the matrix of the UHPC. This is not to say that cracks may not exist or occur, but they are indiscernible and the low permeability of the cementitious material inhibits chloride ingress to the primary reinforcement.

Tests have shown the chloride-ion diffusion coefficient of UHPC is an order of magnitude less than that of HPC, which has been readily implemented in structures designed to have 100-year service lives.[1] UHPC samples have been tested in a variety of extreme conditions. The FHWA has conducted a suite of tests in accordance with various ASTM procedures as well as placed samples at the U.S. Army Corps of Engineers facility at Treat Island and tested them regularly for over a decade. This suite of tests includes those with exposure to heavy freezing and thawing along with extreme exposure to a splash zone.[1] In addition, Dura Technology has placed samples in a high-salinity tank and left them for more than 8 years. A 9 mm (0.35 in.) thick saw-cut sample revealed corrosion only on the surface.

Camber, creep, and shrinkage

One of the most commonly documented properties of conventional concrete is volume change. Decades of research and empirical data have produced some complex models.[5] The upper and lower bounds have been deciphered, and operating procedures have been established for the industry for design, fabrication, and assembly.

The behavior of UHPC renders these prediction models obsolete after a secondary stage of curing at 194°F (90°C) for 48 hours, which may be implemented up to 14 days after detensioning or demolding. During casting operations, the autogenous, or chemical, shrinkage is large and can exhibit strains equivalent to those of the full life cycle of conventional concrete (casting, curing, and service life). The creep values are also similar to HPC until this secondary curing stage. Thereafter, the creep and shrinkage are essentially eliminated or are similar to day 10,000 in current models, where creep is virtually constant and shrinkage may be considered zero for computations.[1]

This is important to the industry for two reasons:

- Camber can be measured in a fabricator's yard and will no longer change, aside from solar effects, leading to a predictability and a tolerance more like steel products.
- Posttensioned systems will incur significantly less losses due to creep and shrinkage of the prefabricated UHPC component.

Compression-controlled release strength and temporary tensile stress control

Longer-span precast, prestressed concrete components or slender components are often controlled by the concrete compressive strength at the prestressing transfer. To control the compressive stress at the end of a beam to less than 65% of the concrete compressive strength can lead to numerous rows of debonded strands and potentially draped strands depending on the region and beam type. Tensile stresses may control at the ends of the beams or at the harp point of draped strands, leading to further refinement and detailing of the prestressing strand pattern and reinforcement. Lifting, handling, and stability further exacerbate these requirements and

This 9 mm (0.35 in.) thick, saw-cut, eight-year-old sample from a high-salinity, long-term bath at Dura Technology in Malaysia shows corrosion on the surface only. Courtesy of J. P. Binard.

In storage at Dura Technology's facility in Malaysia, these U beams were produced with ultra-high-performance concrete and will be posttensioned in the field. Courtesy of J. P. Binard.

limitations. Thus, the strength at prestressing transfer may need to increase, which can extend common cycles of casting and curing with traditional concrete. Last, this balancing act at the ends of products may also limit shear capacity.

A precast UHPC component is likely to have a reduced cross section because cover is no longer a limiting factor. Hence, using the higher available early and long-term compressive and tensile strengths allows these components to contain a high amount of prestressing force over a smaller area, providing a more efficient design. Stress control throughout construction may be related to principal web stresses or global stability in lieu of the common temporary conditions noted.

Development and bond

The bond capability of UHPC is chemical rather than because of aggregate interlock. The chemical bond with the fibers at ultimate results in pullout rather than fracture, which leads to stress relief instead of large damage.

Tests have shown UHPC's bond to properly prepared conventional concrete surfaces, such as for connections, is significantly greater than the bond between two layers of conventional concrete, and the development of strand and mild reinforcement and lap splice lengths are also greatly reduced compared with conventional concrete.[2,3,6]

The Federal Highway Administration conducts lap splice tests of untensioned strands at the Turner-Fairbank Highway Research Center as part of the research by Graybeal (2014). Courtesy of Ben Graybeal, Federal Highway Administration.

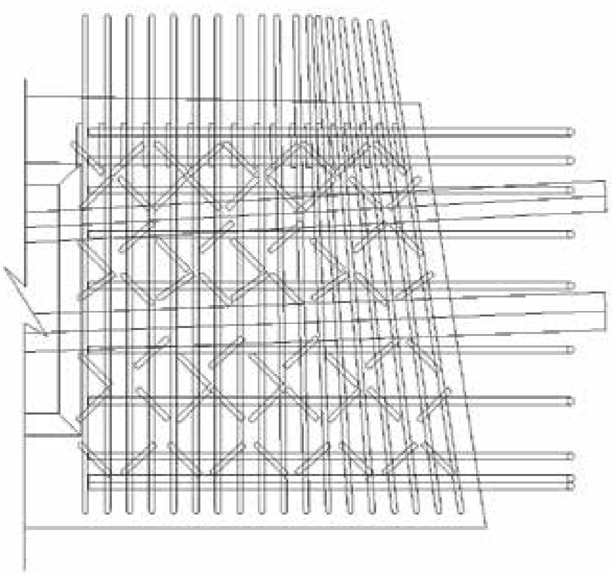
End regions

The detailing of end regions of prestressed concrete beams is complex. The compressive force generated in the inclined struts in shear design can be large, and the development of the tension-tie reinforcement is critical. The use of UHPC simplifies this entire process by greatly reducing or eliminating the need for shear reinforcement, splitting reinforcement, and confinement reinforcement[7] along with shortening the required development length of longitudinal reinforcement. Use of UHPC may also cause global stability and principal stresses to be more critical than the detailed design of the component.

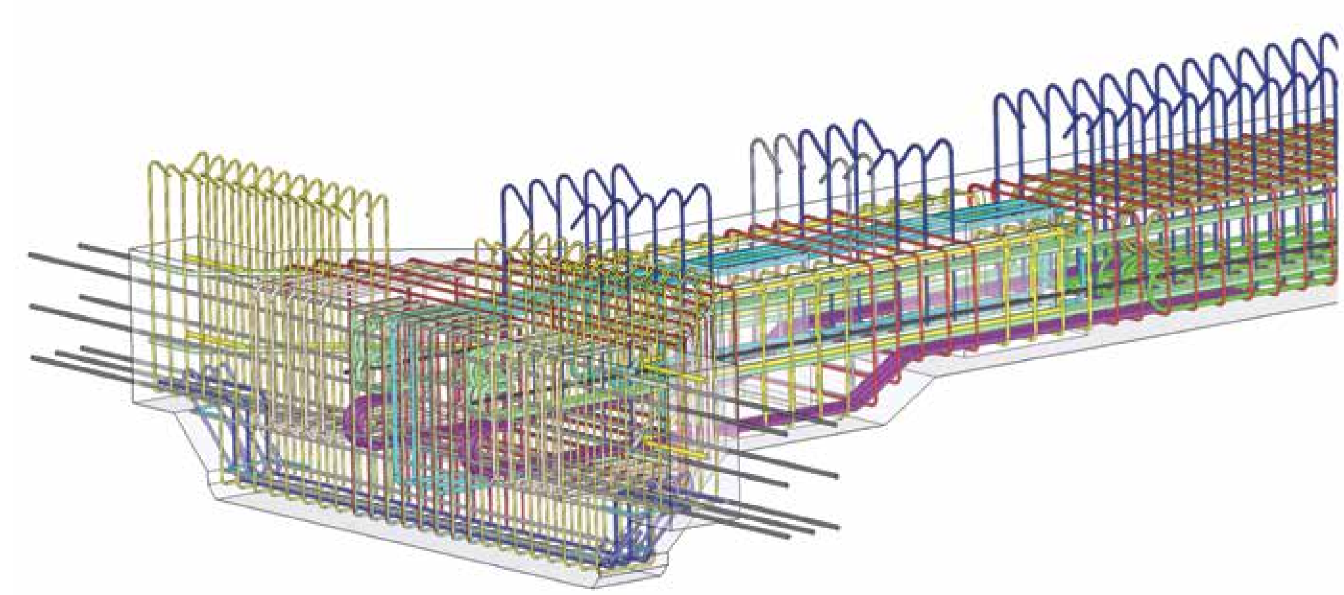
Producers and designers may be familiar with products that contain many smaller stirrups crossing the plane of vertical stirrups at 45-degree angles to control cracks. However, instead of discrete stirrups crossing the plane, UHPC contains this confinement within the mixture composition.

Detailing and reinforcement placement

Producers and designers of precast, prestressed concrete are affected greatly by the nonprestressed reinforcement within the components. All of the efforts that precede



This diagram shows an example of reinforcement congestion typical in an end-block region of a conventional concrete component with additional cross ties. Courtesy of Bayshore Concrete Products.

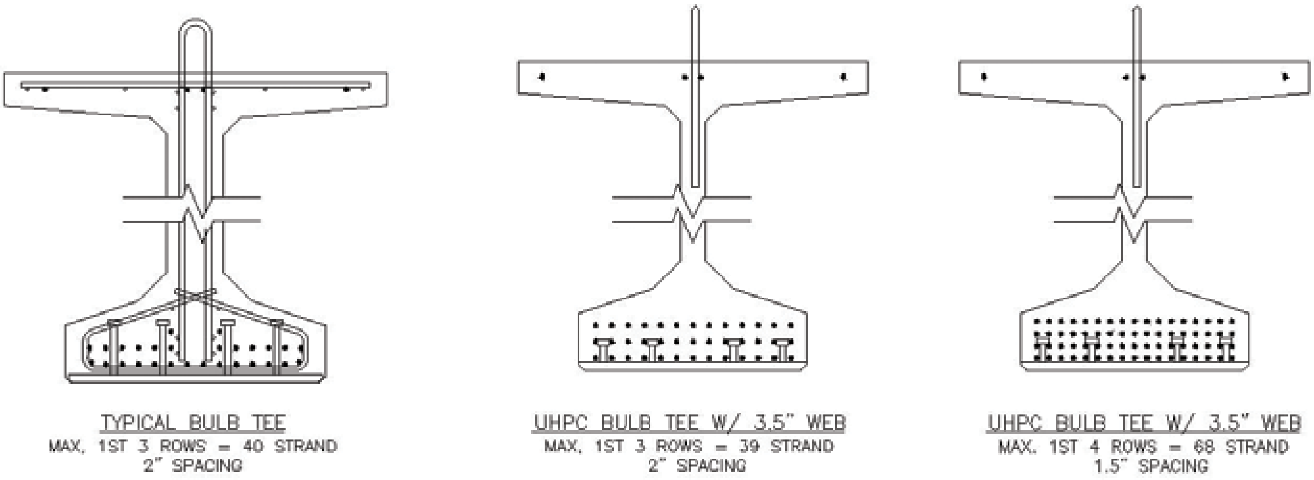


This diagram shows a complex reinforcing cage for a precast concrete component that doesn't use ultra-high-performance concrete. Courtesy of Bayshore Concrete Products.

concrete placement require knowledge of reinforcing details, coordination of reinforcement placement in accordance with approved shop drawings, and coordination with other jobsite practices that may affect where this reinforcement is placed in the component. The lead time, receipt, and steady methodical installation of reinforcement before concrete placement all affect schedules. The various coatings and ASTM standards associated with the reinforcement are known, and bars not detailed or fabricated properly can slow down a project or have a negative impact on daily production.

UHPC may not require nonprestressed reinforcement aside from potential connections for continuity, if applicable (such as to the cast-in-place concrete deck or closure placements). Therefore, prestressing the strand and possibly securing the posttensioning ducts might be the only operations required by personnel on a casting bed for UHPC components. Furthermore, standard rules for detailing may no longer apply. Examples might include the spacing of strand where a spacing of 1½ in. (38 mm) and a clear cover no longer governed by confinement will allow a greater eccentricity of the prestressing force, leading to more efficient use of the material.

Therefore, a solution such as UHPC, where casting the concrete is the most important endeavor of the facility, is certainly a different enterprise than U.S. producers



Standard bulb-tee details are compared with ultra-high-performance concrete (UHPC) alternatives. UHPC bulb tees are more-efficient sections and weigh less than those made with conventional concrete. Note: 1 in. = 25.4 mm. Courtesy of J. P. Binard.

are used to and one in which the common means and methods of precast concrete production may no longer apply, as was observed in Malaysia.

The next level

Steel fibers and a variety of synthetic fibers have been used for many years as an additive to concrete.[8] These additives are commonly used to prevent shrinkage cracks or promote fire resistance. The fibers used in UHPC were the result of a pragmatic search for an additional use of an existing product: fibers used in the tire industry. Today there are numerous publications and research projects related to steel fibers. This topic can become the focal point of a UHPC discussion because fibers are the most expensive ingredient and, more practically, the most important.

Strain hardening behavior, or a material gaining strength after cracking, is not associated with conventional concrete or HPC but may be achieved with a high volume of steel fibers. The value of the fibers lies in their ability to create the UHPC behavior sought; however, to be competitive, as in all industries, the right amount is desired for the right application. This is where complexity exists in codification and consensus among professionals. If a component is unreinforced, there might be a bias toward using a larger amount of fibers because of a concern about a lack of redundancy. However, in a prestressed concrete component, where the fibers may serve less as a flexural mechanism, there may be a bias toward using less. Furthermore, the manner in which a product is cast can affect the orientation of the fibers, which may influence adding more fibers. Therefore, some countries have selected a set of provisions for this ingredient, and this will be a challenge for the United States as progress is made.

High doses of steel fibers are used in ultra-high-performance concrete to improve ductility and promote a strain-hardening response. Courtesy of Ben Graybeal, Federal Highway Administration.

It is known, in general, that steel fibers for UHPC are typically drawn to a small wire diameter (slightly larger than a hair). Parameters such as thickness, length, and curvature of the wire are being studied. In some drawing processes, the friction on the equipment gets too high. Therefore, a lubricant (commonly brass) is necessary. The brass is simply an added benefit to the process as a coating to protect the fibers until they are embedded in the concrete. Generally, the coating seems to wear off in the mixer. However, before trying to improve something (for example, looking to stainless fibers or a better coating) the desired characteristics from the fibers need to be determined and preconceived notions about the durability of a UHPC system need to be changed. To inhibit surface rusting for aesthetic reasons, Dura Technology uses a simple polyurethane paint on all completed products.

Fibers are typically selected based on an aspect ratio (length to diameter), toughness, and strength. A strength of 300 ksi (2100 MPa) has traditionally been used, but others have used lower-strength fibers with similar results. Because the fibers do not yield before they pull out, the strength is important, but in many ways is simply a byproduct of drawing a wire to such a small diameter.

Dura Technology has evaluated the fibers for its mixture proportions and the properties of the components produced to maximize the efficiency of the UHPC matrix. They use a greater aspect ratio than most—the maximum allowable, in fact. As nonprestressed reinforcement, the fibers will be more effective with a longer length, thus requiring fewer fibers in the system. Dura Technology further employs two different types of fibers: straight and kinked. The longer fibers require less refinement in the mixture constituents compared with other UHPC mixtures. This symbiotic relationship in addressing the mixture proportions aids in producing a material that has the performance of UHPC and a cost structure that is competitive with conventional concrete bridge solutions. The tradeoff may be in the time of mixing being perceived by some to deter active fabrication relative to the U.S. bridge producer's common product basis. However, this basis may no longer be valid as there is no longer a dependence on the time for concrete mixing and delivery. It is, rather, an environment where the concrete mixing and delivery are the central and vital events of casting. This is what was observed at the Dura Technology facility in Malaysia.

Means and methods

There is essentially no change from the general contractor's perspective if UHPC is selected as the material for a component in lieu of another material. However, there is a net gain potential in the overall solution. In terms of means and methods, the status quo may continue for the contractor aside from potentially having to drill holes, which may require an increase in the number of drill bits used in the task. From a producer standpoint, this removes one of the greatest impediments because the contractor's acceptance of risk or complexity may vary much like the capabilities and nuances of the different producers. Fabrication activities, however, are affected as follows.

Casting

The activity of casting, independent of mixing and delivery, is similar to that of self-consolidating concrete (SCC). Form tightness related to the pressures observed and expense of the material is strongly advised. Delivery via a bucket seems wise due to low waste and visibility of the status of the material during casting; however, other conveyance methods may be viable under the appropriate circumstances.

Cleaning

Cleaning UHPC from a smooth surface is relatively easy. A simple putty knife can work. However, if there is anything for the UHPC to bond to, such as bolts, nuts, and dimpled concrete surfaces, then jackhammers may be required or extended periods of time with needle guns.

Storage of constituent materials

The standard of care is similar to that required for an SCC with lightweight aggregates. Storage can be problematic, but attention to every detail is required. Keeping the sand dry and using a very fine sand are reported to be key aspects for effective operations.

Form geometry

Form geometry is typically thought of in two dimensions or as a slice through a component. If that section is well braced or the form can withstand the hydrostatic pressure and there is confidence that the concrete can be placed without concerns of honeycombing or excessive bugholes, then the form is ready to proceed. Forming with UHPC has an additional dimension because autogenous shrinkage, which occurs before form removal, is high. This can prohibit removing the forms or cause cracking when there are end blocks or reentrant corners. Therefore, careful attention to free shrinkage during initial curing is necessary.

Sections and volume

Dura Technology sizes molds to accommodate a single batch from its mixer. The consistency and uniformity of the mixture is paramount to Dura Technology, as is entirely removing the risk of a cold joint or anomaly during a multiple batch casting. By discretizing the components of the bridge, Dura Technology ensures the best quality in each piece. These components are match cast in a long line, checkerboard method, where in the case of a span with five components, the ends and middle pieces are cast first, followed by match casting of the two interior segments. All products cast in this manner are connected by thin shear keys that have been validated through testing.[9] These are all then posttensioned together in the field to achieve the span length.

In the United States, products are not typically cast this way. However, if the most successful producer of this material in the world approaches projects in this manner, heed should be taken prior to diverting from this approach. Inevitably, measures may need to be sought to cast larger volumes in multiple batches. Progress by other companies as it relates to bridge overlays, for example, was presented in July 2016 at the First Interactive International Symposium on Ultra High Performance Concrete, which was held in Des Moines, Iowa.

Curing

Initial curing at Dura Technology comprises essentially covering the finished products for moisture retention and maintaining an ambient temperature with a low volume of steam. Malaysia's climate is like a summer day in Florida year-round. Therefore, no active steam is required at its facility for the initial curing. Within 14 days of casting, typically all of the individually batched, discretized segments for a given span of a bridge undergo a secondary cure at 194°F (90°C) for 48 hours.

Two points about the use of high curing temperatures are as follows:

- High-temperature curing is not deleterious to the matrix or composition of the concrete as it pertains to alkali-silica reactivity and delayed ettringite formation because there is no coarse aggregate, greatly reducing the size of the interfacial transition zone. The system also has low permeability, relieving concerns about the penetration of water to allow delayed ettringite formation.

- The high temperatures, even up to 14 days later, produce additional reactions, further hydrating the cementitious material and densifying the system such that maximum strengths (compressive and tensile) are achieved.

This secondary curing zone at Dura Technology, which is not on the casting beds, is where products are covered and cured in bulk after typical casting and stripping cycles. Courtesy of J. P. Binard.

Quality control testing

For sampling, testing was observed at Dura Technology's batch plant mixer relating to flow using a drop table and making grout cubes for compressive strength and beams to test in flexure under three-point bending. Dura Technology has calibrated its requirements over years of testing such that a measured capacity at first crack and failure using a bending test has proved more valuable than a direct tensile test.

At Dura Technology, grout cubes and beams are cast for compressive and tensile strength testing (left). A worker uses the drop table near the mixer (right). Courtesy of J. P. Binard.

Waste

UHPC is expensive. For example, creating 6 × 12 in. (150 × 300 mm) cylinders could be considered an exorbitant cost and would require a heavy-duty test machine to even garner a result. Therefore, smaller specimens are used. This may be coordinated up front, but inevitably there is a little material left over after batching. Certainly, this approach far outweighs the alternative in the case of casting UHPC, and, as observed at Dura Technology, "waste" concrete can be used to make small, ¾ in. (19 mm) thick, stay-in-place, noncomposite forms for cast-in-place concrete deck placement. In fact, the edges of the finished beams are notched to allow a simple seat for the panels to be set easily by the contractor and not affect the overall deck thickness.

UHPC's future in the United States

The future of UHPC in the United States depends on the willingness of champions of the precast, prestressed concrete industry to collaborate and foster exploration of new opportunities in the marketplace. Champions of the technology could be owners, designers, consultants, precast concrete producers, and PCI technical personnel and committees.

PCI's UHPC Bridge Subcommittee of the Bridges Committee is working on a design example to determine a common assumption basis for the design of a bridge component: a long-span bridge girder. This example may

Dura Technology workers use waste ultra-high-performance concrete for a stay-in-place, noncomposite form for cast-in-place concrete deck placement. Courtesy of J. P. Binard.

serve as a springboard for producers to realize UHPC applications that may be competitive with the current price structure. New shapes and sections that optimize the use of the material or localized use of the material in key bridge components, such as a pier segment in segmental construction, could promote valuable labor- and form-saving techniques. This makes UHPC an obvious choice to reduce construction and fabrication costs while improving the durability of these key components. Products that undergo large stress reversals during construction, such as cable-stayed bridges, could use UHPC in a much simpler manner akin to steel members.

One aspect not detailed previously is the architectural characteristics of this material. In general, it is preferred that gray be used, minor blemishes be permitted, and the surface be somewhat smooth. Concrete coloring, which includes matching other components cast on different days, can be challenging and an obstruction to regular protocols in casting. With UHPC, however, the level of architectural detail is striking. This is somewhat intuitive because the mixture is nearly all paste. Nevertheless, white concrete, embossed decals, and textures are viable and perhaps a major delineating aspect of this material compared with HPC and steel for bridges.

Two other barriers could limit marketplace entry for UHPC: codification and an acceptable standard of care and state of the practice for producers.

In terms of codification, there are existing provisions and many publications for fiber-reinforced concrete.[10] Although UHPC may require a more sophisticated version of these provisions, the framework exists, and this may be more of a synthesis exercise rather than a new standalone document. Add to this that Australia, Switzerland, Japan, and France have all published codes for UHPC and that Canada is nearing completion of its code. These can serve as resource documents for U.S. design specifications that need to be compatible with the existing bridge specifications.

For the standard of care as it relates to PCI producers, this may require a bigger effort. Currently, the PCI Concrete Materials Technology Committee is investigating developing a guide specification for mixing, placing, and producing UHPC. The guide specification would be similar to the document produced by PCI for SCC and would discuss materials, mixing times, rheology requirements, fiber percentage requirements, testing means and methods, casting, curing, and potential pitfalls. A complete approach would be used so that the producer could follow baseline protocols. Furthermore, specification templates for owners and designers to use in their documents would also be a furnished.

Segmental U beams were used for this five-span bridge along the Koridor Ekologi Central Forest Spine, Gerik, Perak Darul Ridzuan in Malaysia. Courtesy of J. P. Binard.

This 10-span bridge connecting Kampung Bahru and Kampung Teluk in Malaysia is shown under construction. Courtesy of J. P. Binard.

For UHPC to become a cost-effective, regularly implemented solution, the bridge sector has a variety of research needs, especially related to the following:

- means and methods associated with larger placements and multiple batches for standard production
- quality control measures and systems for repeatability in performance
- development of larger bar splices and strand
- lateral stability limits
- continuity detailing and connections
- appropriate design and detailing for end zones and joint treatment
- composite components (UHPC–UHPC or UHPC–conventional materials)
- strut-and-tie models
- fiber alignment, orientation effects, and mitigation techniques, as well as verification methods
- appropriate stress limits in design
- optimization of structural components

Therefore, PCI will develop design and production guidance, and it will be up to the PCI producers to carry this effort forward to the marketplace and aim to achieve widespread success in the United States, like the success that Dura Technology and Voo have achieved in Malaysia.

Conclusion

Voo's energy and enthusiasm for UHPC enhanced its remarkable acceleration of bridge construction throughout Malaysia. Therefore, U.S. designers and producers should also embrace this material technology. Opportunities to redefine an industry or define new markets do not occur often. Incremental refinement of precast, prestressed concrete has occurred over the past decades; however, UHPC is a revolutionary material capable of spawning a renaissance for the industry while we meet the current and future infrastructure demands.

Therefore, when looking at how UHPC will benefit the future of bridges, producers cannot compare it solely with the way they currently do business. When this industry was starting, materials were expensive and testing was not as ubiquitous as it is today. The founders of the industry were bold and had incredible acumen for creating business models. PCI must embrace UHPC. There is enough evidence of code-based provisions to proceed now. This precast concrete industry can embrace the future by following the lead of innovators such as Voo.

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Abstract

Ultra-high-performance concrete (UHPC) has become a prominent subject in the construction industry, and particularly the precast, prestressed concrete industry, for connections of components, as well as various pilot projects using prefabricated components. The well-documented and researched material characteristics of UHPC offer a new suite of bridge solutions that have yet to be fully implemented by PCI producers.

Inspired by Dura Technology founder and chief executive officer Yen Lei Voo, six PCI representatives in conjunction with the *fib* (International Federation for Structural Concrete) Task Group 6.5, Precast Concrete Bridges, took a TechnoQuest trip to Malaysia, where they investigated Voo's company. The purpose of the visit was to observe a facility solely focused on fabricating UHPC components for bridges and other heavy civil structures. The idiosyncrasies of the manufacturing facility illustrated many similarities to the current means and methods of fabrication in the United States by PCI bridge producers, aside from the material difference. The observations of the group, both in terms of means and methods as well as possible advantages for future endeavors in the United States, are presented.

Keywords

Bridge, Dura Technology, Malaysia, posttensioned, prestressed, UHPC, ultra-high-performance concrete.

Reader comments

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