Precast/prestressed pavement, deck panels drive research at TRB

The annual Transportation Research Board meeting in January is one of the highlights of the pavement and bridge research community. This year's event drew over 13,000 transportation engineers and specialists from the United States and other countries to Washington, D.C. Delegates could audit 5,000-plus presentations in over 800 sessions addressing topics in transportation construction, including projects based on precast/prestressed concrete structures and methods. *Concrete Products* was there and this month presents a report on new research findings in precast/prestressed research at TRB 2018. We looked at ready-mixed and cast-in-place concrete previously, see March 2018, pages 54-57. For more information, visit www.trb.org.

PRECAST PANELS EQUAL SUSTAINABLE INFRASTRUCTURE

Precast/prestressed concrete panels for the repair and rehabilitation of existing pavements offer significant benefits to the environment, say David Merritt, The Transtec Group, Inc., Austin, and Sam Tyson, P.E., Federal Highway Administration, in their 2018 TRB paper, *Sustainable Pavements with Precast Prestressed Concrete.* Benefits include rapid construction during nighttime and other off-peak hours with minimum disruption to traffic, and high-quality, durable concrete pavement offering long-life performance with little or no maintenance, they note.

"Precast prestressed concrete pavement (PPCP) applications on repair and rehabilitation projects throughout the United States during the last 10 years have firmly established its ability to deliver these important aspects of sustainability," Merritt and Tyson write. "Projects constructed in California and Texas have been in service for more than six and eight years, respectively, [and] required no maintenance to date, providing initial support for the competitive life cycle cost of the PPCP system that was anticipated during design and construction."

In 1998, FHWA started a feasibility study examining PPCP as a method for expediting rehabilitation and reconstruction of existing concrete pavements. It produced a concept for such pavements which has since been implemented on projects throughout the U.S., and features sustainability benefits realized in the design, manufacture, construction and life cycle of PPCP.

- **Existing subgrades utilized**. "A number of sustainability benefits are realized through the design of PPCP," the authors write. PPCP utilizes full-depth precast panels installed over the existing subbase and subgrade whenever possible, they say. Full-depth panels eliminate the need for any additional paving operations on-site, like asphalt or concrete overlays. "By utilizing the existing subbase and subgrade whenever possible, the additional step of subgrade and/or subbase reconstruction and the new materials, construction processes, and disposal of existing materials associated with it are eliminated," Merritt and Tyson observe.

Also, standardization of panels permits a much more efficient process for the fabricator, by allowing the panels to be mass-produced to the extent possible, they add, noting: "Standardized panels also facilitate efficient storage and shipping procedures since all panels of a particular type can be interchanged."

- **Manufacturing offers additional environmental benefits**. "Supplementary cementitious materials, such as fly ash recycled from coal combustion, are commonly used in precast concrete elements," Merritt and Tyson say. "PPCP projects completed to date have been produced using concrete mixtures containing up to 25 percent fly ash replacement of cement. Panels are produced in existing plants which produce a variety of precast elements. This eliminates the need to set up batch plants at or near the project site specifically for the paving concrete."

"Established precast plants with diverse product lines also readily reuse formwork for various types of precast elements," they add. "Manufacturing of new formwork for PPCP panels is generally restricted to only the side forms, which in turn can be re-used for other precast elements. Finally, while all concrete batch plants generate a certain percentage of waste material, precast plants seek to minimize any waste and readily reuse waste that is generated. It has been estimated that approximately 2 percent of concrete generated at a precast plant is waste, but approximately 95 percent of this waste is beneficially reused elsewhere in the plant or separated back into constituent materials for use in fresh concrete."

- **Sustainable construction**. This is primarily realized through the reduction in traffic congestion during construction. "This benefits the contractor, owner agency, and the traveling public," Merritt and Tyson affirm. "PPCP permits construction to be completed during non-peak travel times, such as at night or over weekends, thereby greatly reducing or even eliminating construction-related traffic congestion."
- **Life cycle sustainability** benefits of PPCP are realized through the durability of the finished product. PPCP is utilized as a long-lasting, low-maintenance product, and not as a temporary fix. Minimal maintenance over the lifespan of the pavement reduces environmental impacts.

In November 2009, the Virginia Department of Transportation completed construction of a PPCP project on Interstate 66 near Fairfax City. It demonstrated the precast pavement concept for overnight pavement reconstruction in order to reduce construction-related traffic congestion, but under high traffic volumes and shorter nightly closures.

The existing pavement slab thickness was 9 in. in the three inside lanes and 11 in. in the outside 15-ft. lane. Although reconstruction with conventional cast-in-place concrete pavement would have likely required a slab thickness of 10 to 12 in., PPCP permitted the use of thinner panels so it was not necessary to excavate any underlying base or raise the pavement profile to accommodate the additional thickness. The precast panel thickness was specified as 8-3/4 in.

The panels were produced on a long-line fabrication bed with up to three 27 ft. or five 12-ft. panels cast at a time. "In general, one set of panels was fabricated every day or every other day, with the exception of joint panels, which required additional form set-up time," Merritt and Tyson explain. "A concrete mixture with approximately 20 percent fly ash replacement of cement was used."

Bar tendons were used for temporary post-tensioning of each section of panels. The bars provided the necessary clamping force for the joint epoxy and temporary post-tensioning force for the pavement to be opened to traffic each day. The two bars for each panel were coupled to the bars from the panels already in place, and tensioned simultaneously after the installation of every two panels.

After the post-tensioning strands for each section (between joint panels) were installed and stressed, the stressing pockets where filled with a rapid-strength-gain concrete patch material. The post-tensioning tendons were then grouted, followed by grouting beneath the slabs using ports cast into each of the precast panels. Tie-bar slots were cut into the existing pavement at the beginning of the section to receive tie-bars from the first precast panel, and closure pours were required at the end of the section to transition back to the existing pavement. After all panels were installed, the pavement was diamond-ground for smoothness, and the expansion and longitudinal joints between lanes sealed.

"The use of PPCP has clearly been demonstrated to be a practical solution for agencies needing to repair and rehabilitate existing pavements, especially in high-volume traffic situations where construction must be performed during nighttime and other off-peak hours after which all lanes must be returned to service for daily use," Merritt and Tyson conclude. "The precast concrete industry in the U.S. is fully capable of supplying this new market for precast products, and with the support of contractors and agencies that have utilized PPCP for repair and rehabilitation of high-volume roadways, it will quickly become a more commonly used solution."

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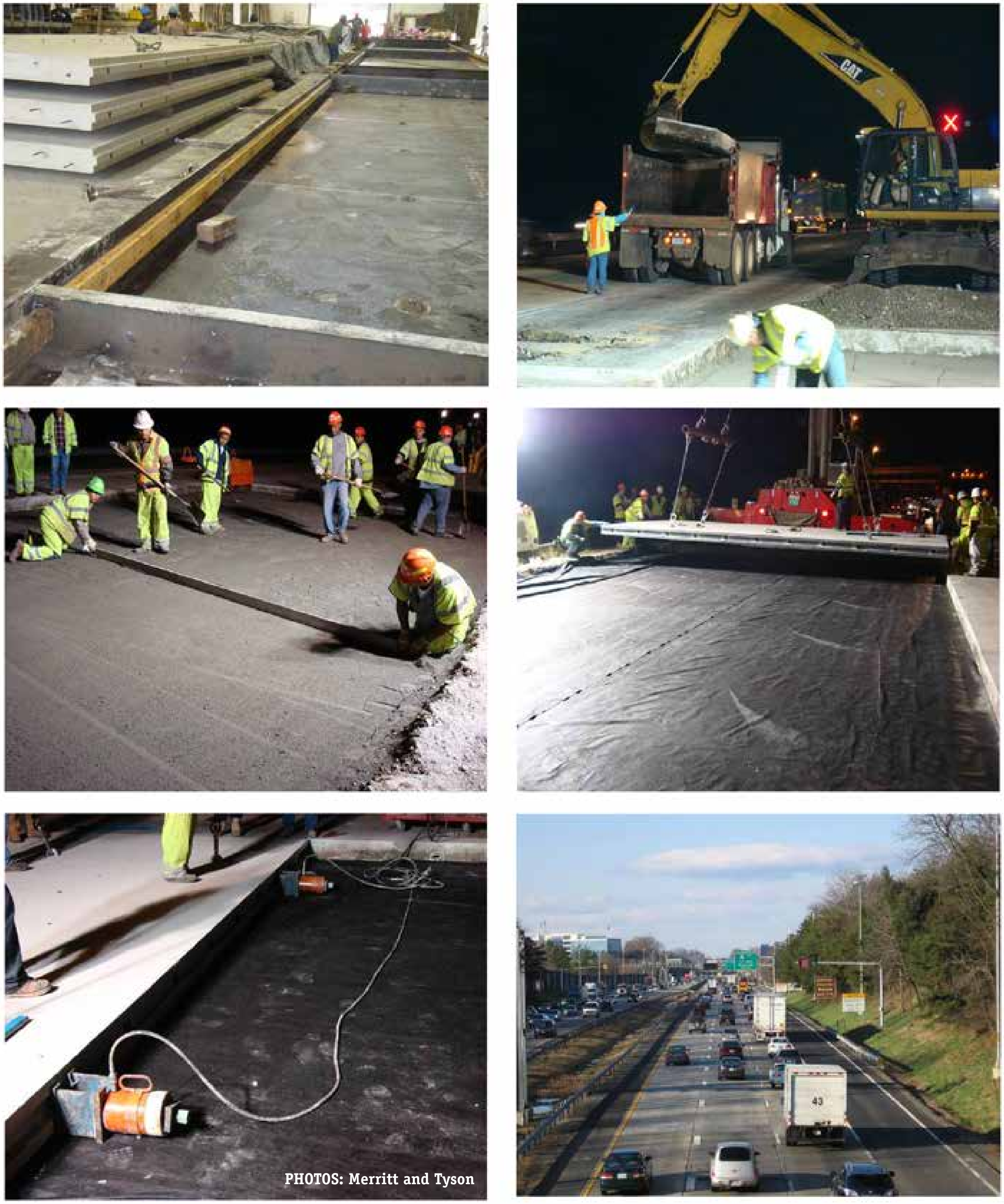

Virginia DOT PPCP project, from top left: Precast panel fabrication bed; removal of existing pavement for recycling; base preparation; panel installation; post-tensioning of bar tendons; and, completed project open to traffic

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BRIDGE DECK SYSTEM: COMPOSITE WITH GIRDERS

A new-design deck in Kearney, Neb., behaves as fully composite with the girders, note Raed Tawadrous, M.S., P.E. and George Morcous, Ph.D., P.E., University of Nebraska at Lincoln, and Marc Maguire, Ph.D., Utah State University at Logan, in their 2018 TRB paper, *Performance Evaluation of a New Precast Concrete Bridge Deck System*.

"Precast concrete (PC) deck systems have several advantages over cast-in-place (CIP) concrete decks commonly used in highway bridge construction, such as improved construction quality, reduced construction duration, and minimized maintenance cost," Tawadrous, Morcous and Maguire say. Composite PC deck systems, they add, are commonly used due to their structural efficiency and reduced overall depth and cost of the bridge superstructure. "Existing systems use either continuous open channels (troughs) or discrete openings (pockets) over girder lines to accommodate the shear connectors (i.e. studs, rods, bars) of the supporting girders," they write.

"These troughs or pockets are then field-grouted using flowable concrete/grout to connect the precast components," Tawadrous, Morcous and Maguire add. "Deck surface is usually covered by an overlay, similar to CIP concrete decks, for protection, which increases construction duration and cost. In addition, transverse joints between adjacent deck panels are either conventionally reinforced or longitudinally post-tensioned using embedded ducts, which complicate panel fabrication and erection processes and, consequently, reduce the attractiveness of precast concrete deck systems as an accelerated, economical, and durable alternative to CIP concrete decks."

In response, a new precast concrete deck system was developed jointly by the Nebraska Department of Transportation and University of Nebraska-Lincoln to address the shortfalls of existing systems. The system has these features and performance characteristics:

- **Shear connectors are** spaced at the largest spacing allowed by AASHTO LRFD to simplify panel and girder fabrication and erection;
- **Full-width full-depth** long PC deck panels are designed to reduce the number of panels to be produced, transported, and erected, as well as the number of transverse joints;
- **No reinforcing bars** and post-tensioning ducts are used at the transverse joints to simplify panel forming and avoid conflicts/misalignments between adjacent panels during erection;
- **Covered shear pockets** are used to minimize penetrations to panel surface, which eliminate the need for deck overlay;
- **Panels are transversely** pre-tensioned and longitudinally post-tensioned to control panel cracking during construction and in service;
- **Post-tensioning strands** are located underneath the deck soffit and above the girder top flange (i.e. haunch area) to eliminate the need for placing post-tensioning ducts inside the panels, threading strands through embedded ducts and across the joints, and grouting the ducts after post-tensioning, which are tedious and laborious operations; and,
- **Live load continuity** reinforcement is located at the haunch area below the deck panels and over each girder line to enhance deck durability.

The new precast concrete deck system was first implemented in the construction of the Kearney East Bypass in summer 2015. This project has twin bridges: southbound bridge with CIP concrete deck; and northbound bridge with the new PC deck system.

"Live load testing was conducted to evaluate the performance of the new system as well as a twin bridge constructed using the conventional CIP concrete deck," say Tawadrous, Morcous and Maguire. "Also, finite element analysis (FEA) was conducted to model the structural behavior of the new system."

Based on the results of the live load testing of that bridge and comparison with CIP concrete deck bridge and FEA, the authors conclude:

- **The new precast concrete deck** system was fully-composite with the supporting prestressed concrete girder. This was proven by comparing the measured strains and deflections with those obtained from the CIP concrete deck bridge. Therefore, the use of threaded rods as discrete shear connectors and HSS formed shear pockets at 4 ft. spacing was adequate;
- **Placing negative moment** reinforcement in the haunch area over each girder line was sufficient for achieving live load continuity. This was proven by comparing the measured strains and deflections with those obtained from the CIP concrete deck bridge;
- **Placing the deck** post-tensioning strands in the haunch area over each girder line was not only simpler in construction, but also structurally efficient as it results in pre-compression of the PC deck panels and transverse joints, which was evident in linear variable differential transformers (LVDT) measurements;
- **The unreinforced post-tensioned** transverse joint between adjacent precast concrete deck panels performed very well under live load with no signs of relative movements across the 24 joints in either horizontal or vertical directions, which also indicated the adequacy of the new post-tensioning system; and,
- **Moment distribution factors** of the new system were accurately predicted by the FEA, which were significantly lower than those predicted by AASHTO LRFD provisions for type "k" bridges.

Panel lifting showing shear pockets on precast bridge deck section in Kearney, Neb.

PHOTOS: Tawadrous, Morcous and Maguire

On precast bridge deck in Kearney, Neb., end panel showing post-tensioning anchorage block.

BONNER BRIDGE: MILES OF PRECAST PERFORMANCE

A new causeway connecting mainland North Carolina with the South Outer Banks islands features extensive use of precast concrete construction for quality, durability, economy, and constructability, say Domenic Coletti, P.E., R. Dominick Amico, P.E., Elizabeth Howey, L.G., P.E., John Jamison, AICP, HDR Engineering, Inc. of the Carolinas; Nicholas Burdette, P.E., HDR, Inc., Pittsburgh; Phil Dompe, P.E., INTERA, Inc., St. Augustine, Fla.; and Mohit Garg, P.E., HDR, Inc., Tampa, in their 2018 TRB paper, *Bonner Bridge – Miles of Precast Concrete Provide Economy and Durability*.

The 2.8-mile-long bridge also features a first-of-its-kind driven pile foundation verification method, and innovative, environmentally-sensitive construction approaches. The use of precast bent caps and columns instead of cast-in-place concrete for the pile bents and two-column bents resulted in substantial savings for both overall schedule and cost. Completion is on-target for November 2018.


PHOTO: North Carolina DOT

One of 673 precast pilings, ranging in length from 110 to 130 ft., is installed early in Bonner Bridge project.

In 2011, the North Carolina Department of Transportation selected a design-build team of PCL Civil Constructors as the contractor, and HDR Inc. as the designer. The $246 million replacement will provide a modern link to Hatteras Island with a 100-year service life. As the lead design firm, HDR provided all roadway, geotechnical and bridge design services, as well as environmental permitting services.

The centerpiece of the project is a 3,550-ft.-long, 11-span, segmental concrete box girder bridge. This massive structure provides nine 350-ft. spans, any of which can accommodate the shifting position of the navigation channel through the Oregon Inlet.

According to NC DOT, stainless reinforcing steel and high-durability concrete will be used to protect against corrosion, with high-performance concrete the primary reason for the bridge's increased life span. The agency's request for proposals included numerous prescriptive requirements for the concrete mix designs, among them extensive use of fly ash or ground granulated blast furnace slag and silica fume; low water-cement ratio; and, use of a calcium nitrite corrosion inhibitor admixture.

The Bonner Bridge will be the first North Carolina crossing using stainless reinforcing steel, providing additional protection against corrosion, while reducing rehabilitation and maintenance costs. The structure will have 12-ft.-wide travel lanes and 8-ft.-wide shoulders, which will improve safety. The existing bridge has no shoulders. (A one-minute visualization of the replacement process may be seen at https://www.youtube.com/watch?v=15DKyJvG3Qc.)

A tailored design approach allowed widespread use of repetitive construction elements, Coletti, Amico, Burdette, Dompe, Garg, Howey, Jamison write. "The salt-water environment and the RFP's emphasis on durability, corrosion resistance, and a 100-year service life indicated the need for a concrete structure, while the remote location of the project site also suggested broad use of prefabricated elements and modular construction," they say. "All indicators pointed to the use of precast concrete as the optimum design solution."

Extensive use of precast concrete elements offered multiple advantages, they continue. First among these were durability and quality. "Precasting FIB [Florida I-Beam] girders, box girder segments, bent caps, columns, and piles in an off-site precasting yard, under controlled conditions, results in the production of extremely high quality, durable concrete elements; these levels of quality and durability would have been difficult to achieve in the harsh marine environment of Oregon Inlet," they add.

The precast elements are also very economical; fabrication off-site is much less costly than trying to deliver and place CIP concrete to the remote project site. "The precast elements used in this project are generally very simple and employ significant repetition of detailing," the authors write. "This repetition of detailing led to significant economies of scale in terms of fabrication and familiarity in terms of construction, again reducing costs and speeding up construction."

The extensive use of precast concrete elements—3.4 miles of cylinder piles, 12 miles of square piles, 0.58 miles of bent caps, 0.30 mile of column members, 8.75 miles of FIB girders, and 0.67 miles of segmental box girders—greatly enhanced the quality and durability of the structure, while simultaneously facilitating faster, safer, and more economical construction, Coletti, Amico, Burdette, Dompe, Garg, Howey and Jamison contend. The use of precast bent caps and columns instead of CIP concrete for the 44 pile bents and 25 two-column bents resulted in substantial savings for both overall schedule and cost, they add.

The design-build team was able to develop an extremely economical, durable, constructible design, and foster a spirit of partnership with NC DOT and various affected agencies, resulting in construction approaches which minimize both temporary and permanent environmental impacts, the authors conclude. "The value of this approach was demonstrated by the bid prices for the project—the PCL Team's bid was $64 million less than its nearest competitor," they write.


PHOTO: Coletti, et. al.

Bonner Bridge south approach span construction, showing 96-in.-deep precast concrete Florida I-Beam (FIB) girders supported by precast bent caps and 54-in.-diameter precast cylinder piles.