ABCs of TRB: Accelerated Bridge Construction ideal for precast/prestressed

Technical papers involving accelerated bridge construction and precast/prestressed concrete products were among the 5,000-plus presentations in more than 800 sessions at the 96th annual meeting of the Transportation Research Board. More than 13,000 transportation engineers and specialists from across the country—and around the world—journeyed to Washington, D.C., earlier this year for TRB 2017, and *Concrete Products* was among them.

TRB included materials and design research involving precast/prestressed and ready-mixed concrete. Last month we reported on new research findings in ready-mixed and cast-in-place concrete; this month we examine precast/prestressed research at TRB, including seismic design. For more information, visit www.trb.org.

PREFAB JOINTLESS BRIDGES FAVOR ABC PLACEMENTS

Prefabricated jointless bridges and their special connections are specially suited for Accelerated Bridge Construction (ABC) in seismic design applications, say W. Phillip Yen, Ph.D., P.E., chair, International Association of Bridge Earthquake Engineering; Waseem Dekelbab, Ph.D., P.E., National Cooperative Highway Research Program; and, Bijan Khaleghi, Ph.D., P.E., S.E., Washington State DOT Office of Bridge & Structures, in their peer-reviewed technical paper, *Connections for Accelerated Bridge Construction of Jointless Bridges in Seismic Regions.*

Prefabricated jointless bridges consisting of pretensioned, post-tensioned spliced or trapezoidal open box girders, and other types of superstructure members are often used for ABC, the authors say.

"Jointless bridge superstructures are constructed to work integrally with the abutments," Yen, Dekelbab and Khaleghi write. "Movements due to creep, shrinkage and temperature changes are accommodated by using flexible bearings or foundation, and through incorporating relief joints at the ends of the approach slabs. Benefits of prefab jointless bridges include reduced maintenance costs, improved structural integrity, reliability and redundancy, improved long-term serviceability, improved riding surface, reduced initial cost, and improved aesthetics."

In recent times, jointless bridges have been built in seismically sensitive areas, but that poses a potential problem. "Connections in precast concrete substructures are typically made at the beam-column and column-foundation interfaces to facilitate fabrication and transportation," say Yen, Dekelbab and Khaleghi. "However, for structures in seismic regions, those interfaces represent locations of high moments and shears and large inelastic cyclic strain reversals."

Developing connections that can accommodate inelastic cyclic deformations and are readily constructible is the primary challenge for ABC in seismic regions, they advise, adding, "The AASHTO LRFD Specifications do not explicitly address the jointless precast, pretensioned or post-tensioned elements."

Jointless bridges are defined as those with no expansion joints between the superstructure and the supporting abutments. Jointless bridges consist of superstructures, abutments, intermediate piers and foundations, note Yen, Dekelbab and Khaleghi. "The design of jointless bridges is generally similar to that of conventional bridge design. Special analysis and design considerations required for jointless bridges are primarily associated with the need to accommodate volumetric changes in the structure, such as thermal movements."

Jointless bridges accommodate superstructure movements without conventional expansion joints. The superstructure is rigidly or semi-rigidly connected to the abutments. Approach slabs, connected to the abutment and/or deck slab with reinforcement, move with the superstructure.

"Generally, at its junction with the approach pavement, the approach slab is supported by a sleeper slab or grade beam," note Yen, Dekelbab and Khaleghi. "The superstructure movement here is accommodated using flexible pavement joints. Jointless construction is well-suited to both single- and multiple-span bridges ... [J]ointless bridges could be founded on piles or shafts or spread footings on soil if the soil is well compacted and the possibility of settlement of the foundation is considered in the design as shown in Figure 1."

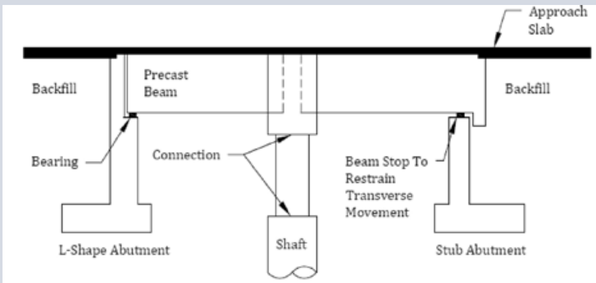
As such, jointless bridges provide substantial reserve capacity to resist potentially damaging overloads by distributing loads along the continuous and full-depth diaphragm at bridge ends, the authors write. Continuity in bridge superstructure provides added redundancy and capacity for all types of catastrophic events.

"Joints introduce a potential collapse mechanism into the overall bridge structure," Yen, Dekelbab and Khaleghi say. "Jointless abutments have consistently performed well in actual seismic events and have significantly reduced or avoided problems of back wall and bearing damage that are associated with seat-type jointed abutments. The dampening arising from soil-abutment interaction has been proven to significantly reduce the lateral loads taken by intermediate substructure columns and footings."

The use of jointless bridges with jointless abutments is growing in the United States, because of the benefits achieved in lowering first cost in construction and minimizing future maintenance, the authors observe.

"Precast concrete superstructures have an important advantage for jointless bridges," they conclude. "This is because the manufacturing process for precast members is such that much of the long term shrinkage will have occurred prior to erection and establishment of continuity in the superstructure. Moreover, the amount of creep that will occur over time decreases with increasing age of concrete at time of erection."

FIGURE 1: CONTINUOUS JOINTLESS BRIDGE PROFILE



DRAWING: Yen, Dekelbab and Khaleghi

100-YEAR BRIDGES SUFFER AFTER A DECADE

Cracking , leaking and spalling in the webs of the precast , prestressed and post-tensioned beams—along with grouted tendon problems—have created a dilemma for the owner, Virginia DOT, as described by Michael Sprinkel P.E., and Soundar Balakumaran Ph.D ., Virginia Transportation Research Council, in *Problems with the Post-Tensioned Prestressed Concrete Tee Bridge Spans at West Point, Virginia.*

The Lord Delaware and Eltham Bridges carry traffic on U.S. 33 over the Mattaponi and Pamunkee Rivers in Virginia. Completed in 2006 and 2007, respectively, the bridges are similar in that they have precast/prestressed tee beam approach spans and two, four-span continuous post-tensioned precast/prestressed tee beam center spans.

"Constructed with the latest precast prestressed post-tensioning technologies, the structures were expected to provide relative maintenance-free performance for more than 100 years," Sprinkel and Balakumaran say. But in May 2015, during a biannual inspection, they note, a spall that exposed a tendon duct was reported in the web of an exterior girder of the Lord Delaware bridge, raising concerns about the life of the of the post-tensioned lightweight concrete girders.

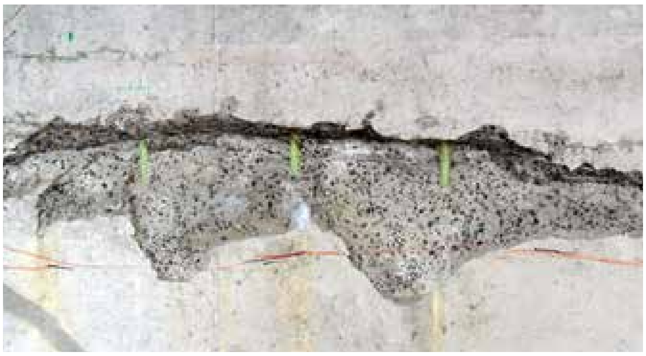
"The tendon grout was a high performance prepackaged mixture," the authors write. "In-depth inspections identified cracking, leaking and spalling in the webs of the beams, and problems with the grouted tendons which included voids, soft grout, water and corroding strands."

Ground penetrating radar worked well to locate the tendons and impact echo testing worked well to determine the condition of the grout. Destructive drilling and sampling was used to confirm the impact echo readings and to evaluate the condition of the grout.

"Access to the strands at the anchors and over the piers where the voids are typically located was not possible, because at the anchors the web thickness is the same as the flange, and over the piers the tendons are in the top flange of the beams," Sprinkel and Balakumaran observe. "A suitable repair has not been determined."

Nonetheless, lessons can be learned from these two bridges, they note: "Evaluations showed that grouting these beams is a challenge and properly grouted tendons are not always achieved. Also, the cast-in-place connection details between girders need to be improved to facilitate successful construction."

"Impact echo works well to evaluate the condition of the grout in tendons with galvanized ducts, except at the anchor ends, where the web thickness is the same as the bottom flange, and at the low and high points in the beams where the tendons are in the flanges," they conclude. "Recommended practices need to be developed for the repair of improperly grouted tendons."



Spall in web of girder 7, span M, Lord Delaware Bridge, Virginia. PHOTO: Sprinkel and Balakumaran

IOWA: LINK SLABS CAN SOLVE EXPANSION JOINT PROBLEMS

Link slabs are a potential solution to the problems associated with expansion joints in bridge decks, but they have to be used under the right conditions, say Shahin Hajilar, Michael Dopko, Behrouz Shafei, Ph.D., P.E., Brent Phares, Ph.D., P.E., Bridge Engineering Center, Institute for Transportation (InTrans), Iowa State University, Ames, and Dean Bierwagen, P.E., Office of Bridges and Structures, Iowa DOT, Ames, in their technical paper, *Feasibility Assessment of Use of Link Slabs in a Case Study Bridge in Iowa.*

Expansion joints can cause long term bridge deck durability issues due to the ingress of corrosive materials through the gap they provide, which prematurely deteriorates the underlying structure. Link slabs, which can be either precast or cast-in-place, are a solution to this problem as they replace expansion joints to create a continuous deck system while the underlying girder system remains simply supported.

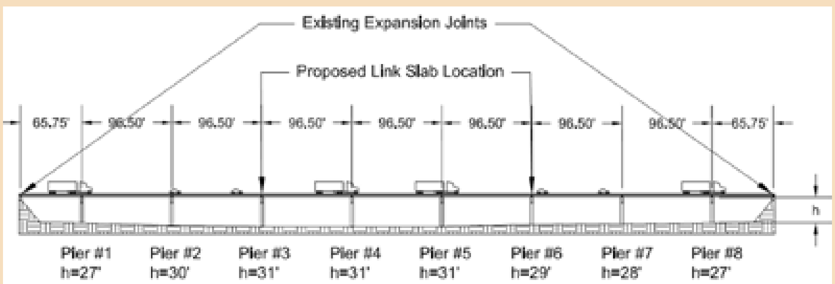
"The cost and maintenance advantages of a link slab bridge are well documented through various research efforts," say Hajilar, Dopko, Shafei, Phares and Bierwagen. "There is, however, an inherent gap in the existing literature about the structural demand that a link slab places on the global bridge structure."

To this end, authors used full-scale 3D finite element (FE) models of a case study bridge in Iowa to provide conclusions regarding which structural elements of a multi-span bridge may be of concern due to a link slab retrofit under varying support conditions and thermal loads. As a bridge ages, the bearing pads that once acted most like ideal roller supports tend to behave more like ideal pin supports as they harden and restrict lateral movement, the authors say.

"Results of this study conclude that under thermal loading," they write, "the replacement of expansion joints in multi-span bridges [with link slabs] would be feasible in older, simply supported bridges with bearing pads. On the contrary, if link slabs replace expansion joints in newer, simply supported multi-span bridges with bearing pads, there could be a resultant build-up of stresses, moments and shear forces in the piers between the link slab and abutment."

Although other solutions may be needed to remediate this stress build up in the girder-deck system, the presence of a link slab would be minimally invasive based on the findings of this study, Hajilar, Dopko, Shafei, Phares and Bierwagen affirm, adding, "it may be beneficial to utilize link slabs on older bridges in retrofit situations from a structural and serviceability standpoint."

IOWA LINK SLAB CASE STUDY BRIDGE



DRAWING: Hajilar, Dopko, Shafei, Phares and Bierwagen

Progression of deterioration of precast girder, New Jersey. PHOTOS: Lou, Nassif, Su and Truban

OVERWEIGHT TRUCKS DAMAGE PRECAST CONCRETE GIRDERS

Shear cracks caused by overloaded trucks, combined with environmental damage, are causing problems with New Jersey prestressed concrete bridge girders, say Peng Lou, Hani Nassif, P.E., Ph.D., Rutgers Infrastructure Monitoring and Evaluation Group; Dan Su, Ph.D., Lamar University, Beaumont, Texas; and, Paul Truban, New Jersey DOT, in their 2017 TRB paper, Impact of Overweight Trucks on the Service Life of Bridge Girders.

State agencies are responsible for making major decisions to allocate the available, but limited, funds for the maintenance and rehabilitation of bridges. In the meantime, over the last two decades, the frequency of overweight trucks has kept increasing.

"Although the AASHTO Load and Resistance Factored Design (LRFD) Bridge Design Specifications mandates a design life of 75 years, the actual service life of bridges is lower and varies from one bridge site to another," explains authors Lou, Nassif, Su and Truban.

In addition, agencies issue permits for trucks with gross vehicle weights that are above legal load limits. "However, the deterioration of bridges under the effects of both overweight truck loading and environmental attacks remains implicit," the authors say. "As such, there is a need to quantify the impact of overweight trucks on the service life of bridge girders."

Their study presents a rational procedure to investigate the impact of truck loads on bridges in New Jersey through the utilization of bridge inspection reports, truck weight-in-motion (WIM) data, and the National Bridge Inventory database.

Actual bridge deterioration modes were identified from their respective inspection reports and the expected bridge service life was successfully correlated with WIM truck loading. It was found that the deterioration mode of prestressed concrete girders was the corrosion near the beam ends induced by cracking and spalling. Additionally, there was a strong correlation between the expected service life of prestressed girders and overweight truck counts. Lastly, the results indicated that the expected service life of prestressed concrete bridges was greatly affected by the condition of the bridge deck.

Lou, Nassif, Su and Truban conclude:

- The main deterioration mode of prestressed concrete girders is the corrosion at beam ends due to both truck loading causing shear cracks, and environmental (weather) attacks. This process is highly affected by the condition of the reinforced concrete deck, while deterioration of steel girders is mainly due to corrosion such as leaking joints at the bridge bearing, bottom flange and web of stringers.
- Overall, prestressed concrete girders have a slightly better performance than steel girders, especially on interstate highways. But over the lifetime of a bridge, concrete girder deterioration accelerated once cracking was initiated.
- The expected service life of prestressed girders has relatively higher variation

than that of steel girders, and is highly sensitive to heavy truck loads, while steel girders did not exhibit such sensitivity.

- The condition of prestressed concrete bridges is hard to preserve once cracks and spalling of concrete are present.

STEEL-CONCRETE 'SANDWICH' USEFUL FOR ABC, TESTS SHOW

A steel-concrete-steel system can combine enhanced structural performance and construction efficiency in ABC projects, say Mahsa Farzad, Alireza Mohammadi, Mohamadreza Shafieifar, Huy Pham, graduate students, and Atorod Azizinamini, Ph.D., P.E., director, Accelerated Bridge Construction, University Transportation Center, Florida International University, Miami, in their 2017 TRB paper, *Development of Innovative Bridge Systems Utilizing Steel-Concrete-Steel Sandwich System.*

"Steel-concrete sandwich composite members, also known as double-skinned composite members, consist of a concrete core, sandwiched between two comparatively thin steel plates or tubes," the authors note.

The interaction between the steel tube and concrete core provides stiffness and strength. "Since the concrete in such members is laterally confined, the strength and ductility of the concrete are expected to be noticeably greater than that of similar unconfined concrete," write Farzad, Mohammadi, Shafieifar, Pham and Azizinamini.

"Additionally, local buckling of the steel tube is delayed by the presence of concrete," they note. "The other motivating influence for using sandwich members is eliminating the need for formwork to place concrete, allowing prefabrication of large panels in the factory and rapid installation into the main structure, leading to dramatically reduced fabrication cost and construction time," appropriate for ABC applications.

Compared to fully concrete-filled steel tubes, steel-concrete sandwich systems show increased section modulus, lighter weight, enhanced stability, improved damping characteristics, and better cyclic performance, observe Farzad, Mohammadi, Shafieifar, Pham and Azizinamini.

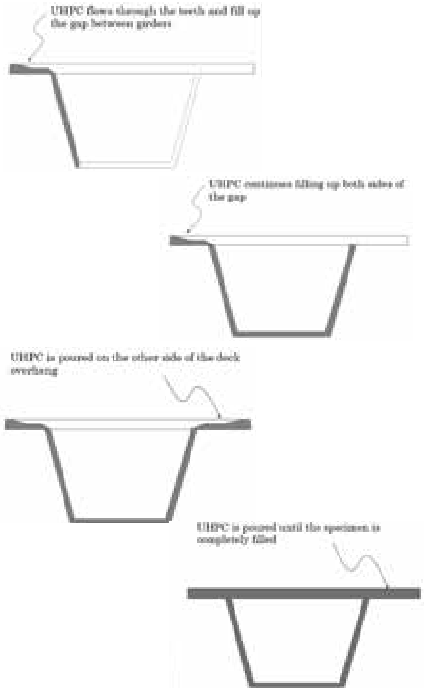
"This bridge girder cross section comprises two folded thin steel plates and ultra-high performance concrete (UHPC) sandwiched between the plates," they write. "The open side of the system, the deck, is sealed by a thin layer of UHPC which provides an economical and maintenance-free alternative for simple and short span bridges."

Reducing fabrication costs and time, along with easy construction are the main advantages of the Steel-UHPC sandwich folded plates system, the authors write. Moreover, taking advantage of high-corrosion resistant steel and UHPC minimize maintenance actions and provide protection against infiltrating moisture from above or below the systems.

Furthermore, this system is best suited where an accelerated delivery and construction is a priority, they add. In this system, the outer plate could be A1010 steel, which is very resistant to corrosion. Such corrosion-resistant steel will seal the system from outside. The thin layer of UHPC seals the system from the top. Consequently, the finished product is completely sealed and could be used in a corrosive environment.

To evaluate implementation of steel-concrete sandwich members in bridge construction, two sets of experiments studied bending behavior in the system. Results obtained from the column test show the failure is associated with buckling of the outer tube in compression side, followed by crack initiation and propagation in the tension side. The ultimate strength test is performed on the laboratory girder model to evaluate the bending behavior of the proposed bridge system. Failure of this system is controlled by yielding of the bottom steel plate. Furthermore, in both cases, column and girder, the force-displacement responses indicate high ductility associated with a plateau maximum strength.

STEEL-CONCRETE SYSTEM CASTING



DRAWING: Farzad, Mohammadi, Shafieifar, Pham and Azizinamini