PRECAST, POST-TENSIONED BRIDGE REPAIR SOLUTIONS

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ABSTRACT

Bridge owners are frequently faced by the need to replace critical bridge components during strictly limited or overnight road closure periods. This paper presents the development, testing, installation and monitoring of two precast concrete bridge elements specifically designed for the Iowa Department of Transportation to address this condition.

A precast, post-tensioned concrete approach pavement has been designed as part of the FHWA Concrete Pavement Technology program. The precast approach pavement system is intended for use in either new construction or retrofit applications and can be installed in single-lane-widths to permit staged construction under traffic.

A rapid paving notch replacement has been developed which can be installed using a single overnight bridge closure. The system consists of a precast Ultra-High Performance Concrete (UHPC) element that is connected to the rear of the abutment using high-strength post-tensioning rods and epoxy adhesive similar to that used in segmental bridge construction. Researchers at Iowa State University are performing full-scale laboratory testing of the paving notch replacement system.

In addition, a structural health monitoring system will be installed and used to document and evaluate the performance of these bridge components following their installation in field demonstration projects. This paper presents the development of these two fast-track bridge repair systems, discusses their laboratory testing, and current status of the projects.

Keywords: precast, post-tensioning, bridge repair, ultra-high performance concrete, steel fibers, Lafarge North America, Post-tensioned Pavement, Paving Support,

INTRODUCTION

Bridge and vehicle owners around the world are familiar with the "bump at the end of the bridge" (Fig. 1). This phenomenon is experienced by drivers each time their vehicle encounters a bridge approach pavement, which has settled and no longer provides a smooth ride. The dynamic loads generated by this bump cause additional wear on vehicles and increased damage to the bridge abutment and approach pavement. This bridge approach pavement settlement can approach 2 inches or more under certain conditions (see Fig. 2).

Fig. 1 "The bump at the end of the bridge"

Fig. 2 Approach pavement settlement

The bridge approach often fails to receive appropriate attention during construction of a new bridge, which may contribute to the settlement problem. The approach pavement is often constructed by neither a bridge contractor, who would be most familiar with reinforcing and placement of structural concrete, or by a paving contractor, who would be better able to construct a quality pavement. Rather, the frequent practice of hiring a disadvantaged business enterprise (DBE) to construct a percentage of each new project often dictates that the bridge approach pavement is constructed by a smaller, less experienced contractor who may be ill-equipped to properly construct bridge approach pavement.

Researchers at Iowa State University, working closely with the Iowa Department of Transportation, have been studying the problem of bridge approach settlement for some time. Recent work by (White et al., 2005) have determined the causes and recommended improved construction methods to reduce approach pavement settlement. The use of more porous backfill, combined with geo-composite drainage systems and the use of improved compaction practices, has become standard practice on approach construction. In addition, the Iowa DOT is working to develop and test a tied connection between the approach pavement and the commonly-constructed integral abutment bridge.

The structural performance of bridge approach pavement has been the subject of numerous studies including (Wahls, 1990), (Schaefer and Koch, 1992) and (Briaud, 1997). Past research has concentrated on improving the design and geotechnical aspects of the bridge approach pavement system. However, the problem of repairing existing bridges and bridge approach pavement quickly with limited interruption of traffic, has not been addressed and is the subject of the current study.

PRECAST, POST-TENSIONED BRIDGE APPROACH PAVEMENT

A precast, post-tensioned (PT) concrete approach pavement has been designed as part of the Federal Highway Administration (FHWA) Concrete Pavement Technology (CPTP) program. The precast approach pavement system is intended for use in either new construction or retrofit applications and can be installed in single-lane-widths to permit staged construction under traffic. Other suitable applications for precast pavement include locations where rapid replacement is necessary including: ramp pavement, mainline widening under bridges and pavement patching.

The CPTP has conducted research on improved methods of using concrete pavement in the accelerated construction, reconstruction and repair of Federal-aid highways since 1999 (Tyson and Merritt, 2005). As part of the CPTP program, precast, post-tensioned pavement projects have been recently completed in California, Texas, Indiana and Missouri. Fig. 3 presents a recent project pavement project in Missouri. Because of the expanded interest in this technology, the Precast/Prestressed Concrete Institute (PCI) has established a national committee to investigate and enhance the use of precast, post-tension pavement.

Funding for the current study was provided through the FHWA CPTP program ($200,000 to reimburse incremental construction costs). In addition, the Iowa Highway Research Board provided funding to support the installation of instrumentation and monitoring.

Fig. 3 Precast, post-tensioned pavement as constructed in Missouri

BACKGROUND

The Office of Bridges and Structures at the Iowa Department of Transportation has had to deal with the ongoing problem of settlement and deterioration of approaches slabs due to bridge and back fill settlement, as shown in Fig. 4. This settlement may be caused by a number of factors, such as integral abutment action, poor compaction of backfill, poor casting of the concrete, heavy traffic and poor drainage of backfill.

Replacement of the approaches in locations with high traffic counts is hazardous and disruptive to the traveling public. Precast, post-tensioned pavement offers a number of benefits over conventional cast-in-place concrete, including:

- Reduced danger to workers and the traveling public. In addition, a rapid replacement system also reduces the delay cost to the public.
- Higher quality concrete due to the production of the panels in precast plants.
- Post-tensioning reduces cracking due to elimination of tension stresses, which provides a stronger, longer-lasting pavement.
- Ability of the approach pavement to span voided areas beneath caused by erosion and settlement.
- Reducing the amount of water, which is able to infiltrate the backfill through the joint adjacent to the abutment.

Fig. 4 Bridge approach pavement settlement and damage caused by erosion and construction errors

SELECTED IOWA PROJECT (O'BRIEN COUNTY)

The site selected for the demonstration project is located on Iowa Highway 60 in O'Brien County in northwest Iowa. This particular project site was selected for several reasons including suitable construction scheduling. One additional benefit of this particular site is the useful comparison it offers to a concurrent study on the connection of a cast-in-place bridge approach pavement to an integral abutment. The northbound bridge will be constructed with precast, post-tensioned approach pavement, while the southbound bridge will feature the standard cast-in-place concrete. However, the 30-degree skewed alignment added considerable to the complexity of the panel details and required thorough consideration during preliminary design. See Fig. 5.

The bridge approaches for the North bound lanes will be attached directly to the 303 ft prestressed concrete beam bridge. Eight 12-inch-thick panels will be placed at each end for a total length of 76 feet 11 inches measured along centerline. The panels adjacent to the abutment will be skewed and the remaining panels will be constructed as 14 foot by 20 foot rectangular sections. The panels will be post-tensioned both transversely and longitudinally using 0.6 inch diameter, 270 ksi strands. Cost of casting the panels is approximately $190, 000 or $44.00 per square foot compared to $12.80 per square foot for cast-in-place double reinforced approach pavement.

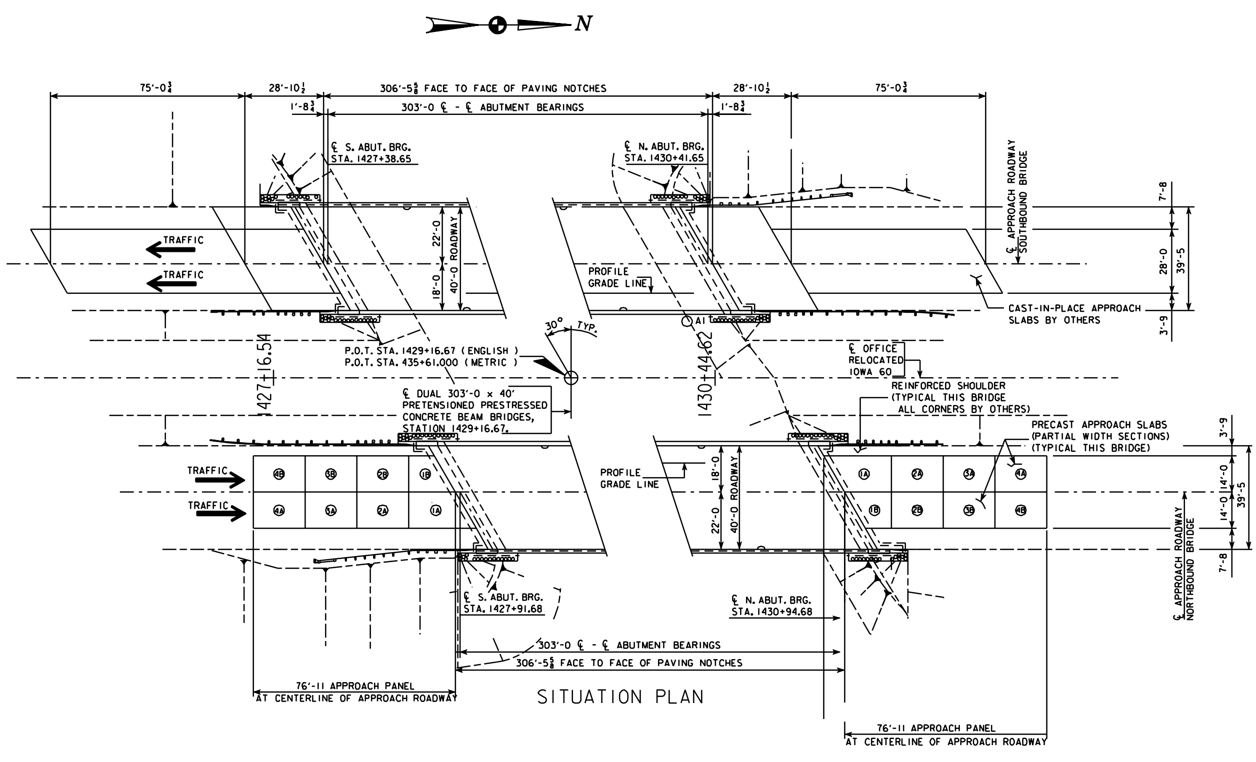

Fig. 5 Situation plan for O'Brien County bridge site

Design

Design of the precast pavement panels was performed jointly by the Iowa DOT Office of Bridges and Structures, Iowa State University Bridge Engineering Center, and the Transtech Group of Austin, Texas. The Iowa State University Bridge Engineering Center will provide instrumentation, long-term monitoring and evaluation of the structural performance during and after construction.

Once a suitable site was selected for the project, a number of challenging issues were studied during the design of the panels. Each of these challenges required the design team to carefully consider the most efficient method of casting and construction.

Cost

The initial set of details would have required local precasters to purchase special forms exclusively for a single project. Following conversations with industry leaders, the estimated costs of casting were prohibitive. The Office of Bridges and Structures worked with the local precaster to simplify the details and utilize existing forms to reduce the cost of the panels.

Skew

Initially, the proposed details maintained the skewed alignment throughout the precast portion of the approaches and then provided a cast-in-place transition to the standard pavement. This detail also contributed to the high cost of the project, reduced the benefits of accelerated construction, and was later revised to show a transition to a square panel at the bridge abutment.

Post-tensioning pockets and expansion joints

In order to simplify the details for the approach pavement, a decision was made to reduce the number of pockets as much as possible. This was accomplished by eliminating the expansion joint in the precast panel area and providing a pocket that would allow post-tensioning in both longitudinal and transverse directions near the abutment. See Fig. 6 for post-tensioning layout. Post-tensioning was spaced at approximately two feet on center in both direction.

Friction between slab and backfill

As the bridge expands and contracts with ambient thermal conditions, the connected approach pavement must move by sliding along the subgrade material. In order to reduce the drag forces imparted on the bridge superstructure and the abutment/approach connection, a number of friction-reducing systems were considered (Chia, 1986). A single layer of polyethylene was selected as the best compromise between friction and cost effectiveness.

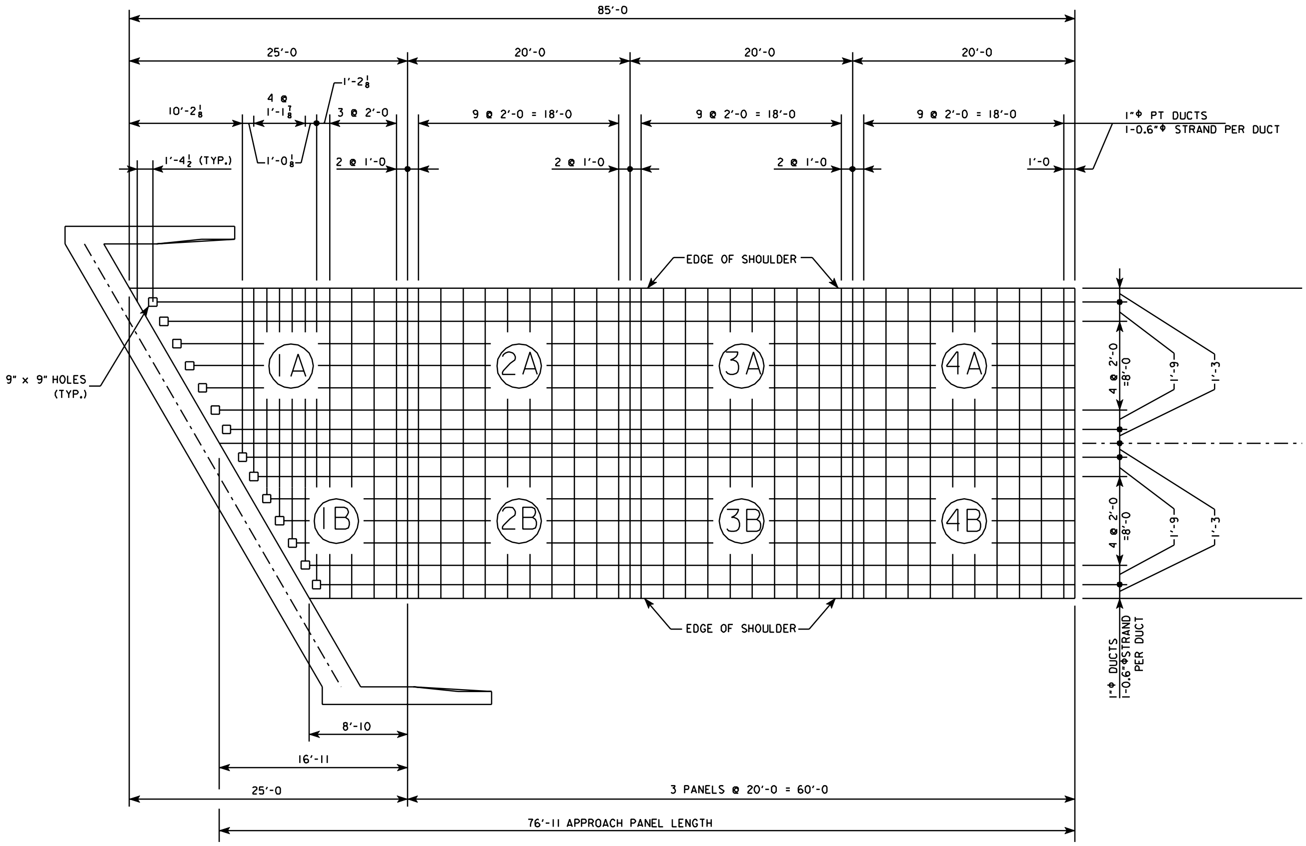

Fig. 6 Precast approach panel layout – north end of bridge

Shear keys for adjacent panel alignment and load transfer

Shear keys for adjacent panel alignment and load transfer were used at the joints between adjacent panels and were carefully considered during design. It was decided that the longitudinal joint between panels would best be constructed and aligned without a matching shear key, but rather with an open key that could be filled with cementitous grout following installation (see Fig. 7).

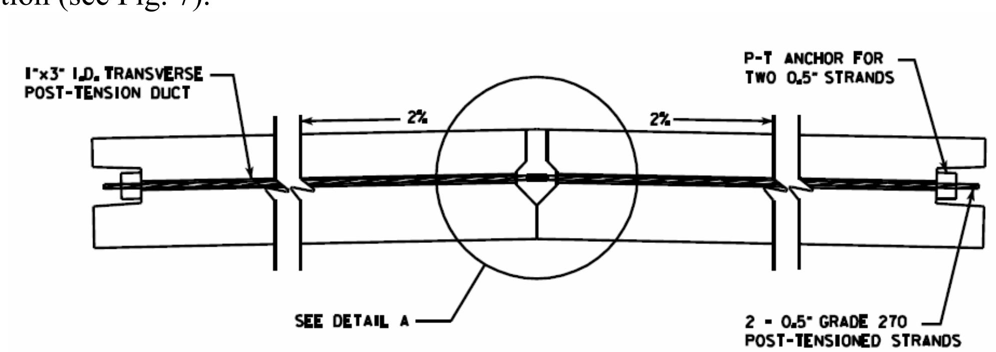

Fig. 7 Longitudinal joint between adjacent panels showing grouted key

INSTRUMENTATION AND MONITORING

A detailed structural monitoring plan was developed by the research team working closely with the Iowa DOT Office of Bridges and Structures. A number of key components of the dual bridge structures will be monitored using an extensive network of sensors starting in August 2006. These sensors will document the structural behavior of the bridge and approach pavement over a 16 month period following the installation of the precast concrete approach panels. A brief summary of the instrumentation plan is presented in the following paragraphs.

Approach pavement and bridge joint relative movement

The relative movement between the approach pavement and the bridge abutment (and between adjacent precast panels) will be monitored using embedded crackmeter-type displacement transducers "straddling" the panel joints along the longitudinal edges of the approach pavement.

Precast concrete approach pavement panels

A total of 16 strain sensors will be embedded in the precast concrete panels during the casting operations. These sensors will be aligned with the longitudinal reinforcing steel (using a "sister bar" configuration). These sensors will be used to study the effective drag forces caused by friction between the subgrade and the precast panels.

Long-term post-tensioning losses

Losses in both the longitudinal and transverse post-tensioning forces, caused by creep and shrinkage of the concrete panels, will be monitored using vibrating wire strain transducers. A total of 8 transverse tendons (2 per panel) and 6 longitudinal tendons (3 per panel) will be monitored.

Global abutment movement (displacement and rotation)

A set of 3 vibrating wire displacement transducers (DCDT) will be installed to monitor the global longitudinal and transverse movement of the bridge abutments due to long-term thermal expansion and contraction of the bridge superstructure. In addition, two vibrating wire tiltmeters will be installed on the front face of the abutment to monitor rotation. One goal of this arrangement is to quantify the tendency of skewed bridges to "rotate" over the duration of the study.

Girder strains

In order to document the effects of flexural strains caused by thermal movement of the superstructure, the girders will be monitored using a total of 6 vibrating wire strain transducers. Three interior girders will be instrumented with embedded sensors in the top and bottom flange.

Pile strains

Flexural strain in the steel H-piles will be monitored by a total of 12 vibrating wire strain transducers. The installation of the pile sensors will require excavation beneath the abutment to expose the piles.

The sensors will be connected using a series of multiplexers and three data acquisition units. Data will be recorded once per hour for the duration of the project. A sketch of the instrumented locations for the precast concrete panels is presented in Fig. 8.

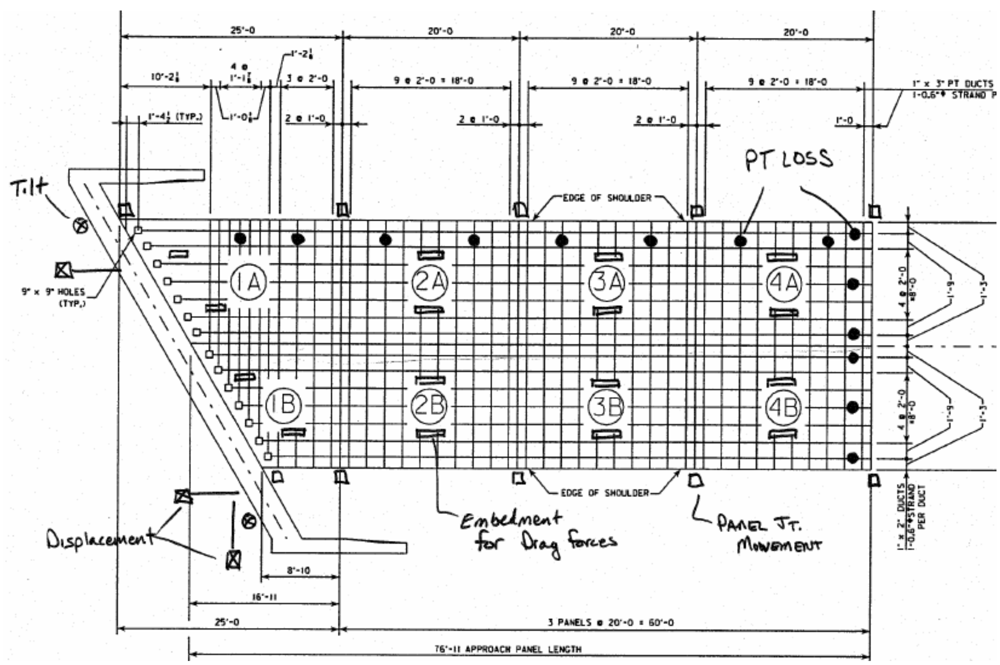

Fig. 8 Instrumentation locations in precast concrete approach panels

CURRENT STATUS OF PROJECT

Originally, this project was planned for construction in late 2005. The design considerations presented above, combined with a search for a suitable precaster, have delayed the project to the 2006 construction season. At this time (September 06), the precaster has cast the panels and the contractor has place the panels at the South end of the bridge. See Figure 9 and 10 showing casting of the panels. Figure 10A and 10B show pictures of placement of the first set of panels on the South end of the project.

Fig. 9 Pouring of Panel 3A

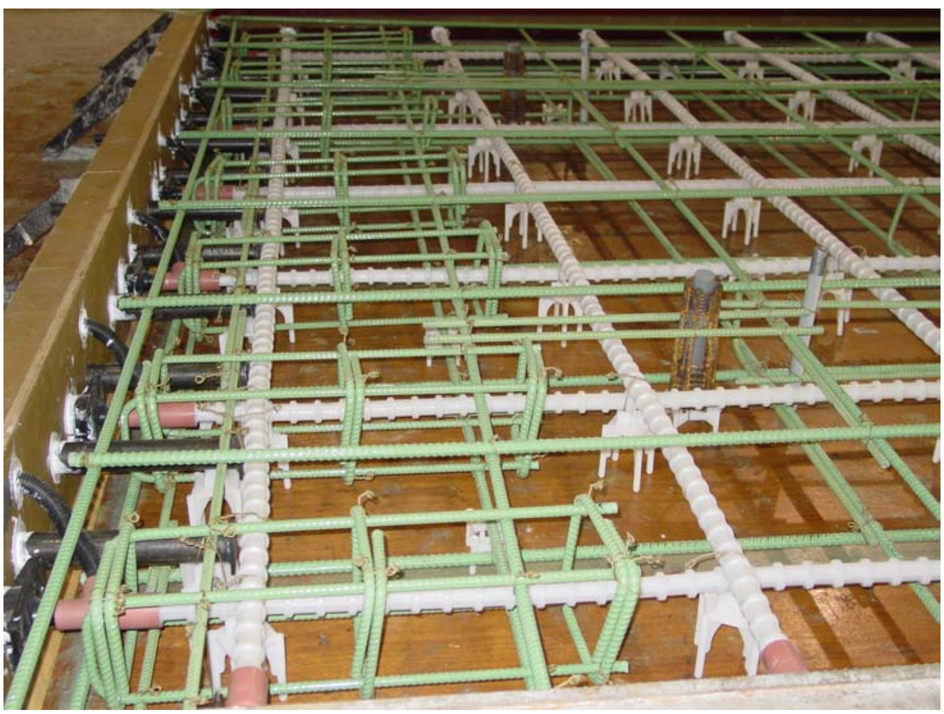

Fig. 10 End Section of Panel 4A

Fig. 10A Placement of Panel 1A

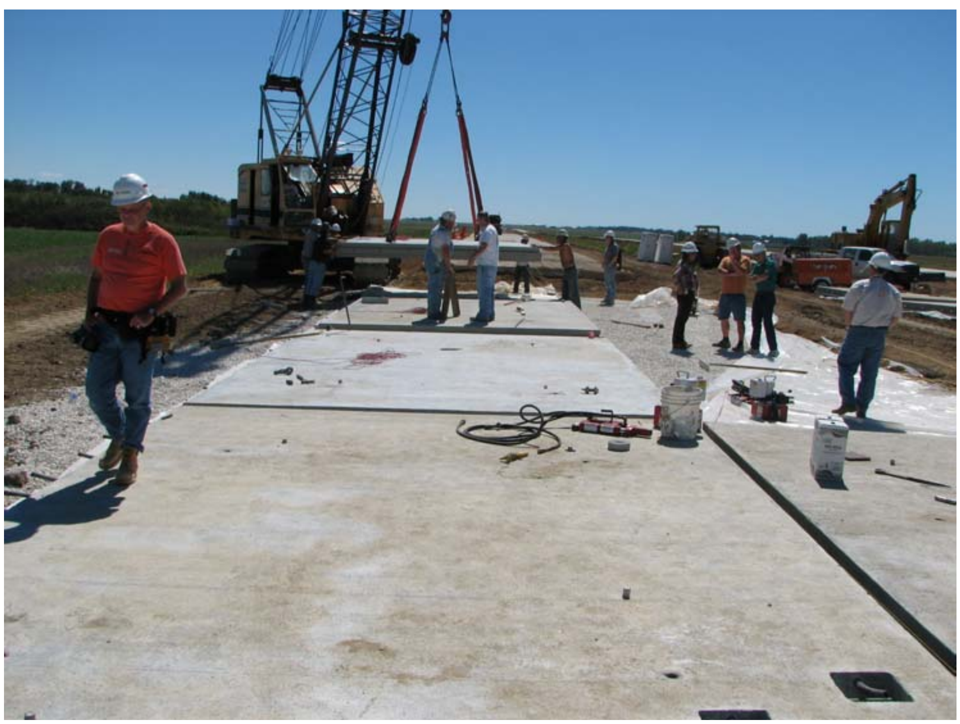

Fig. 10B Keyway with epoxy

Changes that have been made to the panels during the fabrication process are as follows:

1. Duct size: Initially the duct size chosen for the panels were 1"x 2" for the longitudinal ducts and 1" x 3" for the transverse duct. These larger ducts were chosen to provide more room for error in the placement of the ducts in the panel sections. However, because these duct sizes were made for multiple strand use the anchorages were larger than needed for the single strand use. Details were revised to use a single one-inch diameter duct with the understanding that tolerances could be met by the precasters for alignment.

2. Keyway: The plans required the use of steel forms for the casting of the panels to provide better fit up of the panels. Because of the cost of the steel forms, the precaster requested that wood forms be allowed. This request was accepted with the understanding that the panels would still need to pass a fit up check.

PRECAST PAVING NOTCH REPLACEMENT SYSTEM

Approach pavement settlement at the end of the bridge has been observed on a number of Iowa bridges. The failure of the bridge paving notch has been documented through previous investigation by the Iowa DOT as a contributing factor in this settlement. The paving notch is defined as the cast-in-place concrete corbel constructed on the back of an integral abutment, which is used to support the approach roadway pavement. Fig. 11 presents an example of a deteriorated paving notch.

Deterioration of this area is due to a combination of circumstances including:

- Improper construction of the approach pavement. During casting of the approach pavement, the top of the paving notch was not cleaned off and uneven bearing of the approach slab on the notch caused overstresses in the notch.
- Debris collecting in open joint between abutment and approach pavement. This debris is compacted each time the bridge expands with annual thermal cycles, allowing additional material to accumulate. Over the course of time, the approach pavement is “pushed” off the paving notch.
- Improper installation of reinforcing steel in both the paving notch and the end of the approach pavement. These un-reinforced areas are very prone to spalling. Insufficient attention by contractors and inspection personnel has been identified as one of the leading causes of this condition.
- Settlement and erosion of the backfill material beneath the approach pavement permits the pavement to rotate slightly and creating a very highly localized loading at the tip of the paving notch.

The conventional repair procedure for this problem consists of removing the deteriorated paving notch concrete while preserving as much of the existing reinforcing as possible. Wood forms are constructed, and a cast-in-place concrete paving notch is placed. Following sufficient curing of the new support, a replacement approach slab pavement is constructed.

This conventional replacement method requires that the bridge be taken out of service for an extended period of time, which disrupts the traveling public. The large number of bridges that exhibit the failing paving notch problem and, more importantly, their location on highly traveled roadways necessitate a more accelerated replacement method.

The objective of these two related projects is to develop a system which will permit bridge maintenance personnel to replace the entire bridge approach, including both the approach pavement and the paving notch, during limited closure of the highway. The preferred solution would permit removal of the existing bridge approach pavement, replacement of a deteriorated paving notch and the complete replacement of the approach pavement in a weekend operation. It is anticipated that the process for a bridge could be performed in two consecutive weekends (one for each lane of traffic).

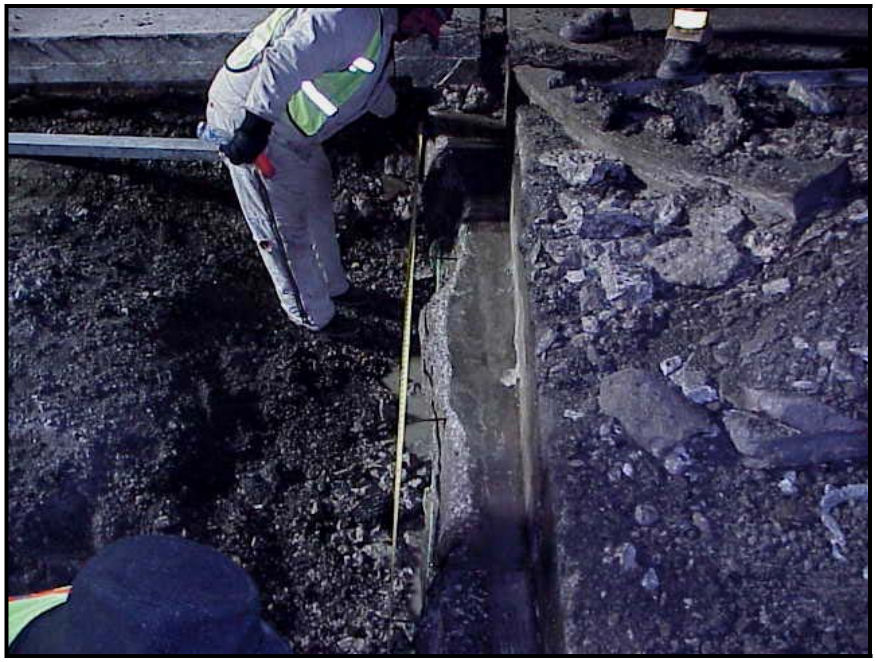

Fig. 11 Deteriorated paving notch on an integral abutment bridge.

A system of precast paving notch elements, which can be attached to an existing abutment using epoxy adhesive and post-tensioning rods, has been developed by the research team. This system offers the potential of a very rapidly installed repair, and when combined with the precast, post-tensioned bridge approach pavement, may allow bridge owners to completely replace a deteriorated approach during an overnight operation.

INNOVATIVE USE OF MATERIALS

The proposed precast paving notch replacement requires a material that provides both high compressive, tensile strength and toughness. In addition, the location of the paving notch beneath an open expansion joint will subject the precast element to considerable chloride exposure during its life and therefore requires a material that is also highly resistant to chloride intrusion. Two possible materials were considered for this environment: conventional precast, pretensioned concrete and a proprietary product known as Ductal®.

Ductal® is an ultra-high performance concrete (UHPC). Its mix design consists of sand, cement, silica fume, ground quartz, and superplasticizers blended with metallic or poly-vinyl alcohol (PVA) fibers in a dense, low water-cement ratio (0.15). To improve ductility, the fibers (approximately 2% by volume) are added, replacing the use of mild reinforcing steel. The fibers then provide a primary reinforcement, which allows the material to be used in architectural panels and other thin profile, low load-bearing conditions where weight reduction is sought. Conventional wire strand and prestressing equip Ductal® members for larger structural applications. Lafarge officials note that the material's uniqueness is owed to a combination of high compressive strengths up to 30,000 psi and flexural strengths up to 6,000 psi, plus a high resistance to abrasion and corrosive elements (Marsh, 2001).

The research team contracted with Lafarge North America, a manufacturer of UHPC, and Iowa Prestressed Concrete, to produce full scale specimens of the precast paving notch suitable for both laboratory and field testing. The Iowa Department of Transportation and the Bridge Engineering Center, together with the Wapello County Engineers Office, has recently completed the design, testing and construction of a pretensioned UHPC beam bridge and gained valuable experience working with this new concrete mix.

LABORATORY TESTING

A series of 15 specimens (12”x12”x4’-0”) were obtained including the following variations (Figure 12):

- Precast UHPC with no reinforcing (Section A)
- Precast UHPC with conventional mild steel reinforcing (Section B)
- Precast UHPC with 4-½” diameter strands, no stirrups (Section C)
- Precast UHPC with 4-½” diameter strands, stirrups at 12” centers (Section D)
- Precast (conventional) with 4-½” diameter strands, stirrups at 12” centers (Section D)

A pair of cast-in-place concrete test blocks, designed to closely replicate an existing abutment were constructed. Details of the test block and paving notch specimens are shown in Fig. 13. The test block was post-tensioned down to the test floor to eliminate any movement during the application of the test loads. Test loads were applied to simulate an AASHTO HS-20 wheel load of 16 kips, applied by a calibrated, 50 ton hydraulic jack and distributed by an 8”x 20”x2” steel plate and ½” thick, 60 durometer elastomeric pad.

Two load application locations were investigated. Initially, a single concentrated load applied midspan between the post-tensioning rods was used. Following the results of the initial rounds of testing, the load application was modified to include two concentrated loads, each located directly beneath the post-tensioning rods. Figures 14 and 15 illustrate the laboratory testing setup for the precast paving notch.

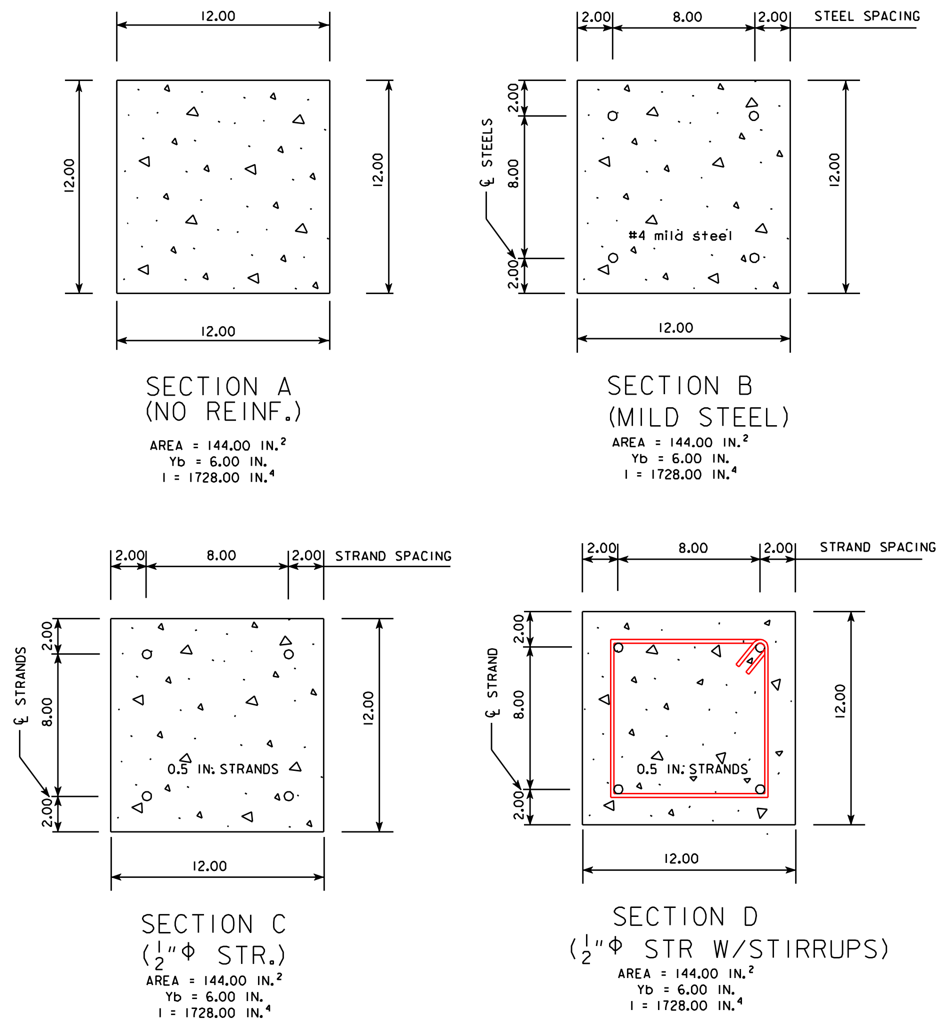

Fig 12 Specimen Cross Sections

Strength Testing - UHPC

The UHPC material was tested using 2-inch cube compressive specimens, which were cast and cured under the same conditions as the actual paving notch components. The curing process specified for the project provides for a moderate temperature curing at 105 degree F for 40 hours, followed by high-temperature curing at 195 degrees F for an additional 48 hours.

Several of the specimens were removed from the curing environment and subjected to compressive testing after the initial 40-hour period. This was to check release strength for the prestressed specimens. These specimens exhibited a compressive strength from 18.3 ksi to 20.1 ksi. The remaining specimens were fully cured at 195 degrees for an additional 48 hours and exhibited a compressive strength of 22.6 ksi to 25.3 ksi. Test strengths were less than expected for the mix. One factor that may have contributed to the lower strength was the use of plastic molds to cast the cubes. The end planes of these molds were not checked and may have caused the lower strength results. Testing that was done by the Iowa Department of Transportation, Office of Materials in an earlier project used machined brass forms for the casting. Compressive strength results from the testing where from 27.5 ksi to 30.61 ksi.

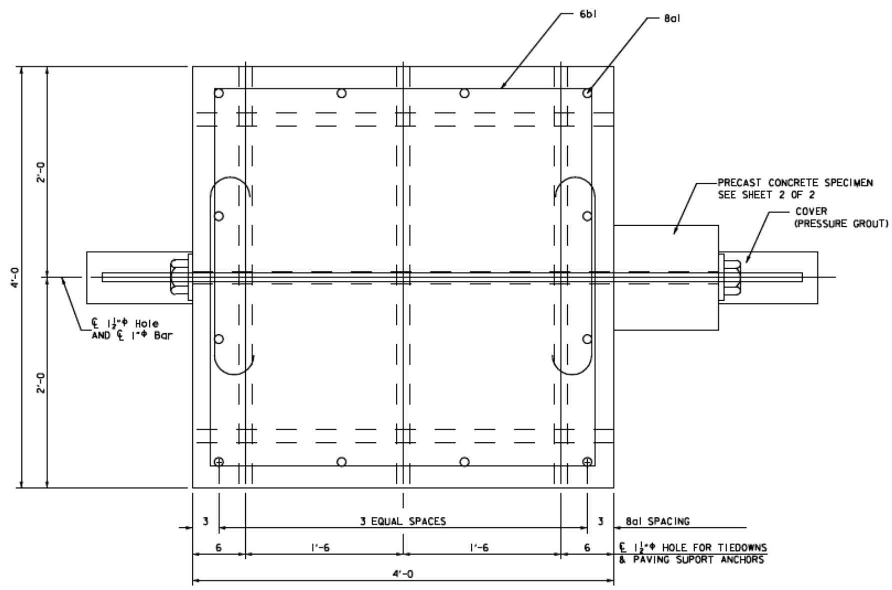

Fig. 13 Test fixture for precast concrete paving notch

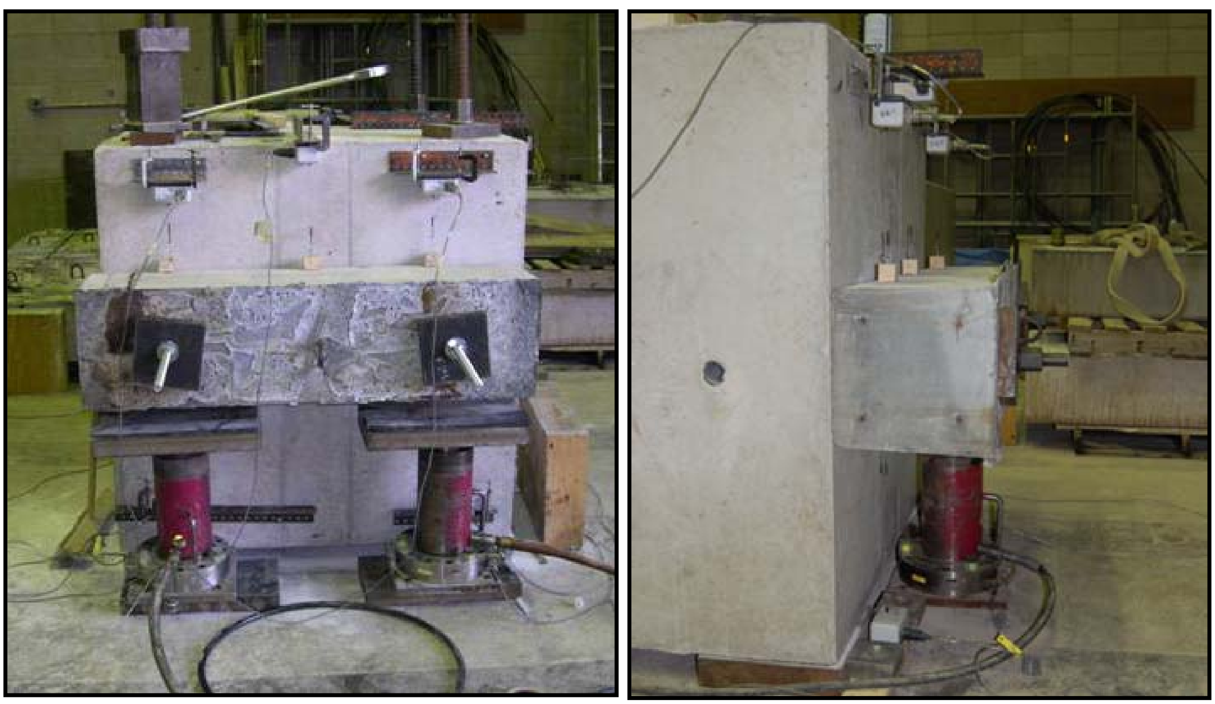

Fig. 14 Precast paving notch lab setup with two concentrated load points

Fig. 15 Precast paving notch laboratory testing setup with single point loading

A total of 5 string potentiometer displacement transducers were used to monitor any movement or tendency of the precast specimen to slip relative to the test fixture. These sensors are considered accurate to within 0.001" during the range of movement anticipate during load testing.

PT without epoxy adhesive

In order to determine the post-tensioning force required to securely attach the paving notch to the abutment, a series of load tests were performed using gradually lower levels of post-tensioning.

Figs. 16 and 17 show the results from successive load tests using reduced levels of post-tensioning force used to prevent slip. The tight, repeated load/displacement loops and return to the neutral position upon removal of load (Fig. 16) indicate that no slip has occurred when 38 kips of post-tensioning force was applied. Conversely, the flattened loops and displacement drift (Fig. 17) indicate that slip, although negligible, has occurred when this post-tensioning force was reduced to 26 kips.

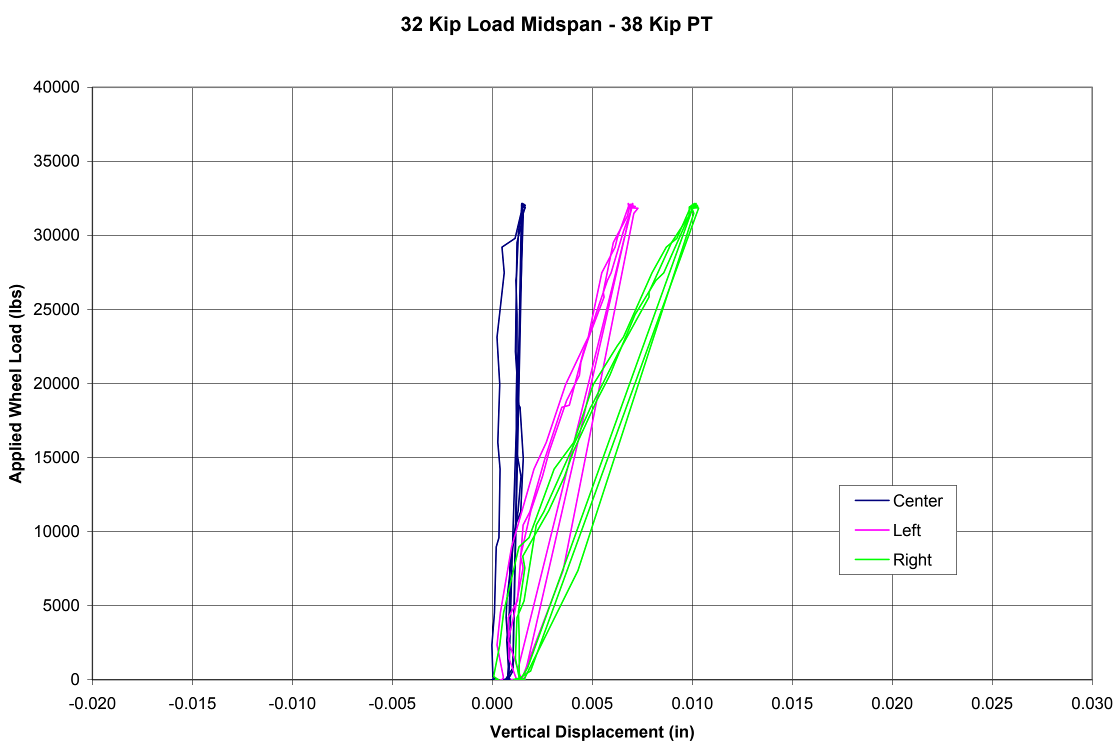

Fig. 16 Load test results indicating no slip between paving notch and abutment fixture

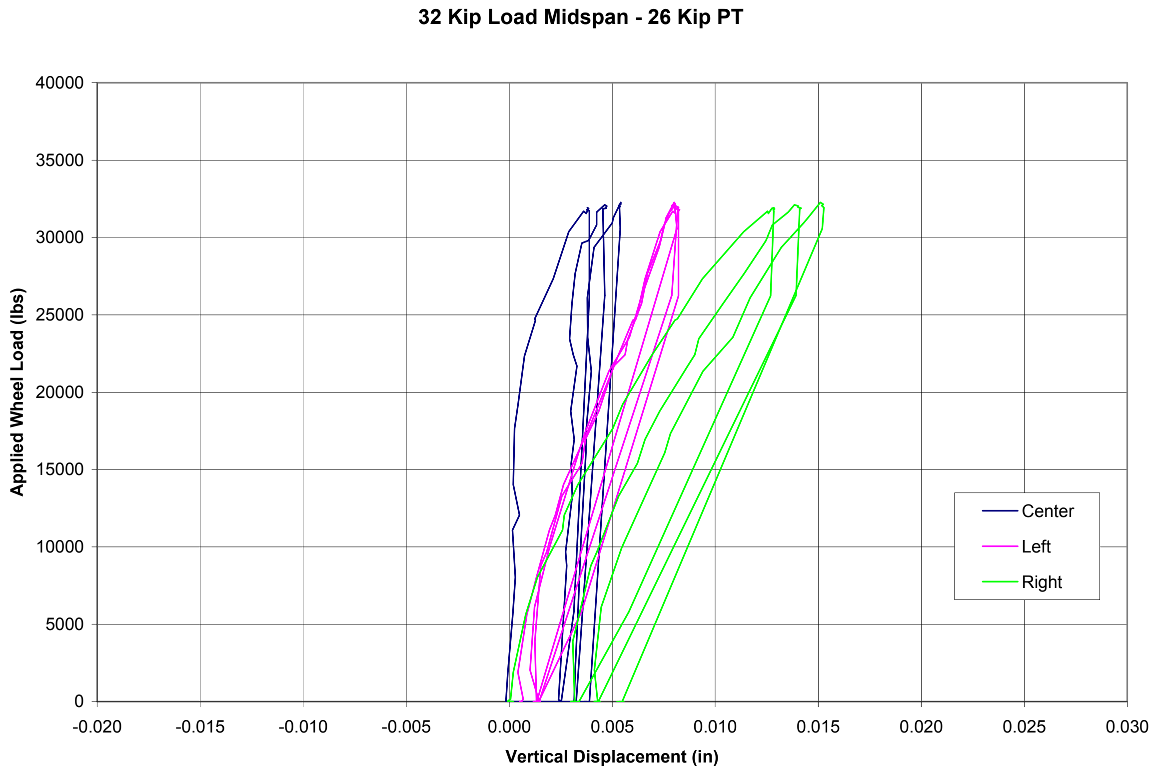

Fig. 17 Load test results indicating onset of slip between paving notch and abutment fixture

Drilled anchors with epoxy adhesive

Based on the lower-than-expected level of post-tensioned force required to secure the paving notch to the test fixture, the research team investigated the use of smaller diameter drilled-and-epoxy grouted anchors in lieu of post-tensioning rods. If the test results prove satisfactory, the use of drilled anchors will considerably simplify, and reduce the required time for, the installation procedure for the paving notch replacement system. It should be noted that this test was performed using two-point loading, while the results presented for PT without adhesive were loaded at the midspan of the specimen between anchors.

This load test included the use of an epoxy adhesive to provide bond between the paving notch and the test fixture. The adhesive used was Unitex Segmental Adhesive, a product specifically designed for construction of precast, post-tensioned segmental bridges. In addition to the load transfer provided by the adhesive, the high viscosity of the glue can be used to create a self-leveling bearing surface between the two concrete components.

It is well known that cast-in-place concrete is not perfectly flat and smooth. It is anticipated that a thick layer of segmental adhesive can be applied to the faying surfaces of each piece and the paving notch anchor rods torqued to only snug-tight condition prior to curing of the adhesive. After the adhesive has reached full strength (approximately 24 hours depending on ambient temperature), the anchor rods can be fully tensioned, which completes the installation.

The results from the drilled anchor and epoxy load test are presented in Fig. 18. It should be noted that the paving notch supported approximately 64 kips of applied load prior to spalling of the cast-in-place concrete text fixture. Following that, considerable surplus load capacity was provided during the elongation of the ¾" drilled anchor rods.

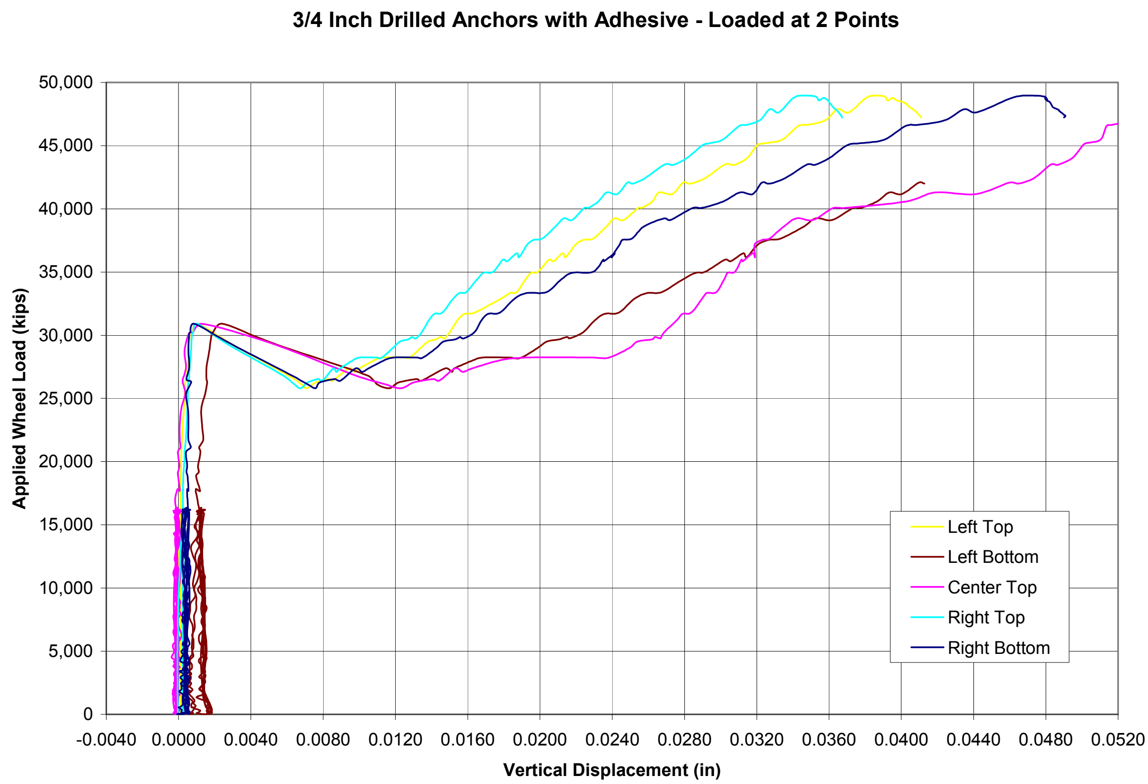

Fig. 18 Load test results for precast paving notch with drilled anchors and epoxy adhesive

FUTURE FIELD DEMONSTRATION AND INSTRUMENTATION

The Iowa DOT is currently searching for a suitable bridge site for a field demonstration project to be constructed during the summer of 2006. The preferred site will include significant truck traffic in order to truly evaluate the performance of the system. The research team will install an array of instrumentation, which will include both strain and displacement transducers and monitor them for an extended period of time to ensure the desired long-term performance of the system is obtained.

Detail changes that are currently planned for the pilot project are as follows:

1. Paving block size will be increased to sixteen inches square.
2. Three - ½ inch diameter strands will be used in the top and bottom of the block
3. ¾ inch diameter drilled in epoxy grouted bars will be used and installed in pairs.

CONCLUSIONS

Bridge owners are frequently faced by the need to replace critical bridge components during strictly limited or overnight road closure periods. This paper presents the development, installation, laboratory testing, instrumentation and current status of two precast concrete bridge elements specifically designed to address this critical need. It should be noted that the research projects are ongoing and the final results will be presented at a future date. It is anticipated that these two projects will permit the Iowa Department of Transportation to develop the experience to apply rapid bridge and pavement repair and construction techniques in high traffic areas where disruption of traffic must be kept to a minimum.

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