Precast Prestressed Concrete Pavement

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Synopsis: With traffic volumes continuing to increase on a rapidly deteriorating infrastructure, new methods are needed for expediting construction of durable, high performance concrete pavements with minimal disruption to traffic. One method, which has received significant attention in recent years, involves the use of precast concrete panels. Precast concrete panels can be cast and cured in a controlled environment, stockpiled, and set in place in a short amount of time, allowing for construction to take place during overnight or weekend operations. In March 2000, the Center for Transportation Research at The University of Texas at Austin completed a feasibility study which investigated the use of precast prestressed concrete panels for pavement construction. Following the feasibility study, a pilot project was initiated by the Texas Department of Transportation to test and refine these concepts on an actual project. Recently, construction of this pilot project was completed on a section of frontage road along northbound Interstate 35 near Georgetown, Texas. Although it was constructed without the time constraints and complexities that will eventually need to be considered for precast pavement construction, the viability of the concept for precast prestressed concrete pavement was clearly demonstrated and will ultimately lead to development of future precast prestressed concrete pavements.

Keywords: expedited construction; post-tensioned pavement; precast concrete pavement; precast pavement panels; prestressed pavement; user costs

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RESEARCH SIGNIFICANCE

New methods are continually being developed for expediting construction of durable concrete pavements. This paper describes one such method using precast prestressed concrete panels. Although other methods for expediting construction, such as fast-setting concretes already exist, precast concrete is presented as an alternative to these methods. With the degree of quality control afforded at a precast plant and the incorporation of post-tensioning, durability should be greatly enhanced, making precast concrete an appealing alternative for transportation agencies.

BACKGROUND

In response to an ever-increasing demand for methods to expedite pavement construction, the Center for Transportation Research (CTR) at The University of Texas at Austin completed a feasibility study, sponsored by the Federal Highway Administration (FHWA), which examined the use of precast concrete panels to expedite the construction of portland cement concrete pavements. From this feasibility study, a concept for precast pavement was developed which incorporated the use of prestressed precast panels.

A final recommendation from the feasibility study was a staged implementation strategy for testing and refining the proposed concept, in order to develop design details and construction specifications that will be acceptable to contractors and transportation agencies and easily adapted to current practices. Staged implementation begins with small pilot projects without stringent time constraints, aimed at streamlining the construction procedures for use on future projects.

The first precast pavement pilot project was constructed by the Texas Department of Transportation (TxDOT) during the fall and winter of 2001 on a section of frontage road along northbound Interstate 35 near Georgetown, Texas. This project incorporated precast concrete pavement panels into the reconstruction of 0.7 km (2,300 ft) of frontage road on either side of a new bridge, based upon the proposed concept described below. Ultimately, this pilot project not only demonstrated the viability of using precast panels to expedite construction of concrete pavements, but also the benefits and viability of incorporating post-tensioning.

PROPOSED CONCEPT

The proposed concept for a precast pavement, constructed on a section of frontage road near Georgetown, Texas, uses full-depth prestressed precast panels. Based upon the feasibility study mentioned previously, it was believed that full-depth precast panels would be the most efficient way to expedite construction, and that a sufficiently smooth riding surface could be attained using full-depth panels with occasional diamond grinding.

Previous experience with prestressed pavements has shown that prestress in both the longitudinal and transverse directions is essential (1). Therefore, prestress is incorporated in a precast pavement by pretensioning the precast panels during fabrication (for transverse prestress), and post-tensioning all of the panels together after placement (for longitudinal prestress). Pretensioning not only accounts for in situ stresses but also counteracts lifting stresses. Post-tensioning not only provides the necessary prestress in the longitudinal direction, but also serves to tie all of the panels together so they act as a continuous slab.

Two key factors which must be considered when using full-depth panels are: 1) base preparation so that the panels are resting on a flat surface and are fully supported, and 2) method for ensuring vertical alignment of adjacent panels to achieve satisfactory ride quality over the joints. With regard to base preparation, profile measurements obtained from a newly placed asphalt pavement in Austin, Texas revealed that it is possible to place a thin (25 – 50 mm) asphalt leveling course smooth enough and flat enough that the panels can be placed directly over the leveling course (2). This is not only an economical solution, but an efficient solution in that the asphalt leveling course can be placed well in advance of the precast panels, allowing traffic onto the leveling course prior to panel placement.

To ensure vertical alignment between adjacent panels, the proposed concept features continuous shear keys cast into the edges of the panels which will interlock the panels as they are set in place. Although shear keys along the panel edges require strict casting tolerances, the panels can be set in place rapidly without the need for additional measures to level-up adjacent panels. This was demonstrated prior to construction by trial assemblies, described below.

A typical panel assembly for the proposed concept is shown in Figure 1. The panels are oriented with the longitudinal axis perpendicular to the flow of traffic, incorporating both traffic lanes and shoulders. There are essentially three types of panels: base panels, joint panels, and central stressing panels, shown individually in Figure 2. As mentioned above, all of the panels are pretensioned lengthwise (transverse pavement direction), and post-tensioning ducts are cast into each panel widthwise (longitudinal pavement direction) to allow the panels to be post-tensioned together after they are set in place. The base panels (Figure 2a) are the "filler" panels between the joint panels and central stressing panels. The number of base panels between the joint panels and central stressing panels will depend on the post-tensioned slab length (between expansion joints). The joint panels (Figure 2b) contain an armored expansion joint, similar to that used for bridge decks, which will absorb the significant expansion and contraction movements of the post-tensioned slabs. The joint panels also contain self-locking post-tensioning anchors to receive the post-tensioning strands. Small access pockets (150 mm x 300 mm) cast into the joint panel provide access to the strand prior to insertion into the self-locking anchors. Finally, the central stressing panels (Figure 2c) are similar to the base panels, with the addition of larger pockets (1.2 m x 0.2 m) cast into the panels at every post-tensioning duct. The purpose of the pockets is to allow for post-tensioning to be completed from the center of the slab rather than at the post-tensioning anchorage in the joint panel. This allows for a more continuous pavement placement operation, as access to the anchorage is not needed in order to tension the strands. The post-tensioning strands coming into the stressing pockets from either side of the slab are coupled in the pocket, and then tensioned, as shown in Figure 3.

In order to protect the post-tensioning strands crossing the joints between each of the panels, epoxy is applied to the edges of the panels as they are assembled, similarly to segmental bridge construction. This not only protects the strands from water intrusion, but also prevents grout from leaking at the panel joints during tendon grouting. The epoxy also serves to bond the panels together so that they act more like a continuous slab, while also serving as a lubricant during assembly of the panels.

In certain cases it may not be possible to replace the entire pavement width, but rather one lane at a time. In this situation, it will be necessary to place two or more "partial-width" precast pavement slabs adjacent to each other and tie them together transversely. To accomplish this, an additional post-tensioning duct is cast into each of the panels in the transverse pavement direction, as shown in Figure 4. A flat, oversized duct will permit slight misalignment of adjacent slabs and will accommodate any differential movement of the slabs.

Following assembly (Figure 1) and post-tensioning of the precast panels, the pockets in both the joint panels and central stressing panels are filled with a fast-setting concrete. If time constraints do not permit filling the pockets, the pockets can simply be covered and filled during a subsequent operation. After filling the pockets, the post-tensioning strands are grouted in the ducts. Grouting not only bonds the strands to the pavement so that there will not be a significant loss of prestress if a strand is cut, but more importantly, provides an extra layer of corrosion protection for the strands, which is particularly important at the joints between panels where the post-tensioning ducts are not continuous. Grouting, also, can be completed during a subsequent operation if time constraints do not permit immediate grouting.

Another aspect of the precast pavement concept is a friction-reducing medium between the precast panels and the asphalt leveling course. A friction-reducing medium is essential for minimizing prestress losses in the pavement due to frictional restraint developed between the bottom of the panels and the leveling course during post-tensioning and over the life of the pavement. Previous research has shown a single layer of polyethylene sheeting to be a very effective and economical material for use as a friction-reducing medium (3). This material was used successfully for construction of a cast-in-place post-tensioned pavement near West, Texas (4). In addition to the friction-reducing medium, the middle of each post-tensioned slab must be anchored to the base. A mid-slab anchor forces the slabs to expand and contract outward from the center, ensuring uniform expansion joint widths. Dowel bars drilled and grouted into the base material at the stressing pockets provide a simple and effective solution for the mid-slab anchor.

DESIGN OF THE GEORGETOWN PRECAST PAVEMENT

Project Site

The precast pavement constructed near Georgetown, Texas was placed on a section of frontage road along northbound Interstate 35. The project consisted of 700 m (2,300 ft) of precast pavement on either side of a new bridge, as shown in Figure 5. The site for this project was ideal for several reasons. First, the frontage road was closed to traffic during construction. This allowed initial problems to be worked out without restrictive time constraints. Although the ultimate application for precast pavement will be in urban areas, under extreme time constraints (overnight or during weekends), the purpose of this initial pilot project was to test and refine the panel details and construction procedures. Secondly, there are no horizontal curves and very gradual vertical curves. Although horizontal curves and superelevations must eventually be addressed, a roadway with a simple geometric layout allowed for the basic details of the precast pavement concept to be worked out first. Finally, the site for the Georgetown precast pavement was ideal because it will eventually experience heavy traffic, particularly truck traffic, as it will become part of an interchange for Interstate 35 and (proposed) State Highway 130. Heavy traffic will provide a good test of the durability of the finished precast pavement.

The precast panels were oriented transverse to the flow of traffic, as shown in the panel assembly (Figure 1). This required panels which would span the full 11 m (36 ft) roadway width (two 3.7 m lanes, 2.4 m outside shoulder, and 1.2 m inside shoulder). To accomplish this, both full-width (11 m) and partial-width (5 m + 6 m) panels were used, although partial-width panels were not required. The full-width panels were placed on the north side of the bridge, and the partial-width panels on the south side of the bridge, with the joint between the 5 m and 6 m panels located at the center stripe of the road. A standard slab length (between expansion joints) of 76 m (250 ft) was selected based upon prior experience with the post-tensioned pavement near West, Texas (4). To meet the project limits, a longer slab length of 100 m (325 ft) for the partial-width panels, and a slightly shorter slab length of 68 m (225 ft) for the full-width panels were also incorporated. A standard panel width of 3 m (10 ft) was selected for all of the panels based upon fabrication (casting bed width) and transportation (weight limit) considerations.

Prestress Requirements

The Georgetown pilot project was designed for an equivalent fatigue life, in terms of expected 80 kN (18-kip) equivalent single axle load (ESAL) applications to that of a 355 mm (14 in) continuously reinforced concrete pavement (CRCP). Although a 355 mm pavement is a much thicker pavement than needed for this frontage road, the purpose of this pilot project was to simulate what might be used on the main lanes of an interstate pavement.

The pavement was placed as a new pavement directly on the asphalt leveling course over compacted subbase material. A 200 mm (8 in) pavement thickness was selected primarily on the basis of handling considerations. Using layered theory analysis, elastic design for fatigue loading was used to determine the prestress requirements for a 200 mm precast pavement with an equivalent design life to a 355 mm CRCP for the given subbase support conditions. Elastic design for environmental and wheel loading was then used to determine the final prestress requirements. Elastic design for environmental and wheel loading takes into account stresses generated from slab curling due to top-bottom temperature differentials in the slab, prestress losses due to both frictional resistance at the bottom of the slab and strand relaxation, and stresses generated from wheel loading (simultaneous to environmental loading).

Based on this design, the maximum required prestress (at the ends of the slab), for a 200 mm (8 in) precast pavement, was found to be approximately 1.45 MPa (210 psi). This translates into 15 mm (0.6 in) diameter 1,860 MPa (270 ksi) post-tensioning strands spaced at approximately 71 cm (28 in) across the width of the pavement (strands to be stressed to 80 percent of ultimate strength). However, for the purpose of standardization of strand spacing for future projects, a strand spacing of 61 cm (24 in) was selected, which further increased the effective thickness of the pavement.

Elastic design for environmental loading was also used to determine the expected minimum and maximum expansion joint widths for the given slab lengths (76 m, 100 m, 68 m). Anticipated joint widths were checked to ensure that the expansion joints would never be open more than 100 mm (4 in) and would never be completely closed under extreme summer and winter temperatures relative to weather typically experienced in Georgetown, Texas. Based upon these joint widths limitations, a table was developed for the recommended initial joint width, at panel placement, based on approximate ambient temperatures during panel placement. The initial joint width was then set, prior to casting the joint panels, by tack welding the armored joint together at the specified width.

In addition to longitudinal prestress requirements, transverse prestress requirements were also determined based on environmental and wheel loading. However, it was determined that the governing factor in transverse prestress design is the stress generated from lifting the precast panels. Therefore, a minimum prestress (from pretensioning the panels during fabrication) of 1.4 MPa (200 psi) was specified in order to prevent cracking in the 11 m (36 ft) long panels when lifted approximately at the quarter points.

<u>Panel Details</u>

The post-tensioning ducts were located at mid-depth of the precast panels. This was to ensure that a camber was not introduced into the pavement during post-tensioning. The pretensioning strands, likewise, were centered at mid-depth by alternating them just above and just below the post-tensioning ducts. Flat, four-strand post-tensioning ducts were cast into the partial-width panels (for transverse post-tensioning) with two standard dead-end post-tensioning anchors at the ends of the ducts.

Mild steel reinforcement in the precast panels was minimal. Although the transverse pretensioning strands provided a significant amount of bonded reinforcement, additional mild steel (13 mm, 414 MPa) reinforcement was provided around the perimeter at the top and bottom of each of the panels. Mild steel was also provided in the central stressing panels and joint panels, with two reinforcing bars crossing though the stressing pockets and access pockets to tie concrete in the pockets to the rest of the panel. Additional "bursting steel" was added to the joint panels directly in front of the post-tensioning anchors and in front of the transverse post-tensioning anchors in the partial-width panels.

To aid with assembly of the panels, sleeves were cast into the edges of each of the precast panels, as shown in Figure 2. The edge sleeves provided a means for pulling the panels together as they were lowered into place to get the joints between panels as tight as possible before post-tensioning. Chain winches or "come-alongs" linked between the edge sleeves were used to pull the panels together.

The armored expansion joints cast into the joint panels were similar to those used for the cast-in-place prestressed pavement near West, Texas, mentioned previously (4). Figure 6 shows the expansion joint detail used for the Georgetown precast pavement project. The seal receiver extrusion at the top of the expansion joint is a standard receiver for bridge decks commonly used in Texas. A 6 mm (0.25 in) thick steel angle was welded to the bottom of the steel extrusion to provide encapsulation of the concrete and a bearing structure for the joint. Deformed bar anchors, 0.6 m (2 ft) in length, were welded to the top and bottom of the expansion joint to tie it to the precast panel and prevent rocking of the joint under repeated wheel loading. The top and bottom anchor bars were alternated over the length of the joint, spaced every 200 mm (8 in). Stainless steel plated dowel bars were spaced at 305 mm (12 in) along the length of the expansion joint with an expansion sleeve cast into one side of the joint to receive the dowel. The self-locking post-tensioning anchors, discussed previously, were fastened to the expansion joint with 13 mm (0.5 in) threaded studs spaced at 61 cm (24 in) over the length of the expansion joint.

PANEL FABRICATION

The panels for the Georgetown precast pavement project were cast on a "long line" casting bed 122 m (400 ft) in length. Long line casting allowed for ten full-width (11 m) panels, and up to twenty partial-width panels to be cast at one time end to end. The pretensioning strands extended continuously the full length of the casting bed passing through all of the panels. After release of prestress, the pretensioning strands between each of the panels were cut and the panels were removed from the forms. Long line casting did require special attention for the side forms to make sure there were no imperfections or misalignment that might prevent the keyed panel edges from matching up.

The mix design for the precast panels was similar to that used for precast prestressed bridge beams. The mix contained seven sacks of Type III portland cement per cubic yard, with a water/cement ratio of 0.42, and superplasticizer for increased workability. A mix of this nature, which is not typically used for pavements, was necessary to develop sufficient strength for release of prestress and removal from the forms the following day. The specifications for the precast panels required that the concrete reach a minimum compressive strength of 24.1 MPa (3,500 psi) at release of prestress, and a 28-day compressive strength of 34.5 Mpa (5,000 psi). The mix was also required to be sufficiently fluid during casting that a carpet drag finish could be applied at sheen loss.

Handheld concrete vibrators and a vibratory screed were used to ensure a flat surface and proper consolidation of the concrete around the keyways, post-tensioning ducts, and pockets during casting. An intermediate curing compound similar to monomolecular film was applied to the panels after screeding to minimize water loss. After any necessary hand finishing, a carpet drag texture was applied to the panels, transverse to the flow of traffic. Immediately following the carpet drag, two coats of curing compound were applied to the panels to minimize further water loss from the surface of the panels. Adequate curing was particularly important as many of the panels were cast during the hot months of July and August. The panels were generally cured in the forms overnight before releasing prestress, then removed from the forms and stacked. Once the panels were stacked, wet mats were applied to the stack of panels and a tarp was used to cover the stack. The panels were allowed to cure in this condition until 48 hours from the time of casting. In total, 123 full-width (11 m) panels and 216 partial-width (5 m and 6 m) panels were cast.

PANEL ASSEMBLY

Trial Assemblies

Prior to actual construction on the frontage road, two trial panel assemblies were conducted. The first trial assembly was conducted at Ferguson Structural Engineering Laboratory at The University of Texas at Austin. For this trial assembly, three panels were cast representing one half of a joint panel, and two base panels. The panels were all 200 mm (8 in) thick and 3 m (10 ft) wide (half joint panel was 1.5 m wide). However, due to the scale of the trial assembly, the panels were only 1.5 m (60 in) long, as opposed to the full length of 11 m. The panels were all cast with the same details, including edge keyway dimensions, specified for the actual panels with the exception of pretensioning. The laboratory trial assembly proved the viability of several aspects of the precast pavement concept, including keyed panel edges, assembly the panels over the plastic sheeting, edge sleeves used to pull the panels together, and self-locking post-tensioning anchors.

The second trial assembly was carried out at the precast plant in Victoria, Texas. The primary purpose of this trial assembly was to evaluate how well full-width

(11 m) panels could be assembled using the same methods demonstrated in the laboratory. For the second trial assembly, three full size panels were cast and assembled using equipment available at the precast plant. The three panels fit together tightly, as they did in the laboratory test, assuring the viability of assembly on the frontage road.

Both trial assemblies proved to be very useful for evaluating the viability of some of the aspects of the proposed precast pavement concept with only minimal expense. After completion of these trial assemblies, approval was given for full-scale panel production.

Frontage Road Assembly

As the pavement panels were being cast, the asphalt leveling course was placed on the frontage road. To achieve the full 11 m roadway width, three sections of asphalt were placed, being careful that ridges were not created at the joints between the three sections. To ensure that the leveling course was placed as flat and uniform as possible, a string line was staked to the subbase material as a depth gauge approximately every 7.5 m (25 ft). After final compaction of the leveling course, any obvious defects were marked and removed, and a laser profilometer was used to check the smoothness.

After all of the full-width (11 m) precast panels had been cast, panel assembly began on the frontage road. The panels were delivered to the site and placed one section (between expansion joints) at a time. The panels were delivered to the site one panel per truck due to weight restrictions. As each truck was waiting to unload, epoxy was applied to the panel edges. The polyethylene sheeting was rolled out prior to the placement of each panel. A 578 kN (65 ton) capacity crane was then used to lift each panel off of the truck and set it directly in place. In general, two 11 m panels could be set in place before the crane had to be moved. This prevented excessive extension of the boom, reducing the amount of sway as the panels were being set in place. To ensure that the lifting lines were nearly vertical (to minimize bending stresses in the panels), lifting lines approximately 9 m (30 ft) in length were used. During placement of the first few sections, approximately 25 full-width (11 m) panels could be placed over an 8-hour period. This placement rate varied depending on the number of workers available. At the end of the project 25 panels could be placed in approximately 6 hours.

As the panels were being set in place, the post-tensioning strands were cut to length. Once all of the panels had been set in place, the post-tensioning strands were fed into the ducts at the central stressing pockets and through the panels on either side of the central stressing panels. The strands were each fed to the access pockets in the joint panels where the end of each strand was inspected prior to being pushed into the self-locking anchors. After all of the strands were anchored, a coupler similar to that shown in Figure 3 was used to couple the strands coming