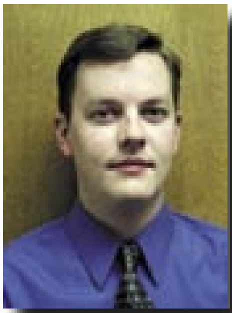
Design-Construction of a Precast, Prestressed Concrete Pavement for Interstate 10, El Monte, California



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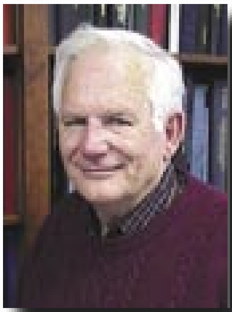

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In April 2004, the California Department of Transportation (CALTRANS) completed the construction of a precast, prestressed concrete pavement demonstration project on Interstate 10 in El Monte, California. This project allowed CALTRANS to evaluate the viability of precast concrete pavements for rapid pavement construction and rehabilitation, while also familiarizing local contractors with this innovative construction technique. The majority of construction of the 248 ft (76 m) section of precast, prestressed concrete pavement was completed at night when lane closures were permitted on I-10. The construction added 27 ft (8 m) of traffic lanes and 10 ft (3 m) of shoulder to the existing lanes on I-10. To maximize the pavement's performance, the precast concrete panels were pretensioned in the transverse direction during fabrication and post-tensioned in the longitudinal direction after installation. This project has demonstrated the expediency of precast concrete pavement construction and has generated considerable interest for further applications.

Transportation agencies are continually seeking new and innovative solutions for rapid reconstruction of a quickly deteriorating pavement infrastructure. These solutions must not only provide long life, providing a minimum of 30 to 50 years of service, but they also must be constructed under increasingly shorter construction windows, minimizing disruption to the motoring public. Agencies such as CALTRANS are frequently limited to seven-hour overnight construction windows for pavement reconstruction in urban areas. Precast or modular pavement construction has received significant attention in recent years due to its proven track record of providing a durable product that can be fabricated off-site and quickly installed on-site.

In 2000, the Center for Transportation Research at the University of Texas at Austin completed a Federal Highway Administration (FHWA) sponsored feasibility study that examined the use of precast, prestressed concrete panels for expedited pavement construction.[1] This study was followed by an FHWA-sponsored implementation study that resulted in the construction of a 2300 ft (700 m) precast, prestressed concrete pavement near Georgetown, Texas, in 2002.[2-4] The success of the initial project in Texas has led to several additional demonstration projects that will permit transportation agencies to evaluate the viability of precast concrete for rapid pavement construction.

The first of these demonstration projects was constructed on Interstate 10 in El Monte, California (near Los Angeles), in April 2004. Using the FHWA feasibility study and Texas demonstration project as the basis for this project, a 248 ft (76 m) section of precast, prestressed concrete pavement was constructed on the primary lanes of I-10.

BENEFITS OF PRECAST PAVEMENT

Perhaps the most obvious benefit of precast concrete for pavement is the ability to open the roadway to traffic immediately after installation of the precast panels. Conventional cast-in-place concrete pavement must be allowed to reach adequate strength before it can be opened to traffic. Even "fast-setting" concrete paving mixes generally require at least four hours of curing time to reach the required strength, and there remain some questions as to the long-term durability of these mixes due to excessive shrinkage cracking.[5,6] Precast concrete panels, on the other hand, are cast and cured well in advance of construction, ensuring they will have the necessary strength characteristics to be opened to traffic immediately after installation. This reduction of construction time facilitates overnight and weekend construction operations.

Precast concrete pavement also offers significant benefits in terms of improved performance. Precast manufacturers are able to produce consistent concrete mixes with a high degree of quality control, and they can cast and cure the product in a controlled environment. Problems that are commonly encountered with cast-in-place concrete pavement — such as built-in curl (from temperature and moisture gradients in the slab), surface strength loss (from insufficient curing), and inadequate air entrainment — can be minimized or eliminated with precast concrete.[1]

Prestressing further improves precast pavement performance by inducing compressive stress in the pavement slab, which greatly reduces or even prevents the occurrence of cracking. This has been demonstrated by several cast-in-place prestressed pavements constructed throughout the United States and abroad.[7-9] Prestressing also permits a significant reduction in slab thickness. By introducing a precompressive stress into the pavement, tensile stresses caused by wheel loads are reduced, thereby reducing the required slab thickness for a given traffic loading. The Texas precast pavement project, for example, was designed such that the 8 in. (200 mm) thick precast pavement would have a design life equivalent to a 14 in. (355 mm) thick continuously reinforced cast-in-place concrete pavement.[2]

The economic benefit of precast concrete pavement is realized through savings in user costs. Reduced construction time and improved performance greatly reduce user costs associated with pavement construction and rehabilitation. User delay costs are accumulated when traffic congestion is caused by construction activities. These costs can be substantial, as demonstrated by the FHWA feasibility study that estimated

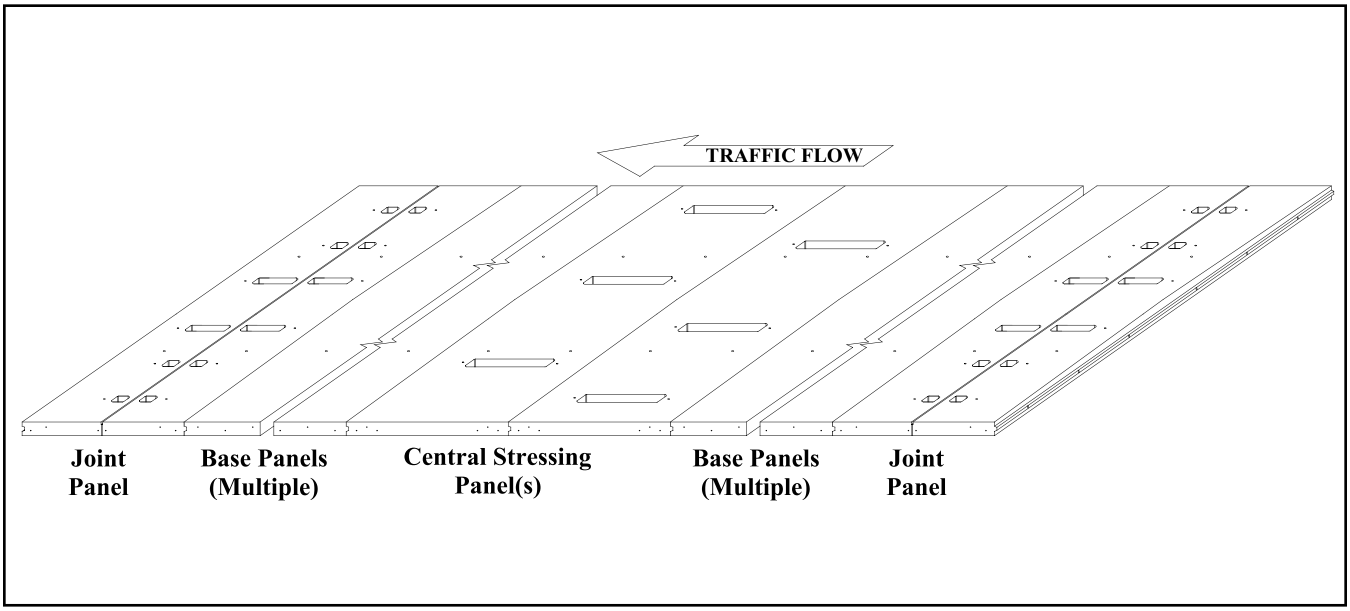

Fig. 1. Typical precast concrete panel assembly showing the three types of precast panels that compose each post-tensioned slab.

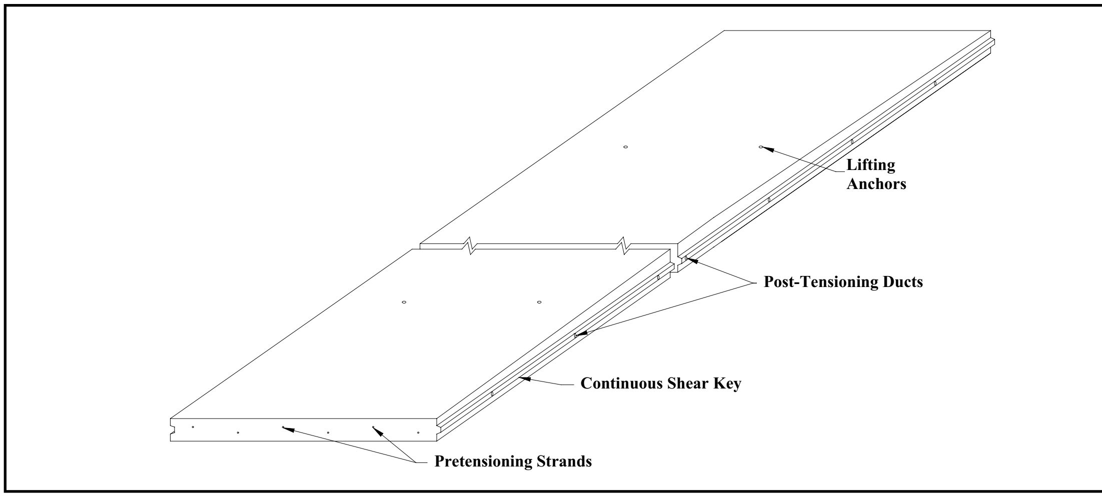

Fig. 2. Typical base panel showing the continuous shear keys, pretensioning strands, and longitudinal post-tensioning ducts.

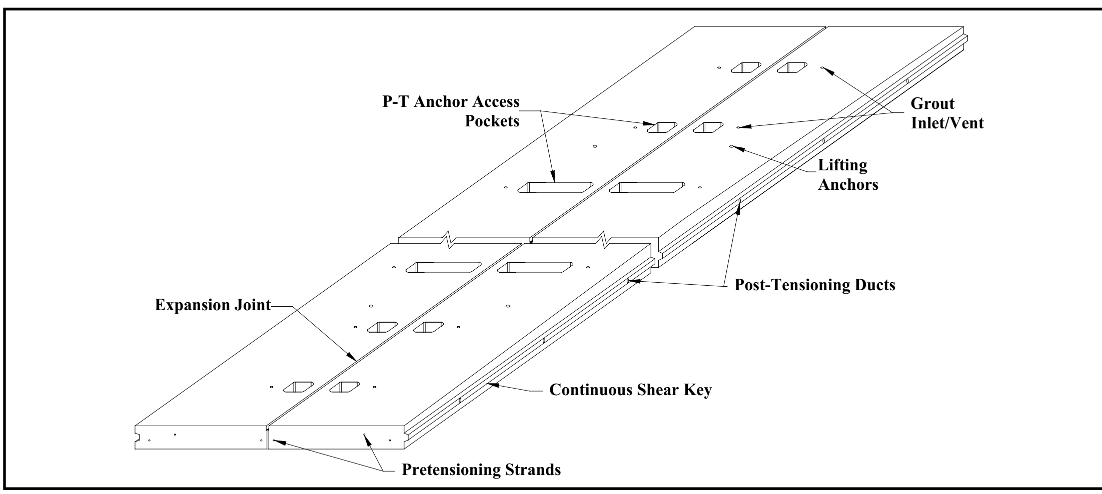

Fig. 3. Typical joint panel showing the doweled expansion joint and post-tensioning anchor access pockets.

daily user delay costs to be as high as $383,000 per day for 24-hour-per-day lane closures versus only $1,800 per day when lane closures are limited to nighttime only.[1]

Likewise, user costs resulting from poor pavement performance can also be substantial. As a 2001 TRIP (The Road Information Program) report indicated, Americans spend more than $41 billion annually on vehicle repair due to poor road conditions.[10] Pavements that last longer and require less maintenance over their design life substantially reduce these types of user costs.

Finally, another benefit of precast concrete, which may not be immediately apparent, is the potential for extending the construction season for paving. Because precast concrete panels are cast and cured in a controlled environment, they are not as susceptible to on-site environmental conditions as conventional cast-in-place concrete pavement. This permits pavement construction to continue even under adverse weather conditions, such as extreme hot or cold temperatures, that normally would prohibit cast-in-place concrete construction.

PRECAST PRESTRESSED PAVEMENT CONCEPT

The concept for the California precast concrete pavement was developed under the FHWA-sponsored feasibility study mentioned above.[1] Based on the initial project constructed in Texas,[2] several refinements were made to the precast concrete panel details for the California project. The pavement consists of full-depth prestressed concrete panels placed over a prepared base. The base provides a stable platform for supporting the precast panels, and is placed to a tolerance that will minimize voids beneath the precast panels.

Over the prepared base, a single layer of polyethylene sheeting is rolled out prior to installation of the panels. The polyethylene sheeting serves as a bond breaker between the panels and base, helping to reduce stresses caused by frictional resistance at the slab-base interface. The precast panels are placed on the polyethylene sheeting transverse to the flow of traffic, as shown in Fig. 1.

Each post-tensioned section of pavement consists of three types of precast panels, as shown in Fig. 1. As Figs. 2 to 4 show, the panels are all pretensioned in the transverse direction (long axis of the panel) to reduce bending stresses in the panels during lifting and transportation. Continuous shear keys are also cast into the panel edges to help ensure vertical alignment between adjacent panels as they are installed and to provide load transfer between panels prior to post-tensioning. Monostrand post-tensioning ducts are cast into the panels in the longitudinal direction (short axis of the panel), for post-tensioning after the panels are installed.

The base panels (see Fig. 2) are placed between the joint panels and central stressing panels, making up the majority of the pavement. The joint panels (see Fig. 3) contain doweled expansion joints that "absorb" the expansion and contraction movements of the post-tensioned slab. The joint panels also contain the post-tensioning anchors, which are accessible from the surface of the slab at the access pockets cast into the panels directly behind the anchors. The central stressing panels (see Fig. 4) have large pockets cast into them where post-tensioning is completed.

After a complete section of panels is installed (see Fig. 1), the post-tensioning strands are fed into the ducts in both directions at these pockets and pushed through the ducts to the anchors in the joint panels. The post-tensioning strands are then coupled together in the pockets using a ring anchor (see Fig. 5) and tensioned using a monostrand stressing ram.

After post-tensioning is complete, the pockets in the joint panels and central stressing panels are patched (using a fast-setting mix if necessary) and the post-tensioning tendons are grouted. Grouting provides an additional layer of corrosion protection for the post-tensioning strands and prevents a total loss of prestress in the pavement slab if any of the tendons are cut, either inadvertently or for removing one of the panels. Finally, if any voids are observed beneath the panels during installation, they are filled by pumping grout beneath the slab through underslab grout ports cast into the panels.

PROJECT SITE

The precast concrete pavement demonstration project was incorporated into a portion of a 3.2 mile (5.1 km) section of Interstate 10 that was being widened from eight to ten lanes to accommodate new high-occupancy vehicle (HOV) lanes. The location of the actual precast pavement section is on eastbound I-10 approximately 2 miles (3.2 km) west of the San Gabriel River Freeway (Interstate 605) in El Monte, California.

The project plans called for widening the existing pavement by 37 ft (11 m) — adding 27 ft (8 m) of traffic lanes and 10 ft (3 m) of shoulder — as shown in Fig. 6. The existing pavement design called for 10 in. (250 mm) of jointed plain concrete pavement (JPCP) over

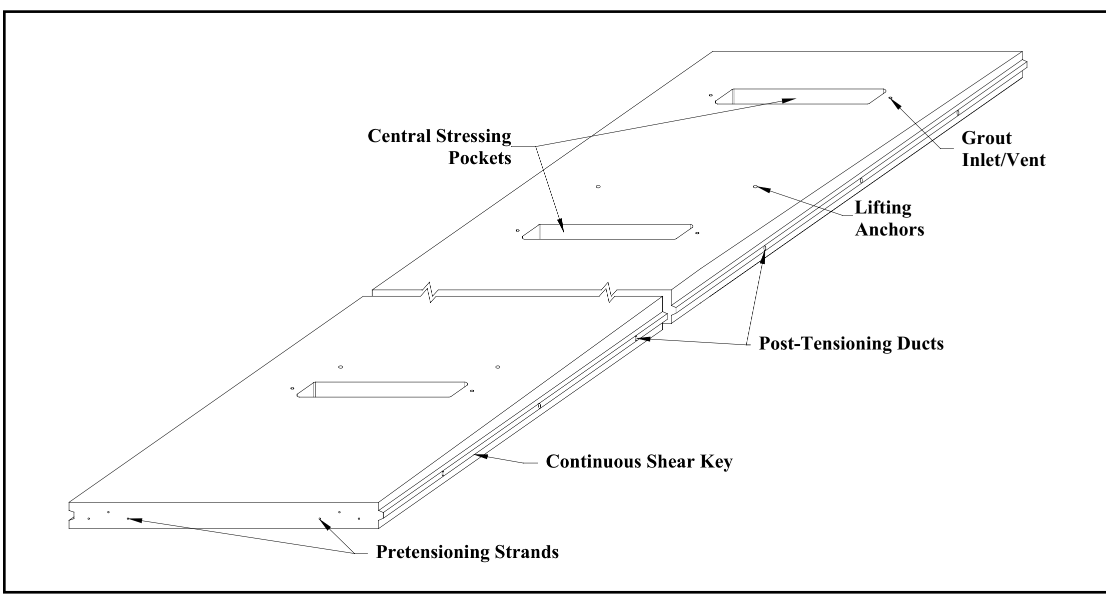

Fig. 4. Typical central stressing panel showing the stressing pockets cast into the panel.

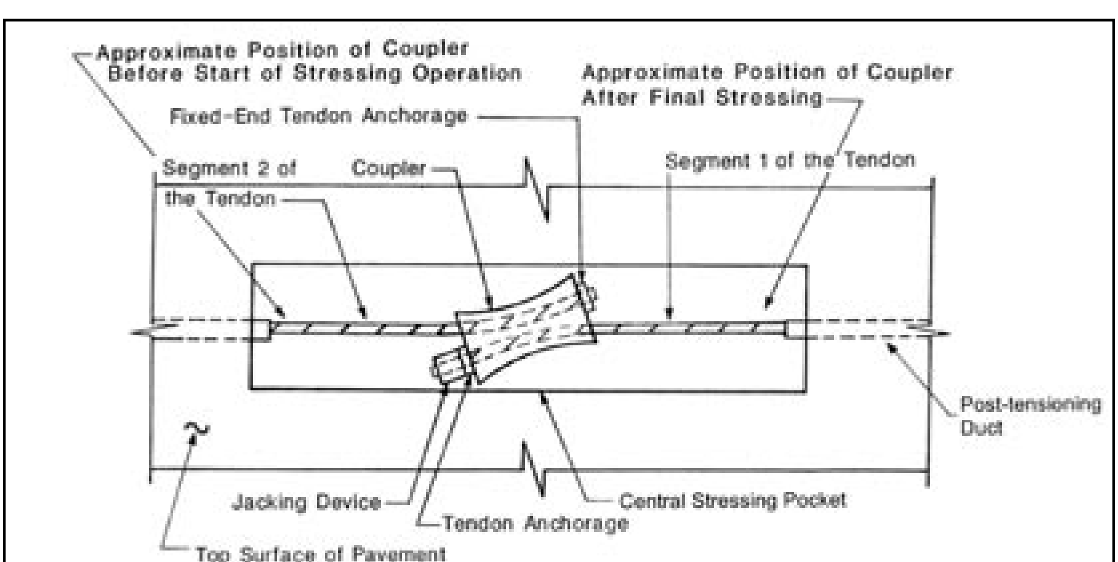

Fig. 5. Diagram of the ring anchor used to couple the post-tensioning strands together in the stressing pockets.

6 in. (150 mm) of lean concrete base (LCB), over 8½ in. (216 mm) of aggregate base. The 10 in. (250 mm) of JPCP was replaced with precast, prestressed concrete pavement.

The demonstration project was located on a section of the interstate that had no change in vertical curvature and very minimal horizontal curvature. The slight horizontal curvature was removed by sawcutting a straight edge onto the existing pavement over the length of the precast pavement section. The precast panels were installed between the existing pavement and a newly constructed sound wall (see Fig. 6).

Whereas the longitudinal geometry of the pavement section was simple, the pavement cross section was more complex, with a change in cross-slope from 1.5 percent in the traffic lanes to 5 percent in the shoulder, as shown in Fig. 6.

Three alternatives were considered by CALTRANS:

- Full-width panels, 37 ft (11 m) in length, with a uniform cross-slope;
- Partial-width panels, with 10 ft (3 m) shoulder panels installed at a 5 percent cross-slope and 27 ft (8 m) lane panels installed at a 1.5 percent cross-slope; or
- Full-width panels, 37 ft (11 m) in length, with the change in cross-slope formed into the surface of the panels.

The first option required a transition from the variable cross-slope in the adjoining pavement to the uniform cross-slope along the precast pavement. The second option not only required more panels to be fabricated, but also required that the panels be tied together with transverse post-tensioning in addition to the longitudinal post-tensioning. The additional expense and effort required for these two options led to the selection of the third option. This solution resulted in precast concrete panels that were 10 in. (250 mm) thick at the ends and 13.1 in. (330 mm) thick at the edge of the traffic lanes (see Fig. 7).

SLAB LENGTH AND PRESTRESS REQUIREMENTS

Although the full 248 ft (76 m) section of pavement could have been constructed with a single post-tensioned slab (between joint panels), it was decided that constructing two shorter slabs, each 124 ft (38 m) in length, would provide additional opportunity to evaluate the construction process. Each precast panel was limited to 8 ft (2.5 m) in width due to transportation restrictions, resulting in a total of 31 panels to achieve the 248 ft (76 m) project length.

The thickness of the precast panels was dictated by the 10 in. (250 mm) thickness of the existing pavement. To demonstrate the benefit of prestressing, however, the precast panels were designed such that the pavement would have a design life equivalent to a 14 in. (355 mm) thick conventional

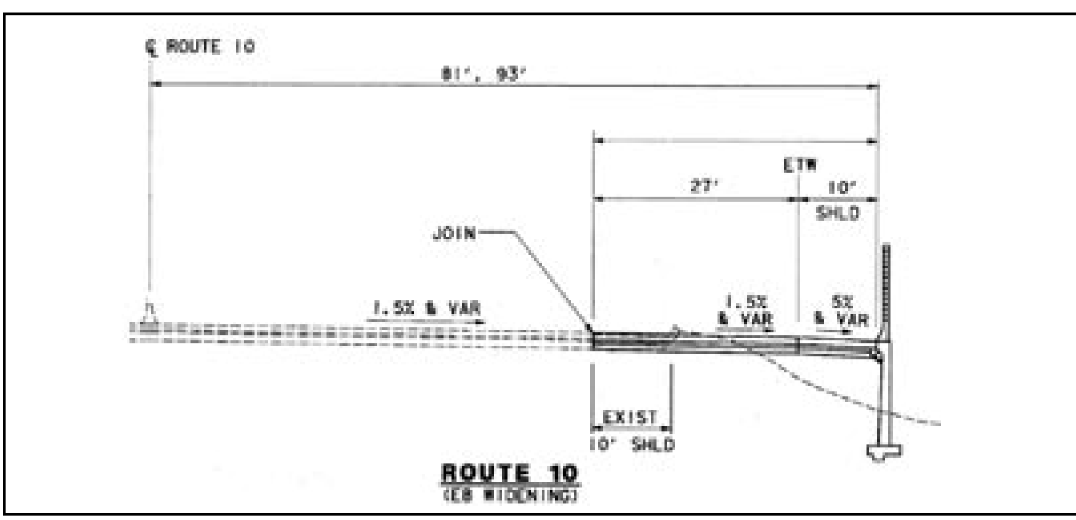

Fig. 6. Original pavement cross section (from the project plans) for widening Interstate 10.

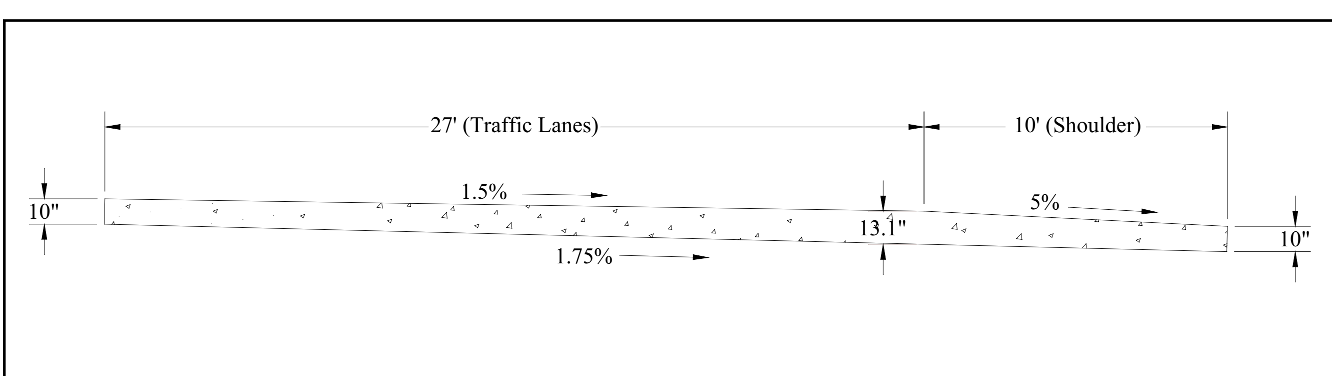

Fig. 7. Cross section of a precast panel. The change in cross-slope was incorporated into the surface of each panel.

(non-prestressed) pavement. This was accomplished by limiting the stresses in the 10 in. (250 mm) precast pavement to those of a 14 in. (355 mm) non-prestressed pavement.

Layered elastic analysis was used to evaluate stresses under a standard 18 kip (80 kN) wheel loading for the pavement support structure shown in the project plans. Stresses caused by slab curling and warping, due to temperature and moisture gradients in the slab, as well as stresses caused by frictional resistance at the slab-base interface, were also evaluated. Based on these analyses, the required spacing of the 0.6 in. (15 mm) diameter Grade 270 longitudinal post-tensioning tendons was 36 in. (914 mm).

As part of the design process, slab movement (expansion and contraction) was calculated to ensure that the expansion joints in the joint panels would never open more than 1 in. (25 mm) and never fully close. Based on the coefficient of thermal expansion of the concrete, the expected frictional resistance at the slab-base interface, and typical climatic conditions in El Monte, the maximum expansion joint width for the 124 ft (38 m) post-tensioned slabs was calculated as approximately ¾ in. (19 mm).

By limiting the stresses in the 10 in. (250 mm) precast pavement to that of a 14 in. (355 mm) pavement, the number of 18 kip (80 kN) equivalent single axle loads (ESALs) required to reach serviceability failure of the pavement more than doubled. Assuming the current traffic distribution on I-10 and an annual growth rate of 2 percent, an almost twofold increase in design life, from 30 to 57 years, would be achieved with this design.

While the longitudinal post-tensioning requirements were dictated by traffic and environmental loading, transverse pretensioning requirements were primarily governed by lifting stresses. A minimum prestress (from pretensioning) of 200 psi (1.4 MPa) was required to prevent cracking in the 37 ft (11 m) long panels when lifted at approximately 0.2*L* (where *L* is the panel length) from the edges of the panels. Six ½ in. (13 mm) diameter, Grade 270 pretensioning strands were specified to meet this requirement. These strands were located at mid-depth of the precast panels to prevent camber after prestress release.

Fig. 8. Concrete placement for a base panel.

PANEL FABRICATION

The original feasibility study, mentioned above, revealed that it would likely be cost-prohibitive to match-cast panels for precast pavement projects.[1] The subsequent demonstration project in Texas further revealed that match-casting was not necessary. With strict tolerances on the dimensions of the side forms, nearly 340 precast concrete panels were fabricated and installed without any problems fitting the panels together.[2] Based on the success of the Texas project, the panels for the California demonstration project were not match-cast.

The precast panels were fabricated by Pomeroy Corporation in Perris, California, approximately 60 miles (97 km) from the project location in El Monte. The unique shape of the precast panel cross section (see Fig. 7) required side forms to be specially manufactured for this project. The cost of these specialty forms, coupled with the limited number of panels to cast (31), made it cost-prohibitive to set up a casting bed for more than just two panels. The casting bed was set up with two panels cast end to end (see Fig. 8). The pretensioning strands extended through both panels, anchored at permanent abutments at each end of the casting bed.

Strict tolerances were required for the precast panels. In particular, the shear-key dimensions, thickness, and squareness (verified by measuring diagonally from corner to corner) of the precast panels were critical dimensions. Straightness and alignment of the post-tensioning ducts and the dowels in the joint panels were also important.

To ensure proper alignment of the dowels in the joint panels, the two halves of the panel (on either side of the expansion joint) were cast separately using a match-cast procedure. A bond breaker helped to ensure that the two halves of the panel did not bond to each other. Steel strongbacks were bolted to the top surface of the joint panels to hold the two halves of the panels together during lifting and transportation.

Galvanized steel ducts, 1 in. (25 mm) in diameter, were used for the longitudinal post-tensioning tendons. Grout inlets, or vents, for the post-tensioning tendons were located at the anchors in the joint panels, at the central stressing pockets, and at every third base panel.

Fig. 9. Precast panel after removal from the forms, showing its unique cross section.

Fig. 10. During installation, each panel is lifted off the truck, swung over the concrete barrier, and set in place.

Underslab grout ports were also cast into each panel. With the exception of the joint panels, only minimal non-prestressed reinforcement was required. Each panel had No. 4 (13 mm) reinforcing bars placed around the top and bottom perimeter of the panel. The joint panels had additional mild steel reinforcement around the post-tensioning anchors and anchor access pockets.

The mix design was a standard bridge girder mix with ½ in. (13 mm) maximum aggregate size. Strength requirements were 4000 psi (27.6 MPa) at release and 6000 psi (41.4 MPa) at 28 days. Type II cement with 15 percent Type F fly ash replacement was used, and the water-cement ratio was 0.37. The panels were hand finished and given a broom texture. The panels were steam cured until they reached the specified release strength and then removed from the forms. In general, two panels were cast every other day, with the exception of the joint panels, which took longer to set up. In total, 31 panels were cast, including three joint panels, four central stressing panels, and 24 base panels. Fig. 9 shows a typical precast panel after removal from the forms.

PANEL INSTALLATION

Installation of the precast panels at the project site took place April 12 and 13, 2004. Installation was limited to the hours of 10 p.m. to 5 a.m. to prevent disruption of rush-hour traffic. Although the panels were installed behind concrete barriers, two of the four existing lanes of eastbound Interstate 10 were closed so that the trucks delivering the panels could be staged outside the concrete barriers. The panels, weighing roughly 21.5 tons (19.5 Mg) each, were delivered one per truck.

Before each panel was lifted from the delivery truck, epoxy was applied to the top and bottom vertical faces of the keyways to help seal the joints between panels. Compressible foam gaskets were also placed around each of the longitudinal post-tensioning ducts to seal the joints from grout leakage between panels. A 100 ton (90 Mg) crane stationed on the lean concrete base lifted each panel off the delivery truck, swung it over the concrete barriers, and set it in place (see Fig. 10). A single layer of polyethylene sheeting (friction-reducing material) was rolled out over the lean concrete base just prior to placement of each panel (see Fig. 11).

After each panel was set in place, two temporary post-tensioning strands were fed through the panel and tensioned in order to pull the panel as tightly as possible against the panels already in place. The strands were then removed in preparation for the next panel. During the first night of installation, 16 of the 31 panels were set in place in approximately five hours. The remaining 15 panels were installed during the second night in just over three hours. No problems or difficulties were encountered during the installation of the panels on either night.

POST-TENSIONING AND GROUTING

Post-tensioning was completed the morning following the installation of each 124 ft (38 m) section of pavement. Fine-grit-impregnated epoxy-coated strand, supplied by Sumiden Wire Products Corporation, served as the longitudinal post-tensioning tendons. The epoxy coating provided an additional layer of corrosion protection for the post-tensioning strands, particularly at the joints between panels.

The post-tensioning strands were inserted into the ducts at the pockets in the central stressing panels and fed in both directions to the post-tensioning anchors in the joint panels (see Fig. 12). After anchoring the strands at the joint panels, the ends of the two strands coming into each stressing pocket were coupled together using a ring anchor, or "dog bone" (see Fig. 5), and a monostrand stressing ram was used to tension the strands from the pocket (see Fig. 13).

Stressing began with the tendons at the center of the pavement, alternating outward to the edges of the pavement until all tendons had been stressed. Post-tensioning was completed by Dywidag-Systems International.

After post-tensioning was completed for both sections of the pavement, the pockets in the central stressing panels and joint panels were filled with a pea gravel [3/8 in. (9.5 mm) maximum aggregate size] concrete mix. Each post-tensioning tendon was then grouted from the ports cast into the panels. A cement-and-water grout mix (CALTRANS standard) was used for the post-tensioning tendons. Grout was pumped into the end of each tendon from the ports located in the central stressing pockets until it flowed out of each intermediate grout port and finally the end port at the joint panels (see Fig. 14).

Using the underslab grout ports cast into the panels, grout was then pumped beneath the precast panels to fill any voids between the pavement and the lean concrete base. Only minimal pressure [less than 5 psi (35 kPa)] was applied to ensure that the underslab grouting operation did not lift the panels. Other than minor leakage onto the surface of the pavement, no major problems were encountered during the grouting operations.

Fig. 11. The polyethylene sheeting is rolled out over the concrete base just prior to the placement of each panel.

Fig. 12. Workers feed the post-tensioning strands into the ducts at the pockets in the central stressing panels.

The final step was to diamond grind the surface of the pavement. Although the pavement was smooth enough to open to traffic after construction, diamond grinding was required in order to meet CALTRANS' pavement smoothness specifications. The finished pavement after diamond grinding is shown in Fig. 15.

Fig. 13. A monostrand stressing ram is used to tension the post-tensioning strands from the central stressing pockets.

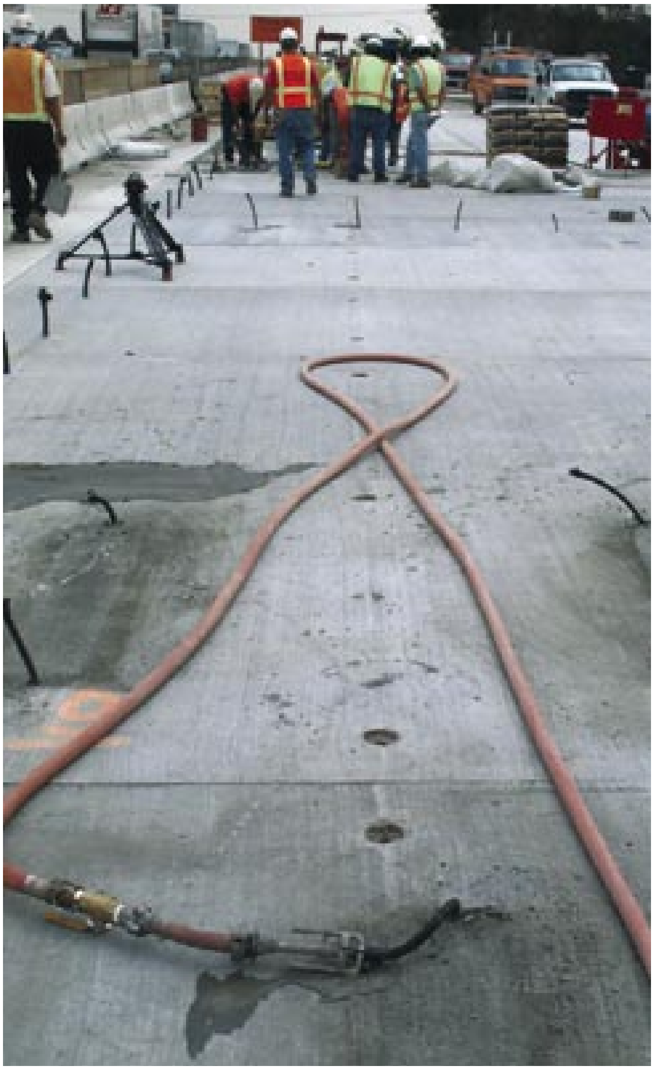

Fig. 14. Grout is pumped into the post-tensioning tendons from ports at the central stressing pockets.

PROJECT COST

As discussed previously, the biggest economic benefit of precast, prestressed concrete pavement construction is the reduction in user costs — not only in terms of user delay costs associated with construction, but also user costs associated with long-term pavement performance. Although user-delay costs during construction can be substantial, particularly for a busy corridor such as I-10 near Los Angeles, user costs associated with continual pavement maintenance and vehicle maintenance due to poor pavement conditions can be much more substantial. For this reason, construction costs should always be evaluated with user cost implications in mind.

The total in-place unit cost for the California demonstration project was approximately \$224 per sq yd (\$268/m^2) or \$697 per cu yd (\$912/m^3). Although this cost is significantly higher than conventional cast-in-place pavement construction, it compares favorably with fast-setting concrete mixes, which cost between \$600 and \$1,200 per cu yd (\$785 and \$1,570/m^3). It should also be noted that this was a very small experimental project, and, as with any construction project, there are economies of scale. As contractors and precast concrete manufacturers become more familiar with this construction technique, a significant reduction in construction costs can be expected.

CONCLUSIONS

Transportation agencies such as CALTRANS are continually seeking new construction techniques that will allow them to "get in, get out, and stay out," particularly in major metropolitan areas such as Los Angeles. Through this demonstration project, CALTRANS has identified yet another tool to help them meet this need. Although this project was not constructed under stringent time constraints and complex geometries that are anticipated for future applications, it provided an opportunity to evaluate this technique as a high-speed, long-lasting solution for pavement construction.

Precast, prestressed concrete has a proven track record in the bridge and commercial building industries not only for providing a rapid construction solution but also — and more importantly — for providing a long-lasting solution. Applying this expertise to the paving industry is a logical step. The long-term performance of this one particular pavement project has yet to be proven, but the quality of the finished product should ensure that it will meet or exceed its intended design life.

Currently, The Transtec Group, Inc., of Austin, Texas, under contract with FHWA, is providing design and construction support for additional demonstration projects in Texas, Missouri, and Indiana. These projects will use precast, prestressed concrete pavements for applications such as weigh-in-motion (Texas), replacement of original Interstate-era jointed reinforced concrete pavement (Missouri), and replacement of pavement under bridge overpasses to increase overhead clearance (Indiana). These projects will further demonstrate the flexibility of this rapid pavement construction solution.

Fig. 15. The finished precast pavement prior to opening to traffic.

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