Expedited Construction Using Precast Prestressed Concrete Pavement in California

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Abstract

Faced with shorter and shorter windows for reconstructing deteriorating pavements in urban areas, transportation agencies are continually searching for new and innovative techniques for rapid pavement construction. The California Department of Transportation (Caltrans) is one such agency, often limited to 7-hour nighttime construction windows in the Los Angeles and other metropolitan areas. One innovation recently examined by Caltrans is precast concrete pavement. A 76 m (248 ft) section of precast, prestressed concrete pavement was constructed on Interstate 10 in El Monte, California, adding 8 m (27 ft) of traffic lanes and 3 m (10 ft) of shoulder to the existing pavement. The majority of the work was completed at night when lane closures were permitted on Interstate 10. The precast panels were pretensioned during fabrication and then post-tensioned in place to enhance the performance of the pavement. The successful completion of this project provided Caltrans yet another tool for rapid pavement construction in one of the busiest urban areas in the world.

Project Background

Caltrans District 7, which encompasses the greater Los Angeles metropolitan area, currently uses high-early-strength concrete mixes for rapid pavement repair and reconstruction. However, there is still some question as to the long-term durability of these mixes due to excessive shrinkage cracking (Waalkes; Heath and Roesler 1999), and new rapid construction techniques are continually being sought. Based on these needs, Caltrans initiated a precast pavement demonstration project in order to evaluate this technology under the traffic conditions that exist in the Los Angeles area.

In April 2004 Caltrans completed construction of a precast concrete pavement on Interstate 10 in El Monte, California. This project was one of several demonstration projects initiated by the Federal Highway Administration (FHWA) to evaluate the viability of precast prestressed concrete pavement for expedited pavement construction, and was based on a concept developed during an FHWA-

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sponsored feasibility completed by the Center for Transportation Research (CTR) at The University of Texas at Austin in 2000 (Merritt et al. 2000).

Research Significance

The California precast pavement demonstration project represents the successful implementation of research which began with an FHWA-sponsored feasibility study. (Merritt et al. 2000; Merritt et al. 2001). The project is part of a major effort by FHWA to evaluate the viability and benefits of precast prestressed concrete pavement construction through actual implementation. This effort is intended to help familiarize transportation agencies, designers, and contractors with this new and innovative construction technique in order to provide them with a new tool for rapid pavement construction.

Prior to the California demonstration project, a demonstration project was constructed near Georgetown, Texas in 2002 (Merritt et al. 2002). Many new ideas and improvements to the overall precast pavement concept were identified during the Texas demonstration project, and subsequently applied to the California demonstration project. While the Texas project was constructed on a section of highway that could be closed to traffic for long periods of time during construction, the California project was limited to overnight construction windows. Additionally, while the Texas project consisted of pavement with a uniform cross-slope, a change in cross-slope (described below) was required for the California project. Therefore, the California demonstration project represented the "next step" in implementation of precast prestressed pavement technology.

Prestressed Precast Pavement Concept

The concept for the California precast pavement was developed through the FHWA-sponsored feasibility study, mentioned previously. While refinements were made to several of the design details based on the initial demonstration project in Texas (Merritt et al. 2002), the basic concept remained the same. The pavement consists of full-depth prestressed panels placed over a prepared base. The prepared base provides a stable platform for supporting the precast panels and may either be a cementitious or bituminous material. The base is placed as smooth and flat as possible to minimize voids beneath the precast panels. Over the prepared base, a single layer of polyethylene sheeting is laid to serve as a bond-breaking and friction reducing material between the precast panels and base. The precast panels are then placed over the polyethylene sheeting, transverse to the flow of traffic, as shown in Figure 1. Continuous shear keys cast into the adjoining edges of the panels ensure vertical alignment between adjacent panels and also provide load transfer prior to post-tensioning.

The panels are pretensioned during fabrication in the transverse direction (normal to the direction of traffic flow) to reduce bending stresses during panel lifting and transportation. After installation of a full section of panels, they are post-tensioned together in the longitudinal direction (parallel to the direction of traffic flow). As shown in Figure 1, there are three types of panels that constitute each post-tensioned section of pavement. Figure 2 shows a typical Base Panel, indicating the shear keys along the edges of the panel, the transverse pretensioning strands, and the ducts for the longitudinal post-tensioning tendons. Joint Panels (Figure 3) are placed at the end of each post-tensioned section. The Joint Panels contain both dowelled expansion joints and the post-tensioning anchors. The dowelled expansion joints “absorb” the expansion and contraction movements of the post-tensioned slab while providing load transfer across the joint. Small pockets cast into the Joint Panel provide access to the post-tensioning anchors located on either side of the expansion joint.

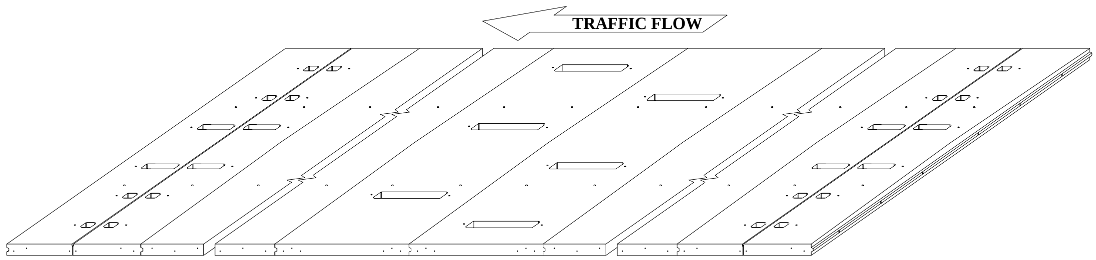

Figure 1. Typical precast panel assembly showing the three types of precast panels that make up each post-tensioned slab.

Central Stressing Panels (Figure 4) are placed at the middle of each post-tensioned section (Figure 1). Large pockets cast into these panels provide access to the post-tensioning ducts from the top of the slab. After a complete section of panels are installed, the post-tensioning strands are fed into the ducts at these pockets and pushed through the ducts to the anchors in the Joint Panels. The post-tensioning strands are coupled together in the pockets using a ring anchor (Figure 5) and tensioned using a monostrand stressing ram.

After post-tensioning is complete, the pockets in the Central Stressing Panels are patched (using either a normal-set or fast-setting concrete), and the post-tensioning tendons are grouted. Grouting not only provides an additional layer of corrosion protection for the post-tensioning strands, but also prevents total loss of prestress if a strand is severed, either inadvertently or to remove and replace an individual precast panel. Finally, in order to fill any possible voids beneath the pavement, grout is pumped beneath the slab from grout ports at the surface of the precast panels.

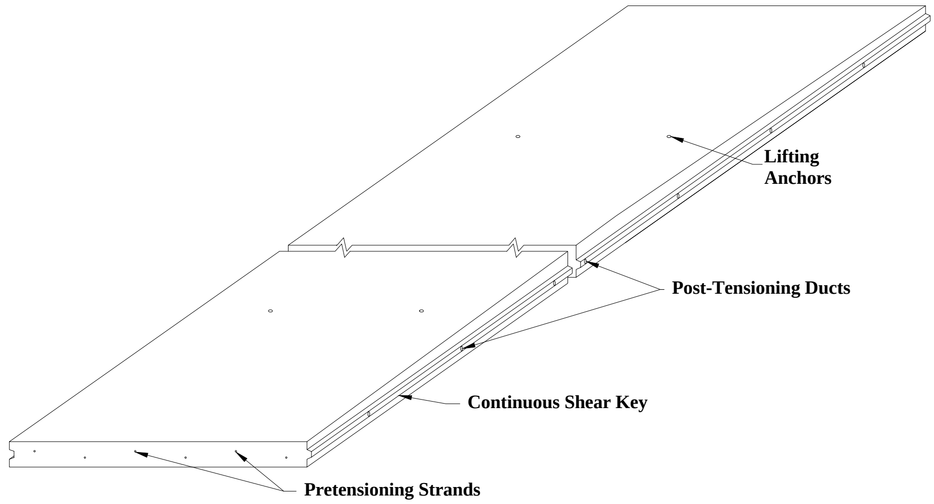

Figure 2. Diagram of a typical Base Panel showing the continuous shear keys, pretensioning strands, and longitudinal post-tensioning ducts.

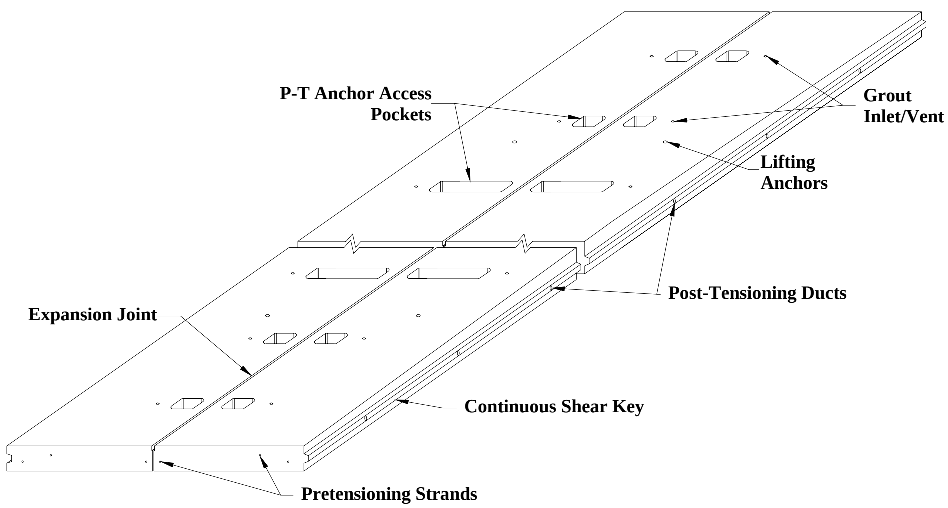

Figure 3. Diagram of a typical Joint Panel showing the dowelled expansion joint and post-tensioning anchor access pockets.

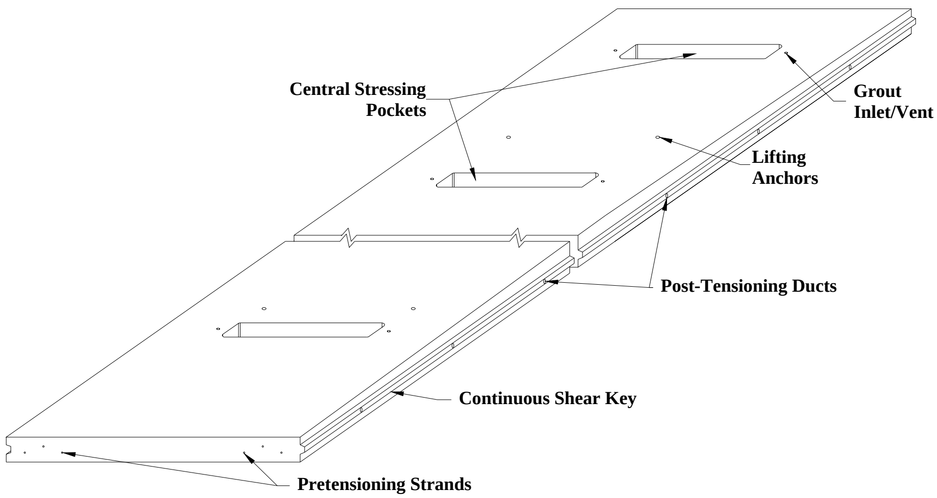

Figure 4. Diagram of a typical Central Stressing Panel showing the stressing pockets.

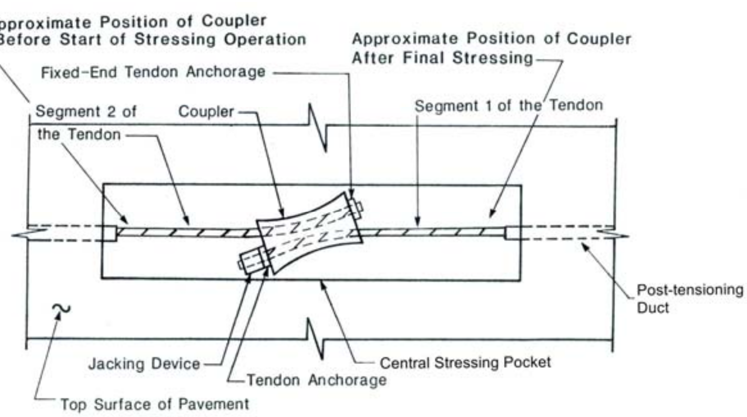

Figure 5. Diagram of the ring anchor used to couple post-tensioning strands together in the stressing pockets.

Benefits of Precast Concrete Pavement

The first and foremost benefit of precast concrete pavement is the ability to open the pavement to traffic immediately after the precast panels are installed. Conventional (cast-in-place) portland cement concrete pavement must be allowed to reach adequate strength before it can be opened to traffic. Even rapid-set concrete mixes generally require at least four hours of cure time before opening to traffic. Precast concrete panels, on the other hand, are cast and cured well in advance of construction, ensuring that the concrete has reached its required design strength before installation on site. This permits precast pavements to be opened to traffic immediately after installation, facilitating overnight (or 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 are able to cast and cure pavement panels 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. (Merritt et al. 2000)

Prestressing further benefits precast pavement performance by inducing a 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 U.S. and abroad. (Mandel et al. 1989; Mendoza Diaz et al. 1986; Tayabji et al. 2001) Prestressing also permits a significant reduction in slab thickness. The precompressive stress in the slab counteracts tensile stresses caused by wheel loads, reducing the required slab thickness for given traffic loading.

Prestressed precast panels can also better span small voids beneath the pavement. While voids beneath pavements are not desirable, it is often not possible to achieve a perfectly flat base under the time constraints normally associated with rapid reconstruction. Prestressed precast panels are better able to withstand the additional stresses caused by voids beneath the pavement, permitting installation of the panels over a base that may not be perfectly flat.

The economic benefit of precast concrete pavement will be realized through savings in user costs. Reducing construction time, which minimizes traffic delays, and improving performance, which reduces future maintenance and rehabilitation, are two primary benefits in terms of user costs. User delay costs, which are attributable to traffic congestion caused by construction activities, can be as high as $383,000/day for 24-hour/day lane closure versus only $1,800/day for nighttime lane closure only. (Merritt et al. 2000) User costs resulting from poor pavement condition can also be substantial, as indicated by a 2001 TRIP ("The Road Information Program") report which revealed that Americans spend over $41 billion annually on vehicle repair due to roads in poor condition. (TRIP 2001) Pavements which last longer and require less maintenance over their design life will substantially reduce these types of user costs.

Finally, another benefit of precast concrete that may not be immediately apparent is the potential for extending the construction season for paving. Because precast 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. This permits pavement construction to continue under adverse weather conditions, such as extreme hot or cold temperatures, that would normally prohibit cast-in-place concrete paving.

Project Site

The precast pavement demonstration project was incorporated into a portion of a 5.1 km (3.2 mile) section of Interstate 10 which was being widened from eight lanes to ten lanes to accommodate new high occupancy vehicle (HOV) lanes. The location of the actual precast pavement test section is on eastbound I-10, approximately 3.2 km (2 miles) west of the San Gabriel River Freeway (Interstate 605) in El Monte. The project plans called for widening the existing pavement by 11 m (37 ft), adding 8 m (27 ft) of traffic lanes and 3 m (10 ft) of shoulder, as shown in Figure 6. The existing pavement design specified 250 mm (10 inches) of jointed plain concrete pavement (JPCP) over 150 mm (6 inches) of lean concrete base (LCB), over 216 mm (8 1/2 inches) of aggregate base. The 250 mm (10 inches) JPCP was simply replaced with precast prestressed concrete pavement.

The precast pavement was constructed on a section of the Interstate with no change in vertical curvature and very slight horizontal curvature. The horizontal curvature was removed by sawcutting a straight edge onto the existing pavement over the length of the precast pavement test section to ensure the panels would fit flush against the existing pavement. As Figure 6 shows, the precast panels were required to fit between the existing pavement and a newly constructed retaining wall.

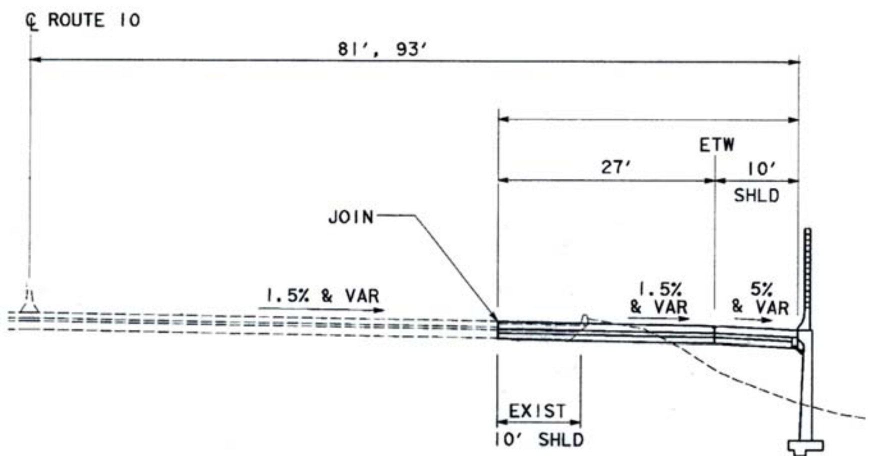

Figure 6. Original pavement cross-section (from the project plans) for widening Interstate 10. (*Note: 10 ft = 3 m, 27 ft = 8 m*)

The pavement cross-section presented some unique challenges. The plans called for a change in cross-slope from 1.5 percent for the traffic lanes to 5 percent for the shoulder, as shown in Figure 6. Three different alternatives were considered by Caltrans:

1. Full-width panels: 11 m (37 ft) in length, with uniform cross-slope,
2. Partial-width panels: 3 m (10 ft) "shoulder panels" installed at 5 percent cross-slope and 8 m (27 ft) "lane panels" installed at 1.5 percent cross-slope, or
3. Full-width panels: 11 m (37 ft) in length, with the change in cross-slope cast 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 cast, but also required that the panels be tied together with transverse post-tensioning in addition to longitudinal post-tensioning. The additional expense and effort required for these two options led to selection of the third option. This resulted in precast panels that were 250 mm (10 inch) thick at the ends and 330 mm (13.1 inch) thick at the edge of the traffic lanes, as shown in Figure 7.

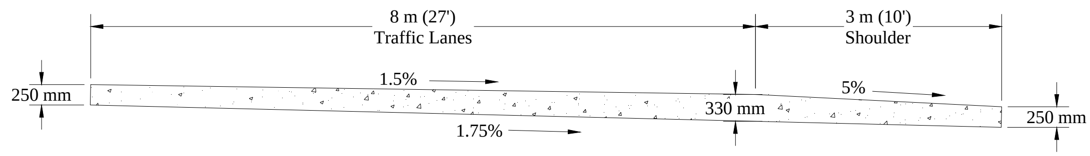

Figure 7. Cross-section of the precast panels with the change in cross-slope incorporated into the surface of the panel.

Pavement Design

As discussed previously, one of the advantages of prestressed concrete pavement is a reduction in the required slab thickness for given traffic loading. Essentially, the designer can select the slab thickness based on the project restrictions (i.e. thickness of existing surrounding pavement), and then vary the prestress in the pavement to achieve an equivalent design life to a much thicker slab.

Although 200 mm (8 inch) thick precast panels could have been designed to provide an equivalent design life to the original 250 mm (10 inch) JPCP, the existing pavement adjacent to the precast pavement was 250 mm (10 inch) thick (Figure 6), requiring that the precast panels also be 250 mm (10 inches) thick. However, to demonstrate the benefit of prestress, the precast panels were designed such that pavement would have an equivalent design life to a 355 mm (14 inch) thick conventional (non-prestressed) pavement. This was accomplished by limiting the stresses in the 250 mm (10 inch) precast pavement to those of a 355 mm (14 inch) non-prestressed pavement.

Layered elastic analysis was used to determine bottom fiber tensile stresses in both 250 mm (10 inch) and 355 mm (14 inch) concrete pavements, with the same support structure, under a typical 80 kN (18 kip) axle load. The layer properties for the pavement support structure were estimated from the Job Special Provisions for the project. The difference in bottom fiber tensile stress between the two pavements thicknesses was determined to be the minimum compressive stress required in the 250 mm (10 inch) precast pavement at all points along the length of the slab under all environmental conditions.

The next step in the design process was to evaluate pavement stresses due to ambient or environmental conditions. This included an evaluation of stresses caused by friction at the slab-base interface as the pavement expands and contracts with temperature, as well as stresses caused by curling and warping of the pavement slab due to temperature and moisture gradients in the slab. The level of prestress was varied by increasing or decreasing the spacing of the longitudinal post-tensioning tendons until stresses due to environmental conditions were within the limits obtained from the layered elastic analysis. Using monostrand 15 mm (0.6 inch) post-tensioning strands, the required spacing of the post-tensioning tendons to achieve this condition was 0.9 m (3 ft).

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

In addition to longitudinal prestress requirements, transverse prestress requirements were also determined. Transverse prestress requirements are primarily governed by bending stresses during lifting and handling of the panels, particularly as they are removed from precast bed. Lifting stresses dictated a minimum prestress (from pretensioning) of 1.4 MPa (200 psi) to prevent cracking in the 11 m (37 ft) long panels when lifted approximately at the quarter-points.

Although the full 76 m (248 ft) long section of precast pavement could have been constructed with a single post-tensioned slab, it was decided that two shorter slabs, each 38 m (124 ft) in length, would provide a better opportunity to evaluate the construction process. The final step in the design process was to calculate the movement of each of these slabs to ensure that the expansion joints (in the Joint Panels) would never open more than 13 mm (1 inch) and never fully close. Based on the slab length of 76 m, the coefficient of thermal expansion of the concrete, the estimated frictional resistance at the slab-base interface, and typical climatic conditions in El Monte, the maximum expansion joint width was calculated to be approximately 19 mm (3/4 inch).

Panel Fabrication

The precast panels were fabricated at a precast plant approximately 97 km (60 miles) from the installation site location in El Monte. Due to transportation restrictions, the width of the precast panels was limited to 2.4 m (8 ft). This resulted in a total of 31 precast panels for the full 76 m (248 ft) demonstration project. Because of the unique shape of the side forms required for the panel cross-section (Figure 7), and the small number of panels to cast, the fabricator limited production to two panels per casting. The panels were fabricated on a long-line casting bed, with the two panels cast end to end. The pretensioning strands extended through both panels, anchored at permanent stressing abutments at either end of the casting bed.

The two main requirements for the mix design were: 1) that it provide the necessary release strength within 24 hours after casting in order to maintain productivity, and 2) that it could be finished to the necessary tolerances for a concrete pavement riding surface. The mix design used for the precast panels was similar to that used for precast concrete bridge girders, and consisted of eight sacks of Type II cement with 15% Type F fly ash replacement, a water/cement ratio of 0.37, superplasticizer, and 13 mm (1/2 inch) maximum size granitic coarse aggregate. The mix had a design release strength of 27.6 MPa (4,000 psi) and 28-day strength of 41.4 MPa (6,000 psi). The precast fabricator reported that they did not have any problems with this mix design for pavement panels.

The panels were finished by hand and given an Astroturf drag texture. The panels were steam cured until they had reached the specified release strength of

27.6 MPa (4,000 psi), 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, 24 base panels, 3 joint panels, and 4 central stressing panels were fabricated. Figure 8 shows the unique cross-section of a typical panel after removal from the forms.

Figure 8. Typical precast panel after removal from the forms.

Panel Installation

Installation of the precast panels took place on April 12 and April 13, 2004. Installation was limited to the hours of 10 PM to 5 AM to prevent disruption to traffic. Although the panels were installed behind concrete barrier, two of the four existing lanes of eastbound Interstate 10 were closed along the project site so that the trucks delivering the panels could stage outside of the concrete barrier.

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. A 90 Mg (100 ton) capacity crane stationed on the lean concrete base lifted each panel from the delivery truck and swung it over the concrete barrier and set it in place (Figure 9). The single layer of polyethylene sheeting (bond breaker/friction reducing material) was rolled out over the lean concrete base just prior to placement of each panel (Figure 10). 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 5 hours. The remaining 15 panels were installed the second night in just over 3 hours.

Figure 9. Each panel was lifted over the concrete barrier and set in place.

Figure 10. The polyethylene sheeting was rolled out just prior to the placement of each panel.

Post-tensioning and Grouting

Post-tensioning was completed the morning following the installation of each 38 m (124 ft) section of panels. Fine-grit-impregnated epoxy-coated strand was used for the longitudinal post-tensioning tendons. The epoxy coating provides additional protection from corrosion at the joints between the panels. The post-tensioning strands were fed into the ducts at the pockets in the central stressing panels (Figure 11) in both directions to the post-tensioning anchors in the joint panels. After anchoring the strands at the joint panels, the ends of the strands in each stressing pocket were coupled together using a ring anchor (Figure 5) and a monostrand stressing ram was used to tension the strands from the pockets (Figure 12).

After post-tensioning was completed, the pockets in the central stressing panels were filled with a "pea gravel" (9.5 mm maximum aggregate size) concrete mix. Each post-tensioning tendon was then grouted by pumping a cement/water grout into the ports at the surface of the pavement. Finally, using grout ports at the surface of the pavement, grout was pumped beneath the precast panels to fill any voids between the pavement and the lean concrete base. Only minimal pressure was applied to ensure that the underslab grouting operation did not lift the 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 requirements. The finished demonstration project is shown in Figure 13.

Figure 11. Workers fed the post-tensioning strands into the ducts at the pockets in the central stressing panels.

Figure 12. A monostrand stressing ram was used to tension the post-tensioning strands from the stressing pockets.

Figure 13. The finished precast pavement prior to opening to traffic.

Project Cost

The most significant economic benefit of any rapid construction technique that permits overnight or "invisible" construction of a durable, long-lasting pavement is the reduction in user costs; not only user delay costs associated with construction, but user costs associated with pavement performance over time. While user delay costs during construction can be substantial, particularly for a very heavily traveled corridor such as Interstate 10 in Los Angeles, user costs associated with continual pavement maintenance and vehicle maintenance due to poor pavement condition can be much more substantial. By constructing a durable, low-maintenance pavement, long-term user costs such as these make precast pavement a very desirable option.

The total in-place unit cost for the California demonstration project was approximately $268/m^2 ($224/yd^2) or $912/m^3 ($697/yd^3). While this is significantly higher than conventional cast-in-place pavement construction, it compares favorably with fast-setting concrete mixes, which cost between $785/m^3 and $1,570/m^3 ($600/yd^3 and $1,200/ yd^3). These costs should always be evaluated with user cost implications in mind. It should also be recognized that this was a very small demonstration project, which was experimental in nature, and as with any construction project, there are economies of scale.

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.

Precast prestressed concrete pavement is not only a rapid construction solution, but more importantly, a long-lasting solution. While the long-term performance of this pavement has yet to be proven, the quality of the finished product should ensure that it will meet or exceed its intended design life. Expertise in producing high quality products already exists in the precast industry. Precast elements for bridges and buildings are produced and installed everyday around the world. Applying this expertise to pavements is the next logical step. While far underutilized in the pavement industry, prestressing also greatly benefits pavement performance. And as with the precast industry, the expertise and technology in the prestressed concrete industry has been established by decades of experience.

While this project was not constructed under stringent time constraints and complex geometries that are anticipated for future applications, it provided an opportunity for further evaluation of this technology by Caltrans and helped to familiarize local contractors and designers with its use. Caltrans is already searching for new opportunities to utilize this technology throughout the State.

FHWA has also initiated additional demonstration projects in Texas, Missouri, and Indiana. These projects will utilize precast prestressed concrete pavement for weigh-in-motion (WIM) applications (Texas), replacement of original Interstate-era jointed reinforced concrete pavement (Missouri), and replacement of pavement under bridge overpasses to increase overhead clearance (Indiana).

Acknowledgments

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