Precast Pavement Installation on I-15 in Ontario, California

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ABSTRACT

The California Department of Transportation (Caltrans) recently completed a large precast pavement project in Ontario, California. This was Caltrans' first experience with construction of a non-prestressed, non-post-tensioned precast pavement. A sole-source, proprietary precast pavement system was specified for the project. The 1.8 lane-miles of precast pavement was part of a larger pavement rehabilitation project on a heavily-traveled portion of Interstate 15 through the city of Ontario, CA. Over 700 precast panels were installed in 8 to 9-hour work windows.

This paper documents the development of the plans and specifications for the precast pavement; the construction process; and the issues experienced while constructing the precast pavement, and how they were resolved. The lessons learned from the project are discussed, as well as recommendations for improving upon the entire process of precast pavement design and construction for future projects. The observations have been reviewed by all parties involved and are based on a full report available from Caltrans by contacting the author.

The lessons learned from this project and several past and ongoing precast pavement projects in Caltrans are being used to develop generic standard plans and specifications for Caltrans to facilitate the use of precast pavements on future projects. The author is a member of a statewide committee working to achieve this goal. A brief update on the work of this committee is included in the paper.

Keywords: Construction, Precast Pavement

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1. System Overview

The proprietary precast concrete pavement (PCP) system used for this project was developed by a company (hereafter referred to as the vendor) that specializes in precast concrete solutions. The basic process for construction of this PCP system is outlined in this section.

The existing pavement to be replaced is surveyed by the contractor using standard surveying equipment. This survey provides the basis for a 3D-model created by the vendor and used to generate shop drawings.

1.1 Casting

Panels are cast on beds using four-sided, adjustable forms developed by the vendor (See Picture 1). The casting beds may be made adjustable vertically on one corner by means of a hydraulic jack, in order to cast warped panels (See Picture 2 below). Warped panels may be required in areas of horizontal curvature where a grade and/or super-elevation transition exists.

Picture 1 – Adjustable forms used to cast PCP panels for this project. The yellow objects at the edge of the form are large magnets, allowing easy adjustment of the dimensions of the panel.

The panels are cast under optimum curing conditions. In this project the panels were cast indoors and steam-cured, to prevent rapid curing (and associated shrinkage) from the hot, dry winds that are common to the region.

Picture 2 – Note the jack in the lower right of the picture used to 'warp' the PCP panel form.

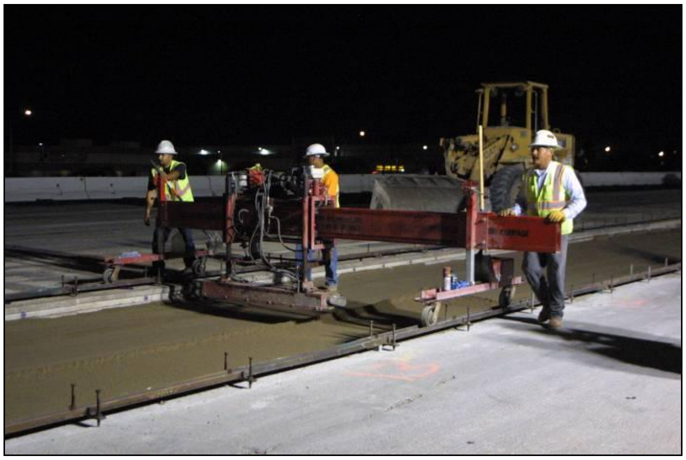
Dowel bars and dowel slots (and if necessary, tie bars and tie bar slots) are cast into the panel. Grouting ports are included for grouting in the dowels and tie bars after panel placement, and to inject bedding grout under the panels for uniform support. One or two mats of reinforcing steel provide for handling and traffic loads prior to grouting.

The completed panels are stacked in the order that they must be delivered to the project. The order that the panels are sent to the project is critical, because the panels are not interchangeable. Each panel is unique, and cast specific to a particular location in the traffic lane. The panels are numbered to ensure installation at the correct location.

1.2 Site Preparation and Placement

Subgrade is prepared by placing a fine layer (minimum 0.5 in / 10 mm) of granular material between the subgrade and the PCP panel. This layer is graded and compacted to a 0.25 inch (6 mm) tolerance using specialized equipment to ensure uniform support. Several alternatives for grading equipment are available for use from the vendor. For this project, a hand-operated grader (HOG) was used (See Picture 3). The HOG moves on rails set to a design profile grade by a surveyor. The rail elevations are fine-tuned using adjustment screws and shims.

Once grading is completed, the panels are set. Because the panels have a male and female end, and are unique to location, they must be set in order, as mentioned previously. The leading edge of the panel is set to a mark established by the surveyor laying out the grades for the grading rails. The panels are *not* set tight against the previous panel, as this could introduce creep, resulting in a gap at the end of the installation.



Picture 3 – Hand-operated grader (HOG) used to perform precise grading. Rails for the HOG are set by a surveyor.

As the panels are set, the crane setting the panels may move forward onto the newly-set panels to set the subsequent panels.

The contractor has the option of opening the panels to traffic prior to grouting. If he chooses this option, the panels must be shimmed on all four sides to prevent movement. The panels are also required to have a second mat of rebar to provide added strength.

Following placement, the panels are grouted, either the same night, or the following night. There are two types of grout involved in the installation process: dowel grout and bedding grout. The dowel grout is a high-strength grout, achieving 2500 psi in 2 hours or less.

Picture 4 – Dowel slots and grout channels cast into the bottom of the panels.

Dowel grout is injected through ports cast into the panels above the dowel slots. Bedding grout is injected through other ports cast in the panel, and travels through channels on the underside of the panel to a port on the opposite end of the channel (See Picture 4), thus ensuring that the channel and any nearby voids are completely filled with grout. Four of these channels are cast into the base of each panel, ensuring a fairly uniform distribution of the bedding grout throughout the underside of the panel. In this project, panels were typically dowel-grouted the night of installation, with the bedding grout completed the following night. Based on deflection studies performed on grouted and ungrouted panels[1], it is advisable to perform bedding grout installation as soon as possible, to reduce flexural stresses applied to the PCP by live traffic.

Once grouted, the PCP may be ground (milled) and joint-sealed similar to cast-in-place PCC pavements.

2. Project Overview

The project (Caltrans EA 08-472214) discussed in this report was located in the city of Ontario, California on Interstate 15. The project limits were from State Route 60 (PM 51.5) in Riverside County to approximately 1 mile north of Interstate 10 (PM 3.8) in San Bernardino County, a distance of approximately 4 miles. The project was a pavement rehabilitation project which included median paving, 12.8 lane-miles of traditional lane replacement, random-slab replacements, shoulder and ramp rehabilitation, and bridge widening to stage traffic during construction.

The project began construction in April 2009, and was completed in February 2011. Precast pavement constituted approximately $4.6 million of the $51.8 million project construction cost.

The existing pavement and freeway in this area was constructed in the 1970s as approximately 8.4 inches (213 mm) of PCC over 4.8 inches (122 mm) of CTB.

The project area is heavily urbanized, with annual average daily traffic (AADT) of about 196,500 vehicles per day in 2003, with 6% trucks in the peak hour and a peak hour volume (PHV/DHV) of 16,150 vehicles.

The PCP installation was located near the center of the project on the northbound I-15, from the end of the northbound Jurupa Ave onramp to Ontario Mills Parkway Undercrossing just north of I-10. The installation was comprised of approximately 1.8 lane-miles of PCP, as well as 34 intermittent panel replacements.

3. Project Selection

Caltrans, District 8 had been interested in testing the viability of precast pavement systems as a pavement rehabilitation alternative for some time prior to this project. Initially, the challenge was providing evidence of the benefits and viability of PCP, to justify its cost and use as an experimental product in a project.

In 2005 and 2006, Heavy Vehicle Simulator (HVS) testing was performed on a test strip of the PCP system installed near the I-15/I-210 Interchange in San Bernardino. The testing was performed by the Pavement Research Center at the University of California (Davis and Berkeley). The results of the testing were generally positive, as can be summarized from the abstract of one of the test reports prepared:

> "Given the design of the pre-cast PCC pavement tested at the San Bernardino test site, the tight control over the construction process, and the favorable HVS test conditions, no premature failure is anticipated with the use of the pre-cast PCC pavement on actual rehabilitation projects. The ultimate structural capacity of the system will probably exceed 40

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[1] Ye, D. and Tayabji, S., *Performance of Precast Concrete Pavements*, Supplementary Report, prepared under R05, Strategic Highway Research Program 2, Washington, D.C., 2011.

> million ESALS. The structural capacity of the system will, however, have to be determined for a range of support and environmental conditions before it can be used with absolute certainty."[2]

Based on the test results, a decision was made to move forward to include the PCP system on a portion of an actual rehabilitation project.

3.1 Location Selection

The actual PCP installation location within the project limits was selected based upon several criteria:

- An area where a portion of the PCP installation could be used to work through the learning curve of installing an unfamiliar product, without requiring lane closures.
- A large enough area to establish average production rates for PCP installation after the learning curve was completed. This project installed nearly 1.8 lane-miles (2.9 ln-km) of PCP, or over 118,400 square feet (11,000 m^2).
- An area that could test installation in a variety of cross-sectional and geometric configurations. In this project, the following were included:
    - Two tied outside lanes.
    - Two tied interior lanes (No. 3 and 4, with 2 non-PCP adjacent auxiliary lanes).
    - Single outside lane.
    - Tangent and super-elevated sections.
- A heavily-trafficked area that could test the life-span and durability of the PCP. A portion of the area chosen for this project was adjacent to a traditional cast-in-place lane replacement section, allowing a comparison to traditional methods of pavement rehabilitation.
- An area that could benefit from PCP's ability to be installed in short work windows.
- An area of continuous PCP, and an area of intermittent panel replacement, as these types of work can vary considerably in their characteristics. This project included almost 1.8 lane-miles of lane replacement, and replaced 20 existing intermittent panels with 34 PCP panels.

4. Design Procedures and Requirements

4.1 General Design Considerations

4.1.1 Work Windows

The use of precast pavement systems is most beneficial in areas where work windows are small. The vendor has experience with placing the PCP system in work windows as small as 5 hours. This project performed PCP installation in 8-9 hour work windows.

However, the decision to include PCP in a project will require consideration of cost, pavement life and available work windows. Once performance data becomes available for precast pavements, a Life-Cycle Cost Analysis (LCCA) will assist in the decision to include precast pavement in a project.

[2] University of California Pavement Research Center Technical Memorandum UCPRC-TM-2007-04

4.1.2 Work Area Requirements

Consideration should be given during design to the work area needed to construct PCP. Placement of PCP panels will require room for a crane, delivery trucks, and the placement crew.

The maximum size and weight of the individual panels is important in sizing the crane. The crane picking radius required should be considered. Outrigger placement and whether the crane can sit on previously placed panels while placing subsequent panels should also be discussed. The crane should be sized during design to ensure that sufficient space will exist in the work area.

On this project, approximately 3 lane-widths of space were required: The lane being replaced, a half-lane or shoulder on each side of the crane for outriggers, and a lane for delivery.

4.1.3 Lane Replacement Versus Intermittent Panel Replacement

Lane replacement using precast pavement is quite different from intermittent panel replacements, especially when the base layer is to remain in place. Replacing the base layer will require additional operations, possibly longer work windows, and have a negative impact on production rates. Depending on how the base layer is replaced, some of the benefits of PCP may be lost (i.e., placement in cold weather).

The base layer was not replaced in this project. Cores of the pavement and base layer performed during design to check the thickness of the existing pavement and condition of the base layer (cement-treated base, or CTB) showed the base to be in good condition.

In lane replacements where the base remains, it is possible to mill the base to provide space for added thickness in the precast panels, or even to account for variation in the existing pavement thickness. One caveat is that the milling machine should have very little gap between the milling head and the bell housing of the milling head. This allows the milling machine to grind the base layer right to the edge of excavated area.

In intermittent panel replacement, this option is not available, as there is insufficient room within the excavated area to run a milling machine. The only options available are full-depth replacement, to use of a slightly thinner panel (to provide room for the bedding layer), or use of some other way to remove the top portion of the base layer.

4.1.4 Thickness Considerations

If the base material is to remain, variation in the thickness of the existing pavement must be considered. The specifications for this project required that for a thicker (existing) pavement, bedding material would be added; and for a thinner pavement, the CTB would be milled to provide the necessary depth. This is necessary because the actual thickness of the pavement at any spot location will not be known until the PCP panels have already been cast to a prescribed thickness.

In this project, though the asbuilts showed an existing pavement thickness of 8.4 inches (213 mm), the actual pavement varied from 6.4 inches (163 mm) to 10.7 inches (271 mm). Although 25 cores were taken during design, this number of cores was not adequate to anticipate the large amount of variation over the installation area. Thus, it is recommended that for future projects where the base material is not replaced, additional coring be performed to minimize surprises during construction (especially on intermittent slab replacements).

A final consideration that must be taken into account is the possibility of encountering full-depth slab repairs (from previous projects) during pavement removal. Often, these types of repairs are poorly documented in asbuilts (or not at all). Rapid-set concrete can be used as new base material where poor base material or a full-depth repair was encountered. Neither scenario was encountered during construction of this project.

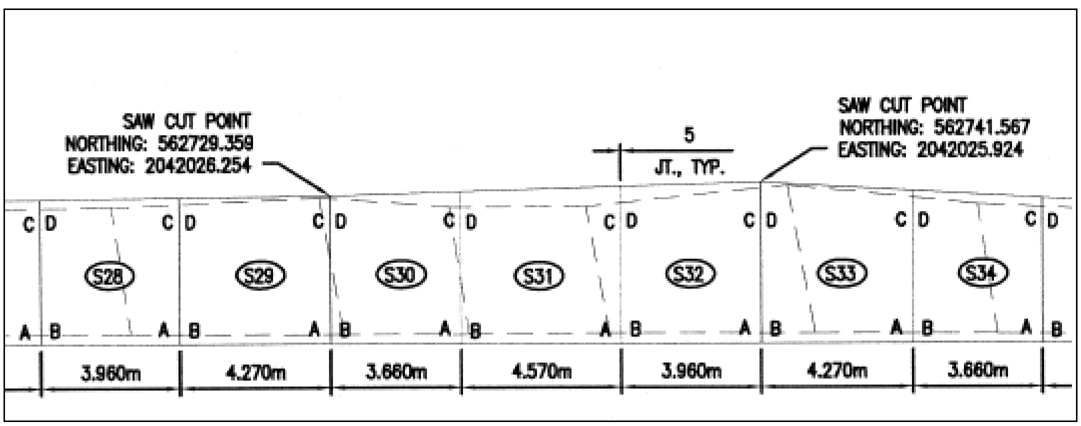
4.1.5 Transverse Joints

Many of the concrete pavements built on the California State Highway System in the past used transverse joints spacings that differ from the standards used today. The current standards call for[3] repeated intervals of 12, 15, 13 and 14-foot spacings (3.66 m, 4.57 m, 3.96 m and 4.27 m respectively), perpendicular to the longitudinal joints. The original pavement in this project was constructed in the mid-1970s using skewed joint spacings of 13, 19, 18 and 12 feet (3.96 m, 5.79 m, 5.49 m and 3.66 m respectively)[4].

While PCP panels can be cast to match most joint spacings, Caltrans' general practice is to use current standards for lane replacements. A longitudinal isolation joint was constructed between existing lanes and the PCP to account for the unmatched transverse joint spacings between lanes.

4.1.6 Longitudinal Joints

The longitudinal joints also require careful consideration during design, especially if the transverse joints of the PCP panels will not match the transverse joint spacing of the existing adjacent lanes. It is likely that during construction of the original pavement, multiple lanes were constructed simultaneously, with the longitudinal joint(s) created by saw cutting. Irregularities in the saw cut line can be significant. Also, since the transverse joint spacing does not match between the existing and proposed lanes, an overcut of the existing pavement is necessary (See Picture 5 below) to avoid the need for a five-sided panel (and additional casting forms).



Picture 5 – Detail from shop drawings for this project, showing the variation between existing longitudinal joint (dashed line) and the edge of the PCP panels (solid line).

[3] Caltrans Standard Plans 2006 P1 (page 121)

[4] Caltrans Standard Plans 1975 A35-A (page 9)

In this project, it was initially proposed to address this issue by requiring a 3-inch (75 mm) overcut along the entire edge of the lane. However, once the construction survey revealed that a 3-inch overcut would not be sufficient for some areas of the installation. In some areas of this project, a much larger overcut was required to address longitudinal joint variation. In one area in particular, a 24-inch (610 mm) overcut was required (See right saw cut point in Picture 5)! Rather than overcut the entire installation area by a large amount, a series of chords were used to increase the overcut as necessary.

A preliminary survey during design would better anticipate these issues. It is still recommended to require a survey by the contractor as well, as this maintains the responsibility for dimensional accuracy of the PCP panels during fabrication and construction with the contractor (See Section 6.2 "Surveying Requirements")

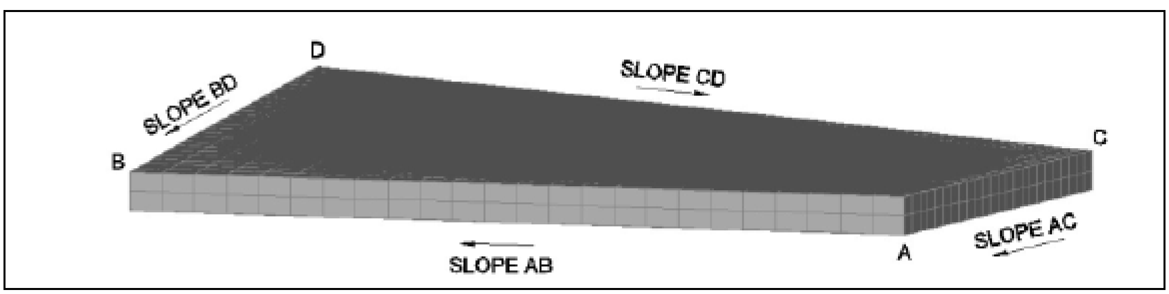
4.1.7 Grinding

While PCP panels are placed to very tight tolerances, the resultant lane profile will likely not be smooth enough to eliminate the need for grinding. For this project, a full grind was required by the contract specifications. The profile achieved prior to grinding was quite good. This was evident from the fact that the tined finish of the PCP panels was not completely removed by the final grind of the lane replacement area. However, to achieve a profile similar to that of cast-in-place pavements, grinding should be anticipated. Consideration should be given to adding a small sacrificial thickness to the panels in anticipation of this.

The final PCP was measured for International Roughness Index (IRI) by Applied Research Associates (ARA) before and after construction was completed[5]. IRI was measured using a high-speed inertial profiler integrated with a test vehicle. Profile data was collected in both wheel paths and averaged to produce an IRI value. All PCP was between 50-100 inches per mile and averaged about 66 inches per mile. This may be compared to the existing distressed pavement (prior to replacement) which had an IRI of 225 inches per mile.

4.1.8 Warped Panels

Warped panels can be defined as panels where the slopes of opposite sides differ. The magnitude of the warp is the vertical difference of one corner from the plane established by the other three corners (See Picture 6). Warped panels are necessary wherever panels are placed on a horizontal curve with a



Picture 6 – Warped panel (exaggerated).

[5] ARA, California I-15 CONCRETE PAVEMENT REPLACEMENT USING INNOVATIVE TECHNOLOGIES, Final Report, Highways for Life, Office of Infrastructure, Federal Highway Administration, 2011 (To be published).

non-zero profile grade, or wherever a super-elevation transition exists.

If the panels at these locations had not been warped in this project, there would have been a 2 inch (47 mm) step at one corner between adjacent panels. A smaller radius curve would have a greater warp. This is not an issue that can be handled by grinding. In addition, the underlying subgrade must be graded to match this warp, in order to ensure uniform support under the panels and prevent cracking.

Warped panels are determined from the construction survey, dimensioned in the development of the shop drawings, fabricated by warping the casting beds, and accommodated in the setting of the rails for the fine grading of the bedding layer.

4.2 Specifications

In addition to detailing the materials and construction processes for PCP, the specifications should address the following issues:

- Pre-construction training: For this proprietary system, this training is performed by the vendor. The need for this is especially important until industry gains some experience with PCP. A test strip is strongly advised for the contractor to demonstrate competency.
- Pre-construction survey: See discussion regarding this in Section 6.2.
- Shop drawings: Development, review and approval procedures, and responsibilities for each of these aspects. Include details on what should be shown on the shop drawings.
- Process for profile correction (to address faulting and/or settlement in the existing pavement).
- Details on warped panel fabrication and construction (See previous section).
- Conditions for opening the PCP to traffic prior to grouting.
- A contingency plan for encountering poor base material, and thick/thin existing pavement.

4.3 Cost Estimating

Estimating the cost for PCP for this project posed several challenges. The first challenge was the lack of industry experience. This translates to additional risk for bidders, which is difficult to price.

The item was paid by unit area, and due to sole source requirement in the project, a unit price was provided by the vendor and included in the specification. However, this unit price only included the precast pavement panels, training, rental of the fine grading equipment and delivery. The specification for the project required a bid unit price that also included existing pavement removal, grading, bedding material placement, installation, grouting, the construction survey, contingency plans, and other elements. Historical data from past projects for pavement removal was used in additional to the price quote provided by the vendor to arrive at a unit price of $312 per square meter for the Engineer’s Estimate. An analysis of this unit price in relation to the actual bid prices is included in Section 5.1.

5. Biddability of the Precast Pavement Pay Item

5.1 Bid Prices

This project had 8 bidders. The bidders and their associated unit prices for PCP are included in table below.

Bidder Rank	Total Contract Bid	PCP Bid Unit Price
1 (awarded)	$51,863,899.55	$418.00
2	$54,105,277.00	$350.00
3	$55,903,709.25	$350.00
4	$56,274,806.85	$340.00
5	$58,908,915.00	$380.00
6	$61,110,763.10	$379.00
7	$63,179,489.00	$420.00
8	$63,655,000.00	$350.00
Average:	$58,125,232.47	$378.38
Standard Deviation:	$4,021,426.39	$29.57

Unit Price in Engineer's Estimate: $312

Price Quote from Vendor: $253

The following is evident from the table:

- The unit price used in the Engineer's Estimate ($312) was low compared to the bid prices received. A $66 difference exists between the average bid and the Engineer's Estimate. This may be due in part to the risk priced into the bids from lack of bidder experience with PCP, and may be mitigated in the future.

- A $125 difference exists between the average bid price and the quoted price from the vendor. This difference must account for the cost of existing pavement removal, grading, bedding material including placement, installation of the panels, grouting, the construction survey, contingency plans, profit, and risk mitigation. Based on the list of construction personnel and equipment found in Section 6.5.1 "Equipment and Construction Personnel", a force-account analysis may be more appropriate for future projects to determine a bid price, until more historical bid data becomes available and industry experience increases.

- The total contract bid and the unit price supplied for PCP were fairly consistent between bidders, as demonstrated by the low standard deviation. This may indicate a certain level of agreement between the bidders on the cost of constructing PCP.

It should be noted that this project advertised during a significant economic recession. Competition on Caltrans projects was strong, and may have contributed to lower prices.

6. Construction

6.1 Relationship Between Material Delivery by the Product Supplier and the State's Contractor Performing the Installation of PCP

Once the project was awarded, the vendor became a subcontractor under the prime. The precaster was a subcontractor under the vendor. The prime contractor performed the actual placement of the panels, aided by the vendor. The prime contractor performed the surveying through a subcontractor of the existing pavement from which the shop drawings were developed. From this survey, the vendor developed detailed shop drawings of the PCP panels, which were subsequently reviewed and approved by Caltrans. Once the shop drawings were approved, they were sent to the precaster for fabrication.

6.2 Surveying Requirements

The specifications for the project required that the contractor perform a 3D survey of the existing pavement prior to preparation of the shop drawings. This served two primary purposes:

- The dimensions used to cast the panels are based on the most recent data available, allowing accurate measurement of recent pavement faulting, settlement, etc.
- Places the responsibility of dimensional errors in fabrication and placement on the contractor.

Several aspects of the survey requirements for this project could be improved on future projects:

- At locations where faulting has occurred two shots should be taken, one at the higher elevation, and one at the lower elevation.
- The contractor should be directed to 'smooth' the existing profile within the limits of vertical tolerance allowed by the specification. An opportunity for owner review and adjustments to this profile should be provided.

6.3 Effectiveness of the Special Provisions

The special provisions for the project were generally effective in allowing the product to be constructed as designed. However, there are some aspects of the specifications that could be improved to reduce the likelihood of conflict on future projects. Some of these suggestions would have issues that arose during this project:

- More detail on the survey requirements should be specified (see previous section).

- The specifications did not address traffic detection loops, and how they should be incorporated into the pavement. This needs to be addressed on future projects.

- The specifications need clearer direction on how to handle areas of thicker or thinner pavement than shown on the asbuilts. Although language was included in this project's specification, the contractor felt that the language was unclear that this could apply to large areas.

- Clarify that the proposed profile of the precast panels is a calculated (design) profile, not an interpolation between edges of pavement. This will help enforce proper grading procedures.

6.4 Shop Drawing Review

Shop drawing review was required by the contract specifications. The following are some of the items checked during the review:

- Nominal dimensions of the panels.
- Starting and ending stations match those shown on the project plans. Special attention should be paid to sections that begin or terminate at structure approach slabs.
- Intermittent panel replacement locations match with those designated by the Resident Engineer in the field.
- Shop drawings, including all notes, comply with the project specifications.

6.5 Construction of Precast Pavement

6.5.1 Equipment and Construction Personnel

The following is a list of the equipment typically used during a nighttime installation of precast pavement:

- Hand-Operated Grader (HOG): For grading the bedding layer.
- Skip Loader: Used to place and rough-grade the bedding layer.
- Water Truck: Used to wet the bedding layer prior to compaction.
- Steel-tired Roller: Used to compact the bedding layer.
- 40-ton Crane: For placing precast panel elements.
- Concrete Saw (sawcutting normally performed the night prior to PCP installation).
- Excavator (for removing concrete)
- Sweeper
- Grinder (for milling CTB if existing concrete is thin)
- Grouting pump, and truck to haul grout and pump
- Haul trucks for concrete removal, delivery truck for bedding material

Typically, the following construction personnel were on hand:

- 1 foreman
- 1 crane operator
- 1 excavator/roller operator
- 1 skip loader operator
- 1 grinder operator
- 1 water truck/sweeper operator
- 4 carpenters (for setting the rails that the HOG ran on)
- 1 grout pump operator
- 2 laborers to help with grouting
- 3-4 laborers operating the HOG
- 3-4 laborers setting panels

6.5.2 Production Rates

<u>Casting Production</u>

Casting production is limited by the number of casting beds and forms available. In this project, there were 8 casting beds, 4 of which were adjustable in the vertical direction (for warped panels). Initially, panels were cast 5 days per week. Once the placement production began to catch up to casting production, casting production accelerated to 6 days per week.

<u>Placement Production</u>

Placement production is listed in the table below. Shaded rows indicate placement in a nighttime closure (8-9 hours). All other placement occurred during daytime hours behind concrete barrier.

Date	Slab From	Slab To	Count	~Length (m)	Activity	Notes
5/3/2010	24	27	4	16.46	Grade, place, grout	Removal was done the prior week

Date	Slab From	Slab To	Count	~Length (m)	Activity	Notes
5/4/2010	28	61	34	139.91	Grade, place, some grouting	Removal was done the prior week
5/5/2010	2	21	20	82.30	Grade, place, some grouting	Removal was done the prior week
5/6/2010	2	61			Grouting	
5/9/2010	147	150			Excavation	
5/26/2010	147	167	21	86.42	All	
6/1/2010	168	200	33	135.80	All	
6/2/2010	201	233	33	135.80	All	
6/3/2010	234	272	39	160.49	All	
6/6/2010	273	293	21	86.42	All	
6/7/2010	294	314	21	86.42	All	
6/8/2010	315	353	39	160.49	All	
6/9/2010	354	392	39	160.49	All	
6/10/2010	393	425	33	135.80	All	
6/14/2010	62	90	29	119.34	All, bedding for 90, 91	
6/15/2010	91,96	145	51	205.75		
6/16/2010	96	145			Grouting	
6/17/2010	427	465	39	160.49		Most slabs (all but the first 6 panels) were not grouted or shimmed before opening to traffic
6/21/2010	466	504	39	160.49		
6/22/2010	505	543	39	160.49		
6/23/2010	544	582	39	160.49		
6/24/2010	583	603	21	86.42		
6/27/2010	604	621	18	74.07		Panels placed without grouting or shimming
6/28/2010						Sawcut and grouting
6/29/2010						Sawcut and bedding grouting
6/30/2010						Bedding grouting 26+00 to I-10 connectors.
7/1/2010						Both types of grouting from 28+50 to Airport Dr
7/9/2010	622	705	84	345.66		

Average production was about 33 panels per shift, or about 447 lane-feet (136 lane-meters). For nighttime work, production was about 32 panels, or about 427 lane-feet (130 lane-meters).

The various operations of placement can identified as follows, assuming sawcutting has been performed on the prior night, and bedding grout is injected on the following night:

- Removal of existing pavement
- Milling of the existing CTB (if required)
- Placement/grading/compaction of the bedding layer
- Placement of the precast panels
- Dowel grouting

During placement, the controlling operation was usually the fine grading of the bedding material. The above operations are generally occurring concurrently, with a lag between start and end times.

About 1 hour is necessary for the pavement removal crew to gain a sufficient lead ahead of the milling or grading crew. If milling of the CTB is required, about 0.25-0.5 hours is needed for the grinder to gain a lead ahead of the grading crew. Placement of the rails to guide the HOG occurs fairly quickly, given the contractor's use of skilled carpenters, and begins immediately after existing pavement removal. As stated earlier, the fine grading operation is normally controlling, and the placement crew is generally operating close behind the grading and compaction. Placement usually begins about 1.5 to 2 hours after the first pavement removal. Each panel takes 10 to 15 minutes to install. Dowel slot grouting must be completed 2 hours prior to opening to traffic (for curing). Usually while waiting for the placement crew to gain a sufficient lead, the grouting crew is installing bedding grout on the previous night's installation.

6.6 Bedding Layer Considerations

6.6.1 CTB Issues

This project did not experience the need for replacement of the cement-treated base (CTB). While provision was made in the specifications for replacement of poor CTB if it was encountered, poor base was not encountered. In the case of thin existing concrete pavement, milling the CTB served as an appropriate solution to accommodate the precast panels.

However, other projects may require replacement of the base layer. Currently, a PCP project is ongoing in Caltrans District 4 which includes base replacement. Several issues may be considered when base material requires replacement:

- Does the replacement method of the base layer eliminate or reduce the advantages of using precast pavement (i.e., no temperature restrictions on placement, etc.)?
- Is there sufficient work window for replacement of the base layer *and* placement of the precast panels?
- Can the poor base material be mitigated by milling and placement of a thicker precast panel?

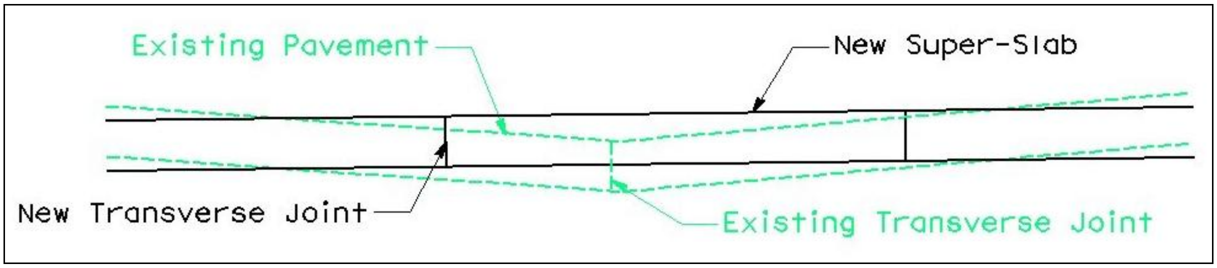
6.6.2 Grading Issues

As noted in the previous section 6.5.2, placement and grading of the bedding layer is often the controlling item of work during installation of the precast panels. This item of work is also a critical element in ensuring that the panels are uniformly supported and will not crack.

The bedding layer is graded to a design profile elevation, calculated as part of the shop drawing preparation process. The elevation is calculated to smooth the existing profile that may have dips or faults due to deterioration of the existing pavement, and accounts for the warped panels. This calculated elevation is marked on the adjacent pavement prior to the installation of the precast panels, for use by the crew setting up the rails for the grading equipment.

It may seem reasonable to simply 'stringline' across the longitudinal edges of the existing pavement in order to arrive at the grade elevation for the bedding layer. It may appear that some efficiency of production could be gained by this (though experience on this project seems to indicate otherwise).

However this 'stringline' approach will likely result in low and high points in the bedding layer that can contribute to cracking of the panels after placement, and should not be used. This is especially true in the case where the new transverse joints do not match the adjacent existing transverse joints.



Picture 7 – Simplified diagram showing the relation of the adjacent lane profiles to the new precast panel profiles.

As can be seen in the above figure (Picture 7), a 'stringline' approach will result in high points in the bedding layer on the left and right side of the picture, and a dip in the bedding layer in the middle of the figure. This concept can be extrapolated to a three-dimensional approach, and to warped panels. It is apparent from this figure that the bedding layer must be graded to the *design profile* to avoid creating voids or high points under the precast panels.

To the untrained observer, it may not be apparent which approach is being used. Both grading methods require the use of rails on each side of the excavation to operate the HOG. The key is in how the rail elevations are set. Owner inspectors should be trained to understand the need for proper grading, and methods of identifying proper grading should be developed for the inspectors' use. One of the challenges on this project was a lack of such methods, making inspection of the grading process difficult.

One approach suggested is to require a calculated cross-slope on the shop drawings at each transverse joint. This cross-slope could be checked using a smart level laid across the grading rails, prior to placement of the panels.

6.7 Placement Tolerances

The placement tolerances for the precast panels defined by the specifications were as follows:

- Vertical: Within 0.25 in (6 mm) of previously placed panel
- Longitudinal joint gap: ≤ 0.75 in (19 mm)
- Transverse joint gap: ≤ 0.4 in (10 mm)

The vertical placement tolerance was generally achievable by close monitoring of the fine grading process.

Achieving the longitudinal and transverse joint placement tolerances was more difficult, as these are dependent on the fabrication process and the accuracy of the existing pavement sawcut for removal. These activities do not allow much room for adjustments in the field to correct panels that are slightly small in width or length, or existing pavement that was overcut. At best, the contractor can split the difference in a wide joint between opposite ends of the panels.

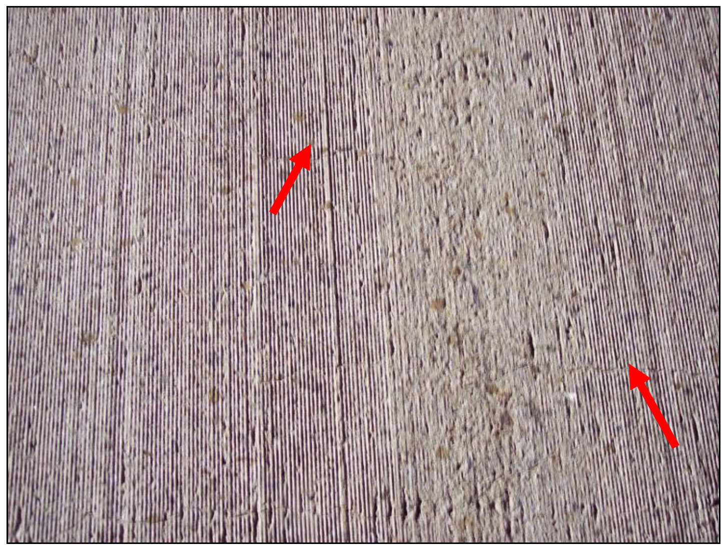
The tolerances specified in this contract are achievable, but they require a conscientious effort on the part of the contractor, the fabricator and the concrete saw operator. In a rough estimate for this project, 75% of the joints for this project were within the tolerances specified above. The remaining 25% of the joints were as wide as 1.5 in (38 mm) for the longitudinal joints, and 1 in (25 mm) for the transverse joints.

Increasing the tolerances may not be the appropriate method of addressing joint tolerances, as it provides less incentive for the contractor to exercise care in the fabrication and sawcut operations. A possible solution is to require a disincentive payment for joints exceeding the tolerances, up to a limit, after which replacement of the panel would be required. Provision should be made for how wider joints would be sealed, either by using a larger backer rod, or specifying a different type of joint seal.

6.8 Cracking

Several months after the precast panels had been placed, cracking was discovered on a number of the panels. The cracking was generally very tight and difficult to see with the naked eye (See pictures below). The cracking was observed after a rain event, when the cracks dried at a different rate than the surrounding pavement. Cracked panels occurred even in areas that had not yet been opened to traffic, but had only experienced construction traffic.

Picture 8 – Core of cracked PCP. Note how the cracking (red arrow) stops at the top mat of steel.



Picture 9 – Cracked PCP (noted with red arrows). Note that it was very difficult to get good photographs of the cracking, due to the tightness of the cracks.

A concerted effort was made to discern the cause of the cracking, including petrographic analysis and statistical analysis of the cracked panel locations. Strength data taken throughout the fabrication of the panels did not reveal any low strength concrete used during fabrication.

6.8.1 Petrographic Analysis

A petrographic analysis was performed on three cores taken from different locations along the installation, from panels that had been cast on different dates. It was observed in all of the cores that the cracks extended from the top of the panel down to either the first or second mat of steel in the panel.

The petrographic analysis concluded the following:

- The cracking appeared to be structural, and not shrinkage cracking. This was evidenced by the fact that the cracks proceeded through the coarse aggregate, instead of around it.
- Concrete was well consolidated and aggregate was well distributed.
- The quality of the concrete did not appear to be a contributor to the cracking.

6.8.2 Statistical Analysis

In order to perform any sort of statistical analysis on the panels that had cracked versus those that had not, the locations of the cracked panels were manually mapped on a copy of the panel layout, including the approximate location of the crack on each panel.

The cracking was divided into two levels. Panels with 1-3 cracks were considered Level 1. Panels with more than 3 cracks were considered Level 2. A summary of the results of the mapping is included below.

Initial Summary:

Total cracked panels (out of 696 panels mapped): 24%
Level 1 vs. Level 2: 21% (Level 1) / 3% (Level 2)
Cracked panels by lane: 20% (Lane 3) / 27% (Lane 4)
Cracked warped panels:
- 42 of the 168 cracked panels
- 25% of the cracked panels
- 6% of the panels mapped

Based on the above statistics, there does not seem to be a major correlation to which lane the cracking occurred in. The slightly higher percentage in Lane 4 may be attributed to a slightly higher truck volume. Whether or not a panel is warped does not appear to correlate to the cracking.

The following is a table showing placement dates and the percentage of panels placed which later cracked. Also included are notes gleaned from Caltrans inspector diaries and the vendor's field notes.

	Panel No.				Crack Count		Vendor
Date	**From**	**To**	**Count**	**Notes**	**# of panels**	**% of work**	**Rep On Site?**
5/3/2010	24	27	4		3	75.0%	Y
5/4/2010	28	61	34		12	35.3%	Y
5/5/2010	2	21	20	Vendor has issues with grading	15	75.0%	Y
5/26/2010	147	167	21	Vendor has issues with grading	8	38.1%	Y
6/1/2010	168	200	33	Vendor has issues with grading	12	36.4%	Y
6/2/2010	201	233	33	Vendor has issues with grading	12	36.4%	Y
6/3/2010	234	272	39		4	10.3%	Y
6/6/2010	273	293	21	Area from 26+68 to 27+54 was 190 mm. Had to use loader to take down base for panels 292 and 293, because milling machine broke down	3	14.3%	
6/7/2010	294	314	21		6	28.6%	
6/8/2010	315	353	39	Sta 28+50 to 29+50 sand was too dry, little or no compaction	7	17.9%	
6/9/2010	354	392	39		2	5.1%	
6/10/2010	393	425	33		2	6.1%	
6/14/2010	62	90	29	Vendor notes a portion of improper grading	7	24.1%	Y

6/15/2010	91	91	1		0	0.0%	
6/15/2010	96	145	50		12	24.0%	
6/17/2010	427	465	39	No inspector on site until late because contractor failed to give notice of work. Many spalls. Most slabs (all but the first 6 panels) were not grouted or shimmed before opening to traffic	16	41.0%	
6/21/2010	466	504	39		5	12.8%	Y
6/22/2010	505	543	39		10	25.6%	Y
6/23/2010	544	582	39		9	23.1%	
6/24/2010	583	603	21	Panels again placed without grouting or shimming.	10	47.6%	
6/27/2010	604	621	18		4	22.2%	
7/9/2010	622	705	84		9	10.7%	

It is clear from the table above that the cracking was not uniformly distributed across the installation area or timeframe.

An explanation of what is indicated by 'vendor has issues with grading' is in order. In these areas, the contractor graded the bedding layer using a 'stringline' approach. This may have resulted in voids and/or high points underneath the panels, and non-uniformly supported panels. Further detail on why the 'stringline' approach does not work is provided in previous Section 6.6.2 "Grading Issues". While the vendor explained the necessity of grading to the design profile during the preconstruction training, the prime contractor attempted a 'stringline' approach in hopes of increasing efficiency.

The vendor representative onsite at the time of installation became aware of this, and repeatedly raised the issue with the prime contractor, but was unable to get him to drop the 'stringline' approach until June 3. At that date a noticeable drop in the amount of cracking can be seen.

Two other occasions of increased cracking can be observed, on June 17 and June 24. On these dates, the contractor installed the panels and opened to traffic without grouting the panels without shimming the panels first.

6.8.3 Conclusions

The above observations indicate a strong correlation between the contractor's grading practice and the incidence of cracking. There is also a strong correlation between a failure to shim ungrouted panels and cracking.

However, neither of these issues entirely explains the cracking, as indicated by the occurrence of some cracking on areas for which no issue was identified. The following other potential causes have been identified by State and other professionals involved:

- The thickness of the panels: The pavement design for the adjacent cast-in-place lane replacement was over 12 inches thick, versus the 8 inches of thickness of the precast panels. However, the No. 1 and 2 lanes in this area are also 8 inches thick, and while truck traffic was placed on these lanes for approximately 6 months during staging, these lanes have not exhibited similar cracking. Furthermore, some cracking was observed on PCP that had not yet been opened to traffic.
- The bedding material used: In previous installations by this vendor (in other states), the bedding layer used was a crushed stone dust. The contractor requested the use of washed concrete sand on this project, which did not quite meet the gradation requirements of the contract specifications (1% out of spec). This request was approved by Caltrans.

However, the sand material had less fines than a stone dust, and was more easily disturbed. The sand material may have been disturbed during placement of the panels, resulting in non-uniform support.

- The direction given by the contractor to his surveyor was not always in accordance with the recommendations given by the vendor. Thus, some of the survey data was inconsistent and incomplete. This may have resulted in errors in the finished grade elevations used.
- In areas of base milling, if the milling machine did not mill completely to the edge of the excavated area and portions of the high base material were not removed by other means from these edges, high points on the supporting base may have remained along the longitudinal edges. This would result in non-uniform support conditions. The occurrence of several longitudinal cracks suggests this may have happened in some instances.

These potential causes would be difficult to completely rule out without extensive further testing. Furthermore, it can reasonably be argued that the thinness of the panels left less margin for error in the contractor's operations.

Ultimately it was decided that due to the tight nature of the cracking and the amount of steel present in the precast panels (which will help maintain the tight nature of the cracks), the cracked panels would be sealed with methacrylate and left in place. The cracked panels will be monitored closely for additional deterioration.

7. Lessons Learned

The following is a summary of the lessons learned from the project and recommendations for future projects. Many of them have been mentioned in previous sections and are included here again for the reader's convenience. The recommendations are not listed in any particular order.

7.1 Recommendations

1. <u>Perform a 3D survey of the pavement to be replaced during the design phase of a project</u>, similar in nature to the survey required of the contractor. This will allow anticipation of many issues of profile and joint alignment prior to construction and account for them in the project plans. See Section 4.1.6 especially for longitudinal joint issues.
2. <u>Consider how wide longitudinal and transverse joints will be handled.</u> Consider allowing a larger backing rod. Consider a disincentive that the contractor may pay to leave wide joints in place (up to a certain width). See Section 6.7 "Placement Tolerances" for more detail.
3. <u>Provide inspection training for construction personnel</u>. Highlight the important aspects of PCP installation (especially grading) and how to check these.
4. <u>If the base material is to remain in place, take *many* cores of the existing pavement</u>. This will allow the designer to evaluate the condition of the base material, and existing pavement thickness issues prior to construction. See Section 4.1.4 "Thickness Considerations".
5. <u>If the base material is to remain in place, and milling of the base is anticipated</u>, show these locations on the plans. Note that a milling machine with minimal distance between the milling head and the bell housing will be required.
6. <u>If the base material is to remain in place, and milling of the base is anticipated</u>, consider increasing the PCP thickness to provide an additional margin of safety. The additional milling will not add a significant delay or cost to the overall PCP placement operation.

7. Require additional fines in the bedding material. Consider the inclusion of a small amount of cement. The cement should be watered down just prior to panel placement. This would result in a bedding layer that is easily compactable and not easily disturbed or eroded.
8. Anticipate the potential for thicker bedding material. Consider what the maximum thickness of bedding material should be and specify what happens if additional thickness is needed.
9. Consider how traffic detection/counting loops will be handled.
10. Consider what should be included in the shop drawings and include those requirements in the contract specifications. Consider who will review the drawings and what will be checked, in order to streamline the review process (See Section 6.4 for suggestions on what to review).
11. In the specifications for the contractor survey, require two shots at faulted joints.
12. Provide more detail in the specifications of how smoothing of the existing profile is to be accomplished. Allow the owner agency an opportunity to review and request revisions to the profile smoothing. Include language in the specification requiring the contractor to grade to this profile. (See Section 6.6.2 for more detail)
13. Consider requiring an electronic (Excel format) submission of the PCP panel dimensions to facilitate shop drawing review and other construction checks.
14. Consider adding some sacrificial thickness to the PCP panels in anticipation of grinding.
15. Consider crane size and work area requirements during design. Consider outrigger placement, lane closure requirements (including delivery), and the picking radius required.
16. Provide more detail regarding warped panels in the specifications. See Section 4.1.8 for more detail.

7.2 Statewide Standards Committee

The author of this paper is a member of a statewide standards committee tasked with the development of standard plans and specifications for the use of precast pavement within Caltrans. The committee also plans to develop design and construction guidelines for precast pavement. These are being developed both for precast pavement (non prestressed and non post-tensioned) and for prestressed, post-tensioned precast pavement.

The committee includes members from Caltrans Headquarters, district personnel and industry. The panel meets approximately on a quarterly basis.

A rough schedule of the committee's work is outlined below, though it is subject to change (See below for abbreviations):

Proposed Work Plan:

PPCP nSSP	6/30/11
PPCP Std. details	7/30/11
PPCP design guide	12/30/11
PNCP (generic) nSSP	3/30/12
PNCP (generic) details	5/30/12
Performance Evaluation Guideline (proprietary systems)	7/30/12
(these activities are done while waiting for construction of I-710)	
PPCP SSP (after I-710 first construction season)	10/30/12
PPCP std. Plan (after I-710 first construction season)	10/30/12
PNCP (generic) SSP (pending on more pilot projects)	(no date set)
PNCP Std. Plans (pending on more pilot projects)	(no date set)

(these two activities could fall under a separate project)

PCP (performance) spec (not in the scope of this project)

Abbreviations: PCP – Precast Concrete Pavement; PPCP – Precast Prestressed Concrete Pavement; PNCP – Precast Non-prestressed Concrete Pavement; SSP – Standard Special Provision; nSSP – non-standard Special Provision.

The above schedule focuses first on Precast Prestressed Concrete pavement, as Caltrans has more pilot projects completed, planned and/or in construction than Precast Non-prestressed Concrete Pavement.

It is worth noting that the proprietary nature of this PCP system presents challenges with regards to its inclusion in public projects. The vendor owns patents on several aspects of the proprietary PCP system. However, this is not necessarily unique to this PCP system. Other precast systems exist that also include proprietary elements. Yet, these issues are not insurmountable, as demonstrated by the fact that New York DOT and other DOTs have successfully incorporated plans and specifications into their standards that allow the use of this system.

7.3 Final Conclusions

Precast pavements have a very specific application. PCP panels are cast under tightly controlled conditions offsite, ensuring a higher quality pavement than may be achievable in the field by cast-in-place methods. The panels may be cast to nearly any shape and size, including warped panels for super-elevated roadway sections.

Due to their higher cost versus cast-in-place pavements, they are primarily useful for pavement replacement in areas of high-traffic volumes with short work windows. In such areas, traditional cast-in-place pavements may not be feasible, or may be difficult to construct in a manner that ensures a long service life.

Experience on this project has demonstrated the feasibility of constructing large areas of pavement replacement in short windows using PCP, and of achieving production rates similar or better than traditional cast-in-place methods when only short work windows are available.

Some issues remain to be resolved regarding achieving acceptable joint widths, the best approach to replace base material in a PCP installation, and how best to prepare base material left in place. Bedding layer materials and the most efficient grading methods for the bedding layer also could benefit from further study.

However, none of these issues are insurmountable. Solutions to some of them are already being tested in ongoing projects in Caltrans.

In short, precast concrete pavement is a technology that presents a very viable option for pavement rehabilitation when faced with the decreasing work windows of urban areas that challenge engineers today.

9. References

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- Caltrans Standard Plans 1975
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- University of California Pavement Research Center Technical Memorandum UCPRC-TM-2007-04
- Ye, D. and Tayabji, S., *Performance of Precast Concrete Pavements*, Supplementary Report, prepared under R05, Strategic Highway Research Program 2, Washington, D.C., 2011.

A more detailed report on the precast pavement installation on this project can be obtained by contacting the author at Jonathan_C_den_Hartog@dot.ca.gov