ENGINEERING A BETTER ROAD - USE OF 2-WAY PRETENSIONED PRECAST CONCRETE PAVEMENT FOR RAPID REHABILITATION

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ABSTRACT

The need for fast, long-lasting roadway rehabilitation strategies is one of the key aspects of today's ageing highway system. For example, current work windows for road construction crews are sometimes as little as 4-5 hours. In these short work windows state transportation agencies are required to maintain our highways to endure the constant wear and tear from high traffic and differing weather conditions.

The California Department of Transportation (Caltrans) rehabilitates concrete pavement exhibiting moderate distress using rapid strength concrete (RSC). RSC is used with or without dowels for load transfer, depending on the contiguous length of repair. The performance of this approach is inadequate and is now under Caltrans review to determine if it is an effective means of repairing our deteriorating highway system.

After years of conventional RSC rehabilitation, Caltrans broke tradition by using 2-way pretensioned precast concrete pavement to rehabilitate a highway in the San Francisco Bay Area. The project incorporates a combination of jointed precast pretensioned concrete pavement (JPPCP) and precast post-tensioned concrete pavement (PPCP) on a large scale and is nearing completion. Differences from other precast projects in the United States are 2-way prestressing (longitudinal and transverse directions), eliminating blockout pockets through the use of end stressing, reducing the number of post-tension ducts, and casting and deploying long panels ranging in length from 18-36 feet.

This paper discusses the fabrication and installation challenges encountered throughout construction resulting from the use of JPPCP and PPCP. Additionally this paper focuses on challenges in getting this innovative project accepted by Caltrans and provides a valuable perspective in establishing successful partnerships between public and private entities for innovative projects.

Keywords: Precast, pavement, post-tensioned, rehabilitation, pretension, panel, slab

INTRODUCTION

The need for fast, long-lasting roadway rehabilitation strategies is one of the key aspects of today's ageing highway system. For example, current work windows for road construction crews are sometimes as little as 4-5 hours. In these short work windows state transportation agencies are required to maintain our highways to endure the constant wear and tear from high traffic and differing weather conditions.

The California Department of Transportation (Caltrans) typically rehabilitates concrete pavement using rapid strength concrete (RSC). RSC mixes achieve high early compressive strengths of around 2500 psi in 1.5 hours. It is common to add water reducing admixtures and plasticizers and accelerators to a mix in an effort to expedite the strength gain.

However, projects completed over the past decade using RSC have underperformed and required further repairs and maintenance. There are instances where the RSC approach was used on long term rehabilitation projects and several sections failed in less than three years. Sections of the existing roadway on these projects outlived the newly replaced RSC areas and in many instances, continue to do so. Caltrans was at a crossroads, especially the district office in the San Francisco Bay Area. An alternate approach to concrete rehabilitation had to be investigated or steps were going to be taken to possibly overlay all of our roadways with hot mix asphalt (HMA).

After years of conventional RSC rehabilitation, Caltrans broke tradition by using 2-way pretensioned precast concrete pavement to rehabilitate a highway in the San Francisco Bay Area. The project incorporates a combination of jointed precast pretensioned concrete pavement (JPPCP) and precast post-tensioned concrete pavement (PPCP) on a large scale and is nearing completion.

The following paper provides an overview of the use of the precast concrete pavement on the RTE 680 project in the San Francisco Bay Area. Discussed is the project delivery process, the design changes that revolutionized the way we use precast concrete pavement, the challenges faced in fabrication and installation as well as innovations in construction using precast pavement technology.

THE PROJECT

The RTE 680 project is located 35 miles east of San Francisco in the San Ramon Valley (see figure 1). It entails a large-scale rehabilitation of 12.5 miles of existing concrete roadway. The following is a summary of the facility and the primary scope of work:

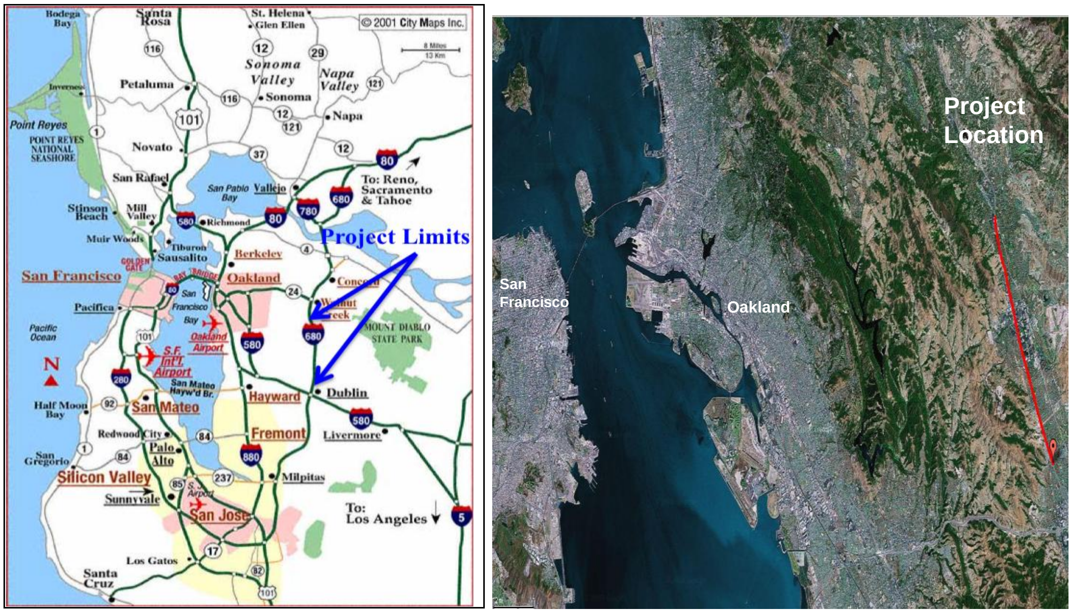


Figure 1 – Project Location

Existing Facility

The existing roadway was constructed in the 1960's. The pavement section is typically 8"-9" of PCC, layered underneath with 4"-5" of cement treated base (CTB) and 12"-14" of aggregate subbase (AS) (see Figure 2).

Figure 2 – Existing concrete pavement section

Below are the geometrics of the RTE 680 facility:

- 8 lane concrete barrier divided freeway that runs in the North/South direction with concrete auxiliary lanes intermittently throughout the project.
- 10 interchanges
- 44 ramps
- Lane 1 is a 12' HMA pavement with an 11' HMA inside shoulder.
- Lanes 2, 3, and 4 are 12' concrete pavement – over 40 years old.

- Outside shoulder varies from 8’ to 12’ HMA pavement.

Rehabilitation Strategies of Existing Concrete Pavement

Alcosta Blvd – Diablo Blvd (Post Mile 0-7.5)

- 0.65’ mill/fill of existing lane1 and outside shoulder
- 0.2’ mill/fill of inside shoulder
- Cast-in-place JPCP – lane 4
- PPCP slab replacement – lanes 2,3, and 4 (at onramp/off ramp tapers)
- JPPCP panel/slab replacement – lanes 2 and 3

Beyond Diablo Blvd (Post Mile 7.5-12)

- Crack, seat and overlay of existing concrete pavement (6” HMA and rubberized HMA)

There has been some maintenance work done including two grinding projects and a minor skin patch of HMA to correct poor ride quality due to faulting in the area between PM 0-7.5, which is the focus of this paper.

PROJECT DELIVERY CHALLENGES

The initial concept of using prefabricated concrete panels as an alternative form of PCC rehabilitation came in 2005 at a Caltrans sponsored pavement workshop. Our office just wrapped up a forensic investigation into a recently completed project using RSC. The RSC exhibited premature distress although it initially met the performance requirements outlined in our specifications. We were noticing a similar pattern on other RSC projects and questioned the material durability for long-term performance. We felt is was time to find an alternative approach that was durable and long lasting.

The idea of using precast concrete pavement was intriguing and we soon realized part of the 680 project would be an ideal candidate for such an approach. We educated ourselves by attending conferences and workshops and once comfortable enough approved the concept and moved forward with putting draft plans and specifications together. We acquired specifications from other projects, namely ones done in Virginia and Southern California and used them as a template for ours.

During all this fact-finding and preparation, the upper management at Caltrans had some reservations with the precast concrete pavement concept. There were concerns with constructability and cost and it was suggested a small pilot project be done first. These were legitimate concerns and all we could do was provide factual information about the performance of precast pavement and its relative ease of construction from published reports and demonstrate its cost effectiveness through a life cycle cost analysis (LCCA). It was beneficial that innovation was part of the Caltrans mission statement and strategic plan. These two documents represent the core principle of what our agency embodies. Eventually, the precast concept was approved and in late 2009 the project was programmed and funded.

Next, we set up a meet and greet with industry by inviting local general contractors and precast concrete manufacturers. Also invited were representatives from the Precast/Pretensioned Concrete Institute (PCI) and the National Precast Concrete Association (NPCA) to talk about their respective organizations. The goal of this meeting was to introduce everyone to the precast pavement project. We wanted industry to know that Caltrans was looking to think outside the box and hoped industry would join in our quest. We felt it was important to develop this partnership because both Caltrans and industry needed to work together on this project and others like it.

After the meet and greet, we proceeded to put all the plans and specifications together. We established a specification writing team that met weekly and had construction involved every step of the way. Two different specifications were written, one for the each precast system.

We decided to model the plans and specifications for this project after the one done by the Virginia Department of Transportation (VDOT) on Interstate Route 66. Thus, plans were developed for the PPCP system to go with its respective specification and a performance specification was written for the JPPCP system as a result of the several proprietary systems available for commercial use.

Two value analysis (VA) studies were conducted at different stages of the project delivery process to ensure Caltrans was pursuing the best strategy. Team members in a VA study evaluate strategies for practicality, cost effectiveness, and environmental impacts. A consultant serves as facilitator and in the end packages the findings and conclusions of the team. Fortunately, in both studies the precast pavement alternative was deemed the most cost effective, long-lasting alternative for the pavement rehabilitation.

Finally in July 2010 the entire PS&E package was delivered to the Caltrans headquarters office in Sacramento for final review and the project was approved for bid a few months later.

PAVEMENT EVALUATION

Traffic conditions on this stretch of roadway are reasonably high with an average annual daily traffic (AADT) ranging from 145,000 – 171,000 vehicles, based on 2010 numbers. The projected traffic volumes are expected to rise in 2020 to 171,000 – 199,000 vehicles with 4.7% truck traffic.

Initial field condition surveys were done to evaluate the distress levels of the pavement. Pavement evaluations were done by walking the project limits and on maintenance vehicles. Distressed pavement was identified on plan sheets and the limits of precast pavement identified. The field surveys were done to identify PCC exhibiting distress in the form of longitudinal and transverse cracking, joint deficiencies, surface defects, spalling, and roughness and faulting. Reference documents used include the Caltrans Maintenance Technical Advisory Guide (MTAG) for Rigid Pavements and the Caltrans Slab Replacement

Guidelines. In addition to the identifying distressed, cracked PCC, we identified PCC that would exhibit potential for failure in the next 5 years.

Falling weight deflectometer (FWD) tests were done to evaluate the performance of the underlying subbase so the FHWA and their consultant could determine stressing loads during post-tensioning of the epoxy coated steel strands.

No coring was performed as part of the pavement evaluation.

ORIGINAL DESIGN DETAILS

As mentioned previously, the precast pavement concept utilized both post-tensioned (PPCP) and jointed pavement (JPPCP) systems.

Since California uses a rigid base under its entire rigid pavement, the structural section incorporated a rapid setting lean concrete base (LCB-RS) as a base layer for the precast pavement to rest upon. The LCB-RS uses Type III Portland cement and is designed to achieve an opening age compressive strength of 725 psi in 4 hours. The section was designed as follows:

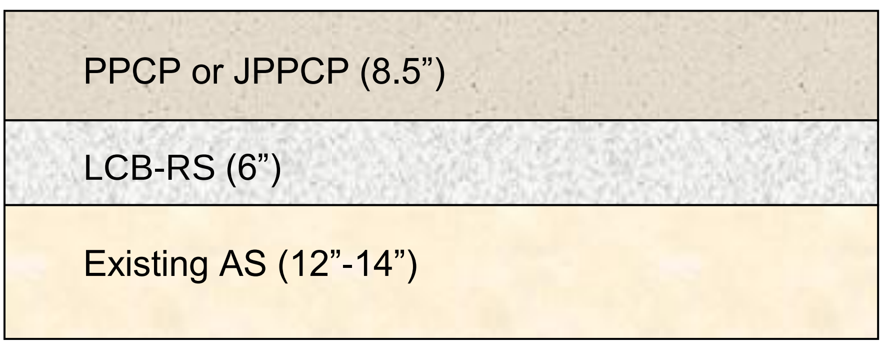


Figure 3 – Typical precast pavement structural section

The concrete mix designs for both precast concrete systems followed requirements in the Caltrans Standard Specifications and used a Type II Portland Cement. All parameters were the same, except we required microfibers in the PPCP system. The fibers were included to provide secondary reinforcement and protect from cracking initially after the panel was poured.

The PPCP system followed the design methodology outlined by the FHWA and is as follows:

- 8' panel length
- 12' panel width
- Use of joint panels, base panels and central stressing panels for post-tensioning (see Figure 4).
- Blockouts on top of panels for access to post-tensioning (PT) strands (see Figure 4).

- 6, 1” diameter PT ducts to accommodate one strand each.
- PT strands stressed to 5600 psi (80% of ultimate tensile strength)
- Minimum PPCP length 64’ and maximum of 152’.
- Longitudinal isolation joints (panels were not tied to adjacent lane)

The figure below shows a schematic of the original PPCP layout (or a one slab layout).

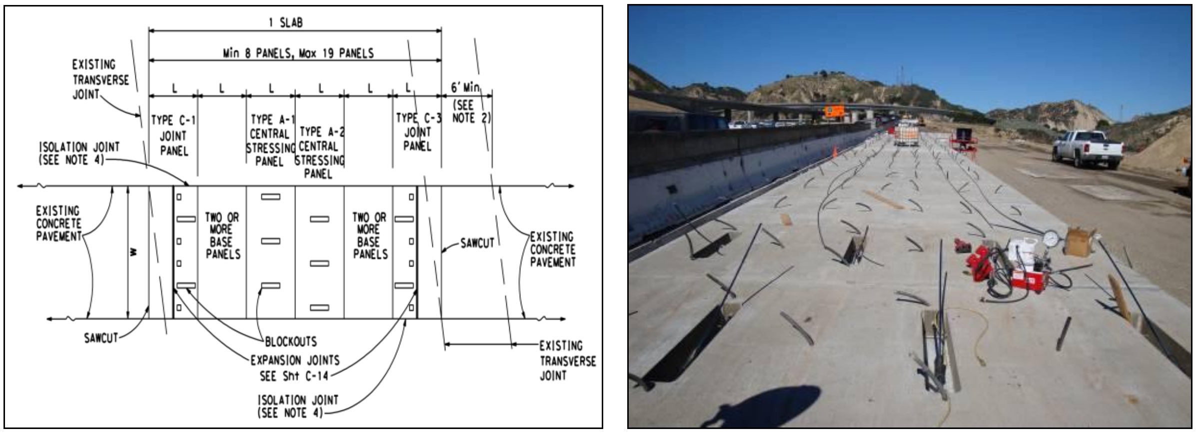


Figure 4 – Original PPCP Slab Layout (Note: A slab is a series of panels) (Sample photo courtesy David Merritt)

The JPPCP system would be designed by the contractor and shop drawings provided to us simply because there were and currently are several proprietary systems commercially available. Therefore, we provided performance-based specifications and guidelines specifically addressing minimum requirements of concrete, steel and load transfer devices, similar to the approach taken by the VDOT.

PRECAST PAVEMENT DESIGN CHANGES

The general contractor and their subcontractor proposed design changes to the PPCP system at the initial preconstruction meeting. The prime motivation was to ease the installation procedure and optimize production quantities in the field. This was a risky proposition, since the precast concept was new to all of us. Caltrans knew our designs would work because they were based on the FHWA concept and used in other states. Nonetheless, the precast and post-tensioning subcontractors both felt their proposals would improve the design and lead to more productivity. It was a risky move, but Caltrans decided to entertain the proposal. The following are the key design changes proposed for the PPCP system.

- 8’-36’ panel length
- No blockouts on top of panel, blockouts at end of panels (see Figure 5).
- 3, 2” diameter PT ducts to accommodate 2 strands per duct (see Figure 5).
- Recessed pocket to fit compressible foam gasket (Figure 5).
- 2-way pretensioning in the longitudinal and transverse directions.
- Minimum PPCP length of 64’ and maximum of 216’.

- 4’ drop-in panels at ends of PPCP section. Drop in panels have dowel slots on both ends.

Similarly, the precast concrete pavement manufacturer developed their own proprietary system for the JPPCP system including the use of 2-way pretensioning in the longitudinal and transverse directions and dowel bars as a load transfer mechanism.

Figure 5 – (a) Blockouts and dowels on end panels only; (b) Keyway and 2-inch diameter PT ducts between PPCP panels

Caltrans quickly saw the benefits of the changes, namely the reduction in the number of joints due to the longer panel lengths as well as the elimination of blockouts on the top of panel. Figure 6 shows a typical 6-panel (maximum 36-foot long panels) PPCP layout.

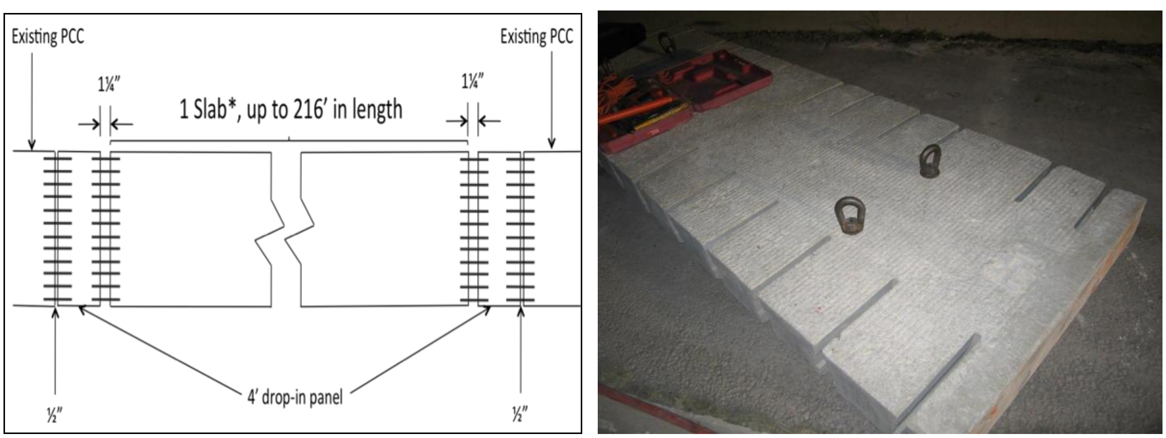


Figure 6 – Modified PPCP Design/Layout and permanent 4’ drop-in panel
(*A slab is a series of panels)

However, the changes did come with some apprehension. There was the issue of ensuring the longer panels fit in the excavated areas within the tolerances specified particularly along the isolation joint. Additionally, there was concern with the ability to properly post-tension the 6 epoxy coated steel strands, as well as the handling of the larger dimension panels. The long-term performance of the 4’ drop-in panels came to question. We felt these panels were susceptible to cracking due to the number of slots on either side of the panel (Figure 6). Nonetheless, Caltrans was excited about the potential demonstrated in the design modifications.

INSTALLATION OF PPCP AND JPPCP SYSTEMS

The installation procedure was established by the contractor and their subcontractors and was loosely based on the procedure outlined in the special provisions of the contract. Below is a step-by step procedure of the PPCP installation:

1. Demolition – This includes the removal of distressed pavement and underlying base (see Figure 7). Most underlying base under PCC in California is rigid and the RTE 680 project was no exception. In our case the existing base was comprised of 4”-5” of CTB (see Figure 2)

Figure 7 – Demolition of distressed pavement and underlying base

2. Grading and compaction – Grade and proofroll the Subbase material in preparation for rapid setting lean concrete base (LCB-RS) material (Figure 8). Perform compaction tests to verify relative compaction levels.

Figure 8 – Grading and compaction of subbase

3. Drill slots in existing pavement for dowels, place joint filler material and set grade for LCB-RS – Place ½" thick foam filler to separate LCB from adjacent lane(s), in the longitudinal direction (Figure 9), since the plans called for longitudinal isolation joints. Rails set up to ensure LCB-RS is graded with appropriate cross slope. Use gang drill to ensure longitudinal alignment when dowels are inserted (hand drilling can lead to hole that is not aligned properly).

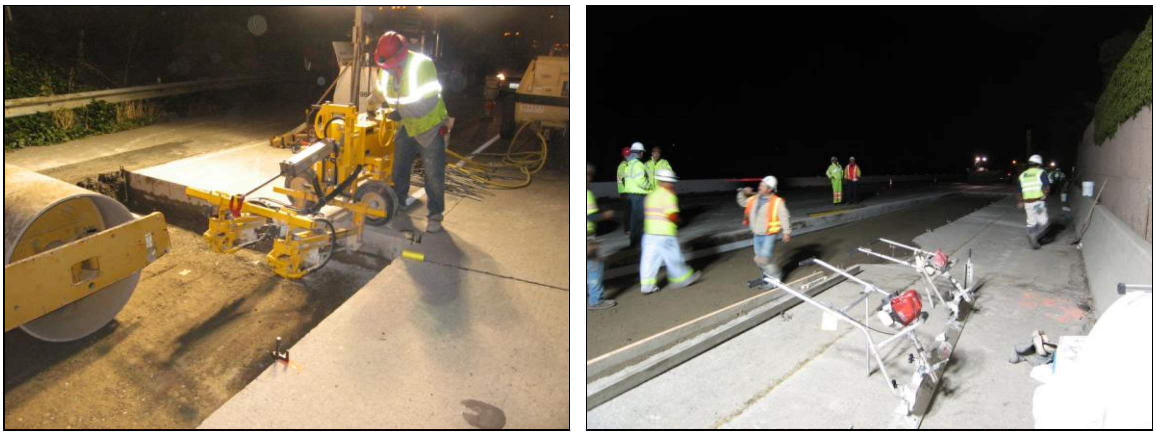


Figure 9 – Drilling dowel slots, placing joint filler material and setting grade for LCB-RS

4. Pour and grade LCB-RS – Pour and grade 6" thick layer of LCB-RS. This will serve as the base for the PPCP. The LCB-RS must achieve and opening age compressive strength of 725 psi prior to opening to traffic (typically 4 hours) (see Figure 10).

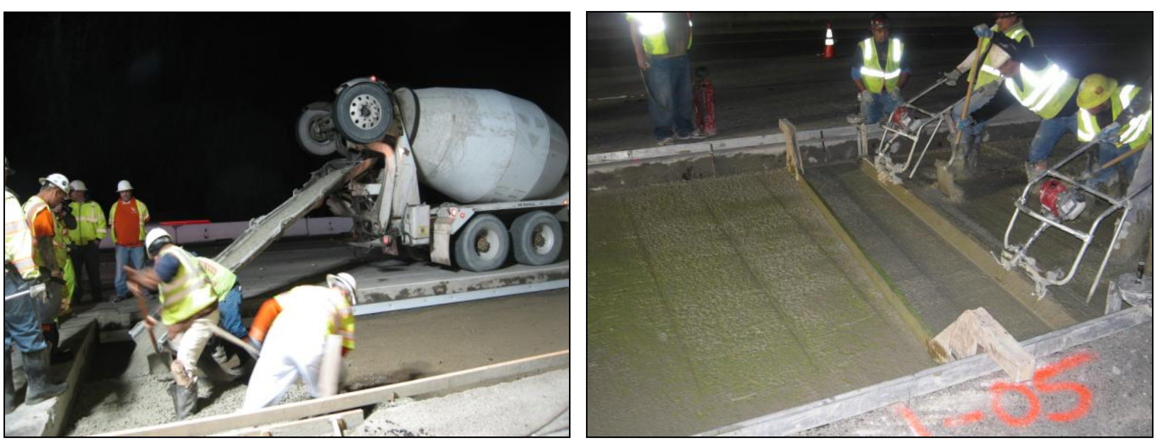


Figure 10 – Pouring and grading LCB-RS

5. Place bond breaker, joint filler and install PPCP panel – Once LCB-RS reaches compressive strength of 100 psi (~2 hours), place bond breaker and install PPCP

panel (Figure 11). Feed PT strands (6 permanent, epoxy coated and 2 temporary uncoated). Apply temporary post tensioning after second panel is placed.

Figure 11 – Installation of PPCP panels

6. <u>Final post tensioning, place temporary 4' drop-in panels</u> – After last panel is placed, remove temporary strands and perform final post tension on epoxy coated strands (5600 psi). Place temporary drop-in panel until next night (Figure 12). Roadway is opened to traffic at the end of the workshift.

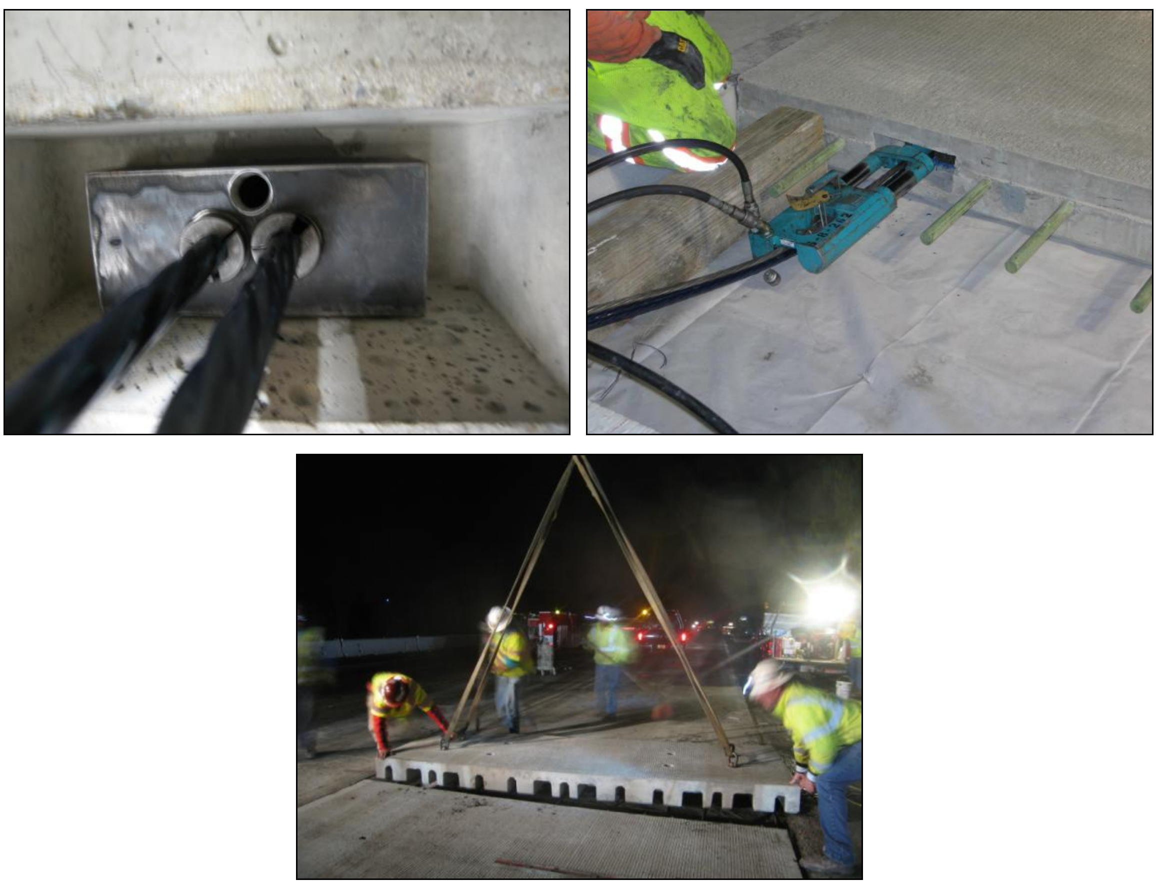


Figure 12 – Final post tensioning and placement of temporary drop-in panel

7. PT duct and underslab grouting – Next night remove temporary drop-in panel and pump grout into PT duct and inject underslab grout (Figure 13). Underslab grout is not pressure injected since it is only used to fill any voids or minor undulations on the LCB-RS, resulting in a smooth surface with contact throughout the base of the precast panel.

Figure 13 – PT duct and underslab grouting

8. Install dowels in existing pavement, place permanent 4’ drop-in panel and place grout for dowel bar slots – After all the PT ducts and underslab grouting is complete, permanent drop-in panels are placed at ends and slots grouted (Figure 14). PPCP slab section is complete and opened to traffic. The only remaining operations are the diamond grind and joint sealing that occurs after all the precast pavement installation is complete.

Figure 14 – (a) Dowels installed in existing pavement; (b) permanent drop-in panel

Figure 14 (continued) – (c) completed installation

The installation procedure for the JPPCP system is very similar to the PPCP process (steps 1-5), except in step 5 a JPPCP is placed in lieu of a PPCP panel. The JPPCP panel has a similar design as the PPCP system, except without post-tensioning, hence the PT strands and 4' drop-in panels are not part of the drawings. However, analogous the PPCP system, dowels are inserted in existing pavement prior to placing JPPCP panel. All JPPCP panels are cast to fit excavations and dowel bar slots are grouted the same night (see Figure 15). Contractor elected to perform underslab grouting on several panels at once; typically this was done once a week.

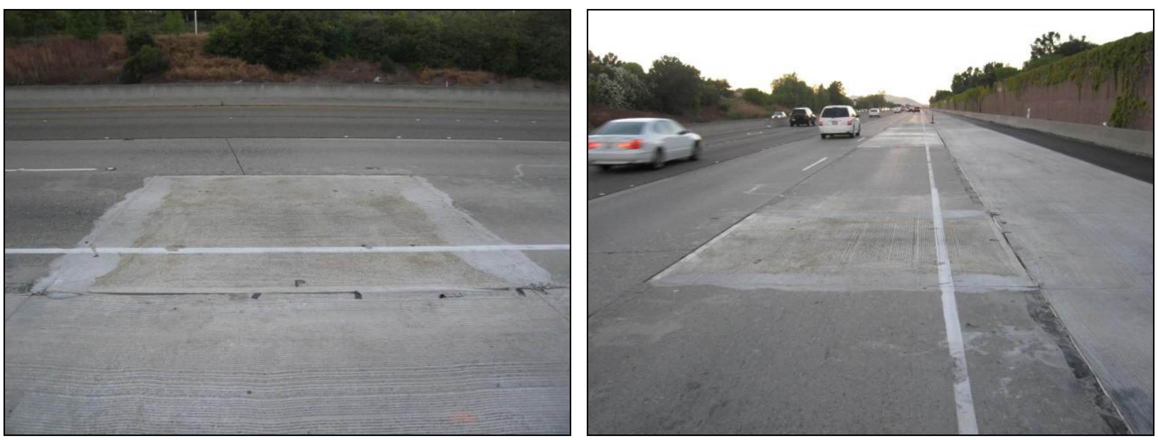


Figure 15 – JPPCP panels

FABRICATION CHALLENGES

The biggest challenge in fabrication was the fast-track nature of the project and the exchange and flow of information, necessitating expedited responses. It was critical that both the precaster and general contractor were in regular communication regarding the locations of work, type of precast system and dimension of panels desired. It was paramount that the precaster provide a quick turnaround based on the production rates required. The precaster and their fabrication crew worked with Caltrans quality control folks that were on site daily to ensure panels met the requirements of the contract. This was important, as it became an integral part of the installation schedule.

Another challenge came in the concrete mix itself. The PPCP system required the use of fiber reinforcement in the mix design. Initially there were inconsistencies with the mix ranging from the very wet, to dry and finally “sticky”. This problem did not exhibit itself in the mix for the JPPCP which did not contain or require fiber. The precaster did work with industry experts to resolve the issue and eventually a consistent, workable mix was developed with the inclusion of fiber.

Precision during fabrication of the PPCP and JPPCP panels was critical. The precaster had to ensure the post tensioning ducts and blockouts on the PPCP system lined up precisely from one panel to the next. Additionally it was critical that the dowels line up accurately in both precast systems. This was achieved through use of precision built steel bulkheads with pre-drilled holes for anchoring the blockouts/dowels.

Weather was a factor as the precaster’s fabrication bay was not enclosed and free of the environmental elements. A mobile shed was developed and used as a traveling cover. Also, the precaster tarped the panels after they were poured and tined and used surface sealers and curing agents to prevent the loss of moisture and cracking due to evaporation. This was really beneficial since the Northern California area experienced an unusually long rainy season combined with high winds. As the temperature rose the precaster adjusted their pour schedules to start earlier in the day to avoid the heat.

Other challenges which are discussed in the installation innovations section involved fabricating tapered drop-in panels to accommodate varying lane widths as well developing curved panels for JPPCP. Regarding the curved panels the precaster specifically designed a side form that allowed them to place a bend in the panels to accommodate curves in roadway alignment. For experimental purposes, they were able to cast a panel to fit an 800’ radius curve, in an effort to demonstrate the adaptability of precast concrete pavement.

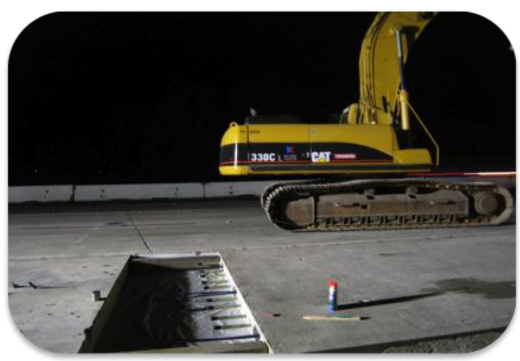
INSTALLATION CHALLENGES

Being the first project in our district, the installation of these systems came with its set of challenges. Below is a list of observations and challenges we faced during the entire PPCP and JPPCP installation.

Drop-in panels - Underslab grouting can't be done until final drop-in panels are installed. Thus, dowels need to be drilled into existing PCC and drop-in panel placed and grouted (Set 45, w/pea gravel – per manufacturers recommendations).

Check alignment and spacing of dowels. Make sure dowels aren't in contact with side slots on drop-in panels as shown above. This alignment could lock up the joint which would eventually lead to premature distress and possible failure around the slot.

Ensure PT grout is pumped upslope. When grout was injected downslope, a void was left on the high side. Pump upslope until grout comes out of the other side of the PT duct. This ensures grout fills the duct.



Ensure PT strands are epoxied on ends after cutting, prior to patching of blockout. This is done to minimize corrosion at the ends of the strands.

Figure 16 – Installation Challenges

Ensure LCB-RS is properly placed and graded. Underslab grouting may need to be done the same night, if large voids exist between LCB-RS and PPCP panels.

Confirm the opening age strength of LCB-RS. In our case it took around 4 hours to reach the desired 725 psi opening age compressive strength. As a result the crane used to hoist the PPCP panels was not allowed to traverse the installed precast panels during placement.

Ensure coating on PT tendons isn't removed exposing steel as a result of from dragging tendons on the ground. Visual inspection showed mostly scuffing and surficial scratching of the PT tendons. Nonetheless, this should be checked every time PT strands are cut and installed.

Check for elongation of epoxy coated steel strands after final post-tensioning. and compare with theoretical - $\delta=PL/AE$.

Figure 17 – Installation Challenges (continued)

In addition we observed the following challenges during the precast pavement installation:

1. Check for elongation of the PT strands after stressing (from Figure 17). We used the following relationship to compare theoretical values with actual elongation measured in the field:

$$\boxed{\delta = \frac{PL}{E_{steel}A_{steel} + E_{epoxy}A_{epoxy}} = \frac{44{,}000 \times L \times 12(inches)}{28 \times 10^{6} \times (\pi \times \frac{0.6^{2}}{4}) + 35 \times 10^{5} \times (\pi \times \frac{0.025^{2}}{4})}}$$

   Where L was the length of the slab and E_{epoxy} was approximated. Random checks were conducted and in all instances the actual elongations were close to the theoretical.

2. Check for other sources of prestress losses, such as joints not closing completely.

3. Loss of epoxy coating on strands due to abrasion from edge of corrugated metal PT duct as well as inside the duct.

4. Check for leaks around ends of PT ducts, couplers should have adequate seal to contain grout.

5. Inspect LCB-RS grades to ensure panels sit flush with adjacent roadway.

6. Contractor needs to find a better way to fasten the foam pad for isolation joint to prevent from coming out in case underslab grout makes its way to the isolation joint.

7. Check for sag in panels coming from precast yard. Check how many panels are stacked. Also, check to ensure adequate dunnage.

8. Spalling due to rough handling of panels during installation and demolition.

9. Varying isolation joint widths at some locations. The existing joints were not consistent and that led to different widths in an excavation. This resulted in isolation joint widths of up to 2.5” after precast panel was installed.

INSTALLATION INNOVATIONS

As the project progressed through construction and the contractor became more and more comfortable with the installation operation, it became apparent that we needed to demonstrate the versatility of precast concrete pavement. Placing post-tensioned pavement on tangent sections was fine, but not many projects have straight alignments without overhead structures. Therefore in an effort to demonstrate the usefulness of precast concrete pavement we decided to apply it in other venues. Below is a list of the innovations we implemented successfully.

1. The installation of PPCP under a structure. (See figure 18) Panels were cast smaller to an 8' length by 12' width for ease of handling under an overcrossing. A total of 27 panels were installed and post-tensioned (216') in a single 10-hour night shift.

Figure 18 - PPCP installation under a structure (17' clearance)

2. The fabrication of tapered panels to correct varying width joints. In a few locations lane widths weren't the standard 12' dimension, but reduced to 11' 6", therefore the precaster was asked to cast tapered panels to accommodate a new sawcut to a standard 12' lane width. Tapered panels were cast carry the joint out and increase the lane width to 12'. The layout of a tapered panel is shown in figure 19.

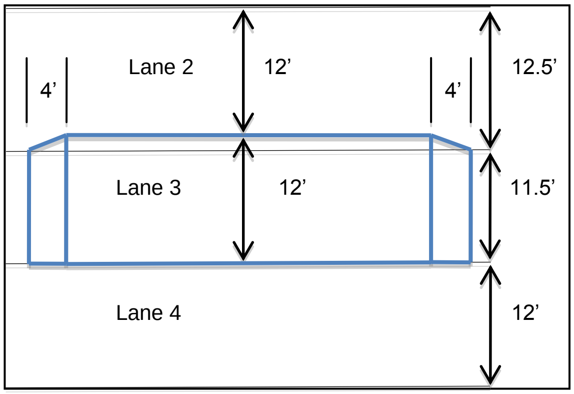


Figure 19 - Tapered panels to accommodate varying lane widths and installed tapered panel (6" over a 4' length).

3. The fabrication of custom fit panels (JPPCP) to accommodate varying lane widths. There were several instances where the lane widths varied slightly from 12' to 12' 2". We quickly found out that we could not use a "one size fits all" panel, but rather custom fit panels to fit varying lane widths. Originally Caltrans agreed to use a fixed 11'11" width panel to fit 12' wide excavations. As the project progressed, we decided to cast two different dimensions, 11'11" and 12' wide panels to accommodate the varying widths.

4. The installation of JPPCP panels on curved sections. JPPCP panels were installed in curved areas whose radius ranged from 10000' to 3200'. Panels were fabricated in a casting bed that had flexible siderails and adjustable bulkheads.

CONCLUSION

The preceding paper provides an overview of the design and construction of the largest precast concrete pavement project done in the United States to date. Although the innovation implemented on the Rte 680 project is the first ever done in the San Francisco Bay region, we feel this project sets the standard for others to follow nationwide.

Caltrans will continue to monitor the performance of the PPCP and JPPCP through nondestructive means and instrumentation. Currently, Caltrans has set up an instrumentation plan to monitor prestress losses as well as the base to panel interaction. Those results will be published in a separate report.

It is important to note that while precast pavements provide a solid alternative to PCC rehabilitation; it by no means is intended to replace other forms of concrete pavement repair. The use of precast concrete pavement is site specific and must meet the needs of the owner/operator.

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