Engineering a better road: Use of two-way prestressed, precast concrete pavement for rapid rehabilitation

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- Rapid, durable roadway rehabilitation is essential for today's aging highway system.
- Current work windows for road repair and rehabilitation are sometimes as short as four to five hours. The performance of rapid-strength concrete rehabilitation has proved inadequate.
- This paper discusses the use of two-way pretensioned precast concrete pavement to rehabilitate a highway in the San Francisco Bay Area.

The aging of the U.S. highway system necessitates rapid, durable roadway rehabilitation. Current work windows for road construction crews are sometimes as short as 4 to 5 hours.

The California Department of Transportation (Caltrans) typically rehabilitates concrete pavement using rapid-strength concrete. These mixtures achieve compressive strengths of about 2500 psi (17 MPa) in 1.5 hours. It is common to add water-reducing admixtures to a mixture to expedite strength gain.

However, projects completed over the past decade using rapid-strength concrete have underperformed and required further repairs and maintenance. There are instances in which rapid-strength concrete 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 rapid-strength concrete and, in many instances, continue to do so. An alternate approach to concrete rehabilitation had to be investigated, or steps were going to be taken to possibly overlay California's concrete roadways with hot mix asphalt.

After years of conventional rapid-strength concrete rehabilitation, two-way prestressed, precast concrete pavement was used to rehabilitate Route 680 in the San Francisco Bay Area. The project incorporated a combination of jointed precast, prestressed concrete pavement and precast, posttensioned concrete pavement on a large scale and was completed on October 12, 2012.

The project

The Route 680 project is 35 mi (56 km) east of San Francisco, Calif., in the San Ramon Valley. It entailed the rehabilitation of 12.5 mi (20 km) of existing concrete roadway.

Existing roadway

The existing roadway was constructed in the 1960s. The pavement section was typically 8 to 9 in. (200 to 230 mm) of concrete, layered underneath with 4 to 5 in (100 to 125 mm) of cement treated base and 12 to 14 in. (300 to 360 mm) of aggregate subbase.

Following are the geometrics of Route 680:

- eight-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 comprising 12 ft (3.7 m) hot mix asphalt pavement with an 11 ft (3.4 m) hot mix asphalt inside shoulder
- lanes 2, 3, and 4 comprising 12 ft (3.7 m) concrete pavement over 40 years old
- outside shoulder variance from 8 to 12 ft (2.4 to 3.7 m) hot mix asphalt pavement

Rehabilitation strategies for existing concrete pavement

Alcosta Boulevard to Diablo Boulevard (post mile 0 to 7.5):

- 0.65 ft (200 mm) mill and fill of existing lane 1 and outside shoulder with hot mix asphalt
- 0.2 ft (60 mm) mill and fill of inside shoulder with hot mix asphalt
- cast-in-place jointed concrete pavement for lane 4
- precast, posttensioned concrete pavement slab replacement for lanes 2, 3, and 4 (at on- and off-ramp tapers)
- jointed precast, prestressed concrete pavement panel slab replacement for lanes 2 and 3

Beyond Diablo Boulevard (post mile 7.5 to 12):

- crack, seat, and overlay of existing concrete pavement (comination of 6 in. [150 mm] hot mix asphalt and rubberized hot mix asphalt)

Before the precast concrete project began, there had been some maintenance work, including two grinding projects and a minor skin patch of hot mix asphalt to correct poor ride quality in the areas of concrete pavement rehabilitation between post mile 0 and 7.5, which is the focus of this paper.

Project delivery challenges

The initial concept of using precast concrete panels as an alternative form of rehabilitation came in 2005 at a pavement workshop. A forensic investigation had just been conducted for a recently completed project using rapid-strength concrete. The rapid-strength concrete exhibited premature distress, though it initially met the performance requirements outlined in the specifications. A similar pattern was noticed on other rapid-strength concrete projects, and the material durability was questioned. A more durable alternative approach was required.

The idea of using precast concrete pavement was intriguing, and part of the Route 680 project would be ideal for such an approach. The project team researched this application by attending conferences and workshops, then approved the concept and developed draft plans and specifications. Specifications from projects in Virginia and Southern California were used as templates.

There were some reservations about precast concrete pavement. There were concerns about constructability and cost, and it was suggested a small pilot project be done first. These were legitimate concerns, but proof of its performance and relative ease of construction were provided in published reports, and a life-cycle cost analysis demonstrated its cost effectiveness. Eventually, precast concrete was approved for this project, and in late 2009 the project was programmed and funded.

A meeting with local general contractors and precast concrete fabricators, as well as representatives from PCI and the National Precast Concrete Association (NPCA) was held to introduce the precast concrete pavement project. It was important to develop a partnership between Caltrans and industry to work together on this project and others like it.

A specification writing team comprised Caltrans pavement designers and construction engineers was established and met weekly to develop specifications for the project. Two specifications were written, one for each precast concrete system.

The plans and specifications for this project were modeled after those of the Virginia Department of Transportation's Interstate 66 precast concrete pavement project. Plans were developed for the precast, posttensioned concrete pavement system to go with its respective specification, and a performance specification was written for the jointed precast, prestressed concrete pavement system.

Two value analysis studies were conducted at different stages of the project delivery process to ensure the best strategy was being pursued. Team members in a value analysis study evaluated strategies for practicality, cost effectiveness, and environmental impacts. A consultant served as facilitator and summarized the findings and conclusions of the team. In both studies, the precast concrete pavement alternative was deemed the most cost-effective, long-lasting alternative for the pavement rehabilitation.

Pavement evaluation

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

Initial field condition surveys were done to evaluate the pavement. Distressed pavement was identified on plan sheets, and the limits of precast concrete pavement were identified. The field surveys were done to identify concrete exhibiting distress in the form of longitudinal and transverse cracking, joint deficiencies, surface defects, spalling, roughness, and faulting. The Caltrans *Maintenance Technical Advisory Guide for Rigid Pavements*[1] and the Caltrans *Slab Replacement Guidelines*[2] were used as reference documents. In addition to identifying distressed, cracked concrete, concrete exhibiting the potential for failure in the next five years was identified.

Falling weight deflectometer tests were conducted to evaluate the performance of the underlying subbase so the stressing loads during posttensioning of the epoxy-coated steel strands could be determined. No coring was performed as part of the pavement evaluation.

Original design details

As mentioned, the precast concrete pavement concept used both posttensioned and jointed pavement systems.

Because California uses a rigid base under its entire rigid pavement, the structural section incorporated a rapid-setting lean concrete base to support the precast concrete pavement. The lean concrete base uses Type III portland cement and is designed to achieve a compressive strength of 725 psi in 4 hours.

The concrete mixture designs for both precast concrete systems followed requirements in the Caltrans *Standard Specifications*[3] and used Type II portland cement. All parameters were the same, except that fiberglass microfibers were required in the precast, posttensioned concrete pavement system. The microfibers were included to provide secondary reinforcement and limit shrinkage cracking initially after the panel was cast.

The precast, posttensioned concrete pavement system followed the design methodology outlined by the Federal Highway Administration[4] and is as follows:

- 8 ft (2.4 m) panel length
- 12 ft (3.6 m) panel width
- use of joint panels, base panels, and central stressing panels for posttensioning
- blockouts on top of panels for access to posttensioning strands
- six 1 in. (25 mm) diameter posttensioning ducts to accommodate one strand each
- possttensioning strands stressed to 5600 psi (39 MPa) (80% of ultimate tensile strength)
- minimum precast, posttensioned concrete pavement length of 64 ft(19.5 m) and maximum of 152 ft (46.3 m)
- longitudinal isolation joints (panels were not tied to adjacent lane)

Figure 1 shows a schematic of the original precast, posttensioned concrete pavement layout (or a one-slab layout).

The jointed precast, prestressed concrete pavement system was designed by the contractor because several proprietary systems were available. Performance-based specifications and guidelines addressing minimum requirements of concrete, steel, and load transfer devices were provided.

Precast concrete pavement design changes

The precaster and contractor proposed design changes to the precast, posttensioned concrete pavement system at the initial preconstruction meeting. The changes would facilitate installation and optimize production in the field. The changes were accepted because Caltrans believed the mod-

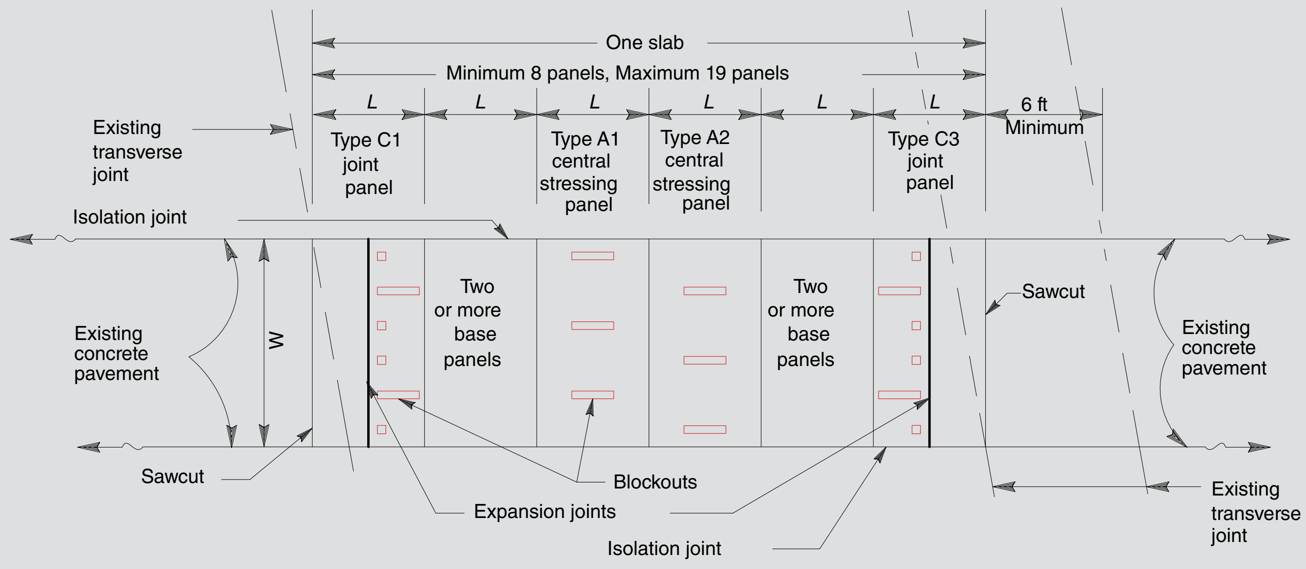

Figure 1. Original precast, posttensioned concrete pavement slab layout. Note: A slab is a series of panels *L* = length of panel. 1 ft = 0.305 m.

ifications improved the design and would lead to increased productivity in the designated night time work windows. The following are the key design changes proposed for the precast, posttensioned concrete pavement system:

- 8 to 36 ft (2.4 to 11 m) panel length
- no blockouts on top of panel, blockouts at end of panels
- three 2 in. (50 mm) diameter posttensioning ducts to accommodate two strands per duct (Fig. 3)
- recessed pocket to fit compressible foam gasket (**Fig. 2**)
- two-way pretensioning in the longitudinal and transverse directions
- minimum precast, posttensioned concrete pavement length of 64 ft (19.5 m) and maximum of 216 ft (65.8 m)
- 4 ft (1.2 m) drop-in panels (with dowel slots on both ends) at ends of precast, posttensioned concrete pavement section

Similarly, the precast concrete pavement manufacturer developed a proprietary system for the jointed precast, prestressed concrete pavement, including the use of pretensioning in both longitudinal and transverse directions and dowel bars as the load transfer mechanism.

The benefits of the changes included a reduction in the number of joints due to the longer panel lengths as well as the elimination of blockouts on the tops of panels. **Figure 3** shows a typical six-panel (maximum 36 ft [11 m] long panels) precast, posttensioned concrete pavement layout.

However, the changes did cause some concerns. The longer panels had to fit in the excavated areas within the tolerances specified, particularly along the isolation joint. Properly posttensioning the six epoxy-coated steel strands and handling of the larger panels were additional concerns. There was some concern about the long-term performance of the 4 ft (1.2 m) drop-in panels because they were susceptible to cracking due to the number of slots on either side of the panel (Fig. 3). However, the potential benefits in the design modifications outweighed the concerns.

Installation of the pavement systems

The installation procedure was established by the contractor and was loosely based on the procedure outlined in the special provisions of the contract.

1. Demolish existing pavement. This includes the removal of distressed pavement and underlying base (**Fig. 4**). Most base under concrete pavement in California is rigid, and the Route 680 project was no exception. The existing base comprised 4 to 5 in. (100 to 125 mm) of cement treated base.

2. Grade and compact. Grade and proofroll the subbase material in preparation for rapid-setting lean concrete base material. Perform compaction tests to verify relative compaction levels.

Figure 2. Keyway and 2 in. (50 mm) diameter posttensioning ducts between precast, posttensioned concrete pavement panels.

3. Drill slots in existing pavement for dowels, place joint filler material, and set grade for lean concrete base. Place $^1/_2$ in. (13 mm) thick foam filler to separate lean concrete base from adjacent lanes in the longitudinal direction because the plans called for longitudinal isolation joints. Set up rails to ensure the lean concrete

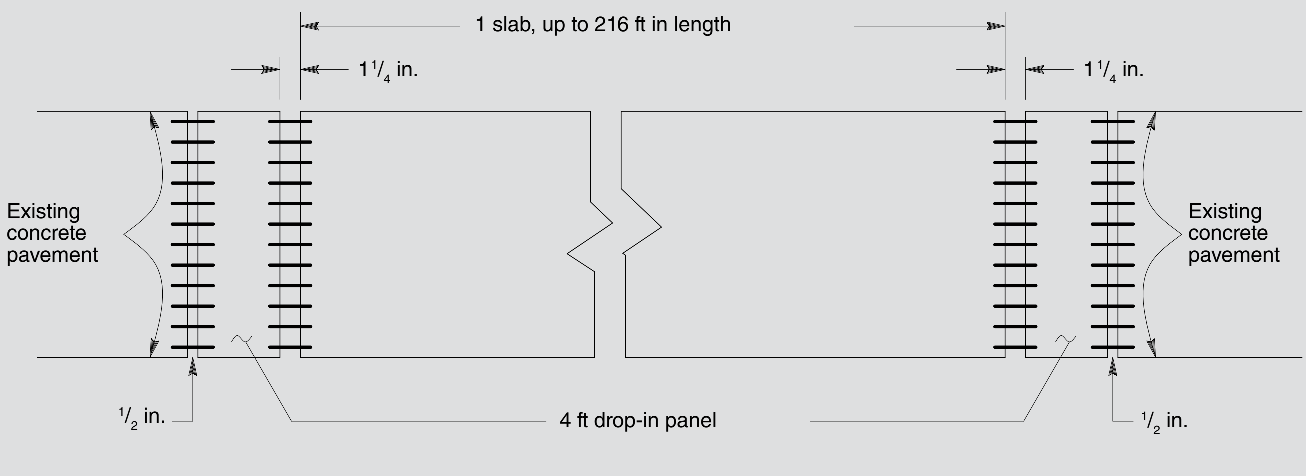

Figure 3. Modified precast, posttensioned concrete pavement layout and permanent 4 ft drop-in panel. Note: A slab is a series of panels. 1 in. = 25.4 in.; 1 ft = 0.305 m.

Figure 4. Demolition of distressed pavement and underlying base.

base is graded with appropriate cross slope. Use gang drill (**Fig. 5**) to ensure longitudinal alignment when dowels are inserted (hand drilling can lead to a hole that is not aligned properly).

4. Place and grade the rapid setting lean concrete base (**Fig. 6**). Place and grade a 6 in. (150 mm) layer of lean concrete base for the precast, posttensioned concrete pavement. The lean concrete base must achieve a compressive strength of 725 psi (5 MPa) before opening to traffic (typically 4 hours).

5. Place bond breaker and joint filler and install the precast, posttensioned concrete pavement panel. Once the lean concrete base reaches a compressive strength of 100 psi (0.7 MPa) (at approximately 2 hours), place the bond breaker and install the precast, posttensioned concrete pavement panel (**Fig. 7**). Feed posttensioning strands (six permanent epoxy-coated and two temporary uncoated). Apply temporary posttensioning after the second panel is placed.

6. Apply final posttensioning and place temporary 4 ft (1.2 m) drop-in panels. After the last panel is placed, remove the temporary strands and perform the final posttension on epoxy-coated strands. Place the temporary drop-in panel until the next night (**Fig. 8**). The roadway is opened to traffic at the end of the work shift.

7. Posttension the duct and grout the underslab. Remove the temporary drop-in panel and pump grout into the posttensioning duct and inject underslab grout. Underslab grout is not pressure injected because it is only used to fill voids or minor undulations on the lean concrete base, resulting in a smooth surface with contact throughout the base of the precast concrete panel.

8. Install dowels in existing pavement, place the permanent 4 ft (1.2 m) drop-in panel, and place grout for dowel bar slots. After the grouting of all of the posttensioning ducts and underslab is complete, permanent drop-in panels are placed at ends and slots grouted.

Figure 5. Drilling dowel slots.

The precast, posttensioned concrete pavement slab section is complete and opened to traffic (**Fig. 9**).

9. Grind and seal joints after precast concrete pavement installation is complete.

The installation procedure for the jointed precast, prestressed concrete pavement system is similar to that of the precast, posttensioned concrete pavement (steps 1 to 5), except that in step 5 a jointed precast, prestressed concrete pavement is placed in lieu of a precast, posttensioned concrete pavement panel. The jointed precast, prestressed concrete pavement panel has a design similar to the precast, posttensioned concrete pavement system, except without posttensioning, hence the posttensioning strands and 4 ft (1.2 m) drop-in panels are not part of the design. However, analogous to the precast, posttensioned concrete pavement system, dowels are inserted in existing pavement before placing jointed precast, prestressed concrete pavement panel. All jointed precast, prestressed concrete pavement panels are cast to fit excavations, and dowel bar slots are grouted the same night. The contractor performed underslab grouting on several panels at once, typically once a week.

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 concrete system, and dimension of panels desired. It was paramount that the precaster provide a quick turnaround based on the production rates required. Caltrans provided quality control personnel on-site daily to ensure that panels met the requirements of the contract. This was important because it became an integral part of the installation schedule.

Figure 6. Placing and grading lean concrete base.

The concrete mixture was another challenge. The precast, posttensioned concrete pavement system required the use of fiberglass microfiber reinforcement. Initially there were inconsistencies with the workability of the mixture, which ranged from wet to dry to sticky. This problem did not exhibit itself in the mixture for the jointed precast, prestressed concrete pavement, which did not contain fiber. The precaster worked with industry experts and eventually developed a consistent workable mixture incorporating fiber.

Figure 7. Installation of precast, posttensioned concrete pavement panels.

Figure 8. Final posttensioning and placement of temporary drop-in panel.

Precision during fabrication of the precast, posttensioned concrete pavement and jointed precast, prestressed concrete pavement panels was critical. The precaster had to ensure that the posttensioning ducts and blockouts of the precast, posttensioned concrete pavement lined up precisely from one panel to the next. In addition, it was critical that the dowels line up accurately in both precast concrete systems. This was achieved through use of precision-built steel bulkheads with predrilled holes for anchoring the blockouts and dowels.

Weather was a factor because the precaster's fabrication bay was not enclosed. A mobile shed was developed and used as a traveling cover. Also, the precaster covered the panels with tarp after placing and tining them and used surface sealers and curing agents to limit drying and cracking. This was beneficial because Northern California experienced an unusually long rainy season combined with high winds. As the temperature rose, the precaster adjusted the placement schedules to start earlier in the day to avoid the heat.

Another challenge was developing curved panels for jointed precast, prestressed concrete pavement. The precaster specifically designed a side form that allowed placement of a bend in the panels to accommodate curves in roadway alignment. A panel was cast to fit an 800 ft (240 m) radius curve to demonstrate the adaptability of precast concrete pavement.

Installation challenges

As the first project of its kind in northern California, the installation of these systems came with its set of challenges. Following is a list of observations and challenges faced during the entire precast, posttensioned concrete pavement and jointed precast, prestressed concrete pavement installation.

- Elongation of the posttensioning strands after stressing was observed. The following relationship compares theoretical values with actual elongation measured in the field:

$$\delta = \frac{PL}{E_s A_s + E_e A_e}$$

$$= \frac{(44{,}000)(L)(12)}{\left(28\times10^6\right)\left(\pi\times\frac{0.6^2}{4}\right)+\left(35\times10^5\right)\left(\frac{0.025^2}{4}\right)}$$

where

δ = deformation

P = load

L = length of the slab

E_s = modulus of elasticity of steel

A_s = surface area of steel

E_e = modulus of elasticity of epoxy (approximated)

A_e = surface area of epoxy

Random checks were conducted, and in all instances the actual elongations did not exceed 10% of the theoretical.

- Other sources of prestress losses occurred, such as joints not closing completely.

- Loss of epoxy coating on strands occurred due to abrasion from edges of corrugated metal posttensioning ducts as well as inside the ducts.

Figure 9. Completed precast, posttensioned concrete pavement.

- Leaks developed around ends of posttensioning ducts. Couplers should have adequate seal to contain grout.
- Lean concrete base grades had to be inspected to ensure that panels sit flush with the adjacent roadway.
- Improvements were needed for fastening foam filler along the isolation joints to prevent foam from being displaced by underslab grout. A nail gun or adhesive was used to ensure proper installation.
- Sag developed in some panels coming from the precast concrete yard, which was remedied by limiting the number of panels in a stack and using adequate dunnage.
- Spalling occurred due to rough handling of panels during installation and demolition.
- There were 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 in. (64 mm) after the panel was installed.

Installation innovations

As the project progressed through construction a goal was established to demonstrate the versatility of precast concrete pavement. There are not many projects that have straight alignments without overhead structures. Therefore, to demonstrate the usefulness of precast concrete pavement, it was applied in other venues. Following is a list of the innovations successfully implemented:

- Precast, posttensioned concrete pavement was installed under a structure (**Fig. 10**). Smaller panels were cast (8 ft [2.4 m] long × 12 ft [3.6 m] wide) for ease of handling under an overcrossing. A total of 27 panels were installed and posttensioned (216 ft [65.8 m]) in a single 10-hour weekend night shift.
- Tapered panels were fabricated to correct varying-width joints. In a few locations, lane widths were reduced to 11 ft 6 in. (3.5 m) from the standard 12 ft (3.7 m). Therefore, tapered panels were cast to accommodate a new sawcut to a standard 12 ft lane width. Tapered panels were cast to carry the joint out and increase the lane width to 12 ft.

Figure 10. Precast, posttensioned concrete pavement installation under a structure (17 ft [5.2 m] clearance).

- Jointed precast, prestressed concrete pavement panels were installed in curved areas with radii ranging from 10,000 to 3200 ft (3000 to 980 m). Panels were fabricated in a casting bed that had flexible siderails and adjustable bulkheads.

Conclusion

This paper provides an overview of the design and construction of a large precast concrete pavement project completed in the United States. Although the innovation implemented on Route 680 is the first used in the San Francisco Bay region, it sets a standard for others to follow nationwide due to its application in a typical nighttime highway closure work period.

The performance of the precast, posttensioned concrete pavement and jointed precast, prestressed concrete pavement will be monitored periodically through nondestructive means and instrumentation. An instrumentation plan was set up during installation to monitor prestress losses as well as the base-to-panel interaction. Those results will be published in a separate report.

Although precast concrete pavements provide a solid alternative to cast-in-place concrete pavement rehabilitation, they are not 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 and operator.

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Notation

A_e = surface area of epoxy

A_s = surface area of steel

E_e = modulus of elasticity of epoxy (approximated)

E_s = modulus of elasticity of steel

L = length

P = load

δ = deformation

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Abstract

The need for rapid, durable roadway rehabilitation strategies is one of the key aspects of today's aging highway system. Current work windows for road construction crews are sometimes as short as four to five hours. In these short work windows, state transportation agencies are required to maintain highways to endure the constant wear and tear from high traffic volumes and differing weather conditions.

The California Department of Transportation (Caltrans) rehabilitates concrete pavement exhibiting moderate distress using rapid-strength concrete. Rapid-strength concrete is used with or without dowels for load transfer, depending on the contiguous length of repair. The inadequacy of this approach led Caltrans to pursue a more effective means of repairing the deteriorating highway system.

After years of conventional rapid-strength concrete rehabilitation, two-way pretensioned precast concrete pavement was used to rehabilitate a highway in the San Francisco Bay Area. The project incorporates a combination of jointed precast, pretensioned concrete pavement and precast, posttensioned concrete pavement on a large scale and is nearing completion. Differences from other precast concrete projects in the United States are two-way prestressing (longitudinal and transverse directions), eliminating blockout pockets through the use of end stressing, reducing the number of posttensioning ducts, and casting and deploying panels ranging in length from 18 to 36 ft (5.5 to 11 m).

This paper discusses the challenges encountered during construction. In addition, this paper discusses innovations developed to addresses various issues encountered during construction.

Keywords

Panel, pavement, posttensioned, pretension, rehabilitation, slab.

Review policy

This paper was reviewed in accordance with the Precast/Prestressed Concrete Institute's peer-review process.

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