Precast Concrete Pavement Innovations

Technical considerations related to design, fabrication, and installation

by Shiraz Tayabji and Sam Tyson

Repair and rehabilitation of the aging highway infrastructure continues to be a challenging endeavor for all U.S. highway agencies. Thousands of miles of highway pavements need rehabilitation, yet many of these carry over 100,000 vehicles/day, including a large percentage of trucks. Extended lane closures must be therefore avoided to prevent compounding congestion—that means that rehabilitation work must be completed rapidly. While many projects have been completed using rapid-setting concrete, results have been inconsistent. Precast concrete pavements (PCPs) have been shown to be promising alternatives.

In the April 2017 issue of *CI*,[1] details were provided on the application of PCP for rapid rehabilitation of heavily trafficked hot-mix asphalt (HMA) and portland cement concrete pavements. As discussed in that article, PCP is being used to make intermittent, full-depth repairs of distressed concrete pavement joints and panels as well as for complete full-depth replacements of large contiguous areas of concrete or HMA pavements.

The current article presents details on technical considerations related to design, fabrication, and installation of PCP. It should be noted that PCP is a relatively new technology in the United States, as the first two full-scale projects were constructed in 2001. Since then, significant technological advances have been made that have increased panel installation productivity and reduced overall cost,[2] even though many projects are being constructed by contractors with no prior experience with PCP.

Technical Considerations

There are several different PCP systems available for intermittent repair and continuous applications. Although these systems may be different with respect to certain aspects of design, fabrication, and installation, they share many common features and requirements. The differences in the systems typically relate to how the load transfer is achieved at transverse joints and the provisions for placing the panel over the prepared base (support condition).

The key design and construction features for any PCP system include:

- Concrete requirements;
- Joint spacing;
- Support conditions;
- Load transfer at joints;
- Panel reinforcement and prestressing; and
- Panel production and installation rates.

Concrete Requirements

Concrete mixture requirements for PCP panels are similar to those specified by transportation departments for cast-in-place (CIP) concrete pavements. An advantage of PCP is that early-age concrete volume changes associated with drying shrinkage are not of significant concern, because these effects take place over a smaller panel length and typically before panel installation. It should also be noted that many of the concerns related to CIP concrete such as hot- or cold-weather placement, placement during rainfall, equipment breakdown, concrete delivery delays, and stop-and-go operations are not applicable to PCP panel fabrication. In other words, placement of concrete in well-monitored facilities is a significant benefit of using PCP.

A typical PCP concrete specification should include the following requirements[3]:

- Concrete strength (at 14 or 28 days):
  Flexural strength for design purposes—650 psi (4.5 MPa),
  Compressive strength for acceptance purposes—4000 psi (27.5 MPa);
- Maximum water-cementitious materials ratio (*w/cm*)—0.45 for pavement exposed to cycles of freezing and thawing, 0.50 for other pavements;
- Air content—As appropriate for the maximum aggregate size used and severity of exposure (climatic region), as defined in ASTM C94/C94M[4];
- Durability—Concrete must be durable and should not be susceptible to materials-related distress, such as alkali-silica reactivity (ASR), sulfate attack, or D-cracking; and

- Finish texture.

Mixture consistency should be the choice of the producer. While many producers successfully use mixtures that require vibration for consolidation, self-consolidating concrete (SCC) has also been used.

The strength at stripping the panel from the form is also an important consideration. To maintain daily panel production, precasters generally strive to strip panels about 16 hours after casting—many use steam curing to achieve rapid strength gain. The required concrete strength is determined by limiting panel stresses, based on a lifting stress analysis for specific panel dimensions and prestressing levels, to a value below the cracking strength. However, most precasters try to achieve concrete strength of at least 2500 psi (17.2 MPa) at about 16 hours of age or at the time of form stripping.

Joint Spacing

Joint spacing is an important design parameter for PCP. For isolated repairs, the transverse pavement joint spacing may be limited by the extent of the repair. For continuous applications, transverse pavement joint spacing is often based on traditional CIP pavement joint spacing but also may be limited by panel fabrication, shipping, and structural performance requirements.

Joint spacing details for PCP repair and continuous application include[3]:

- Intermittent repairs—PCP panels used for intermittent applications typically cover a single-lane width. The panel dimension in the direction of traffic may range from a minimum of 6 ft (1.8 m) to about 15 ft (4.6 m). The shorter panels are generally used to correct joint-related distress; and
- Continuous applications—PCP panels used for continuous applications can cover a single-lane width, with panel dimensions of about 12 to 13 ft (3.6 to 4.0 m), or a double-lane width, with panel dimensions of 24 ft (7.3 m) or more. Panels may also incorporate a shoulder segment. The panel dimension in the direction of traffic is generally 15 ft (4.6 m) for 8 to 10 in. (200 to 250 mm) thick panels, resulting in transverse joint spacing matching that of typical CIP jointed concrete pavement and which has provided good performance throughout the United States. PCP joint spacing can increase up to 20 ft (6.1 m) for 10 to 12 in. (250 to 305 mm) thick panels.

Overall Panel Support Condition

Base

For most PCP repair or rehabilitation (reconstruction) applications, support alternatives include reusing an existing base. An existing granular base may be reworked, trimmed, graded, and compacted; a thin bedding material can then be used to level the base grade. If not damaged in the process of removing the existing slab, an existing stabilized base (cement-treated soil or lean concrete) may be used as is. It also may be trimmed to accommodate the panel thickness. In either case, a thin bedding layer may be used to provide a level surface for setting the panels.

A new base may be needed if it is determined that the existing base will be damaged during existing slab removal or will not serve the long-term needs of the new PCP. This option is common when PCP is used to rehabilitate existing HMA pavements. The new base type may include dense-graded, free-draining granular base, or rapid-setting lean concrete base.

Many PCP applications, particularly in California, have successfully used rapid-setting lean concrete base material. The compressive strength requirements for this material are:

- 100 psi (0.7 MPa) minimum within 2 hours of placement to allow installation of panels;
- 500 psi (3.4 MPa) minimum at the time of opening to traffic; and
- 750 psi (5.2 MPa) minimum to 1200 psi (8.3 MPa) maximum at 7 days.

Bedding layer

The bedding layer (or interlayer) is important to ensure uniform contact between the bottom of a panel and the base—these two surfaces will not match each other perfectly. The choice of this interlayer material is affected by the way the panels are installed.

The bedding material may be[5]:

- A thin layer of cemented granular material or cemented sand for grade-placed systems (Fig. 1). Generally, the

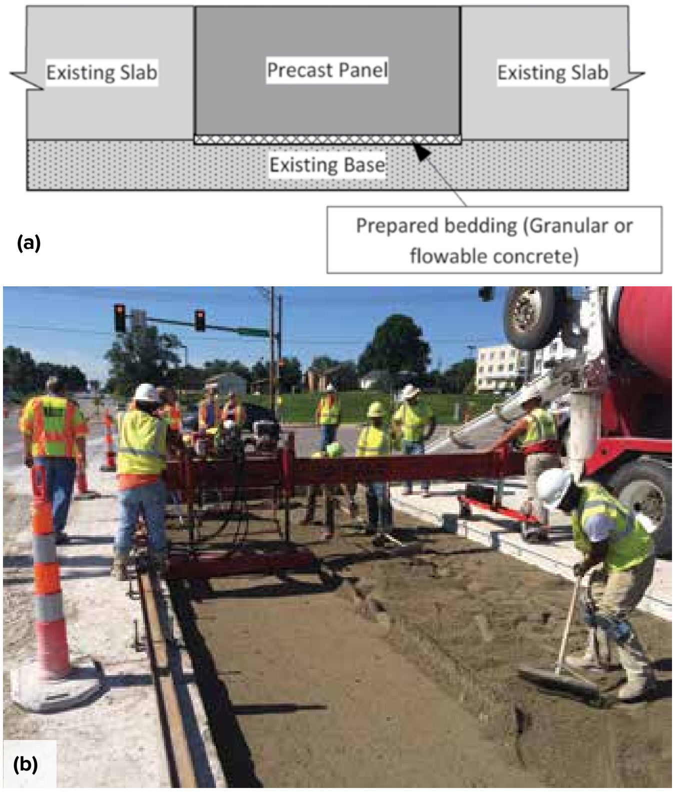

Fig. 1: Grade supported panel placement: (a) schematic; and (b) cement-treated bedding layer placement

bedding layer is placed about 1/2 in. (13 mm) over the base. Because this method provides little means for adjustment, surface grinding of the panels is normally required to meet pavement smoothness requirements; or

- Fast-setting flowable cementitious grout in conjunction with a panel leveling lift system for grout-placed systems. The grout fills the gap under the panel (1/4 in. [6 mm] < gap < 1/2 in.), shown in Fig. 2. The compressive strength requirement for the grout is about 500 psi at the time of opening to traffic and about 3000 psi (20.7 MPa) at 28 days. Because the level of the upper surface can be adjusted to match the adjacent pavement, surface grinding of the panels may not be necessary to meet smoothness requirements.

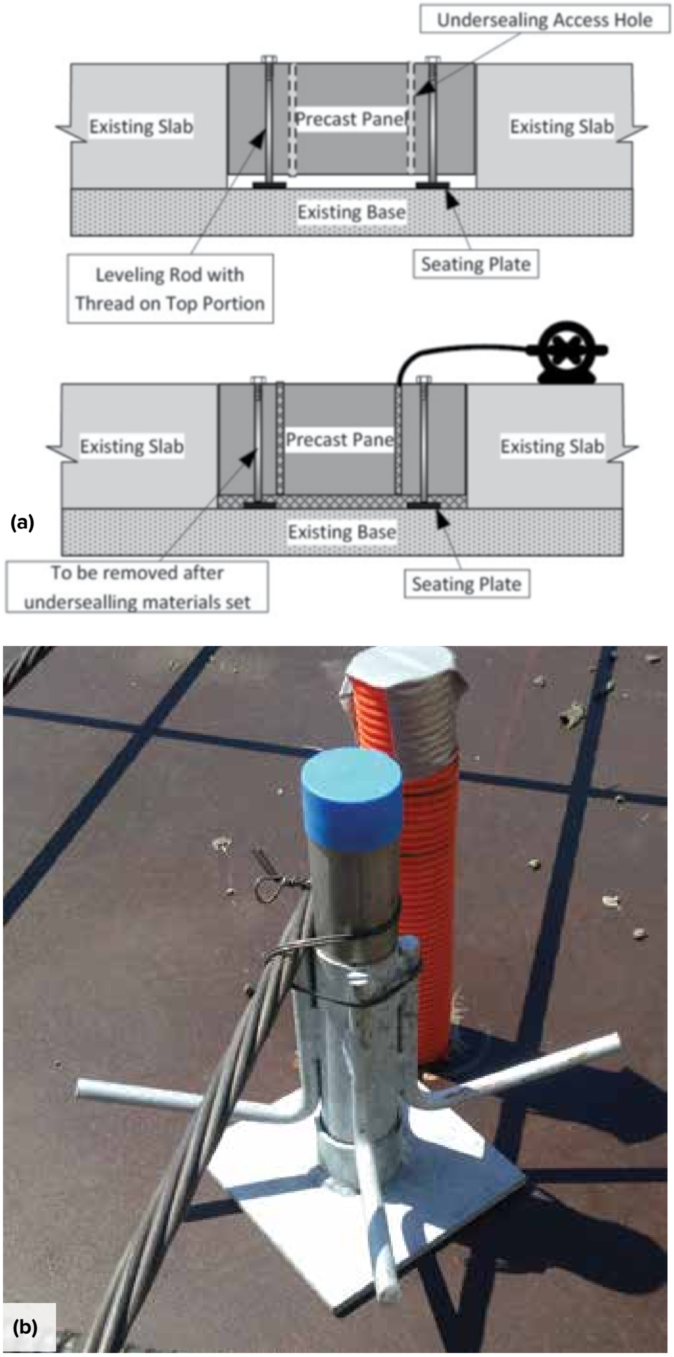

Fig. 2: Grout supported panel placement: (a) schematic; and (b) panel leveling lift system that also serves as a lifting insert

Subsealing

Subsealing is performed when using the cemented granular bedding layer to fill any voids that may exist under the slab panels. The subsealing does not strengthen the base or change any other characteristics of the base material. The subsealing materials are free-flowing and are introduced through uniformly spaced grout holes at the panel surface. For both subsealing and cementitious bedding materials, the compressive strength requirement is about 500 psi at the time of opening to traffic.[5]

Load Transfer at Transverse Joints

Load transfer at transverse joints is also an important design feature. Load transfer requirements for jointed PCP systems are much like the provisions for dowel bar retrofitting in existing concrete pavements. Essentially, load transfer is provided by dowel bars installed in slots fabricated along one transverse side of a panel.[6] One patented system comprises dowel slots formed in the bottom surface of the panel. Other systems have dowel slots formed in the top (riding) surface of the panel.

Dowel slot types

The surface slots typically incorporate a narrow mouth at the surface and may be fully open at the surface or open along a partial length of the slot. The following techniques/features associated with dowel bar slots are commonly used in the United States[6]:

- Dowel bar slots at the panel bottom—The proprietary Fort Miller Company (FMC) Super-Slab® system incorporates dowel bar slots at the slab bottom (Fig. 3). A flowable grout is used to fill the slots and the vertical gap along the four edges of the panel. The slot locations in a panel are positioned to match the locations of the projecting dowel

Fig. 3: Super-Slab® with dowel bar slots at bottom of panel

bars in an existing pavement or a new adjacent panel.

- Narrow-mouth dowel bar slots at the panel surface (Fig. 4)—The slots are about 1 in. (25 mm) wide at the surface and flare out to about 3 in. (75 mm) in width about 1 in. below panel middepth. The slots are up to 18 in. (460 mm) long for repair application and about 9 in. (230 mm) for continuous applications.

  For repair applications, the 18 in. long dowel bars are placed into the 18 in. long slots just before the slab is placed on the base/bedding. The bars do not project from the panel edge during panel installation. Later, 9 in. long predrilled holes in the existing pavement are partially filled with epoxy and the dowels are inserted into the holes by sliding them from the slots in the PCP panel.

  For continuous applications, 18 in. long surface slots are cast along one edge of the panel and 9 in. long surface slots are cast along the opposite edge. Just before panel installation, 18 in. long dowel bars are introduced into the 18 in. long slots. After the panel is placed, the dowel bars are slid into the 9 in. long slots in the previously placed panels.

  For either application type, the final step is filling the dowel bar slots with grout.

- Rapid Roadway System's Barra Glide® load transfer feature—In this system, dowel bars are preplaced in 18 in. long narrow-mouth slots that are partially open at the surface (Fig. 5). After the panel is installed, the dowel bar is pushed into a 9 in. long circular or oblong hole in the adjacent panel or existing slab. The dowel bar slots are then patched (the material is discussed in a following section).
- California generic teardrop surface slot feature—This system is like the system using flared slots, but the slot shape may be different. A version of the slot shape is shown in Fig. 6(a). Surface slots are located on one transverse side of each panel, and dowel bars are embedded at the opposite edge. During panel installation, the panel is lowered to about its final elevation and then shifted horizontally so that the dowels advance into the flared-out bottom portion of the slot in the previously placed panel, as shown in Fig. 6(b). The slots are then patched.

Fig. 4: A repair made using the Illinois Tollway version of a surface slot system

Dowel bar features

Dowel bars used in highway pavement construction are smooth, cylindrical, solid steel bars conforming to ASTM A615/A615M[7] or AASHTO M 31M/M 314.[8] In addition, corrosion protection is typically provided in the form of a fusion-bonded epoxy coating. Dowel bar features critical to long-term PCP performance include[6]:

Fig. 5: Barra Glide® dowel system, showing the partially open narrow slots at the surface of the precast panel. Here, the worker is using a small diameter bar to push a dowel into the adjacent panel

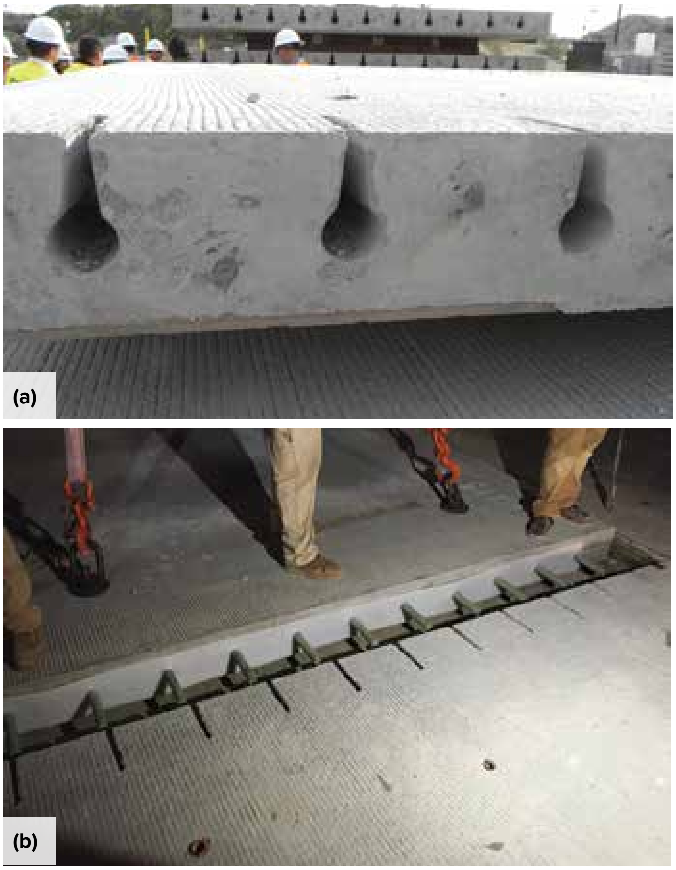

Fig. 6: California teardrop-shaped surface slot: (a) shape of slots; and (b) panel installation

- Dowel diameter—For precast panels less than 10 in. thick, a dowel diameter of 1-1/4 in. (32 mm) is recommended. For slab thicknesses between 10 and 14 in. (250 and 360 mm), a dowel diameter of 1-1/2 in. (38 mm) is recommended;
- Dowel length—Typical dowel length used in the United States for CIP paving is 18 in. However, because precise locations of the dowel bars are known in PCP, the use of 15 in. (380 mm) long dowel bars is considered adequate, allowing for embedment of at least 7 in. (180 mm) at each side of the joint and accounting for a joint width of up to 1/2 to 1 in.; and
- Dowel spacing—Dowels are typically placed at a spacing of 12 in.; however, a cluster of four dowels per wheel-path, spaced at 12 in., is considered adequate for both intermittent and continuous applications.

Dowel bar slot patching material

The dowel bar slots may be patched right after the panel installation—that is, during a single lane closure or during the next night's lane closure. In any case, the joint slot patching material needs to develop strength rapidly. Typical strength requirements are 2500 to 3000 psi within 4 hours or by the time of opening the PCP section to early-morning traffic. The dowel bar slot patching materials are typically rapid-setting proprietary materials and may be free-flowing cementitious or polymer-based, with or without aggregate beneficiation.

Panel Reinforcement

To mitigate any cracking that may develop due to lifting and transporting operations, a double mat of reinforcement is typically used for jointed PCP panels. While the reinforcement is not necessary for pavement performance, it will keep any cracks that develop tight, thus extending the service life of the panels. The amount of reinforcement is typically at least about 0.20% of the panel cross-sectional area in both directions, depending on the panel dimensions. For pretensioned panels, a single layer of reinforcement, transverse to the pretensioning strands, is used.

All steel used in the precast pavement system must be protected against corrosion. The requirements for steel and steel cover should follow established highway agency practices. Typical reinforcement arrangement for a jointed PCP panel is shown in Fig. 7. Views of a long outdoor prestressing bed capable of fabricating over 30 panels per shift is shown in Fig. 8.

Fig. 7: Typical reinforcement layout *(photo courtesy of FMC)*

Panel Production and Installation Rates

The panel installation rate is one of the most critical factors for considering use of the PCP technology, as it sets lane closure requirements. The panel installation activities conducted during a given lane closure—typically from about 8 p.m. to about 5 a.m. the next morning—include[3]:

- Existing pavement removal;
- Drilling and grouting of the dowel bars for repair applications (based on system design);
- Preparing the base and bedding layer;
- Placing the panel(s);
- Underslab grouting for systems using leveling lifts or subsealing;
- Grouting/patching of slots; and
- Installing transition sections between the PCP and existing pavements—for a given lane closure for continuous application, a temporary transition is required at the end of the PCP installation.

To execute intermittent repairs located within a given lane closure area, the typical production rate is about 15 to 20 panels per nighttime lane closure. Ideally, two crews are used for repair installations: one crew preparing the repair area, including drilling and epoxy-grouting the dowel bars, and the second crew installing the panels.

For continuous applications, a higher panel installation rate per nighttime lane closure can be achieved because work is performed along a longer rehabilitation area. The typical production rate for continuous panel installation is about 40 to 50 panels per night or about 600 to 800 ft (183 to 245 m) of installed length. Greater production can be achieved using longer panels.

Summary

In less than 16 years of experience with PCP systems, significant advances have been made in both design and construction. Current PCP systems can be installed rapidly and can be expected to provide long-term service. The installed cost of a typical PCP rehabilitation project has

Fig. 8: Panel production using outdoor prestressing beds: (a) view of a prestressing bed; (b) panel hardware including prestressing tendons; and (c) concrete placement

decreased dramatically—50% or more—over the past 16 years. PCP is therefore now very cost-competitive with traditional rehabilitation methods. However, as with any new technology, there is room for new systems and refinements to improve speed of panel installation and to reduce overall cost.

Producers and contractors with no prior PCP construction experience are successfully installing precast panels. As PCP technology is gaining wider acceptance in the United States, we can expect more to successfully enter the field.

Acknowledgments

The information presented in this article was developed under FHWA contract DTFH61-13-C-00028.

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Selected for reader interest by the editors.

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