SHRP2 PROJECT R05 ON PRECAST CONCRETE PAVEMENTS: TECHNOLOGY OVERVIEW AND SOME TECHNICAL CONSIDERATIONS

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ABSTRACT

The use of precast concrete pavement (PCP) is an emerging technology in the US for application to rapid repair and rehabilitation of existing pavements. The technology is currently being applied in high volume, congested urban/suburban roadways where lane closures are very difficult and work on the roadways can only be conducted at nighttime during short lane closures. The demonstration and production use of the PCP technology began in earnest during 2001. Over the last 10 years, several US highway agencies have begun to implement this technology and a few others have constructed demonstration projects. The implemented PCP systems include proprietary as well as non-proprietary systems and components. Recently, The Strategic Highway Research Program 2 (SHRP2) sponsored a study, Project R05 on Modular Pavement Technology, aimed at developing the necessary information and guidelines that will help encourage the rapid and successful adoption of this new technology.

The results of the study indicate that the PCP technology in the US is maturing with an increase in projects constructed every year and an increase in user agencies specifying use, or allowing use as an alternate for concrete pavement repair and pavement rehabilitation (reconstruction or resurfacing). The performance of projects constructed in the US indicates that sufficient advances have been made to reliably achieve the following four key attributes of PCPs: constructability, concrete durability, effective load transfer at joints, and effective panel support condition.

This paper presents a summary of the work performed under the SHRP2 Project R05 and reports on potential refinements to the PCP technologies.

Keywords: Concrete pavements, Pavement construction, Pavement design, Precast concrete, Precast concrete pavements

INTRODUCTION

Pavement rehabilitation and reconstruction are major activities for all U.S. highway agencies. These activities have significant impact on agency resources and are a source of traffic disruptions caused by extensive and extended lane closures. Traffic volumes on the primary highway system, especially in urban areas, have increased tremendously over the last 20 years, leading in many instances to an earlier-than-expected need to rehabilitate and reconstruct highway pavements. Pavement rehabilitation in urban areas is resulting in serious challenges for highway agencies because of construction-related traffic congestion and safety issues. Many agencies also continue to wrestle with the age-old dilemma: longer delays now and longer service life versus shorter delays now but shorter service life.

In recent years, many agencies have started investigating strategies for pavement rehabilitation and reconstruction that are faster but can produce durable pavements. Expedient rehabilitation that results in a shorter pavement lifespan is no longer considered acceptable by most highway agencies. A promising alternative rehabilitation strategy is the effective use of modular pavement technologies, principally precast concrete pavement (PCP) systems, which provide for rapid repair and rehabilitation of pavements and also result in durable, longer-lasting pavements. Rapid construction techniques can significantly minimize the impact on the driving public, as lane closures and traffic congestion are kept to a minimum. Road user and worker safety is also improved by reducing road users' and workers' exposure to construction traffic.

PCP technologies have been investigated sporadically over the last 40 plus years. In the early years, the technology was looked into either as a matter of technical curiosity, that is, to learn whether PCP technology was technically feasible, or as an emergency repair technique with minimal concerns regarding long-life performance. No serious attempts had been made until more recently to fully develop the technology as a cost-effective strategy or to implement the technology on a production basis. Today, the maturing highway system in high-traffic-volume urban corridors makes the need for timely pavement repair and rehabilitation urgent, and highway agencies are looking at innovative technologies, including PCP technologies that require shorter lane closures and result in economical, long-life pavements that will not require major interventions for repair or rehabilitation during their service life. Over the last 10 years, new PCP technologies have been developed whose use is becoming technically feasible and economically justifiable on a project-by-project basis.

BACKGROUND

PCPs use prefabricated concrete panels for rapid repair of existing concrete pavements and for rehabilitation of existing concrete and asphalt pavements. PCPs may also be used for reconstruction or as an overlay application. PCP applications include but are not limited to isolated repairs, intersection and ramp rehabilitation, urban street rehabilitation, and rehabilitation of longer mainline pavement sections. A generic definition of a PCP system is as follows:

> *Precast pavement systems are fabricated or assembled off-site, transported to the project site and installed on a prepared foundation (existing pavement or regraded foundation). The system components require minimal field curing or time to achieve strength before opening to traffic*.

The specific advantages of using PCPs versus cast-in-place (CIP) concrete pavements include the following:

1. Better quality concrete - There are no issues related to fresh concrete delivery or paving equipment operation, including issues related to poor concrete quality, concrete consolidation and over-finishing of the concrete surface.
2. Better concrete curing conditions - Curing of the precast panels takes place under controlled condition at the precast concrete plant.
3. Minimal weather restrictions on placement - The construction season can be extended as panels can be placed in cooler weather or during light rainfall.
4. Reduced delay before opening to traffic - On-site curing of concrete is not required. As a result, PCPs can be installed during night-time lane closures and be ready to be opened to traffic the following mornings.
5. Elimination of construction related early age failures - Issues related to late or shallow sawing do not develop.

The PCP systems are used in highway corridors with high traffic volume and where lane closures are a challenge. For production use, *the PCP work is performed during the night and with short closures*, typically from about 8 p.m. to about 6 a.m. The production rate per lane closure is about 15 to 20 repair locations and about 300 to 600 ft (91 to 183 m) lengthwise for continuous rehabilitation. The key issues of concern for PCP are constructability, concrete durability, and pavement performance as primarily affected by joint load transfer and panel support condition. Sufficient advances have been made in the PCP technology to reliably achieve the following four key attributes:

1. Constructability - Techniques and equipment are now available to ensure acceptable production rate for *rapid* installation of the PCP systems.
2. Concrete durability - Plant fabrication of the precast panels can result in excellent concrete quality with respect to strength and durability.
3. Load transfers at joints - Reliable and economical techniques are now available to incorporate effective load transfer at transverse joints of jointed PCP systems.
4. Panel support condition - The techniques to provide adequate and uniform support conditions continue to be improved.

However, it must be emphasized that PCPs are not “super pavements” and should not be expected to perform at a “significantly” superior level than CIP concrete pavements. Once installed, PCP systems can be expected to behave, under traffic and environmental loadings, similarly to CIP concrete pavement systems. The primary difference in the two technologies is how each system is constructed. The main advantage of PCP is that it is a truly rapid rehabilitation technology that can also result in longer-lasting treatments. In addition, as discussed later, prestressing techniques allow the use of PCP to achieve higher load-carrying capacity within a constrained pavement cross section when reconstructing existing pavements.

PRECAST CONCRETE PAVEMENT CONCEPTS

The application of precast concrete pavement technology can be classified as follows:

1. Intermittent repairs of concrete pavements.
2. Continuous applications.

Intermittent Repairs of Concrete Pavements

Under this approach, isolated pavement repairs are conducted using precast concrete slab panels. Two types of repairs are possible:

1. Full-depth repairs (FDRs) - to repair deteriorated joints or cracking. Also, as discussed later, this technique can be used to repair punchouts and deteriorated cracks in CRCP.
2. Full-panel replacement - to replace severely cracked or shattered slab panels.

The repairs are always full-lane width. The process is similar for FDRs and full-panel replacement, except for the length of the repair area. A schematic of the repair is shown in Figure 1.

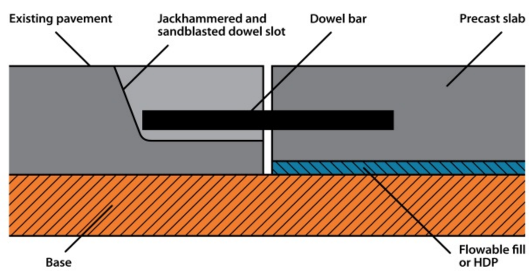


Fig. 1 Schematic of the Intermittent Repair Application.
(Hall and Tayabji, 2008)

Under the scheme shown in Figure 1, dowel bars are embedded in the precast panel, and slots for dowel bars are cut in the existing concrete pavement, similar to the dowel bar retrofit (DBR) method, as illustrated in Figure 2. The dowel slots are then filled with fast-setting patching material. In a variation of this scheme, no dowel bars are embedded in the precast panel and dowel bars are installed after panel installation using the DBR technique, as shown in Figure 3.

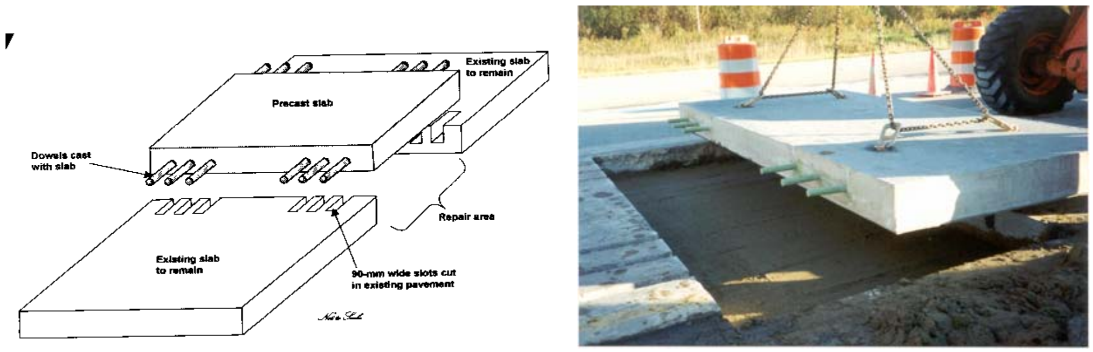


Fig. 2 One scheme for Intermittent Repairs

Fig. 3 A variation for Installing Dowel Bars Using the DBR Method

In another scheme for intermittent repairs, the dowel bars are positioned in the existing concrete pavement by drilling and epoxy-grouting, similar to CIP FDRs or full slab repairs, and the slots for the dowel bars are fabricated in the repair panels along the bottom of the transverse sides, as illustrated and shown in Figure 4. The slots and the joint perimeter gap are then filled with fast-setting grout.

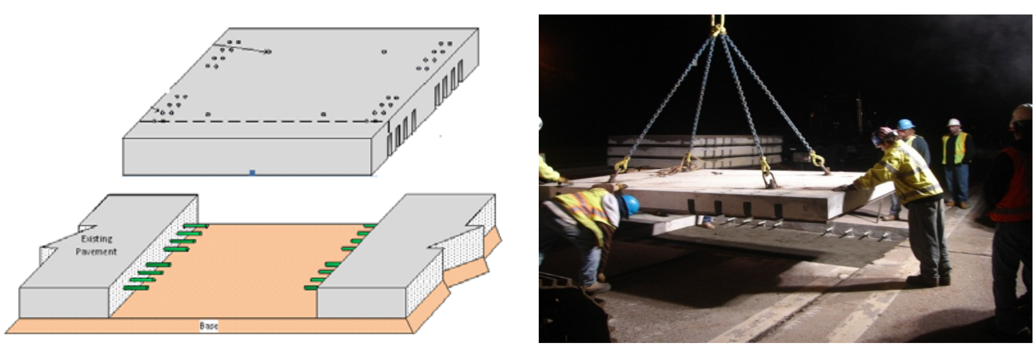


Fig. 4 Another Scheme for Intermittent Repairs

Each of the above methods of panel installation, with respect to the load transfer provisions, has certain advantages and disadvantages that are discussed later. In addition, the actual panel installation and the base support under the panel can be achieved using several techniques as follows:

1. Panel placed directly over the prepared base.
2. Panel placed and raised to proper elevation using expandable polyurethane foam.
3. Panel held in place using strongback beams and bedding material injected under the panel.
4. Panel positioned at the proper elevation using setting bolts and bedding material injected under the panel.

Key features of the intermittent repair applications are:

1. The need to establish good support condition under the panels.
2. The need to provide adequate load transfer at transverse joints.
3. The need to install the panel so that the elevation differences between the panel and the existing pavement are minimized.
4. Acceptable long-term performance of the repair area.

<u>Continuous Application</u>

Under this approach, full-scale project level rehabilitation (reconstruction or overlay application) of asphalt and concrete pavements is performed using precast concrete panels. Two types of systems, discussed later in detail, have been used in the United States:

1. Jointed precast concrete pavement (JPrCP) systems:
    a. Reinforced concrete panels.
    b. Prestressed (pre-tensioned) concrete panels.
2. Precast prestressed concrete pavement (PPCP) systems.

As part of the SHRP2 Project R05 study, a third category of continuous systems has been established. This category is referred to as the incrementally connected precast concrete panel (ICPCP) systems and includes systems that simulate the hinged jointed reinforced concrete pavement (JRCP) behavior. The panels for ICPCP systems may be reinforced or prestressed.

Jointed Precast Concrete Pavements

Jointed precast concrete pavements (JPrCPs) are very similar to CIP JCPs. Once installed, the JPrCPs behave similarly to CIP JCPs. Some specific differences that influence the performance of the JPrCP are as follows:

1. The panels are installed flat. As a result the panels do not exhibit construction-related, built-in curl/warp behavior.

2. The panels incorporate steel reinforcement. Therefore, any in-service cracking that may develop over time due to traffic loading can be maintained tight.
3. The panel transverse joint faces are smooth (fabricated); therefore, aggregate interlock cannot be counted on for load transfer at these joints.

All JPrCP systems used in the United States incorporate load transfer at transverse joints. In fact, it is necessary that load transfer provisions be incorporated in all JPrCP systems. All currently used JPrCP systems use round dowel bars, typically steel bars, for load transfer. One scheme that is used to incorporate the load transfer is shown in Figure 5, similar in concept to the system shown in Figure 4 for intermittent repairs. Under this scheme, one side of the panel has slots along the slab bottom to accommodate the dowel bars and the other side has embedded dowel bars at locations that match the dowel slot locations. After installation, the slots and the joint perimeter gap are filled with fast-setting grout.

Fig. 5 A Scheme for Providing Load Transfer in JPrCP.

A simpler scheme using the DBR technique can also be used for JPrCP applications. Such a scheme requires patching of the dowel slots during the same lane closure as the panel installation because of use of wide-mouth dowel slots. The primary reason for not using this scheme is not related to performance but to avoid leaving open, wide-mouth slots exposed to highway traffic for a day or two. The retrofitted dowel bar scheme was used at an airfield demonstration application. Under this scheme, the dowel bars were embedded along one transverse side of the panel and dowel bar slots were placed at the top side of the panel along the other transverse side. The panels were then interconnected by positioning one panel with the embedded dowels adjacent to another panel with the dowel slots as shown in Figure 6. At this demonstration project, both reinforced panels and thinner prestressed panels were used.

A scheme developed under Project R05, and discussed in this report, allows use of the DBR technique by using narrow-mouth dowel bar slots. In this scheme, the narrow-mouth dowel slots can be left open to traffic until the next lane closure (within a day or two) when the slots are patched.

Fig. 6 Alternate Scheme for Providing Load Transfer in JPrCP.

Precast Prestressed Concrete Pavements

The PPCP systems simulate CIP prestressed concrete pavements (CIP-PCP). These systems incorporate longer lengths of posttensioned sections (PTSections) and expansion joints between these sections. The PTSections are formed by posttensioning together a series of panels. The section length may vary from 150 to 250 ft (46 to 76 m). The individual panel width may be single-lane or multiple-lane, and panel length can vary from 8 to 10 ft (2.4 to 3 m) for multilane panels to 10 to 30 ft (3 to 9 m) or more for single-lane panels. A project in California (I-680 freeway near Oakland, May 2011) is using panels up to 36 ft (11.0 m) long.

Three types of PPCP systems have been developed. The three versions of PPCP are illustrated in Figure 7. The top drawing illustrates the original version, using base panels, central stressing panels, and expansion joint panels. The middle drawing illustrates the second version, using only the base panels and the joint panels. The bottom drawing illustrates the third version, using the gap panel. The second and third versions of the PPCP system are also shown in Figure 8.

In the original version, used at the first PCP project in Texas (Merritt et al, 2000, 2002 and 2009), base, central stressing, and expansion joint panels were used:

1. Base panels - the majority of the connected (posttensioned) panels.
2. Central stressing panels - to apply posttensioning from the mid-portion of the connected panels using slots prefabricated in the panels.
3. Expansion joint panels - one at each end of the PTSections. These panels include dowel bars for load transfer and provisions for joint sealing.

In the second version of the PPCP system, used at the Delaware, Missouri, and the Virginia projects (Merritt et al., 2008), only base and expansion joint panels were used:

1. Base panels - the majority of the connected (posttensioned) panels.

2. Expansion joint panels - one at each end of the PTSections. These panels include dowel bars for load transfer, provisions for joint sealing, and provisions for applying posttensioning using slots prefabricated in the panels.

In a third version of the PPCP system, used at the I-680 project in California, base, end joint, and expansion joint gap panels were used:

1. Base panels - the majority of the connected (posttensioned) panels.
2. End joint panels - one at each end of the PTSections. These panels include dowel bars for load transfer, provisions for joint sealing and provisions for applying posttensioning from the face of the panel using anchorage system pockets prefabricated in the end panels.
3. Expansion joint gap panels - one expansion joint gap panel, about 4 ft (1.2 m) long to fill in the gap left between adjacent panels to accommodate the posttensioning operation. For new construction where lane closure is not a concern, the gap panel may be cast in place. The gap panel includes provisions for dowel bars for load transfer and for joint sealing.

It should be noted that the gap slab concept has been successfully used in CIP prestressed concrete pavements constructed during the 1970's and 1980's (Tayabji, et al., 2001). These CIP prestressed concrete pavements were post-tensioned from the joint face and a CIP gap slab was constructed between adjacent PTSections after the posttensioning was completed.

The posttensioning of the series of panels induces compressive stress in the connected panels, which allows for reduction in the panel thickness by 2 to 4 in. (50 to 100 mm) compared to an equivalently designed CIP JCP or JPrCP. *This results in the need for less concrete, making the PPCP a more sustainable alternative with respect to material consumption and CO_2 production*. Based on a small number of demonstration-type PPCP projects constructed in the United States, PPCP costs are comparable to that for JPrCP. In any case, well-designed and well-constructed PPCP systems can be considered long-life concrete pavements with very little need for major repairs or rehabilitation during their service life.

Incrementally Connected Precast Concrete Pavements (ICPCP)

As discussed, ICPCP is a new category of PCP systems that has been established as part of SHRP2 Project R05 project. ICPCP systems simulate a JRCP with hinged joints and incorporate panels of varying lengths, typically 15 to 30 ft (4.5 to 9 m), which are connected together to achieve a continuous section length of 60 to 100 ft (18 to 30 m). The panels are connected using deformed dowel bars that lock up the connected joint and also provide the required load transfer across these joints. A small-width expansion joint is provided between connected panels.

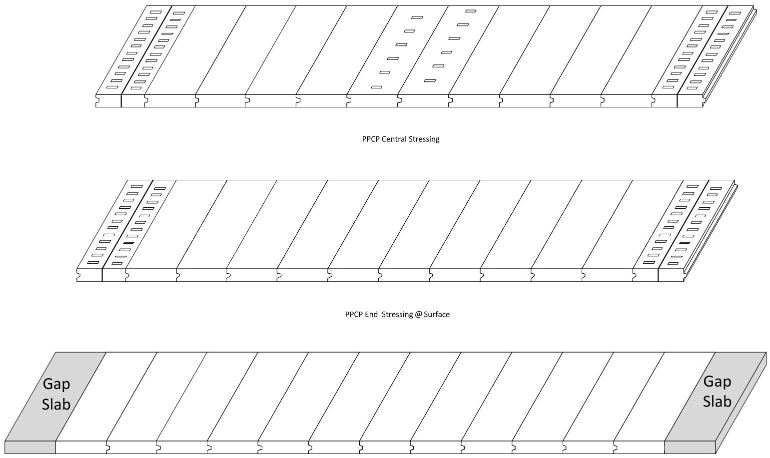
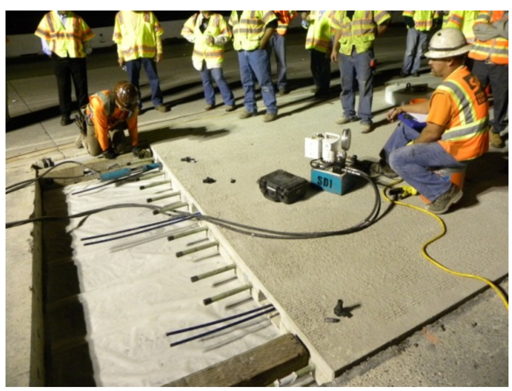


Fig. 7 Schematic of Three PPCP Systems

a. PPCP system with stressing pockets at expansion panels.



b. PPCP system with posttensioning performed at joint face.

Fig. 8 Views of the Installation of Two Current Versions of PPCP Systems

The advantages of ICPCP are the reduction in the number of active joints and the use of smaller-width expansion joints. Both nominally reinforced and prestressed panels can be considered for use. The ICPCP system is illustrated in Figure 9. The prestressed panels allow use of thinner panels but require good support under the panel, similar to the good support needed for PPCPs.

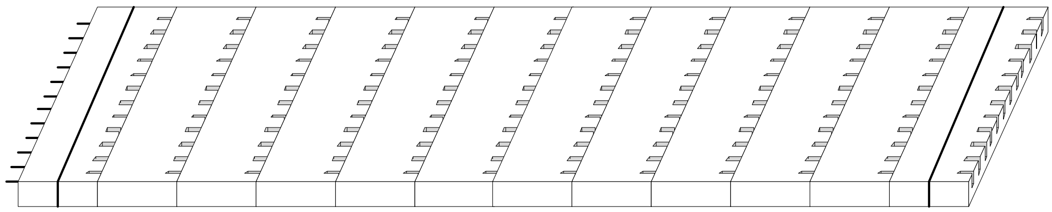


Fig. 9 Incrementally Connected PCP.

U.S. DEVELOPED PRECAST CONCRETE PAVEMENT SYSTEMS

As discussed, many PCP systems are available for production use or have been used on an experimental basis in the United States. These systems are discussed in more detail in this section.

PRECAST PRESTRESSED CONCRETE PAVEMENT (PPCP) SYSTEM

The PPCP system, illustrated and shown in Figures 7 and 8, was developed at the University of Texas at Austin, under the sponsorship of FHWA and the Texas DOT. This PCP technology is well suited for continuous paving. The basic PPCP system consists of a series of individual precast panels that are posttensioned together in the longitudinal direction after installation on site. Each panel may also be pre-tensioned in the transverse and/or the longitudinal direction during fabrication. Ducts for longitudinal posttensioning are cast into each of the panels during fabrication. The posttensioning and pre-tensioning introduce compressive stress in the concrete that helps offset some of the tensile/flexural stress that develop in the precast panels under traffic and environmental loadings.

The compressive stress (or the prestress) introduced by the longitudinal posttensioning varies along the length of the PTSection, with a maximum prestress developing at the ends of the PTSection and a minimum (effective) prestress developing near the mid-section. The reduction in the prestress is due to the panel–base friction and other prestress losses, discussed later. Also, as discussed, the effective prestress in the concrete allows for a reduction in the thickness of the panel for PPCP systems.

The basic features of the PPCP system are as follows:

1. Panel size: up to 40 ft (12 m) wide, typically 10 to 30 ft (3 to 9 m) long, and 8 to 10 in. thick (200 to 250 mm) (as per design requirements).

2. Panel types:
    a. System 1: Base, joint, and central stressing panels (as originally developed).
    b. System 2: Base and joint stressing panels.
    c. System 3: Base, end stressing, and gap panels.
3. A mechanism for connecting panels at intermediate joints (e.g., a keyway detail).
4. Posttensioning details:
    a. Typically, use of 0.6-in. (15 mm) diameter, 7-wire monostrand tendons, typically spaced at 18 to 24 in. (455 to 600 mm).
    b. Tendon load: 75% of ultimate tendon load, typically.
    c. Applied prestress: sufficient to ensure about 100 to 200 lbf/in^2 (690 to 1,379 kPa) (effective prestress at the midpoint of each PTSection, after accounting for prestress losses due to panel–base interface friction, concrete creep and shrinkage, and steel relaxation). The smoother the panel–base interface, the greater is the effective prestress at the midpoint of the PTSection.
    d. Grouted posttensioning ducts.
5. Pre-tensioning details:
    a. Typically, use of a 0.5-in. (13 mm) diameter, 7-wire monostrand tendons.
    b. Tendon load: 75% of ultimate tendon load, typically.
    c. Pre-tensioning is achieved as part of the panel fabrication process.
    d. Expansion joint spacing: 150 to 250 ft (46 to 76 m), typically.
6. Base type: A stabilized base is the preferred base because of the thinner panels used for the PPCP systems (to keep panel deflections under truck traffic as low as possible).
7. Panel–base interface treatment: A membrane, typically 6 mil polyethylene or geotextile, is used to ensure low frictional resistance between the panel and the base during posttensioning.
8. Injection of bedding grout to firmly seat panels (after posttensioning).

THE FORT MILLER SUPER-SLAB SYSTEM

The Fort Miller Company's Super-Slab system, shown in Figures 4 and 5, is a proprietary PCP technology suitable for both intermittent and continuous paving operations (FMC, 2011). This paving system consists of precast panels placed on a graded and compacted bedding material or placed over a graded existing granular base. This particular PCP technology lends itself to the construction and rehabilitation of freeway entry and exit ramps and along curved sections because the manufacturer can produce panels with varying cross slopes (warped panels). This system has the most production paving experience to date in the United States and Canada.

PRECAST CONCRETE PANELS FOR FULL-DEPTH REPAIR - THE MICHIGAN METHOD

The "Michigan" method, a nonproprietary PCP technology, is a doweled FDR system that can be used for intermittent repair applications. This system was refined at the Michigan

State University under a project sponsored by FHWA and the Michigan DOT (Buch, 2007). The repair panels are typically 6 ft (1.8 m) long and 12 ft (3.6 m) wide, fitted with three or four dowel bars in each wheelpath. The Michigan method can be used for FDR as well as full-panel replacement. This method utilizes a partial or full DRB technique to install dowel bars at the transverse joints formed by the precast panel, as shown in Figure 1.

THE ROMAN ROAD SYSTEM®

The Roman Road System® was introduced in 2009 by the Roman Road Construction Company for intermittent repairs (RSCC, 2011). In this system, dowel bars are not embedded in the panels, but are installed using the DBR technique after the panels are placed. The slots for dowel placement are cut in the existing concrete as well as in the panel after the panel is set in final position (elevation). The unique feature of this system is the use of polyurethane foam material as a bedding material. The panel is cast about 1 in. (25 mm) less in thickness than the existing pavement. The panel is placed in the prepared hole after removal of the deteriorated portion of the existing pavement and the panel sits about an inch below final elevation. The polyurethane material is then injected under the panel, raising the panel to the desired elevation and providing uniform seating of the panel over the existing base. The Roman Road System® is shown in Figure 10. In the figure, the left-hand photo shows the injection of the urethane grout and the raising of the panel and the right-hand photo shows the final position of the panel before cutting of the dowel slots. The panel has dark shading indicating the locations of the dowel slots.

Fig. 10. The Roman Road System®.

THE KWIK SLAB SYSTEM

The Kwik Slab system, which includes the patented Kwik joint steel couplers, interlocks reinforced precast concrete panels, allowing reinforcement continuity throughout the length of the connected section (Kwik Slab, 2011). The system essentially simulates JRCP sections. As such, there is a limit to the total length of panels that can be connected, and there is a need to provide expansion joints between connected sections. Use of active or expansion joints has not yet been incorporated into the Kwik Slab system. The Kwik Slab system is shown in Figure 11.

Fig. 11. The Kwik Slab Joint Interlocking System.

PORT AUTHORITY OF NEW YORK AND NEW JERSEY SYSTEM

During 2000, the PANY/NJ investigated the use of PCP to rehabilitate Taxiway A at New York's La Guardia International Airport. The PANY/NJ is considering use of precast paving to rehabilitate sections of a taxiway over several 55-hour weekend closures. The PANY/NJ constructed two 200-ft (61 m) test sections at a noncritical taxiway during 2002 (Yue, et al., 2003). One test section used nominally reinforced panels 16 in. (400 mm) thick and 12.5 ft by 25 ft (3.8 m by 7.6 m), and the second test section used prestressed panels 12 in. (300 mm) thick and 12.5 ft by 25 ft (3.8 m by 7.6 m). The two systems were developed as generic systems. A unique feature of this system is that the panel elevation was controlled using threaded setting bolts and a 0.5 to 1 in. (13 to 25 mm) gap was maintained under the panels. The gap was then filled with fast-setting cementitious grout. Another unique feature was that the dowel slots were fabricated at the plant. The panels used and the installation process is shown in Figure 6. The PANY/NJ is continuing to evaluate the performance of the two test sections as they are subjected to aircraft loadings.

HIGHWAY AGENCY–DEVELOPED SYSTEMS

Highway agencies have shown increased interest in developing generic PCP systems because many states prohibit procurement of proprietary products and also to encourage competitive bidding. In such cases, the highway agencies have developed end-product specifications or have developed plans and specifications for nonproprietary systems. The following agencies have developed nonproprietary systems:

1. The Illinois Tollway system - The Illinois Tollway began specifying the Tollway-developed intermittent repair system or equivalent for projects beginning in 2010. The Tollway-developed system uses standard panel details for panels 6 ft (1.8 m) long and 12 to 14 ft (3.7 to 4.3 m) wide. A drawing for one of the standard panel designs developed by the Tollway and a trial installation of the system are shown in Figure 12.

Fig. 12 Illinois Tollway Intermittent Repair System.

2. The Utah DOT has developed a nonproprietary PCP system. The precast panels in this system are positioned at the desired elevation using a threaded setting bolt system, similar to the PANY/NJ-designed system. The gap between the panel and the base is filled with fast-setting cementitious grout. Also, the DBR technique is used for joint load transfer after the panels are set. A 600 ft long section of I-215 was rehabilitated using this technique during June 2011.

PERFORMANCE EVALUATION OF PCP SYSTEMS

The early effort under Project R05 identified a serious lack of field performance data from installed PCP systems. Only a limited amount of field monitoring of installed PCPs had been carried out by highway agencies. When field data were collected, these were generally not publicly reported. The lack of well-documented data on the performance of the installed PCP projects is resulting in many questions related to field performance of PCPs and detracting from wider implementation of the PCP technology.

Several U.S. highway agencies were contacted to request support with field testing of the installed PCP projects. All agencies contacted agreed to cooperate with the field testing and data collection effort. A detailed documentation of the field testing for each project tested is given in a supplemental report available from SHRP2 (Ye and Tayabji, 2011). The following precast pavement projects were tested between December 2009 and November 2010:

1. PPCP projects (all based on the Texas PPCP system).
   a. Georgetown Frontage Road, Texas.
   b. I-57, Missouri.
   c. Route 896, Delaware.
   d. I-66, Virginia.
2. Continuous jointed PCP projects (Fort Miller Super-Slab® system).

   a. Tappan Zee Toll Plaza, New York (Fort Miller Super-Slab® system).
   b. TH 62, Minnesota (Fort Miller Super-Slab® system).
   c. I-66, Virginia (Fort Miller Super-Slab® system).
   d. I-15, California (with and without panel subsealing).
   e. Illinois Tollway (Illinois Tollway generic system).
   f. NJ 130, New Jersey (Fort Miller Super-Slab® system) with fiber-reinforced polymer (FRP) dowel bars.
3. Intermittent repair projects
   a. I-295, New Jersey (Fort Miller Super-Slab® system).
   b. I-280, New Jersey (Fort Miller Super-Slab® system).
   c. I-675, Michigan (Michigan system).
   d. Route 27, New York (Roman Stone system®).

The following data were planned to be collected at each project to provide an assessment of the structural and functional performance of the in-service precast pavement systems:

1. Condition data - visual condition survey.
2. Ride (smoothness) - using a high speed profiler to determine the section's International Roughness Index (IRI) values.
3. Joint elevation difference - using the Georgia Faultmeter. This measure can include the built-in joint elevation difference for newer projects as well as traffic-related faulting for older projects.
4. Joint width measurement - joint width was measured for the jointed PCP as well as the PPCP systems.
5. Deflection testing - using a falling-weight deflectometer (FWD).
   a. Midpanel (basin) testing.
   b. Testing at joints (wheelpath) for load transfer effectiveness (LTE) and void detection.

The field testing indicates that once installed, the PCP systems behave similar to CIP concrete pavements. The PCP systems tested and evaluated do not exhibit any unusual distress or failure mechanisms. However, there is concern about the risk of cracking at the JPrCP systems used for continuous applications. A primary cause of such early cracking is considered to be the use of thicker fine-grained granular bedding material placed over the existing base. Therefore, care must be exercised in specifying the type and thickness of the bedding material for PCP systems subjected to heavy truck traffic. Overall, there does not appear to be any concern about the long-term performance of the PCP systems that are designed well and installed well. The quality of the concrete used for the precast panels appears to meet the expectations for durable concrete and there is no evidence of early age concrete failures.

TECHNICAL CONSIDERATIONS FOR PCP SYSTEMS

The key technical considerations related to use of PCP systems are summarized below.

CONCRETE REQUIREMENTS

Concrete requirements need to be similar to those specified by the highway agency for CIP concrete pavements. However, because the precast pavements are used for highways with high traffic volumes where lanes closures are at a premium, *concrete durability is of great importance. Concrete must not fail because of materials-related distress or poor-quality construction (during fabrication)*. The fabricator may optimize the aggregate size and gradation to achieve an economical and sustainable concrete mixture that is workable for fabrication of the panels. An added benefit of using precast panels is that the concrete strength that is typically achieved is higher that the concrete used for CIP concrete pavement. This is due to the need to strip the formwork within about 16 to 20 hours of concrete placement to allow formwork re-use every day.

PANEL REINFORCEMENT

A double mat of epoxy-coated reinforcement is typically used for precast concrete panels to mitigate any cracking that may develop due to lifting and transporting operations. 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. The reinforcement is not necessary for pavement performance unless the panels are designed as reinforced concrete pavements. Some agencies require a higher level of reinforcement if the installed precast panels are subjected to traffic before panel subsealing is carried out. An advantage of panel reinforcement is that if the PCP panels develop cracking over the long term due to traffic loading, the cracking can be expected to remain tight without affecting pavement serviceability

PRODUCTION RATES

The panel installation rate is one of the most critical factors for considering use of the PCP technology. The panel installation rate determines productivity and lane closure requirements. The panel installation includes all activities that are conducted during a given lane closure, as listed below:

1. Existing pavement removal - Existing pavement removal, including a portion or all of the existing base material. This operation may require milling of a stabilized base, as per design requirements.
2. Drilling and grouting of the dowel bars - For repair applications (based on system design).
3. Base preparation - Regrading the existing base or placing a new base and placing of a bedding material to achieve proper base grade. Base is compacted if granular or placed and finished if it is cementitious (rapid-setting LCB). The bedding material may be granular, fast-setting flowable fill or polyurethane foam material.
4. Panel–base interface treatment - Placement of the panel–base interface treatment, typically, polyethylene fabric or geotextile membrane.
5. Panel placement.

6. PCP to existing pavement transition - Use of a temporary transition at the end of the PCP installation for a given lane closure.

For an intermittent repairs location within a given lane closure area, the typical production rate is about 14 to 18 panels per 6- to 8-hour lane closure, or about one panel per 20 to 25 minutes. Ideally, two crews should be 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 can be achieved since work is performed along a longer rehabilitation area. The typical production rate for panel installation is about 30 to 40 panels for jointed systems or about 400 to 600 ft (122 to 183 m) of installation length. The production rate can vary for PPCP systems and is dependent on the panel width and length. Greater production can be achieved using longer panels, as fewer panels need to be set and temporarily posttensioned. The PPCP panel installation can range from about 200 ft to over 600 ft (61 to 183 m) per lane closure, depending on the panel length and width.

THE JOINT LOAD-TRANSFER SYSTEM

Jointing and load-transfer provisions at transverse joints are two important design features for PCP. The joint spacing must be optimized for intermittent repair and for continuous applications by considering constraints on panel size fabrication and shipping and structural performance requirements. In addition, it is necessary to ensure that adequate load transfer will be available at all active transverse joints, including PPCP expansion joints, over the long term. The PCP installations with poor or no load-transfer provisions at active transverse joints cannot be expected to provide the desired level of service under truck traffic. The PCP joints incorporate smooth joint faces and are typically wider than the joints in CIP JCP. As a result, aggregate interlock at the joints does not exist and cannot be counted upon. Typically, load transfer at transverse joints of concrete pavements is provided by use of dowel bars. Dowel bars used in highway pavement construction are smooth, round, solid steel bars conforming to ASTM A615 or AASHTO M31. In addition, corrosion protection is typically provided in the form of a fusion-bonded epoxy coating, about 0.008 to 0.012 in. (0.203 to 0.305 mm) thick, which acts as a barrier against moisture and chloride intrusion. In recent years, because of concerns about the long-term effectiveness of epoxy coating and with the movement toward longer-life pavement designs, a number of agencies have started specifying use of alternate dowel bar materials. These are materials that either are constructed of a corrosion-resistant material or contain a corrosion-resistant cladding for protection against degradation caused by moisture and deicing chemicals. Examples of alternate dowel bar materials include:

1. FRP constructed with a range of composite materials and manufactured in solid form.
2. Stainless steel of varying grades (most commonly Type 304 and Type 316) manufactured as a hollow tube that is filled with cement grout. In some cases, stainless steel may also be used as a cladding on a conventional carbon-steel bar.

3. Microcomposite steel (also referred to as MMFX), a more corrosion-resistant steel material than conventional carbon steel, used to produce solid dowel bars.
4. Rolled zinc alloy used as a cladding over conventional carbon steel for corrosion protection.

Dowels are typically placed at a spacing of 12 in. However, the middle dowels do not contribute to the load transfer at a joint. Therefore, a cluster of 4 to 5 dowels per wheelpath, spaced at 12 in., are considered adequate for both intermittent as well as continuous applications. For jointed PCPs, the incorporation of a well-designed load transfer system at active transverse joints is critical to long-term performance of the PCP systems. The practice for providing load transfer at active transverse joints should be similar to the well-established and well-performing practices used for CIP JCP. If a practice has not been successful for CIP JCP or has not yet been used, it should not be considered for PCP systems without additional investigation or field verification. The risk of failure of the load-transfer system should be as low as possible.

THE PANEL SUPPORT CONDITION

For new construction as well as for repair application, pavement support is critical to the long-term performance of PCP systems. The proper seating of the panels on the base is a critical design and construction element. The support under the panels needs to be firm (strong) as well as uniform.

For most PCP repair or rehabilitation (reconstruction) applications, the following support alternatives may need to be considered:

1. Use of existing base:
    a. Granular base may be reworked, graded, and compacted. The panel is placed on the compacted granular base.
    b. Granular base may be reworked, trimmed, graded, and compacted; additional bedding material is then used to make up the difference in the base grade needed. The bedding material may be:
        i. Thin layer of finely graded granular material or sand.
        ii. Fast-setting flowable cementitious grout or flowable fill.
        iii. Polyurethane foam material, applied after the panel is placed or set in position. For repair application, a foam thickness of up to 1 in. (25 mm) may be used.
    c. Stabilized base, if not damaged in the existing slab removal process, may be used as is. A thin layer of finely graded granular material or sand may be used to provide a level surface for setting the panel.
    d. Stabilized base may be trimmed, as necessary, to accommodate the panel thickness. A thin layer of finely graded granular material or sand is then used to provide a level surface for setting the panel.
2. New base use:

a. A new base may be used if it is determined that the existing base will not serve the long-term needs of the new PCP. Because of time constraints, it is necessary that the new base material be of good quality and can be placed, graded, and compacted, if granular, fairly quickly within the same nighttime closure as the panel installation. This option is common when PCP is used to rehabilitate existing AC pavements. The new base type may include the following:
    i. Dense-graded, free-draining granular base.
    ii. Rapid-setting LCB (RSLCB).
    iii. Cement-treated or asphalt-treated bases are not considered viable options for PCP installed during nighttime lane closures, but may be considered if full-lane closure is available and duration of lane closure is not a concern.

For both repair and continuous applications, the granular bedding material should be kept as thin as possible (not greater than 0.25 in. (6 mm)). If thicker bedding is necessary, then consideration should be given to the use of a fast-setting cementitious fill material. In addition, for lane replacement applications, *the use of new base should not result in a “bathtub” detail*.

It should be noted that very little testing has been performed on site to ensure that the granular base used for PCP applications (repair or continuous) is adequately compacted. Poor compaction of the granular base or the fine-grained bedding layer can lead to excessive non-uniform settlement and early distress development in the PCP. As indicated previously, the support condition requirements for PCP systems should be as good as or better than required for CIP concrete pavements. An example of poor support condition is shown in Figure 14. At this project, a 0.5 in. to 1 in. (13 to 25 mm) thick manufactured sand was used over a trimmed existing CTB. As can be seen from the footprints in Figure 13, the bedding material is not stable and will most likely not provide good uniform support under the precast panels. The use of thicker non-compactible fine-grained bedding material is not a good practice.

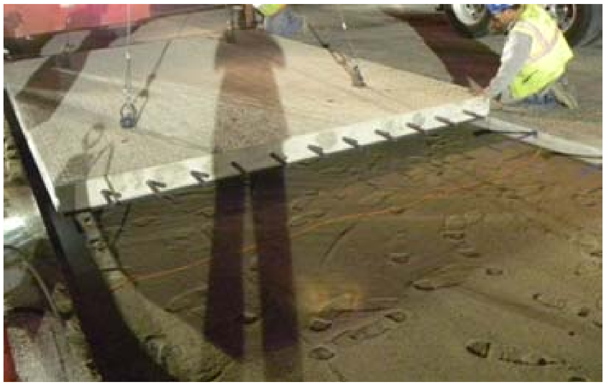


Fig. 13 Poorly Compacted Fine-grained Bedding Layer

It is recommended that agencies specify quality control/quality assurance (QC/QA) testing of the granular bases to monitor the level of compaction using the light-weight deflectometer (LWD). The LWD was introduced in the United States during the 1990s, and several agencies use it for acceptance testing of granular paving material (base, subbase, and subgrade (Minnesota DOT, 2008 and 2011).

PRESTRESSED PAVEMENT RELATED CONSIDERATIONS

The use of prestressed pavement requires consideration of a number of features related to prestressing. These features include the following:

1. Prestressing tendons.
2. Prestressing accessories.
3. Posttensioning methods.
4. Prestress losses for posttensioned system.
5. Pre-tensioning considerations.
6. Expansion joint system.
7. Load transfer at expansion joints.

These features are discussed are discussed in detail in the SHRP2 Precast Pavement Study Final Report and are not presented here. (Tayabji, Ye, and Buch, 2011). The US experience with PPCP is based on used of the bonded tendon technique. This is considered a safer approach for highway applications and allows localized repair work in the PPCP to be performed without concern related to prestress loss in the system. The use of the prestressing results in use of thinner panels to achieve a desired structural capacity for the pavement for jointed applications and for PPCP applications.

PANEL STRUCTURAL DESIGN

The design of PCP is based on the recognition that, once constructed (installed), the overall behavior of the PCP under traffic loading and environmental loading is not significantly different from that of a like CIP concrete pavement. Thus, a JPrCP is expected to behave similarly to a CIPJCP, and a PPCP is expected to behave similarly to a CIP-PCP. Concrete pavements are typically designed, constructed, and rehabilitated to provide long-life performance. The U.S. definition for long-life concrete pavements is as follows:

1. Original concrete service life of 40+ years.
2. Pavement will not exhibit premature failures and materials-related distress.
3. Pavement will have reduced potential for cracking, faulting, and spalling.
4. Pavement will maintain desirable ride and surface texture characteristics with minimal intervention activities to correct for ride and texture, joint resealing, and minor repairs.

Although PCPs are of recent use and in-service performance information of the oldest U.S. projects is available for less than 10 years, PCPs can be designed to provide long-term service. In fact, the warrant for use of PCPs is rapid repair and rehabilitation *with recognition of the need for long-term service*. Specific design procedures have not been developed for PCP systems. Development of reliable pavement design procedures requires a sound understanding of the pavement's behavior and validation of the design concepts on the basis of field performance. At this time, there are not sufficient projects available with long service to allow field validation. The PCP systems can be designed for long-term performance using design procedures currently used for design of CIP concrete pavements. The use of these design procedures requires some refinements to allow consideration of some of the specific characteristics of the different PCP systems (Tayabji, Ye, and Buch, 2011).

A significant advantage of the PCP systems is that the panels used are either reinforced or prestressed. As a result, if any panel cracking develops prematurely or as a result of the design traffic loading, the panels can be expected to perform well as the cracking will be held tightly and not deteriorate. The performance of the thinner prestressed systems, jointed or PPCP, is greatly dependent on the quality of the support condition. The support for such systems should be good to ensure that joint deflections under loading remain low

SUMMARY

This paper presented an overview of the precast pavement technology as it is currently practiced in the US. The paper also addressed some technical considerations related to the design of PCP systems. The load transfer provision at transverse joints and the support condition under the precast panels are two critical design features and must be addressed well for any PCP system. The PCP technology is maturing and continues to evolve. Significant improvements have been made in the PCP technology over the last 10 years. The next 10 years are promising to be full of innovations that will ensure a permanent place for the application of the PCP technology for longer-lasting rapid repair and rehabilitation of existing pavements. These future innovations are expected to reduce the cost of panel fabrication and panel installation.

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