

Precast Prestressed Concrete Pavements for Sustainable Pavement Rehabilitation in the USA

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Abstract

During the last ten years significant progress has been made in the USA to demonstrate precast prestressed concrete pavement (PPCP) technology and the benefits associated with its use for pavement rehabilitation. Precast concrete is receiving broad recognition as a preferred method for the rapid rehabilitation of highway pavements in high-volume traffic corridors where lane closures must be kept to a minimum. The PPCP system is being embraced not only for rapid installation and facilitating the return of the roadway to daily service; but also as long-life sustainable solution to the growing need to rehabilitate pavements that have served admirably since the late 1950s and early 1960s. The primary reasons for using the PPCP technology are two-fold: to accelerate construction during nighttime and other off-peak traffic windows thereby reducing the user delays; and to produce a highly durable long-lasting pavement structure. Additionally, through the use of prestressing, the precast concrete pavement provides significant benefits associated with increased load carrying capacity, improved life cycle cost, and enhanced sustainability. The use of prestressing allows the use of a thinner pavement slab, thereby increasing load carrying capacity while maintaining the elevation of the existing roadway and reducing concrete quantities by up to forty percent compared to conventional jointed concrete pavement alternatives. Furthermore, with fewer working joints following post-tensioning, the prestressed pavement inhibits the ingress of rainwater to the base and offers reductions in anticipated maintenance activities. This paper will discuss sustainability benefits and provide a summary of advances in the use of PPCP in the USA through 2011 that have occurred since the publication of a paper by the authors in the proceedings of the 8th ICCP conference in 2005. Case studies will be presented, in chronological order, for PPCP projects constructed or planned for construction in Missouri, Iowa, Delaware, Indonesia, Virginia, California and Florida. A brief summary of a major adaptation of the PPCP technology for roadways to enhance transportation networks in Indonesia will also be provided.

Introduction

Since the introduction of the FHWA PPCP concept at 7th International Conference on Concrete Pavements (ICCP) in 2001 (Merritt et al. 2001) and subsequent discussion of a demonstration project in California at the 8th ICCP in 2005 (Merritt et al. 2005), significant advancements in PPCP technology have been made through 2011 over the course of numerous projects constructed and planned in the U.S. While the basic philosophy behind the technology has remained the same, the wide variety of

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applications constructed to date has resulted in numerous enhancements to the original concept.

New applications and completed projects have demonstrated the numerous benefits of precast pavement technology. The sustainability benefits of PPCP, in particular, have been realized through projects completed to date. Most notable has been the long-term performance of the first PPCP demonstration project in the U.S., which has been in service nearly 10 years (Merritt et al 2002; Tayabji et al 2010).

This paper highlights numerous case studies of PPCP technology deployment throughout the U.S. over the past decade. With recognition of the ever-increasing importance of assessing the sustainability of pavement rehabilitation technologies, this paper also describes the sustainability benefits that have been noted from projects completed to date.

Research Significance

Over the past decade, precast pavement technology has moved from research and trial projects to deployment on large-scale projects. Several state Departments of Transportation (DOTs) have embraced precast pavement as a viable alternative to other rapid construction techniques for pavement rehabilitation and reconstruction. The California Department of Transportation (Caltrans), for example, is developing standard plans and special provisions for precast pavement such that it can be incorporated into any project as may be deemed appropriate by designers.

The precast concrete industry, likewise, has embraced precast pavement as a viable new market for their products. Numerous industry efforts are currently underway to help provide guidance to both the precast concrete industry and state DOTs for deployment and implementation of precast pavement technology.

In short, precast pavement technology is here to stay, and more and more DOTs are seeing the benefits for various applications where rapid construction and long-term performance are paramount. Furthermore, U.S. precast pavement technology has been embraced and deployed internationally, as will be described below.

Evolution of PPCP Technology

PPCP technology has significantly advanced over the past decade in order to adapt to the needs and various applications identified by state DOTs. Most notably, PPCP technology has been refined specifically to satisfy the requirements for overnight reconstruction of existing concrete pavement, which has become the most prevalent use for the technology to date.

As mentioned above, the basic philosophy behind PPCP has remained unchanged – to provide a long-lasting concrete pavement solution for reconstruction or rehabilitation of existing pavements that can be constructed quickly with minimal disruption to the traveling public. PPCP provides an alternative to the significantly less durable rapid-strength concretes and hot-mix asphalt typically used for short lane closures; and, an alternative to extended lane closures and detours required for conventional cast-in-place concrete.

Likewise, two basic components of PPCP have remained the same through numerous demonstration projects: full-depth precast panels, standardized in size as much as possible; and, two-way prestressing in the finished pavement. Full-depth panels provide an efficient solution for construction during short (overnight or weekend) lane closures in that the top surface of the precast panels provides the riding

surface for the finished pavement. No additional overlay is required for achieving the functional or structural performance requirements. The size of the panels is standardized as much as possible for a particular project to help maximize production rates for panel fabrication. Two-way prestressing ensures the pavement remains in compression over the life of the pavement, minimizing or even eliminating the occurrence of cracking. While full-depth panels and two-way prestressing have taken on various shapes and forms, they have been incorporated in all projects completed to date.

While the first PPCP pilot projects completed in Texas (Merritt et al. 2002) and California (Merritt et al. 2005) demonstrated the viability of PPCP construction, subsequent projects applied the technology to projects constructed under short closures. This required development of details that would permit the pavement to be opened to traffic “intermittently” or prior to installation of all of the panels of a particular section of pavement. This required reconsideration of details such as stressing pockets in the surface of the pavement, temporary post-tensioning, and transitions at the ends of the precast pavement. The case studies described below provide examples of how these details were addressed.

Sustainability Benefits of PPCP

The numerous benefits of PPCP have been described in more detail elsewhere (Merritt et al 2006). A summary of these benefits as they pertain to sustainability is provided below.

Design. A number of sustainability benefits are realized through the design of PPCP. As discussed previously, PPCP utilizes full-depth precast panels, which are installed over the existing subbase and subgrade whenever possible. By utilizing the existing subbase and subgrade whenever possible, the additional step of subgrade and/or subbase reconstruction and the new materials, construction processes, and disposal of existing materials associated with it are eliminated.

Additionally, because the panels are prestressed the slab thickness required for the specified design life can be greatly reduced. PPCP projects completed to date have utilized precast panels up to 40 percent thinner than that which would have been required for a non-prestressed cast-in-place pavement. Typically, this means that the existing pavement can be replaced with PPCP of equal thickness but greater load-carrying capacity. This results in savings in concrete materials as well as shipping costs due to a reduction in the weight of the panels.

Finally, as discussed above, PPCP panels are typically designed in “standard” types and sizes for a given project. Standardization of panels permits a much more efficient process for the fabricator by allowing the panels to be mass-produced to the extent possible. Standardized panels also facilitate efficient storage and shipping procedures since all panels of a particular type can be interchanged.

Manufacture. The precast concrete manufacturing process also presents a number of sustainability benefits for PPCP. As with slipformed pavements, supplementary cementitious materials, such as fly ash recycled from coal combustion, are commonly used in precast concrete elements for paving applications. PPCP projects completed to date have been produced using concrete mixtures containing up to 25 percent fly ash replacement of cement.

PPCP panels are produced in existing precast plants, which produce a variety of precast elements. This eliminates the need to set up batch plants at or near the project site specifically for the paving concrete. Established precast plants with diverse product lines also readily reuse formwork for various types of precast elements. Manufacturing of new formwork for PPCP panels is generally restricted to only the side forms, which in turn can be re-used for other precast elements.

Finally, while all concrete batch plants generate a certain percentage of waste material, precast plants seek to minimize any waste and readily reuse waste that is generated. It has been estimated that approximately 2 percent of concrete generated at a precast plant is waste, but approximately 95 percent of this waste is beneficially reused elsewhere in the plant or separated back into constituent materials for use in fresh concrete. (VanGeem 2006)

Construction. The sustainability benefits of PPCP as it pertains to construction are primarily realized through the reduction in traffic congestion during construction. This benefits the contractor, owner agency, and the travelling public. PPCP permits construction to be completed during non-peak travel times, such as at night or over weekends, thereby greatly reducing or even eliminating construction-related traffic congestion. This reduces the pollution associated with idling or slowly-moving traffic. Additionally, by limiting construction to off-peak times, any pollution generated by construction occurs when pollution from other sources is minimal. Finally, PPCP generally requires less construction equipment on-site than conventional paving operations, thereby reducing the environmental impact of construction equipment.

Life Cycle. Life cycle sustainability benefits of PPCP are realized through the durability of the finished product. PPCP is utilized as a long-lasting, low-maintenance product, and not as a short-term fix. Minimal maintenance over the lifespan of the pavement reduces the environmental impact of maintenance operations, and the anticipated longevity of the product greatly increases the reconstruction cycle time. While the oldest PPCP in the U.S. has only been in service for approximately 10 years, it has required no maintenance over that time, and shows few signs of deterioration. (Tayabji et al 2010)

PPCP Case Studies

The following project descriptions provide brief case studies demonstrating the evolution of PPCP technology – from initial demonstrations to production projects.

Missouri. In December 2005, the Missouri Department of Transportation (MoDOT) completed construction of a 308 m (1,010 ft) section of PPCP on a section of northbound Interstate 57 in southeastern Missouri (Merritt et al. 2008). This section of interstate carries a heavy percentage of truck traffic, and the existing 45-year-old jointed reinforced concrete pavement was in need of reconstruction.

Although the PPCP was constructed during a full closure of the northbound lanes, the project demonstrated some new concepts, including the use of end-stressing where the post-tensioning blockouts were located at the ends of the section, rather than in the middle. The project also utilized panels which spanned the full 11.6-m (38-ft) width of the roadway, including two lanes and both shoulders; and, the crowned pavement cross-section was formed into the precast panels. Figure 1 shows

the layout for the PPCP panels used in Missouri; and, views of the precast panels during and after installation.

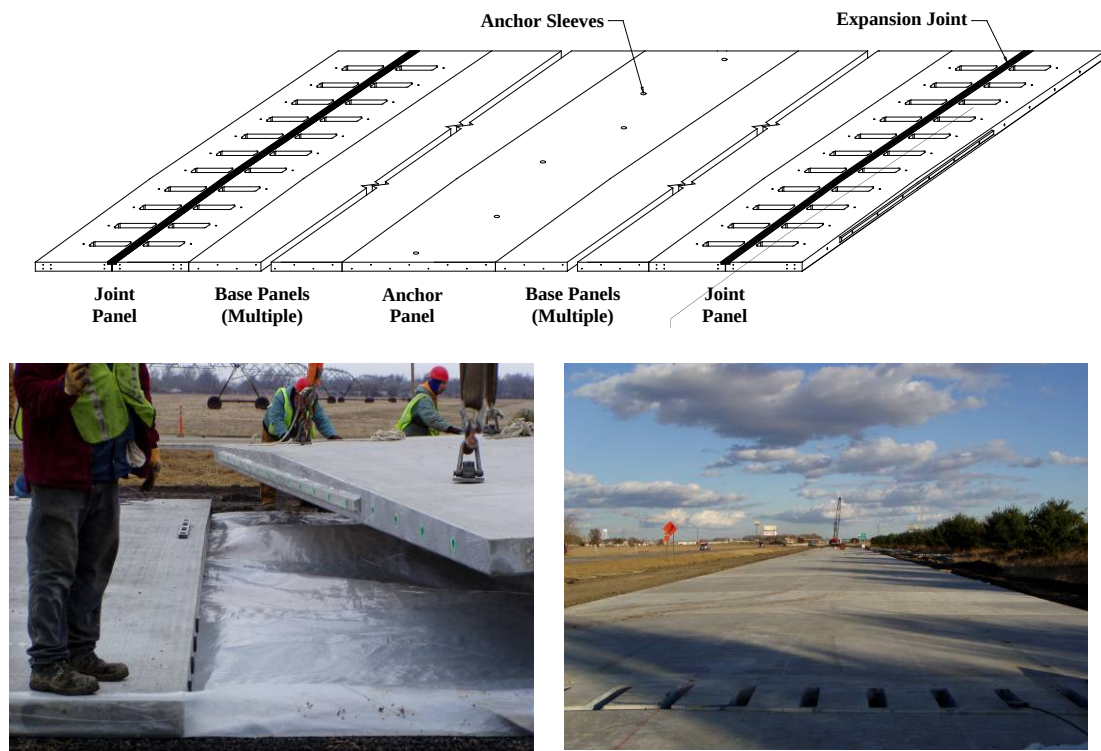


Figure 1. Typical precast panel assembly, utilized for the Missouri DOT project (top) and panel installation (bottom).

The pavement section for this project was optimized by replacing the existing 200-mm (8-inch)-thick JRCR with precast panels of the same thickness, and by leaving the existing subgrade layers intact. Using a single precast panel for the full pavement width also optimized the panel fabrication, delivery and installation processes.

Iowa. In September 2006, the Iowa Department of Transportation utilized PPCP for the construction of approach slabs at either end of a bridge (Dunn et al 2007). The demonstration project was developed to evaluate the viability of using PPCP for rapid replacement of failed approach slabs. Although the project was constructed at a bridge closed to traffic, the success of this demonstration led to future projects where approach slabs were reconstructed one lane at a time with live traffic in the adjacent lane (Bierwagen et al 2009).

PPCP permits bridge approach slabs to be reconstructed with minimal reconstruction of the underlying embankment. While embankment drainage and compaction issues must be addressed through improved construction practices, PPCP approach slabs can be designed, due to prestressing, to span over voids that may form beneath the approach slab over time. This is advantageous for approach slab reconstruction applications where it may not be possible to fully address drainage and compaction issues during a short closure time. Figure 2 shows the precast panel layout for the Iowa project and photos from construction of the project.

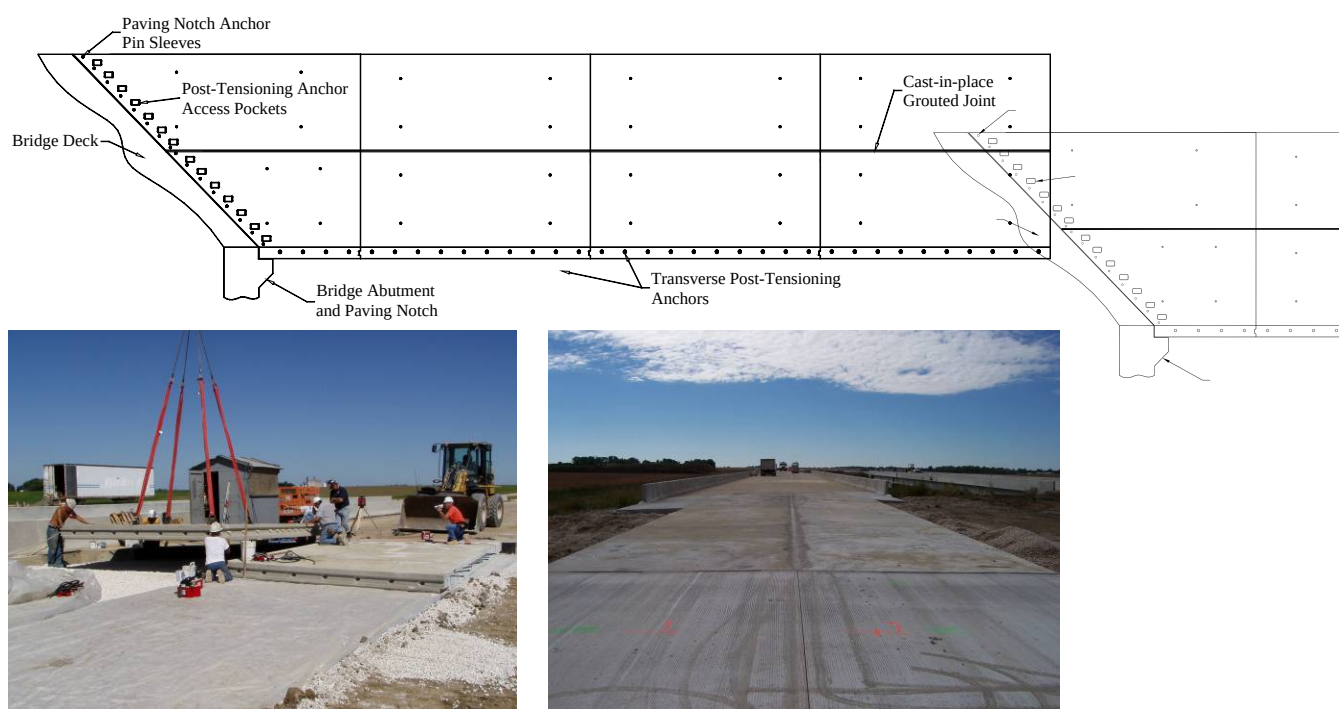


Figure 2. Panel layout for the Iowa PPCP approach slabs (top) and construction of the project (bottom).

Delaware. In the summer of 2009, the Delaware Department of Transportation (DelDOT) completed construction of a PPCP on northbound Route 896 at the intersection with U.S. Highway 40 in Newark, Delaware. (Merritt and Tyson 2011) Route 896 is a major arterial carrying approximately 38,000 vehicles per day with 9 percent trucks, and closing any of the lanes to traffic during daytime hours was not a viable option. The existing concrete pavement in the left and right turn lanes was exhibiting severe deterioration requiring continual maintenance at the joints due to alkali-silica reactivity (ASR), and therefore DelDOT opted to fully reconstruct those lanes.

PPCP was selected in order to permit reconstruction to take place during overnight closures, ensuring that all lanes were open to traffic during daytime hours. Pavement thickness was optimized by replacing the existing 300 mm (12 in) JPCP with a 200-mm (8-inch)-thick PPCP having a remaining life equivalent to that of the existing pavement. The precast panels were installed over a 100-mm (4-inch)-thick lean concrete base which provided drainage beneath the pavement and provided a firm working platform for supporting the precast panels as they were installed.

One innovation incorporated into the Delaware demonstration project was the use of threaded post-tensioning bars to replace two of the strand tendons. The threaded bars permitted the contractor to partially post-tension the pavement after each night's production, regardless of how many precast panels were installed. The contractor also deployed other innovative techniques during construction, such as using a front-end loader to install precast panels, rather than a crane which could not be advanced as quickly. Figure 3 shows the precast panel installation and finished pavement surface.



Figure 3. Installation of a precast panel for the DelDOT project (left) and completed project (right). (Photos courtesy of Delaware DOT)

Indonesia. In 2009, the largest PPCP project ever undertaken was completed on a toll road near Cirebon, West Java in the country of Indonesia (Nantung et al. 2010). Based largely on the original PPCP concept (Merritt et al 2000), the project consists of 35 km (22 mi) of a four-lane highway, or 140 lane-km (88 lane-mi) of PPCP. The rationale for using PPCP stemmed from the need to improve mobility and expand the network of roads in a remote area of the country. Mobilization of large paving equipment was not practical or economically feasible. However, producing precast panels at a fabrication plant established on-site for this project proved to be very effective, and it employed hundreds of local workers and provided a boost to the local economy. The goal of constructing a long-lasting, low-maintenance pavement was also satisfied. The project was successfully completed on time, and demonstrated the viability of utilizing PPCP technology for expanding roadway networks in developing countries. Figure 4 shows the installation of a PPCP panel and a completed section of pavement.



Figure 4. Installation of PPCP panels and a section of finished pavement in Indonesia (photos courtesy of Tommy Nantung)

Virginia. In the fall of 2009, the Virginia Department of Transportation (VDOT) utilized PPCP for the reconstruction of all four lanes of westbound Interstate 66, just outside of Washington, D.C. (Merritt and Tyson 2011) Traffic volumes in excess of 180,000 vehicles per day, with 5 percent trucks, required that lane closures for reconstruction be restricted to the hours of 10 PM – 5 AM. PPCP was selected as a

long-life solution for reconstruction of the existing 40-year-old jointed concrete pavement.

The existing 230-mm (9-in) and 280-mm (11-in)-thick JPCP lanes were reconstructed with 222-mm (8.75-in)-thick PPCP panels that were designed to have at least the same design life as that of the original existing pavement. To maximize production, the existing base and subgrade layers were left in place to eliminate the need for excavation and replacement of those layers. Investigation of the existing pavement did not reveal any problems with the underlying base and subgrade or drainage, such that replacement would be required.

A unique aspect of this project was the use of multiple precast panels to span the full width of the roadway, with a crown between the two inside lanes. This was necessitated due to requirements for maintenance of traffic on this busy roadway. The two inside lanes were constructed on separate nights with 3.7-m (12-ft)-wide panels, and the outside two lanes were constructed with a single 8.2-m (27-ft)-wide precast panel. The three panels were tied together transversely using an unstressed post-tensioning strand inserted through all three panels and grouted in place. Temporary, removable precast panels were used to provide the transition from the PPCP to the existing pavement at the end of each night's installation. Figure 5 shows photos during installation and after completion of the I-66 PPCP project.



Figure 5. Installation of a precast panel for the Virginia project (left) and the completed pavement after opening to traffic (right).

(Photo courtesy of Virginia DOT)

California. In the summer of 2011, the largest PPCP project in the U.S. was completed by the Caltrans District 4 on Interstate 680 in the San Francisco Bay Area. (Mishra et al 2011) PPCP was used for “spot reconstruction” of sections of various lengths up to 488 m (1,600 ft) in each of the three inside lanes in both the northbound and southbound directions of this four-lane pavement. The existing 200- to 230-mm (8- to 9-in)-thick concrete pavement and underlying cement treated base (CTB) was reconstructed with 216-mm (8-1/2 in)-thick PPCP over 150 mm (6 in) of rapid-setting lean concrete base.

Several innovative features were incorporated into this project, most of which were proposed by the contractor and precaster after the project had been awarded in order to optimize production. The precast panels were oriented in the longitudinal pavement direction, such that each panel was one lane wide and up to 11 m (36 ft) in length. The panels were pretensioned in both directions during fabrication in order to

provide the transverse prestress through pretensioning and the longitudinal prestress through both pretensioning and on-site post-tensioning.

Additional features included larger, two-strand post-tensioning tendons and a reduced number of post-tensioning ducts. Post-tensioning blockouts in the surface of the precast panels were also eliminated by post-tensioning from the ends of each post-tensioned section. A 1.2-m (4-ft)-wide gap was left between post-tensioned sections for this purpose, and the gap was later filled in with a precast “drop-in” panel connected to the abutting PPCP sections with dowel bars. Each of these enhancements greatly improved the rate of production for fabrication and installation, while still ensuring a long-lasting finished product. Figure 6 shows a general layout of the PPCP sections and gap slabs, and the installation of a panel and a completed PPCP section.

In addition to PPCP, Caltrans also used jointed prestressed precast concrete pavement (JPPCP) for sections of the project less than 19.5 m (64 ft) in length. The JPPCP panels were pretensioned in both directions during fabrication and dowels were used to provide load transfer between panels and between the panels and the existing pavement. JPPCP panels were also used on non-tangent sections of the project where it was not practical to post-tension sections of PPCP.

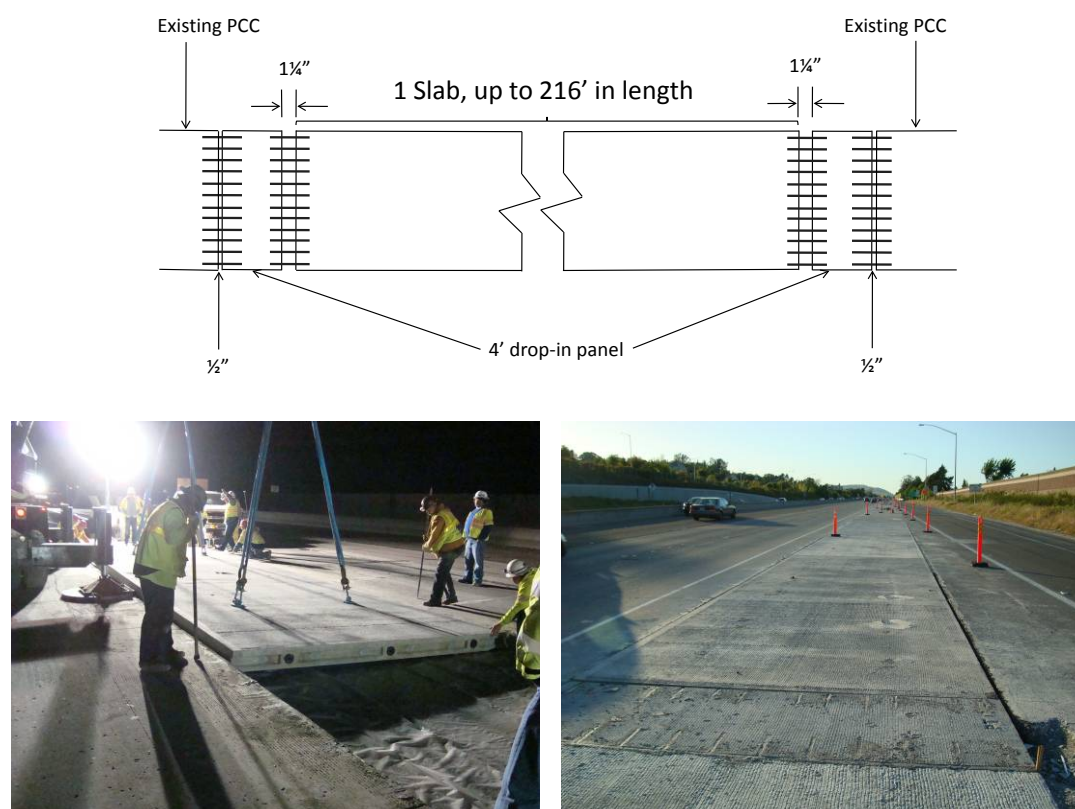


Figure 6. General layout of PPCP sections and drop-in panels (top), and installation of a PPCP panel and a completed PPCP section (bottom) (Mishra et al. 2011).

Florida. In 2011, the Florida Department of Transportation (FDOT) advertised a project on U.S. Highway 92, which will use PPCP as an unbonded overlay of an existing jointed concrete pavement. Unbonded concrete overlays provide a very

efficient solution for pavement rehabilitation as the existing pavement is left in place and acts as the base for the new pavement. This eliminates the need for removal and disposal of the existing pavement and any treatment of the base. The unbonded PPCP overlay on U.S. 92 will also serve to raise the profile of the pavement in a location that is susceptible to flooding. Construction of this project is expected to be completed in 2012.

Conclusions

Advancements of PPCP technology during the last ten years have been substantial. Following an initial proof-of-concept pilot project in Texas in 2001, additional demonstrations of the technology were completed in California and Missouri in 2004 and 2005, respectively. A project in Iowa further provided a unique application of the technology for bridge approach slabs in 2006. Subsequent projects in Delaware and Virginia applied the technology where it provides the greatest benefit – long-life reconstruction of pavements on heavily traveled roadways during nighttime and other off-peak traffic windows. The record-setting project in Indonesia demonstrated that PPCP is a viable option for expanding highway networks in developing countries. The Interstate 680 project in California demonstrated new innovations to the original concept, which significantly improved production rates while still ensuring a durable, long-lasting product. Finally, the project in Florida has been designed to demonstrate the use of PPCP as an unbonded overlay, a unique and very promising application of the technology.

The series of PPCP projects completed in the past decade have demonstrated several sustainability benefits. From durable and long-life pavement rehabilitation, to a reduction in material usage and utilization of “recycled” cementitious materials, to less invasive construction techniques and reduced material waste, and a significant reduction in construction-related traffic congestion, PPCP is establishing itself as a sustainable alternative for pavement rehabilitation.

Precast concrete pavement has become a mature technology during the last decade. While only projects utilizing PPCP were discussed in this paper, numerous other projects using jointed reinforced precast concrete pavement systems have also been constructed over the past decade. Numerous applications on a variety of projects have shown the versatility of the technology in satisfying the needs of highway agencies, contractors, and the traveling public.

Promising signs of advancement of PPCP technology in particular and precast pavement in general are its use beyond demonstration projects and the implementation of specifications for its use. Both Caltrans and Iowa DOT have used precast pavement for additional projects beyond the initial demonstrations described in this paper, and Caltrans currently is developing standard plans and special provisions that will allow PPCP to be incorporated into any project.

As more projects are constructed and highway agencies and contractors become more familiar with the technology, PPCP will continue to evolve and new applications will be developed. For high-volume traffic corridors where lane closures must be kept to a minimum, it will provide a sustainable, long-lasting alternative for pavement rehabilitation.

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