

Precast Concrete Pavements: Current Technology and Future Directions

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Abstract

Precast concrete pavement technologies have been looked into sporadically over the last 20 plus years. In the early years, the technology was looked into as a matter of technical curiosity, that is, to investigate if precast concrete pavement technology was technically feasible. No serious attempts were made then to fully develop the technology as a cost-effective strategy and to implement the technology on a production basis. Now, as more mileage on the primary highway system and urban roadways are reaching maturity and need for timely pavement repair and rehabilitation becomes acute and urgent, highway agencies are looking at new/innovative technologies, including precast concrete pavement technologies, that will result in shorter lane closures and long-life pavements that are economical over the life cycle and do not require major interventions for repair or rehabilitation during their service life. Over the last ten years, significant developments have resulted in precast concrete pavement technologies and use of these technologies is becoming technically feasible and economically justifiable.

This paper summarizes the current state of precast concrete pavement technology and provides a framework for advancing the technology in future years.

Introduction

Pavement rehabilitation and reconstruction are major activities for all US highway agencies, and have significant impact on agency resources and traffic disruptions because of extensive and extended lane closures. The traffic volumes on the primary highway system, especially in urban areas, have seen tremendous increases 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 problem: longer delays now and longer service life versus shorter delays now and shorter service life. In recent years, many agencies have started investigating alternative strategies for pavement rehabilitation and reconstruction that allow for faster and durable rehabilitation and reconstruction of pavements. A promising alternative strategy is the effective use of precast concrete pavement technologies that provide for accelerated repair and

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rehabilitation of pavements and also result in durable, longer-lasting pavements. Accelerated 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 users' and workers' exposure to construction traffic.

Background

The developments related to prefabricated pavement technology have focused primarily on the use of precast concrete slab panels. Only recently has the concept of prefabricated pavements been applied to use of asphalt-based products. This section presents a brief overview of the historical development of precast concrete pavement technologies.

Pre-1995 State of Practice. One of the earliest reported uses of precast concrete pavement technology in the US was during 1960 in South Dakota where a precast pavement was constructed over a granular bedding layer (Merrit 2000). Since then, several minor efforts were made to investigate the use of precast pavements, primarily as rapid repair alternatives. The Japanese have over the years (at least since the early 1970's) used precast slab panels in various applications (Hara et al. 1997), including highways, tunnel pavements, and high speed slab track applications. The use of precast paving was also a practice in the Soviet Union, and several Soviet-occupied air bases (during the 1980's) in Afghanistan incorporated the use of precast concrete pavements. No significant efforts were made in the US before about 1995 to seriously investigate use of precast concrete pavements for repair of concrete pavements or for rehabilitation of concrete as well as asphalt pavements. Since about 1995, there has been significant interest in the US to investigate the effective application of precast concrete pavements as a strategy for accelerated repair, rehabilitation, and reconstruction of pavements. The interest has come from the Federal Highway Administration working in cooperation with State DOTs as well as from industry.

FHW- CPTP Initiative. Recognizing the need to develop effective solutions for rapid rehabilitation of the nation's highway system, the Federal Highway Administration (FHWA) and the Texas Department of Transportation (TxDOT), as part of the FHWA's Concrete Pavement Technology Program (CPTP), sponsored a study during the late 1990's that investigated the feasibility of using precast concrete for pavement rehabilitation. At the conclusion of the study, performed by the Center for Transportation Research (CTR) at The University of Texas at Austin, a concept for precast concrete pavement was developed. In March 2002, TxDOT completed the first pilot project using this innovative concept that incorporated the use of prestressed precast concrete pavement along a frontage road near Georgetown, Texas. Since then, FHWA has aggressively marketed the concept of precast pavement to State DOTs and several demonstration projects have been constructed to develop field experience with this technology (Kohler et al. 2007).

FHWA, under CPTP, also sponsored the development of precast pavement technology for full-depth repair of concrete pavements. This work was conducted at the Michigan State University and has resulted in several field trials of this technology (Buch et al. 2006).

Industry Initiatives. Parallel to the FHWA sponsored efforts; several organizations in the US also initiated development activities to refine precast concrete pavement technologies. These technologies have certain proprietary features to the products and as such require licensing for use of the technologies. The significant technologies developed privately include the following:

1. The Fort Miller Super Slab system
2. The Uretek Stitch-in time system
3. The Kwik Slab system

Since about 2001, the Fort Miller system has been used on several production projects (continuous and intermittent) for repair and rehabilitation applications. In continuous application, this system simulates conventional jointed plain concrete pavement sections. The Uretek system has also been widely used according to the developer. However, as currently engineered, the system is better suited to intermittent/isolated repair applications. The Kwik Slab system has been used on a limited basis in Hawaii. This system essentially simulates long jointed reinforced concrete pavement sections.

In addition to the proprietary precast concrete pavement systems, generic systems have also been used and are under development. The Port authority of New York and New Jersey (PANY/NJ) installed generically developed precast concrete pavement test sections at La Guardia International Airport in New York to investigate the feasibility of rapid rehabilitation of a primary taxiway at La Guardia Airport.

Highway Agency Initiatives. In the last few years, several agencies have developed specifications that allow use of precast concrete pavement systems. These agencies include New York State DOT, Minnesota DOT, MDOT, Virginia DOT, Ontario Ministry of Transport and PANY/NJ. Also, several agencies have also installed test sections to demonstrate the feasibility of the precast concrete pavement systems. Accelerated testing of a precast concrete pavement has also been performed in California.

AASHTO Technology Implementation Group Activities. Recognizing the increasing interest in precast concrete pavement technologies by US highway agencies and to provide an effective platform for technology transfer activities, AASHTO established a Technology Implementation Group (TIG) during 2006, to support technology transfer activities related to precast concrete pavements. The mission of this AASHTO TIG is to promote the use of Precast Concrete Panels for paving, pavement rehabilitation, and pavement repairs to transportation agencies and owners nationwide and to present an unbiased representation to the transportation community on the technical and economic aspects of the current precast paving systems utilized in the market place.

Technical Society Activities. Recognizing the high level of interest in precast concrete pavement technologies and to support their members' need for technical information, the following technical organizations have formed task forces to develop technical information on precast concrete pavement technologies:

1. American Concrete Institute (ACI) - ACI's Committee 325 established the

Subcommittee on Precast Concrete Pavements (originally the Precast and Prestressed Subcommittee). The subcommittee is developing a document summarizing current technologies and providing case studies.

2. Precast/Prestressed Concrete Institute (PCI) – PCI has established a Pavement Committee to develop interest in pavement applications by the precast industry and to develop guidelines for use of precast concrete pavements.

Non-US Developments. Recently, several European countries have started to investigate use of precast concrete and other precast concrete systems for rapid repair/rehabilitation of pavements. The Dutch have developed the ModieSlab system (Smits 2004). The Japanese have used precast concrete slab systems for high speed slab track applications, tunnel roads, and airports

Why Precast Concrete Pavement Technologies?

The primary use of precast concrete pavement technologies is to achieve construction time savings in high traffic volume highway applications and for rapid repair/rehabilitation applications at airfield pavements. Without the benefit of time saving, use of precast concrete pavement technologies cannot be justified economically, at least at current pricing for these systems. Use of precast concrete pavement technologies MUST result in reduced lane closures or better managed lane closures that result in less traffic disruptions and improved safety at construction zones. In addition, precast concrete pavement systems must be capable of providing low-maintenance service life of the desired duration. The continuous applications must be viewed as long-life pavements with the expectation of 40 plus years of low-maintenance service life. In addition, the following factors need to be considered into the assessment of precast concrete pavement technologies as viable candidate strategies for repair or rehabilitation of pavements:

1. Tangent sections versus curved alignment
2. Matching adjacent pavement surface grade for lane replacement
3. Fabricating the precast concrete system components at a nearby plant. Plant location is critical for economical production paving, to reduce cost and to reduce traffic disruptions.
4. Transporting precast concrete system components to the site (traffic issues, especially for night-time operations)
5. Site access for heavy construction equipment (heavy cranes, etc.)
6. Removal of old pavement, as applicable
7. Preparing base/subbase, as applicable
8. Installing precast concrete system components on finished base/foundation
9. Interconnecting precast concrete system components using dowel/slot system, as applicable
10. Post-tensioning precast concrete system components, as applicable
11. Grouting dowel/tie-bar slots, as applicable
12. Injecting bedding grout to firmly seat panels, as applicable.

Precast Concrete Pavement Technology Definition and Concepts

Definition. Precast concrete pavements are systems that are essentially fabricated or assembled off-site and transported to the project site and installed on a prepared foundation (existing pavement or re-graded foundation). These systems do not require field curing time or time to achieve strength before opening to traffic.

Concepts. The use of precast concrete pavement technology can be classified as follows:

1. Intermittent repairs of highway and airfield concrete pavements
2. Continuous concrete paving for highway and airfield applications (project level rehabilitation and reconstruction)
3. Project specific applications, for example, for pavement-tire noise reduction.

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

1. Full-depth repairs – to repair deteriorated joints, corner cracking or cracking adjacent to the joint.
2. Full panel replacement – to replace cracked or shattered slab panels.

The repairs are typically full lane width. The process is similar for full-depth repairs and full panel replacement, except for the length of the repair area. Generic as well proprietary systems are available to perform intermittent repairs of PCC pavements. Key features of this application are (details of the available techniques are discussed later in this section):

1. Slab panel seating
2. Load transfer at joints

Continuous Applications. (*Project Level Rehabilitation/Reconstruction of AC and PCC pavements*). Under this approach, full-scale project level rehabilitation (resurfacing) or reconstruction of AC and PCC pavements is performed using precast concrete panels. Several recently developed techniques are available, as follows:

1. Prestressed precast concrete pavement (PPCP).
Key features of this application are:
 - a. Slab panel dimensions
 - b. Panel/base interface and panel seating
 - c. Number of panels that can be effectively connected
 - d. Panel connection details (use of a keyway, epoxy, etc.)
 - e. Post-tensioning details (at center slab panels or at expansion joint)
 - f. Expansion joint details
2. Jointed precast concrete pavement – proprietary and generic systems
 - a. Fort Miller SuperSlab system
 - b. Kwik Slab system
 - c. Uretek Stitch in time system
 - d. ModieSlab system
 - e. As used at La Guardia International Airport in New York
 - f. Japanese techniques for tunnel roads and for airport pavements

Key features of this application are:

- a. Slab panel dimensions
- b. Slab panel seating
- c. Load transfer at joints
- d. Connectivity, if any, at joints

Details of the available techniques are discussed later in this section.

Other Specific Need-Based Applications. Precast concrete pavements are used in Japan for high speed slab track applications.

Current State of the Practice

Prestressed Precast Concrete Pavement (PPCP).

As mentioned, the PPCP system was developed under the sponsorship of FHWA and TxDOT. The system development is well documented (Precastpavement.com 2007). This precast concrete pavement technology is well suited for continuous paving. The basic precast prestressed pavement concept consists of a series of individual precast panels that are post-tensioned together in the longitudinal direction after installation on site. Each panel is pretensioned in the transverse direction (long axis of the panel) during fabrication and ducts for longitudinal post-tensioning are cast into each of the panels.

The basic features of the PPCP system are as follows:

1. Panel size: up to 36 ft wide, 10 ft long, 7 to 8 in thick.
2. Panel types:
 - a. Base, joint and central stressing panels (as originally developed)
 - b. Base & joint stressing panels (as installed at a demo project in Missouri)
3. Tongue and groove transverse epoxied joint
4. Post-tensioning details
 - a. 0.6-inch diameter 7-wire monostrand tendons
 - b. 75% of ultimate load applied
 - c. Prestress force – residual prestress at mid-point
 - d. Grouting of post-tensioning ducts
5. Expansion joints @ ~ 250 ft
6. Base type
 - a. HMA base with poly sheet over AC base (as developed)
 - b. Permeable base (as used in Missouri demo project)
7. Injecting bedding grout to firmly seat panels (after post-tensioning)

Figure 1 illustrates the design concept underlying this precast concrete pavement technology. The base panels make up the majority of the post-tensioned pavement section and are placed between the joint panels and central stressing panels, if used. All of the panels have continuous tongue and groove keyways along the edges of the panels. The joint panels are located at the ends of each post-tensioned section of pavement. The joint panels contain dowelled expansion joints which allow the expansion and contraction

movements of the post-tensioned section. The joint panels also contain the post-tensioning anchorage for the longitudinal post-tensioning tendons. The anchors are cast into the joint panels on either side of the expansion joint. Blockouts or pockets cast into the joint panels provide access to the post-tensioning anchors. At the Missouri project, post-tensioning was performed at the joint panels. Field trials of this precast concrete pavement technology have been constructed in Texas (Interstate 35 near Georgetown, Texas), California (Interstate 10 near El Monte, California), Missouri (Interstate 57 near Sikeston, Missouri) and Iowa (Highway 60 near Sheldon, Iowa). The Iowa project was a special application of the PPCP system as bridge approach pavement. The PPCP system has not yet been used for production paving.

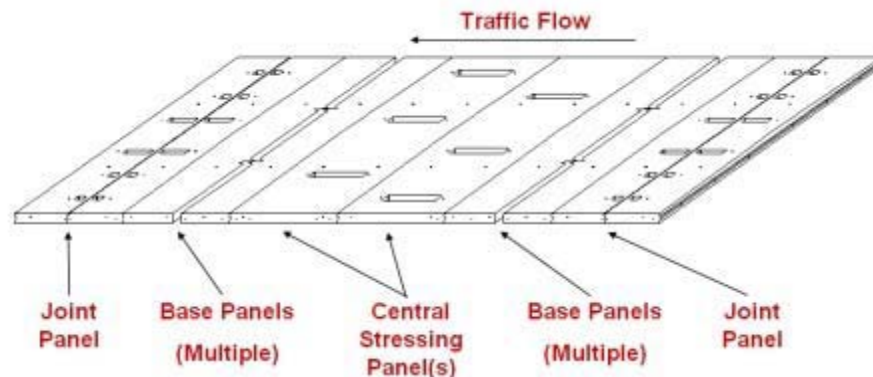


Figure 1(a). Design Details



Figure 1(b). Completed project along I-35 in Georgetown, TX

Fort Miller Super Slab System

This is a proprietary precast concrete pavement technology suitable for both intermittent and continuous paving operations. This paving system is an assemblage of precast slabs placed on a precision graded fine bedding material (maximum aggregate size of 12 mm). The transverse joints in the assembly of precast panels are fitted with standard dowel bars to provide load transfer. The basic features of the Super Slab system are as follows:

1. Produce base within 1/16 in, using laser controlled grading equipment

2. Place slab panels. Subseal with grout to eliminate voids
3. Provide slab-to-slab interlock at joints through dowel/slot system
4. Provide surface with ¼ in. Diamond grinding if better tolerance desired
5. Thickness – as specified (similar to jointed concrete pavement)
6. High performance concrete - 4,000 psi (or as required)

Figure 2 illustrates the typical slab panels used and the joint load transfer system. This particular precast concrete pavement technology lends itself to the construction and rehabilitation of freeway entry and exit ramps because the manufacturer can produce panels with varying cross-slopes (warped slabs). This system has the most production paving experience to date. The system has been field-tested by New York State DOT, the Minnesota DOT, the Ministry of Transport in Ontario, and others. Caltrans conducted accelerated load testing of the system in 2006. The application of the Super Slab system is summarized in Table 1.



Figure 2. The Super Slab System

Uretek System

In 1997, URETEK USA Inc. introduced a new process for fixing faulted joints and restoring load transfer to concrete pavements. URETEK has developed two patented technologies. The first is the URETEK® Method which is the process that employs high density polyurethane foam to lift, realign, under seal, and void fill concrete slabs which are resting directly on base soils. The second is the Stitch-In-Time® Process which is a repair system for restoring load transfer to jointed concrete pavements that are cracked, spalled or otherwise damaged. Pavements undergoing repair are first under sealed using the URETEK Method and then the Stitch-In-Time Process is applied to restore load transfer. The basic features of the Uretek system are as follows:

1. The panels are brought to site on flatbed truck and lowered into the excavated repair site
2. The panels are elevated to proper grade by injecting polyurethane foam under the panels
3. The panels are stitched to the existing slab or another panel using fiberglass boards, as illustrated in Figure 3.

Table 1-List of Super-Slab Projects 2001-2007

PROJECT	OWNER	AREA (SF)	TYPE OF PROJECT	WORK WINDOW	NATURE OF REPAIR	TYPE OF SLABS	DATE OF INSTALL
TAPPAN ZEE BRIDGE TOLL PLAZA	NYS THRUWAY	158,000	PRODUCTION	OFF-PEAK HOURS	CONTINUOUS	SINGLE PLANE	OCT. 2001 - JULY 2002
DULLES AIRPORT TAXIWAY REPAIR	METRO. WASH. AIRPORTS AUTHOR.	3,500	DEMONSTRATION	8 HOUR (NIGHT)	INTERMITTENT	WARPED	NOV. 2002
9A RAMP, TARRYTOWN, NY	NYS THRUWAY	15,750	PRODUCTION	DAY & NIGHT	CONTINUOUS	WARPED	AUGUST, 2003
LINCOLN TUNNEL, NEW JERSEY	PORT AUTHOR. NYNJ	8,100	DEMONSTRATION	OVER WEEKEND	INTERMITTENT	SINGLE PLANE	JULY, 2003
BELT PARKWAY RAMPS JAMAICA, NY	NYSDOT	8,850	DEMONSTRATION	FULL CLOSURE (ONE MONTH)	CONTINUOUS	WARPED	August-03
KOREAN VETERANS PARKWAY STATEN ISLAND, NY	NYSDOT	8,850	DEMO.	8 HOUR (DAY)	INTERMITTENT	SINGLE PLANE	NOV. - DEC. 2003
PORT JEFFERSON, NY (CROSS WALKS)	NYSDOT	2,650	PRODUCTION	8 HOUR (NIGHT)	CROSS WALKS	WARPED	July-05
I-90 - ALBANY, NY	NYSDOT	56,400	PRODUCTION	8 HOUR (NIGHT)	INTERMITTENT	SINGLE PLANE	SUMMER 2005
TORONTO, ONTARIO	MINISTRY TRANS. ONT.	1,220	DEMONSTRATION	8 HOUR (NIGHT)	INTERMITTENT & CONTINUOUS	SINGLE PLANE	NOV. 2004
FONTANA, CA	CALTRANS	1,950	TEST	OFF HIGHWAY	TEST	SINGLE PLANE	May-05
MINNEAPOLIS, MN	MN DOT	2,592	DEMONSTRATION	FULL CLOSURE	CONTINUOUS	SINGLE PLANE	JUNE, 2005
MARINE PARKWAY	METROPOLITAN TRANSIT AUTH. (NY)	2,592	DEMONSTRATION	3 DAY FULL CLOS.	CONTINUOUS	WARPED	JUNE, 2005
FORDHAM RD., BRONX, NY	NYS DOT	3,852	PRODUCTION	8 HOUR (NIGHT)	CONTINUOUS	S & W PLANE	DECEMBER, 2006
ROUTE 7 CROSS TOWN SCHENECTADY, NY	NYSDOT	26,586	PRODUCTION	10 HOUR (NIGHT)	CONTINUOUS INTERSECTION	S & W PLANE	July-06
HIGH SPEED EZ PASS SLABS	NYS THRUWAY	576	PRODUCTION	8 HOUR (NIGHT)	SPECIAL	SINGLE PLANE	August-06
SCHUYLERVILLE, NY (TRIAL)	NYS DOT	1,152	TRIAL INSTALL	OFF HIGHWAY	TRIAL	S & W PLANE	OCTOBER, 2006
SOUTHERN STATE PARKWAY	NYS DOT	2,483	PRODUCTION	8 HOUR (DAY)	INTERMITTENT	SINGLE PLANE	June-07
I- 95, NEW ROCHELLE, NY	NYS THRUWAY	40,000	PRODUCTION	5 HOUR (NIGHT)	INTERMITTENT	SINGLE PLANE	SUMMER, 2007
CHICAGO, IL (TRIAL)	ILLINOIS TOLLWAY	768	TRIAL INSTALL	OFF HIGHWAY	TRIAL	SINGLE PLANE	SEPT. 2007
TOTAL AREA		345,871					
TOTAL PRODUCTION AREA		306,297					



Figure 3 Uretex fiber glass stitches

For this system, expansion joints need to be placed at 45-60 feet intervals, otherwise premature slab cracking can develop.

Kwik Slab System

The Kwik Slab system is a proprietary precast concrete pavement construction system ideal for use in any area where the disruption of traffic due to road construction or repair is a major concern. The Kwik Slab system, which includes Kwik Joint steel couplers rapidly interlocks precast concrete panels allowing two-way rebar continuity throughout the entire pavement slab. The system essentially simulates jointed reinforced concrete pavement 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. Use of expansion joints has not yet been incorporated into the Kwik Slab system. Below are the Kwik Slab projects that have been completed:

1. Experimental Project: GP/RM Precast Plant, Campbell Industrial Park, Hawaii - Kwik Slab system installed in March of 2005. Total of 6 precast slabs were installed over existing asphalt pavement. Each slab measured 14' x 8' x 10" deep.
2. Production Project: Leoku Street Bus Stop, Waipahu, Hawaii - Kwik Slab system was installed in December 2006. Total of 10 precast slabs were installed over existing asphalt pavement to create new concrete bus pad. Each slab measured 13' x 10' x 10" deep.

The Kwik Slab system is illustrated in Figure 4.



Figure 4. The Kwik Slab system

ModieSlab System

This precast concrete pavement technology was developed in the Netherlands as part of the “Roads to the Future” program. The ModieSlab pavement structure is designed as a bridge, as shown in Figure 5. The structure consists of full-width precast concrete slabs. The slabs are connected to underlying precast reinforced concrete crossbeams with prestressed anchors and sliding planes; no dowel bars are present. Developments are being made to place the slabs directly on an existing pavement without the need of using piles and beams.



Figure 5. The ModieSlab technology in tests section along A50 and A12 in Netherlands.

A typical ModieSlab consists of a reinforced concrete layer approximately 320 mm covered with a twin layered porous concrete wearing layer. The top 15 mm of this porous concrete is fine grained, while the bottom 35-55 mm is coarse graded. The slabs contain gutters for the discharge of rainwater penetrated through the porous concrete wearing course. The Modieslab system contains a pipeline system for regulating the temperature of the slabs, which allows control of dilation, snow and ice control. Modieslab test sections have been constructed in the entrance to a rest area along motorway A50 and monitored over a period of 16 months. In addition to the field test section, a second structure was constructed at the LINTRACK APT facility at the Delft University to investigate the structural integrity of the system. In general, the researchers reported a positive experience with this technology from both a technical and economic view point. A 100 m section of ModieSlab was built in July 2006 in the truck lane of motorway A12.

La Guardia International Airport Generic Systems

During 2000, The Port Authority of New York and New Jersey (PANY/NJ) investigated the use of precast concrete pavement to rehabilitate Taxiway A. Taxiway A incorporates a thick AC pavement that requires constant repair due to rutting caused by queuing aircraft. The AC option is not preferred because of past performance issues and the cast-in place concrete pavement option is not feasible because of time constraints. As a result, PANY/NJ is seriously considering use of precast paving to rehabilitate sections of the taxiway over several 55-hour weekend closures. To develop engineering information, PANY/NJ constructed two 200-ft test sections at a non-critical taxiway during 2002. One test section used 16 in. thick, 12.5 by 25 ft panels and the second test section used prestressed 12 in., 12.5 by 25 ft panels. The two systems were developed as generic systems. The PANY/NJ is evaluating the performance of the two test sections. The La Guardia test sections are shown in Figure 6.



Figure 6 – La Guardia Test Sections

Precast Concrete Panels for Full-Depth Repair

This is a doweled full depth system suitable for isolated or intermittent repair of highway pavements. This is a non-proprietary precast concrete pavement technology. The repair panels are typically 6' long and 12' wide fitted with three or four dowel bars in each wheel path. The dowels are placed at 12" on center and the diameter depends on the slab thickness. Typical design and installation details are illustrated in Figure 7. The dowel slots are cut in the adjoining existing pavement. This precast concrete pavement technology was developed in partnership between Michigan State University and the Michigan Department of Transportation. This precast concrete pavement technology can be utilized to repair both jointed and continuously reinforced concrete pavements.

In the several demonstration/test projects constructed in Michigan (I-94 BL, I-196, M-25 and I-675), Virginia and the province of Ontario (Canada) the typical distresses exhibited by the candidate panels scheduled for repair included medium to high severity transverse cracking with associated spalling and faulted joints and cracks. The advantages of this technology include; (i) the transportation to and storage of multiple panels at a jobsite or at the agencies maintenance yard does not present a problem; (ii) the panels can be mass produced at the precast plant or at the ready mix suppliers yard (the latter was demonstrated in Michigan); (iii) based on the geometry and proximity of repair sites eight to ten panels can be installed in a day and ready for traffic shortly thereafter; (iv) a typical agency paving mixture design can be used for the construction of these panels if appropriate moist curing is applied; and (v) presence of dowel bars across the transverse joints ensures adequate load transfer efficiency.



Figure 7. The full depth precast repair system (M-25, MI)

Airfield Applications

Use of precast concrete pavement is considered to be a high pay-off alternative for rapid repair and rehabilitation of airfield pavements. Several agencies have recently investigated use of these technologies, as follows:

1. PANY/NJ, as discussed previously, for possible rehabilitation of Taxiway A at La Guardia Airport
2. St. Louis international Airport – for slab panel replacement
3. Dulles International Airport – for slab panel replacement (Fort Miller and Uretex systems)

The US military has also been evaluating use of precast pavements for expedient airfield pavement repair and rehabilitation. The US currently operates from old Soviet designed/constructed airfields in Afghanistan that incorporate a variety of precast concrete slabs.

Japanese Precast Reinforced Concrete (PRC) Slabs

The Japanese have, over the years, made use of precast concrete pavements to meet project specific needs. Precast reinforced concrete (PRC) slabs are placed on an asphalt interlayer to prevent pumping in the granular base course underneath. Gaps between the slabs and interlayer are filled with a grouting material. The standard dimension of the slab is 1.5 m (4.9 ft) in width and 5.5 m (18.0 ft) in length. The thickness varies from 20 to 25 cm (7.9 to 9.8 in.)

Airport taxiways application with precast reinforced concrete (PRC) slabs of high-strength concrete connected with cotter joints has also been studied in Japan. Through laboratory tests and construction of an experimental pavement at Fukuoka Airport in 2004, the joint design has been improved and fiber reinforced concrete has been tried at the surface portion of the PRC slab to prevent cracking.

French “Removable Urban Pavements”

In France, in the pursuit for “removable urban pavements”, researchers at the Pont et

Chaussées laboratories (LCPC) are evaluating the option of pre-cast concrete slabs. A hexagonal shape, as opposed to a more typical rectangular shape, is being evaluated. As part of the concept, the slabs have to be mechanically independent in order to be easily lifted during maintenance operations, and therefore only a soft polymeric water-proof joint is cast. The slabs are installed over a granular bed. The base course has a structural function, so research continues to find an easy-to-dig material, yet strong enough to resist long-term traffic loadings. The slabs are 200mm thick and have an equivalent diameter of 1,540mm. Accelerated pavement testing has been carried out successfully at LCPC. A second type of slabs was evaluated with smaller panels and keyed joint to provide some level of load transfer. The system is illustrated in Figure 8.



Figure 8. Installation of keyed hexagonal slabs in France

Experiences with Accelerated Pavement Testing of Precast concrete Pavements

There have been at least four experiments that specifically have looked into durability of precast concrete pavement under heavy traffic loads. These experiments have occurred in California, the Netherlands, and France, as shown in the Table 2.

Table 2 – Details of Accelerated Testing of Precast concrete Pavement Systems

Location	Holland	France	California
Precast concrete system	ModieSlab	Removable Urban Pavement (RUP)	SuperSlab
Material	Pre-cast concrete slabs	Hexagonal Pre-cast concrete slabs	Pre-cast concrete slabs
Testing dates	July 2002 to December 2003	~2004-2005	June 2005 to August 2006
Tested by/at	Delft University of Technology, (Road and Railway Engineering Dept)	LCPC circular test track, Nantes	UCPRC and Dynatest. Intersection of I-15 and I-210 in San Bernardino
Load simulation system	LINTRAK	LCPC Fatigue Carrousel	HVS
Precast concrete pavement system developed by	ModieSlab	Laboratoire Central des Ponts et Chaussées (LCPC)	The Fort Miller Company

Based on the experience gained at the University of California Pavement Research Center (UCPRC), and from a literature survey of the other experiments, the precast concrete

slabs systems (at least the ModieSlab®, SuperSlab®, and the hexagonal panels by LCPC) have the potential to be long-life systems capable of adequately resist a great number of heavy traffic load repetitions (Van Dommelen 2004; DeLarrard 2006).

The following conclusions were derived from the experiment conducted by UCPRC for Caltrans in which a Dynatest Heavy Vehicle Simulator was used to test the structural performance of the Super-Slab system (Kohler et al. 2007).

1. The Super-Slab system of pre-cast slabs can be safely opened to traffic in the un-grouted condition, so that the panels can be installed in consecutive nights rather than completing the entire installation at one time. This allows for the old slabs to be removed and pre-cast slabs placed in position one night, and for completing the grouting procedure on the following night.
2. The life of this system of pre-cast slabs, when used as detailed for this test, is estimated to be between 142 and 242 million ESALs. These number results from estimated traffic applied in a section that did not fail, and a section that did fail under very high load levels. Taking as example highway I-15 in San Bernardino County, California, this number of ESALs could be assumed equivalent to more than 25 years of service, perhaps about 37 years before reaching failure.
3. The failure mechanism in this system of pre-cast slabs was no different than failure in cast-in-place jointed concrete pavements. Corner cracks, that are the result of loss of support, created conditions indicative of end of usable pavement life.

Summary of Gaps in Technology and Practice

While much progress has been made in the last few decades to improve precast concrete pavement technologies, many challenges remain. Some of the technical and institutional challenges are listed in Table 3.

Future research Needs

The US Congress established the second strategic highway research program (SHRP 2) in 2006 to investigate the underlying causes of highway crashes and congestion in a short-term program of focused research. As part of this program, a highway renewal research plan has been developed. The *Renewal* focus area emphasizes the need to complete highway pavement projects quickly, with minimal disruption to the users and local communities, and to produce pavements that are long-lasting. The goals of this focus area include applying new methods and materials for preserving, rehabilitating, and reconstructing roadways. The effective use of precast concrete pavement technologies for rapid repair, rehabilitation and reconstruction of pavements addresses this goal.

Table 3 – Technical and Institutional challenges for precast pavements

1. Higher costs for constructing/installing precast concrete pavement systems in view of constrained agency budgets	
2. Field installation (production) rate	
3. Lane closure requirements for rapid installation	a. Daytime between rush hours b. Nighttime c. Weekend d. Extended
4. Sound understanding of factors that affect precast concrete pavement behavior and long-term performance. For precast concrete pavement systems, some of the critical factors are:	a. Load carrying capacity of each system component b. Seating and support condition (bedding requirements) c. Load transfer at joints between precast concrete units and between precast concrete units and existing pavement d. Connectivity at joints e. Expansion joint performance for PPCP systems f. For PPCP, impact of thin slab on deflection response
5. Treatment for curved sections – use of 3D control for slab panel fabrication and base grading.	
6. Optimizing various precast concrete pavement system design features	
7. Ensuring durability of the precast concrete pavement systems	
8. Lack of adequate long-term performance history	
9. Lack of adequate testing of precast concrete system components (e.g., joint connectivity, expansion joint systems)	
10. Ready availability of nearby precast concrete pavement assembly/fabrication plants	
11. Well developed process control (QC) procedures for different systems	
12. Well developed acceptance testing (QA) procedures for different systems	a. Slab panel dimensional tolerances b. Ride/profile c. Load transfer effectiveness at joints d. Initial faulting at joints
13. Treatment procedures for early failures	
14. Opening to traffic requirements	
15. Maintaining precast concrete unit riding characteristics (safety related)	
16. Maintaining vertical alignment at joints	
17. Lack of Best Practices for design, construction and M&R of precast concrete pavement systems	
18. Lack of well developed, experienced based generic specifications for use of precast concrete systems	
19. General lack of support by the precast concrete industry to support refinement of the precast concrete pavement system technologies	
20. General lack of support by the asphalt industry to support development of precast concrete pavement technologies based on asphalt-based systems.	
21. Lack of understanding of the technical capabilities by highway agencies of the potential of precast concrete pavement technologies. Need for technology transfer activities related to:	a. Selection criteria for use of precast concrete technologies b. Generic specifications for use of precast concrete technologies c. Design, construction and M&R issues related to precast concrete technologies

The objective of an ongoing research project known as SHRP2 R05 is to develop tools for use by highway agencies to design, construct, install, maintain, and evaluate precast concrete and modular pavement systems. These tools are to include the following:

1. Guidance on the potential uses of precast concrete pavement systems for specific rapid renewal applications
2. Generic design criteria for precast concrete pavement systems

3. Project selection criteria for precast concrete pavement systems
4. Guidelines and model specifications for construction, installation, acceptance, and maintenance
5. A long-term evaluation plan to assess the performance of precast concrete pavement systems and to refine these systems.

The primary needs for use or promotion of precast concrete pavement technologies is rapid application and long-term durability. If the application is not rapid, it will not be relevant if it is not cost-competitive. If the application is rapid, but not durable, it will not have any future. As such, it is important that structural design features and precast concrete pavement material properties are optimized and integrated to assure rapid applications as well as long-life.

The US definition of long-life concrete pavement is summarized as 1) Original concrete surface service life – 40+ years; 2) Pavement will not exhibit premature construction and materials related distress; 3) Pavement will have reduced potential for cracking, faulting & spalling; and 4) Pavement will maintain desirable ride and surface texture characteristics with minimal intervention activities only to correct for ride and texture, for joint resealing, and minor repairs.

It is essential that precast concrete pavement systems used in continuous applications be able to meet the above requirements. In the past this definition was applied primarily to high volume traffic roadways. However, many agencies are beginning to apply such a definition to most roadway facilities. For repair applications, the service life may be a few years to 20 plus years, depending on the projected rehabilitations needs of the pavement undergoing repair but the other requirements are still applicable.

Although several types of precast concrete pavement systems have been successfully demonstrated and are considered proven systems, further research is needed in several key areas to ensure good long-term pavement performance, to improved constructability, and to make the systems cost-competitive. The areas for improvement include the following:

1. System structural design – to ensure performance under traffic and environmental loadings
2. Fabrication – to ensure that systems can be fabricated to high quality standards, at least equal to, but preferably better than conventional pavement systems
3. Material – to ensure long-term durability of materials used in the systems – for concrete, load transfer systems, grout systems, AC based systems
4. Construction (field installation) – to ensure rapid constructability of the systems with minimum lane closure requirements and to minimize field equipment and personnel. System construction should be as automated as possible with very low risk of construction related delays in installation work. Also, the ability to accommodate curved sections (using “warped” slab panels) need to be considered.
5. Performance – to ensure that ride and surface characteristics are maintained at the desired level over the long term and only minimal intervention activities are required to correct deficiencies in ride and surface texture. In addition, system

maintenance and repair activities need to be kept to a minimum and should be easily applicable without requiring significant equipment, labor, and lane closure requirements in future years.

Based on experience to-date with constructed precast concrete pavement systems, the following areas require additional investigation:

- Structural support beneath the precast panels – uniform support is essential to prevent the development of localized stresses, which can lead to premature faulting, pumping of fines, cracking and crack deterioration. Various methods are in use today, but none are without some shortcomings. Perhaps the most comprehensive of the methods in use today is that developed for Super Slab system. In that system, a thin layer (1 in) of sand material (rock dust) is placed, compacted, and graded using a laser-guided grader to provide a nearly perfect surface profile for the placement of the precast panels. In addition, a highly flowable grout is pumped through a system of grouting channels to further ensure that no voids are present beneath the slabs. While the use of this system ensures full slab support at the time of slab installation, possible pumping of the bedding material (which, over time may result in faulting) is a concern. Also, the requirement to place a relatively thick (1 in or more) of the bedding layer can be an issue on reconstruction projects.
- For the PPCP system, the support system is critical because of the use of thin slab panels. While the prestressing ensures resistance to cracking, there is no direct benefit in terms of the deflection response. As such, there needs to be a stronger emphasis on the need for a strong foundation/support under the PPCP system.
- Various methods of slab jacking are also in use. For that approach, the intrusion of the bedding grout (or foam) beneath the adjacent slabs, causing non-uniform support may be a concern. Also, the process required an experienced crew. From construction expediency perspective, an approach that requires less effort (time) to provide the required support is more desirable.
- With respect to the use of concrete systems in an overlay application, the use of the German-style geotextile layer shows potential. In Germany a 5 mm thick geotextile fabric is used as an interlayer between the concrete slab and a CTB, for cast in place construction. This use is under investigation as an interlayer for unbonded concrete pavements. It is possible that the 5 mm (or other thickness) can be used to provide a more effective bedding under precast concrete panels in continuous paving applications.
- Smoothness – currently, the fabrication tolerance on precast panels is about 1/8 in. While this level of precision is considered the limit of current technology, on a mainline pavement, a built in faulting of 1/8 in is not desirable. Unless the fabrication tolerance can be reduced drastically (e.g., 1/32 in), grinding is required to provide the desirable ride quality. Further research is needed to determine if the fabrication tolerance can be reduced or if grinding is the more cost-effective treatment.
- Load transfer – currently, all jointed systems have dowel bars at the construction joints. Typically, the precast panels have pre-positioned dowel bars at one end and dowel slots at the opposite end of the slab. After placing the slabs, the dowel

slots have to be filled with a grout or patching material. In this process, the intrusion of the grout into the joint is difficult to prevent. Having incompressibles in the transverse joints is not desirable, especially if longer panels (20 ft or longer) are used in precast construction for construction expediency. The performance effects of the grout intrusion need to be investigated. Further research is needed to assess and develop improved methods of establishing load transfer for precast concrete systems.

- Slab fabrication process – although precast slabs are fabricated with the best possible degree of accuracy, the errors due to fabrication tolerance are inevitable. Currently, the fabrication tolerance is about 1/8 in for all dimensions (length, width, thickness, and difference in diagonals). These are very tight tolerances, and it may be difficult to improve on these tolerances. However, over the length of a project, the accumulated errors in slab length can be significant, unless steps are taken to prevent the accumulation of the errors in slab length. One way of preventing the accumulation of the fabrication errors is to establish survey lines where the slabs are to be placed, based on the design slab length and construction tolerance, and placing each slab on the survey line, rather than flush with the previous slab. At the current standard of precast slab fabrication, this means that there would be an average of 1/4 in gap at every joint, which affects the ride quality. Further research is needed to reduce the fabrication tolerance.
- Field performance under a range of traffic loading and environmental conditions – the body of field data have not yet been developed and reported to the extent needed to determine the suitability of precast concrete systems for specific applications.
- Accelerated load testing of specific systems and system components – because there is not adequate long-term performance data on various systems, it is necessary that a limited amount of accelerated load testing be conducted to evaluate the ruggedness of system components, to identify critical system features/components, to determine system failure mechanisms, and to verify structural analysis procedures that can be used to further refine the systems without the need for accelerated load testing. Only the Super Slab and the Modie Slab systems have been subjected to accelerated load testing to date.
- Field performance evaluation – work need to be conducted to determine how the constructed projects are performing in the field to verify design assumptions and to assess refinements needed in the systems. In addition, information on the life cycle of each system needs to be established to support decision making by highway agencies.
- Constructability and traffic management requirements – constructability under a rapid construction scenario and effective traffic management are key requirements for use of precast concrete pavement systems and need to be well understood by highway agencies.
 - Lane closure requirements
 - Single lane versus multiple lane closure requirements
 - Moving lane closures
 - Physical length of closures
 - Site access for construction equipment

- Use of construction traffic optimization software, such as CA4PRS
- Data on construction productivity during pavement repair and rehabilitation projects and traffic impacts

Summary

The precast concrete pavement technology has seen significant improvements in the last decade. Several precast concrete pavement systems have been developed and are being implemented on production projects. Field experience and limited accelerated load testing to date indicate that the precast systems are viable pavement alternatives for rapid rehabilitation and reconstruction of existing pavements. The next few years should see further improvements in the precast pavement technologies as the products from the SHRP 2 research program become available.

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