INTERNATIONAL PRECAST CONCRETE PAVEMENT APPLICATIONS: A SUMMARY OF PRACTICE

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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. Recently, a review was conducted to identify PCP technologies in other countries that show promise for implementation in the US or can support improvements in technologies currently in use in the US. The primary focus of the review was to identify PCP technologies that support rapid renewal of existing pavements and result in longer lasting treatments.

Information for the international PCP practices review was compiled based on published literature, internet searches, and personal contacts with experts in the US and other countries. The counties that were identified as having a reasonably active PCP program or have implemented PCP technologies include Russia, Japan, the Netherlands, France, and Indonesia. The review indicated that the use of the PCP technology in other countries (except Canada) is for rapid and/or longer lasting continuous applications. The PCP technology is not used for intermittent repairs in these countries. The PCP technologies have been used the longest for roadway as well as highway applications in Russia and Japan. This paper presents the findings of the review of international PCP technologies and identifies PCP technologies that may have potential applications in the US.

Keywords: Concrete pavements, pavements, precast concrete, precast concrete pavements

INTRODUCTION

Pavement rehabilitation and reconstruction, major activities for all U.S. highway agencies, have significant impact on agency resources and traffic disruptions because of 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 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, which provide for accelerated repair and 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.

Precast concrete pavement systems are systems that are essentially fabricated or assembled off-site, transported to the project site and installed on a prepared foundation (existing pavement or re-graded foundation). These systems do not require field curing for the precast concrete panels and require only minimal time for system components to achieve strength before opening to traffic. Ideally, PCPS are installed rapidly, cause minimum disruption to traffic, and produce long life for the repaired or rehabilitated pavement areas. Shorter-life pavement rehabilitation cannot be accepted as the price of rapid repair and rehabilitation. The primary warrant for use of PCP technology is the ability to reduce construction time without sacrificing quality or longevity, thus reducing lane closure time in heavily congested traffic corridors. Off-site fabrication also has the potential to permit use of lighter, thinner, and more durable pavement sections through more stringent quality control and use of design details not feasible for in-place construction.

The precast concrete pavement technology is gaining wider acceptance by US highway agencies and contractors and precasters are beginning to seriously explore business opportunities related to precast concrete pavement applications. The US precast concrete pavement technology is generally based on sound technical/engineering considerations and field installation processes appear to be workable given the severe working conditions for many of these projects. Gaps in technology remain and need to be addressed before the use of precast pavement for rapid pavement renewal becomes an established and routine process.

PRECAST PAVEMENT TECHNOLOGY HIGHLIGHTS

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

1. Intermittent Repair of PCC Pavement: Under this approach, isolated pavement repairs are conducted using precast concrete 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. Two types of repairs are possible:
    a. Full-depth repairs, to repair deteriorated joints, corner cracking or cracking adjacent to the joint.
    b. Full-panel replacement, to replace cracked or shattered slab panels.

2. Continuous Applications: Under this approach, full-scale project level rehabilitation (resurfacing or reconstruction) of asphalt and concrete pavements is performed using precast concrete panels.

US PRECAST CONCRETE PAVEMENT SYSTEMS AND EXPERIENCE

Several recently developed techniques are available in the US, as follows:

1. Precast prestressed concrete pavement (PPCP) developed at the University of Texas
2. Jointed precast concrete pavement, proprietary and generic systems:
    a. Fort Miller Super-Slab system (proprietary features)
    b. Kwik Slab system (proprietary features)
    c. Roman Stone system
    d. Michigan system (generic)
    e. Illinois Tollway system (generic)
    f. La Guardia International Airport system (generic)

Discussion of these systems and techniques is given elsewhere (Tayabji et al., 2009; Hall and Tayabji, 2008; Merritt and Tayabji, 2009).

PRECAST PAVEMENT USE IN THE US

Since about 2000, many highway agencies in North America have expressed interest in considering use of precast concrete for intermittent repair or continuous applications in heavily trafficked urban areas where extended lane closures are difficult. The following U.S. and Canadian highway agencies have accepted the use of precast pavement for production work:

1. Caltrans
2. Illinois Tollway Authority
3. Iowa DOT (as an alternate for bridge approach slabs)
4. Ministry of Transport, Ontario
5. Ministry of Transport, Quebec
6. New Jersey DOT
7. New York State DOT
8. New York State Thruway Authority

In addition, several U.S. highway agencies have investigated or are investigating use of precast concrete pavement.

INTERNATIONAL EXPERIENCE WITH PCP TECHNOLOGIES

This section summarizes the use of PCPS in other countries and highlights specific innovations in the PCP technologies in these countries.

CANADA

The PCP technology has been in use in the provinces of Ontario and Quebec. The PCPS practices are based on systems developed and in use in the US. In 2004, the Ministry of Transportation Ontario (MTO) carried out a trial project to evaluate construction techniques for precast concrete slab repairs in concrete pavement. The trial was carried out on Highway 427, in Toronto (Lane and Kazmiorowski, 2007). The trial project included demonstrations of three precast concrete pavement full-depth repair methods: the Fort Miller Super-Slab Intermittent Repair Method, the Fort Miller Super-Slab Continuous Method, and the Michigan Method. Each method involves designing and fabricating precast concrete slabs to replace deteriorated concrete pavement. During 2008 and 2009, the MTO installed about 5,000 sy of PCP using the Fort Miller system at three projects in the Toronto area. There were no PCPS projects installed by the MTO during 2009 and 2010. The MTO has also developed a specification that details the requirements for repairing concrete pavement with PCP (MTO 2010). The specification is applicable to both continuous and intermittent slab repairs. The Ministry of Transport Quebec (MTQ) used the Fort Miller Super-Slab method for an approach slab project the Montreal area during 2008.

FRANCE

In France, in the pursuit for "removable urban pavements", researchers at the Pont et Chaussées laboratories (LCPC) developed a hexagonal shaped PCPS (de Larrard et al., 2006) Two projects were installed by LCPC in cooperation with other organizations, one in 2007 and a second one in 2008 and the technology was widely publicized to urban agencies in France. It is not clear if other local agencies (France has over 36,000 municipalities) did in fact implement this technology as no formal tracking of projects has been done by any organization. A unique advantage of the French PCPS is that the base course used is easy to place and grade and can be worked with light equipment available locally. A second type of the hexagonal PCPS has also been developed. The panels for this system are smaller in size and incorporate keyed joints to provide some level of load transfer at the joints. According to the LCPC experts, the size, base support and the optional keyway connections between panels allow the PCPS to carry heavy trucks loadings, up to 1,500,000 cycles of truck loading. The system was tested successfully at an accelerated load testing facility. Views of the French hexagonal PCPS are shown in Figure 1.

Fig. 1 Installation of Keyed Hexagonal Slabs

Because of the removable requirements, the precast panels have to be mechanically independent in order to be easily lifted during maintenance operations. Therefore no load transfer mechanism is provided along joints and only a soft polymeric water-proof joint sealant is used. 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 typically 8 in. thick and have an equivalent diameter of about 5 ft. Accelerated pavement testing has been carried out successfully at LCPC. A guide for the use of the removable hexagonal-shaped PCPS has been developed (CERTU-LCPC-CIMBETON, 2008). A plan view of the system is shown in Figure CC.

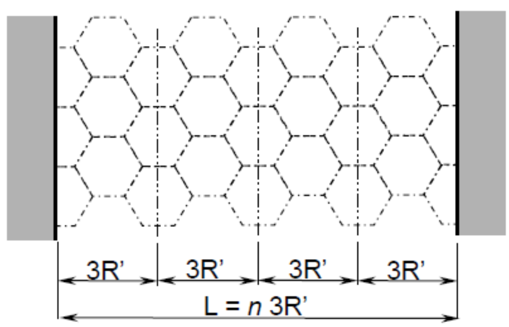

Fig. 2 Details from the French Hexagonal Precast Pavement Guide

INDONESIA

During 2008, a PPCP project was completed on a portion of the Kanci-Pejagan Toll Road near Cirebon on the island of Java in Indonesia (Nantung, 2010). The four-lane project, which is about 22 miles in length, is located between the seaport city of Cirebon (a north coastal city of the West Java province) and Semarang (a north coastal city of the Central Java province). This particular toll road will become a section that connects the Trans-Jawa Toll Way System, which will have a total length of over 515 miles.

The PPCP design was based on the PPCP practices in the US, principally the pilot PPCP project constructed in Georgetown, Texas, during the fall of 2001. The final design selected for this project required use of 8 in. thick panels placed over a 2 in. lean concrete base. The design was based on maintaining a certain level of prestress in the panels (after post-tensioning) that would make the PPCP equivalent to a thicker conventionally designed jointed concrete pavement. The design was based on an Annual Average Daily Traffic (AADT) count of 76,302 vehicles and a total Equivalent Single Axle Load (ESAL) of 43 million over a 30-year period. For the traffic, locally available materials, and climate, a jointed concrete pavement design would have required a thickness of 13.5 in. The panels as fabricated were 8.2 ft long and 27 ft wide. Thirty seven panels were post-tensioned together to result in 320 ft sections. The panels were installed in the following sequence: 1 joint panel, 18 base panels, 1 center panel, 18 base panels, and 1 joint panel. Each panel was also pre-tensioned in the transverse direction. The panels were placed on the lean concrete base that had been covered with a polyethylene sheet to reduce the slab/base interface friction during the post-tensioning.

This project was the first large scale use of the PPCP system and was the first PPCP project to be constructed in a remote area. It demonstrated the advantages that PPCP can offer in overcoming the challenges of building roads in developing countries. Local contractors were able to easily design and construct this project without a large initial capital investment. The quality of the PPCP concrete is considered superior to the quality of cast-in-place concrete for such remote area applications. Other advantages cited by the Toll agency include:

1. Less cost for mobilization for investment in heavy equipment
2. Better controlled construction process for the PPCP panels at one site
3. Higher strength concrete, better concrete curing process, and improved quality control
4. No construction delays as installation was possible 24 hours a day
5. PPCP panels are thinner and use less concrete than conventional jointed concrete pavements due to inclusion of relatively inexpensive prestressing tendon
6. PPCP is considered long-lasting and durable.

For this project, a panel fabrication facility, shown in Figure 3, was constructed in an isolated farming area located near the middle of the project to optimize transport time and costs.

Fig. 3 Indonesia Precast Panel Fabrication Facility

The precast facility had three covered bays with four production lines in each bay. The 12 fabrication lines could manufacture 120 panels in one casting cycle. The main contractor used local laborers as helpers in the labor-intensive fabrication process as an ample supply of workers were readily available from nearby villages and their employment stimulated the local economy. Concrete was mixed on-site according to Indonesian standard K-400 (design compressive strength of about 4,850 psi). Trucks delivered the concrete to the fabrication lines where it was placed by hand, consolidated by spud vibrators, and finished by hand. Surface tining was done during production so the placed panels would have longitudinal tining. After tining, the panels were steam cured with elevated temperatures overnight. Typically, 40 panels were placed each day. Panel installation views are shown in Figure 4.

Fig. 4 Indonesia PPCP Installation

To prevent damage to the lean concrete base, the soil subbase in one direction was used as an access road while the two lanes in the other direction were being constructed. The contractor made a few adjustments to initially match the panel keyways before modifications were made to the formwork. Some base panels were produced with modified dimensions so the panels would be in alignment. Keyway issues occurred while joining the panels to form the post-tensioned sections. These issues were resolved by refining the formwork and adjusting the keyways. The PPCP smoothness was measured to be about 145 inches/mile. A view of a completed PPCP section is shown in Figure 5.

Fig. 5 View of the Completed PPCP Project

The Toll agency is planning to use the PPCP system additional lengths of new toll roadway. In addition, several Indonesian agencies are investigating use of PPCP to rehabilitate existing pavements, typically asphalt pavements, in congested urban areas. A one-mile experimental project has been constructed to refine some of the PPCP design and construction features. Some of the new features being investigated include the use of a reinforced cast-in-place gap slab between the post-tensioned sections, as shown in Figure 6, and use of an AC surface layer over the PPCP.

Fig. 6 Use of Cast-in-place Reinforced Gap Slabs

The production use of the PPCP in Indonesia illustrates how innovative pavement technologies can be readily and cost-effectively applied in developing/emerging countries for new roadway construction as well as for rehabilitation of existing roadways in congested urban areas.

JAPAN

Precast concrete pavements were used in Japan for production paving at container yards and airports in the early 1970's and by the early 1990's researchers began examining the use of PCP for roadway applications. Early projects were constructed using reinforced concrete panels on stabilized bases, but without load transfer at joints. Later projects incorporated the prestressing technology. The use of precast concrete pavement increased in Japan when a special load transfer system called the "horn device," shown in Figure 7, was developed (Hachiya, Y., 2001). Typically, for roadway applications, the 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 4.9 ft in width and 18.0 ft in length. The thickness varies from about 8 to about 10 in.

Some examples of the PCP projects are shown in Figures 8 to 10 (Nishizawa, T., 2008). For tunnel applications, it has been reported that when the precast panel surface is worn, the panels are turned over and re-used.

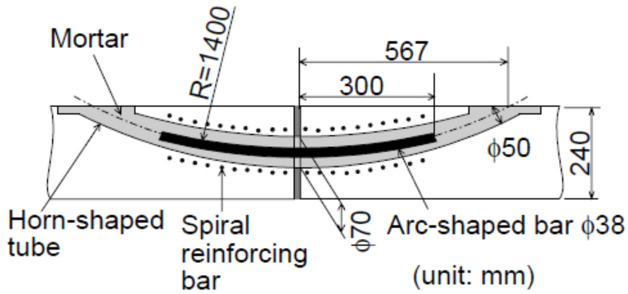

Fig. 7 The "Horn" Load Transfer Device

Fig. 8 Intersection Application (Kanazawa City, 2002) and Roadway Application (Kasugai City, 1998)

Fig. 9 Airport Applications (Osaka Airport, 1998; Fukuoka Airport, 2003)

Fig. 10 Typical Tunnel and Port Applications

For airport applications, the precast panels are about 8 ft wide, 47 ft long, and about 10 in. thick. The panels are prestressed (pre-tensioned) in the long direction. Also, the jointing for airfield pavements may incorporate both the horn device and a compression joint device (Hachiya, Y. et al., 2001) as shown in Figure 11. For the compression joint device, stressing tendons (unbonded) are installed through the joint, tensioned to a pre-determined force, and fixed at both of its ends to the slabs. The compression joint devise is considered to be more efficient in transferring the load across the joint and allows easier replacement of damaged panels. However, because of the higher cost of installing the compression joint device, this system is used in combination with the horn device. The two devices are typically placed alternatively at about 18 in. An installation of the PCP using both joint load transfer devices is shown in Figure 12.

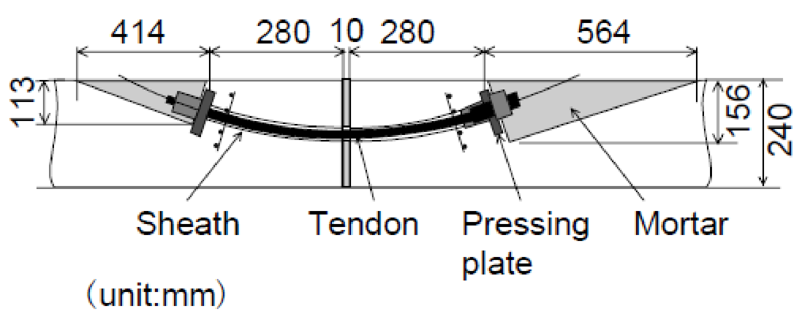

Fig. 11 Compression Joint Unit

Another innovation introduced in Japan is the sliding dowel bar joint concept. This joint system is also widely used.

Fig. 12 Constructed PCP at Sendai Airport

The use of precast panels with heating tubes has also been developed in Japan. Figure 13 shows a panel with heating tubes being fabricated and an installed project showing ice-free/snow-free pavement condition (Nishizawa, T., 2008).

Fig. 13 Heated Precast Panel Fabrication and Installed Project

THE NETHERLANDS

The PCP technology, referred to as the ModieSlab, was developed in 2001 in the Netherlands as a response to the "Roads to the Future" program challenge sponsored by the Dutch Ministry of Transport (Bax, N. et al., 2007). The challenge required that any innovative roadway design solutions result in a noise reduction of at least 5 db(A). The ModieSlab development was carried out by a joint venture team of of Arcadis, Betonson and Heijmans. ModieSlab is a proprietary technology.

As initially conceived, the ModieSlab system was designed as a bridge system with a design life of 100 years. The system incorporates short length panels (11.8 ft) supported by precast concrete beams placed over precast foundation piles, as illustrated in Figure 14. The first pilot project was installed in 2001 at an access road to a rest area along the motorway A50 near Apeldoorn in the Netherlands. During the next 1½ years, the slabs were tested extensively on site with good performance results. The ModieSlab concept has evolved since then with several desk studies and additional demonstration projects along sections of motorway A12 near Utrecht (RWS-DVS, 2008) and a bus/tramway in Blankenberge, Belgium), and on-grade applications. For on-grade applications, a load transfer feature was developed to accommodate load transfer across joints.

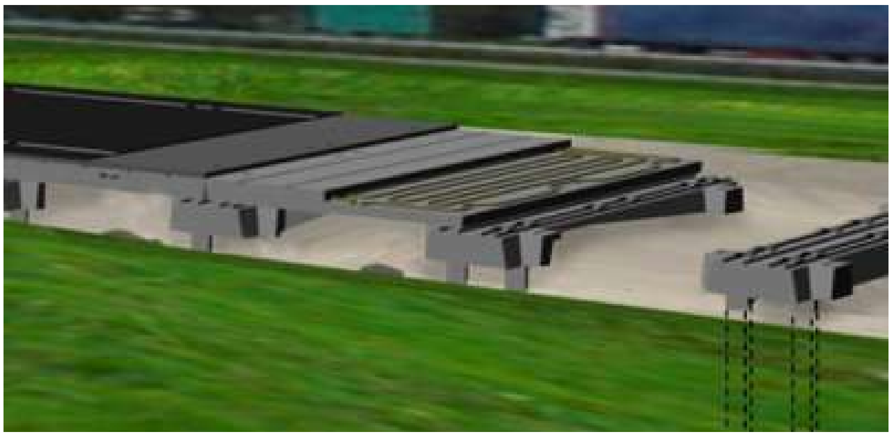

Fig. 14 The Original ModieSlab Concept

For the bridge-type applications, for use over poor soil conditions, the panels are 15 in. thick and consist of 2.75 in. thick two-layer porous concrete, as shown in Figure 15, and a 12.25 in. high quality base concrete (grade C65 with a characteristic compressive strength after 28 days of least 9,400 psi) with two-layer reinforcement. A fine grained top porous layer is used because a fine texture reduces the amount of tire/pavement noise. A high void content (> 20%) is needed for noise absorption. Coarser aggregates are used for the second porous layer in order to obtain larger pores resulting in an easy drainage of water coming through the porous top layer and preventing in that way any clogging of the top layer. The slabs are manufactured upside down which ensures a very even surface for each slab. Views of the ModieSlab installation are shown in Figure 16. ModieSlab has been tested under the accelerated load testing facility, LINTRACK, at the Delft University to investigate the structural integrity of the system (Houben, L. et al., 2004). In general, the researchers reported a positive experience with this technology from both a technical and economic view point.

Fig. 15 The Two-layer Porous Surface

Fig. 16 ModieSlab Installation

The following ModieSlab projects have been completed:

1. ModieSlab Hengelo. Construction of 4 road crossings completed in August 2009 (phase 1) and September 2010 (Phase 2). A total of 600 slabs on grade were placed.
2. ModieSlab Haarlem. Reconstruction of pavements near a train station. 60 (large) slabs were placed.
3. ModieSlab bypass Oudenrijn (Bypass of Motorway A12). Slab on pile system constructed in 2006.
4. Modieslab Trambaan Blankenberge (Belgium). A total of 16 ModieSlab panels were installed to renovate a tram system. Constructed in November 2008 to January 2009. Part of larger project 'Quiet City'. Goad is to design integrated infrastructure to control road and rail noise. Rails were embedded in the panels with porous concrete layer used at the surface.
5. ModieSlab De Somp. Constructed 2001. First project of ModieSlab system on piles. Still in service. However, several improvements were made to ModieSlab based on lessons learned at this project.

RUSSIA

Soviet technical literature of the 1960's and 1970's includes a number of generally favorable descriptions of PCP use for temporary road construction, under heavy industrial traffic in the Donbass, on the Kiev-Odessa highway, under urban traffic in Moscow, and elsewhere (Sapozhnikov, N. and Ray, R., 2007). The road construction using PCP has a rather long background, nearly 60 years, immediately after WWII. The road construction using PCP began to expand intensively since the 1970s, reached its peak in the 1980-1990s, and continues until present due to the development of access roads to the Western Siberia oil and gas fields (predominantly in the Khanty-Mansi Autonomous Area and Yamal-Nenets Autonomous Area). Over six thousand kilometers of roads were paved with PCP in Western Siberia between 1960 to1980s. The average service life of the PCPs was 10-40 years. Precast concrete pavements are still used for roads in the northern and hard-to-reach areas of Russia, including oil and gas fields' access roads and access roads to industrial and agricultural facilities, located predominantly in the I-II traffic climatic zones.

Precast prestressed concrete was thought to be particularly efficient in use of materials, its plant manufacture offered the potential for high quality products, construction could proceed under adverse environmental or site conditions, and precasting allowed rapid repair of damaged pavements. The panels are prestressed (pre-tensioned) using an electro-thermic process. The precast panel use has been standardized in Russia, the last set of standards published during 1992. A view of a recently fabricated standard panel is shown in Figure 17.

Fig. 17 Russian Standard Design Precast Panel

Views of the stored panels for use at an airfield site during the Soviet era and a completed project are shown in Figure 18.

Fig. 18 Soviet Era Precast Panels – Storage and an Installed Site

A unique aspect of the Russian system is the use of the lifting loops, positioned along the long edge of the panels. These lifting loops are welded together. Good welding technique is mandatory. If the spacing between the adjacent loops is 0.15 in. or less, the loops are welded together in a single weld. If the spacing is greater than 0.15 in., a reinforcing bar whose diameter was three to four times greater than the gap is placed on the lifting loops and two welds are made, as shown in Figure 19. The welded connections are then trafficked with two to three passes of a fully loaded truck. Any broken welds are re-welded. The gap where the loops have been welded are cleaned and then filled with mastic.

Fig. 19 Welded Lift Loop Connection

The US Air Force has encountered this system at several military airfields constructed during the Soviet era in countries adjacent to Afghanistan and in Afghanistan. The US Air Force has been testing this system in the US to determine the failure mechanisms and the methods to repair airfields using this system (Tingle, J., 2009).

SUMMARY

A review of the international PCPS practices indicates that innovative PCP technologies have been implemented in several countries and these technologies can support refinements in the US-based technologies or can be imported to provide alternate systems for implementation in the US.

A completely new PCPS, the ModieSlab system, has been developed in the Netherlands. This system can be used for soft foundations using pier supports and for conventional application placed directly on prepared grade (with base/subbase). The system incorporates a multi-layer surface to meet specific needs, such as, noise reductions, surface drainage, and spray/splash reduction. .

The PCP technology has been used for many years in Japan for a range of applications – roadways, urban streets/intersections, tunnels, airfields, and ports. The PCPS used in Japan incorporate many technical innovations including innovative joint load transfer systems, refined structural design procedures, and prestressing techniques.

Indonesia has implemented the US-developed PPCP system for production use. The first implementation was for a new 22 mile project. Although the primary reason for the use of the PCP technology was to construct a longer lasting concrete pavements and not necessarily rapid installation under traffic, several refinements were made to the technology to allow for production use on a large scale. The US experience with PPCP is still limited to a few short length experimental projects.

The PCPS technology was developed in Russia in the 1960's during the Soviet Union era. This technology, although simple in concept, incorporates several unique features, such as, electro-thermic prestressing, use of thinner panels, and a unique method for tying panels together. The technology has been standardized at the national level. This technology, with some refinements for application in the US, has the potential to provide a cost-competitive alternative to current US developed PCPS.

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REFERENCES

Bax. N. et al., 2007. *New Technique for Rapid Construction and Rehabilitation of*

Concrete Pavements, proceedings of the International Conference on Optimizing Concrete Mixtures and Accelerated Concrete Pavement Construction and Rehabilitation, held in Atlanta, Georgia, Federal Highway Administration.

CERTU-LCPC-CIMBETON, 2008. Chaussees Urbain Demontables – Guide Technique 2008, Technical publication of CERTU, LCPC and CIMBETON, Paris, France.

De Larrard, F. et al., *Development of a Removable Urban Pavement Technology,* proceedings of the 10th International Symposium on Concrete Roadsheld 17-22 September 2006, Brussels, Belgium.

Hachiya, Y. et al., 2001. *Rapid Repair with Precast Prestressed Concrete Slab Pavements using Compression Joint System,* proceedings of the 7th International Conference on Concrete Pavements, organized by the International Society for Concrete pavements, Orlando, Florida.

Hall, K. and Tayabji, S., 2008. *Precast Concrete Panels for Repair and Rehabilitation of Jointed Concrete Pavements*, TechBrief No. FHWA-IF-09-003, Federal Highway Administration, Washington, DC.

Houben, L., et al., 2004. *Accelerated Load Testing and Modeling of "Modieslab" Concrete Pavement Structure,* proceedings of the 5th International CROW Workshop on Concrete Pavements. Istanbul, Turkey.

Lane, B. and Kazmiorowski, T., 2007. *Short Term Performance of Innovative Precast Concrete Slab Repairs on Highway 427, Toronto,* paper presented at the 2007 Annual Conference of the Transportation Association of Canada, Saskatoon, Saskatchewan.

Merritt, D. and Tayabji, S., 2009. *Precast Prestressed Concrete Pavement for Reconstruction and Rehabilitation of Existing Pavements*, TechBrief No. FHWA-IF-09-008, Federal Highway Administration, Washington, DC.

MTO, 2010. Precast Concrete Pavement Slab Repair, Specification Item 363-S01, Ministry of Transportation Ontario.

Nantung, T. et al., 2010. Design and Construction of Precast Prestressed Concrete Pavement in Indonesia, paper presented at the 89th Annual Meeting of the Transportation Research Board, Washington, DC.

Nishizawa, T., 2008. *Japanese Experience of Precast Concrete Pavement*, presented at the Precast Concrete Pavement Forum, 9th International Conference on Concrete Pavements, held in San Francisco, California, organized by the International Society for Concrete Pavements.

Sapozhnikov, N. and Ray, R., 2007. *Soviet Precast Prestressed Concrete Pavement Construction for Airfields,* presented at the 2007 FAA Worldwide Airport Technology Transfer Conference, Atlantic City, New Jersey.

Tayabji, S. Buch, N. and Kohler, E., 2009. *Modular Pavement Technology: Interim Report*, report prepared by Fugro Consultants, Inc. for SHRP 2, SHRP 2 Project R05, Transportation Research Board, Washington, DC.

Tayabji, S., Buch, N., and Ye, D., 2010. *Performance of Precast Concrete Pavements*. Paper presented at the 7th International DUT-Workshop on Design and Performance of Sustainable and Durable Concrete Pavements, to be held in Carmona, Spain, October 2010.

Tingle, J., 2009. *Military Experience with Precast Slab Technology*, presentation at the January 2009 Annual Meeting of the Transportation Research Board, Washington, DC.