Precast concrete pavement – systems and performance review

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Abstract. Long-term traffic restrictions belong to the key disadvantages of conventional cast-in-plane concrete pavements which have been used for technical structures such as roads, parking place and airfield pavements. As a consequence, the pressure is put on the development of such systems which have short construction time, low production costs, long-term durability, low maintenance requirements etc.. The paper presents the first step in the development of an entirely new precast concrete pavement (PCP) system applicable to airfield and highway pavements. The main objective of the review of PCP systems is to acquire a better understanding of the current systems and design methods used for transport infrastructure. There is lack of information on using PCP systems for the construction of entirely new pavements. To most extensive experience is dated back to the 20th century when hexagonal slab panels and system PAG were used in the Soviet Union for the military airfields. Since cast-in-situ pavements became more common, the systems based on precast concrete panels have been mainly utilized for the removal of damaged sections of existing structures including roads, highways etc.. Namely, it concerns Fort Miller Super Slab system, Michigan system, Uretek Stitch system and Kwik system. The presented review indicates several issues associated with the listed PCP systems and their applications to the repair and rehabilitation of existing structures. Among others, the type of manufacturing technology, particularly the position of slots for dowel bars, affects the durability and performance of the systems. Gathered information serve for the development of a new system for airfield and highway pavement construction.

1. General instructions

Cast-in-place concrete pavements have been used for more than 20 years and represent a cost-effective solution for the construction of rigid pavements which provide adequate support for loads exerted by vehicles or airplanes. Long-term traffic restrictions because of extensive and extended lane closures, long curing duration required to reach sufficient strength and the inability to place a material in all weather conditions increase the pressure on the use of systems with enhanced manufacturing technology [1]. Such issues might cause delays and consequently increase the costs related to extended construction time. As a consequence, several PCP systems have been developed up to date and used for the construction of technical structures, particularly for the repair and rehabilitation of roads, parking place and airfield pavements. They are defined as the system of precast panels or elements fabricated or assembled off-site, transported to the building site and installed on a prepared foundation [2]. Such systems do not require field curing for the precast concrete panels as well as require only minimal time for system components to achieve strength before opening to traffic. In comparison with conventional cast-in-place concrete pavements, the potential benefits of PCP systems include better concrete curing conditions and quality concrete, minimal weather restrictions on precast element
placement, shorter delay before opening to traffic and elimination of construction related early age failures. Moreover, precast panels can be manufactured in advance and stored until needed. On the contrary, major issues include load transfer between either precast panels themselves or between panels and existing pavement, levelling the panels to avoid bumps at panel edges and costs which is estimated 1.6 to 4 times higher than the cast-in-place repair methods [3]. The other report states that the costs related to the precast concrete panels use for repairs is even 7 times higher [4]. The major reason of higher costs for repairs using precast concrete panels is the cost of engineering and the fabrication of the precast concrete panels in small quantities. On the contrary, cost savings associated with shorter time required for repairs and traffic restrictions increase significantly when PCP systems used and consequently slightly compensate the high production costs.

2. Precast concrete pavement systems

There are only a few PCP systems developed particularly for the construction of airfields. Particularly, it concerns a hexagonal-shaped panel system and PAG system invented in the Soviet Union in the 20th century. Since cast-in-situ pavements became more common due to the production costs, PCP systems have been mostly used in order to achieve construction time savings in highway applications with high traffic volume where lane closures are a challenge and for rapid repair and rehabilitation applications at airfield pavements. Considering the current pricing scenarios, the use of PCP systems cannot be justified economically without the benefit of time saving. As a consequence, precast concrete panels are used in two ways - as permanent pavement or temporary replacement for removed panels until concrete can be placed during the next scheduled closure [5]. The most utilized systems include Fort Miller Super Slab System, Michigan system, Uretek Stitch system and Kwik system.

![Figure 1. (a) hexagonal-shaped panel system; (b) PAG system - loops of adjacent panels welded together. [6]](image-url)

2.1. Soviet PCP systems: hexagonal-shaped system and PAG system

In 1931, the first PCP system was developed in the Soviet Union. It was constructed using hexagonal-shaped panels made of plain concrete with no reinforcement (figure 1). The length and thickness of the panels range from 1.2 m to 1.5 m and from 100 mm to 220 mm, respectively, depending on aircraft weight the airfield pavement was designed for [6]. Since no reinforcement was used for the construction of the panels, the system often had problems with spalling. The other issue was associated with the panel rocking caused by the insufficient panel flatness resulted from high temperature gradient, poor production quality or concrete shrinkage.

In 1970, the other system called PAG system was approved as a standard slab system for airfields in the Soviet Union. It consists of longitudinally pre-stressed rectangular panels reinforced also with both a reinforcement mesh and two layers of 12 mm reinforcement bars top and bottom. The size of the panels varies but mostly they were 6 m long, 2 m wide and 140 mm thick. Owing to the panel size and reinforcement used, they exhibited excellent load-carrying capacity. Two lifting loops exposed on each side enabled to manipulate with the panels and install them into a right position. Then, the loops of adjacent panels were welded together (figure 1) and slots filled with mastic. In most cases, the
panels were placed on sand base since such material provided improved working conditions, low coefficient of friction, uniform support, good drainage and it was also economical and widely available at that time [6].

2.2. Fort Miller Super Slab system
Today, Fort Miller Super Slab System belongs to most utilized PCP systems all over the world. It has been developed for both intermittent and continuous pavement rehabilitation when the replacement of entire mainlines, ramps, intersections and even crosswalks in a series takes only less than 8 hour roadway closures [7]. Precast concrete panels of various sizes are installed directly on a prepared sub-grade with a thin layer of fine bedding material that provides nearly a uniform slab support. The interaction and load transfer between either adjacent precast panels or precast panels and an existing slab is ensured by a unique load transfer system which consists of dowels bars positioned into prepared slots in adjacent panels (existing slab) and grouted (figure 2). In comparison with other systems, the slots are positioned at the bottom of the panels and consequently are not directly exposed to structural and environmental loading. This fact has crucial influence on the structural behavior and performance of the system as pointed out later on. When the panels are placed, the potential air voids underneath the installed panels are filled by bedding grout through bedding grout distribution system bonded to the bottom of the panels with the aim to ensure positive bedding grout distribution [8].

![Figure 2. Fort Millar Super Slab system [9]: (a) sub-grade preparation - bedding material; (b) panels installation; (c) interlock systems between adjacent elements; (d) dowel grout pumped into each inverted dovetail slot.](image)

2.3. Michigan system
The Michigan system represents a very similar system which differs only in small but important details. The system, which was refined at the Michigan State University [10], serves for the intermittent pavement rehabilitation. Precast concrete panels are fitted with three or four dowel bars (in each wheelpath) which ensure the load transfer between the adjacent elements [3]. They are placed directly on a prepared sub-grade covered by a flowable fill as a cement-based self-levelling material (figure 3) in such way that the dowel bars fit into slots cut out in an existing slab or adjacent elements [4]. When the precast concrete panels are installed, the slots at the top of the panels and the dowel bars are grouted with a cement-based composite.
2.4. Uretek Stitch system

The Uretek Stitch system has two characteristic features which include a specific lifting (levelling) technique and an interlock system which ensures the load transfer between adjacent elements. When conventional precast concrete panels are placed on a prepared sub-grade, polyurethane foam is injected through portholes in the precast panels in order to provide uniform support and fill air voids as well as to lift the panels to the desire grade [11]. Such a way of lifting represents a unique method also used for levelling sunken or broken portions of earth-supported floors and slabs [12]. After the precast concrete panel placement, a series of thin saw-cut slots (figure 4) is used for fibreglass-reinforced polymeric inserts bonding adjacent elements together. Then, the slots are grouted using a high-density polymer-based composite. However, the use of such bonding system affects the performance of a slab as the movement between joints caused by thermal and moisture changes are not enabled. As a consequence, it is recommended to use this Uretek Stitch system only for small area in order to avoid any damage.

2.5. Kwik Slab system

The Kwik Slab system represents a precast concrete slab system mainly developed for new construction, extensions or repairs of roadways, bus stops, bridge decks, parking place, airfields, docks, or any project with high demands for the speed of construction and strength of a slab [13]. It is composed of precast concrete panels having a unique interlocking system which allows to forming a slab quickly and easily while maintaining panel reinforcement continuous in two ways with minimum grouting used (figure 5). Each panel has a number of male-type and female-type components in order to easily bond adjacent panels together. The male-type is characterized by a plurality of reinforcing rods extended horizontally through a slab in both ways generally perpendicularly to each other. Whereas the female-type is characterized by steel connector sockets positioned along a side edge which the reinforcing rods are fitted into. As the system is covered by a patent, the detailed description
of the Kwik Slab system including Kwik Joint interlocking system is provided in the listed documents [14].

![Figure 5](image1.png)

**Figure 5.** Kwik slab system [13]: (a) female-type and male-type components of interlocking system; (b) steel connector sockets; (c) panel installation; (d) injection of high-strength grout.

2.6. Other systems

The other PCP systems used for either new construction or repairs of existing slabs usually combine various features of the above-listed methods as well as introduce additional features with the aim to enhance manufacturing technology or the performance of a proposed system. For instance, in order to improve levelling technique, several systems use steel bearing plates placed on the sub-grade and screw jack assemblies casted in precast concrete panels at the location of the plates for lifting the panel to the desired elevation (figure 6). Subsequently, air voids underneath are undersealed with a cementitious grout pumped through holes in the panels [4]. There are also systems which consist of precast concrete panels without any dowel bars or dowel slots used for the load transfer between adjacent elements. The panels of such system usually incorporate keyed joints in order to provide some level of load transfer. For instance, in France it has been developed a new PCP system for removable urban pavements. It is composed of hexagonal-shaped precast concrete panels which are easy to place due to their light-weight. As the first application of the system shows, the unique system with low load transfer between adjacent elements seems to be adequate for conventional loading [15].

![Figure 6](image2.png)

**Figure 6.** (a) Cast-in screw jack assemblies and (b) hexagonal-shaped precast concrete panels. [15]
3. Performance and experience
More than twenty years experience with PCP systems enables to gather enough information on the performance of the systems when used for either new construction or repairs of existing slabs. Panel cracking, joint spalling, panel surface condition, grout condition, joint elevation difference, joint width measurement and quality of ride belong to main attributes which are monitored during a site inspection. The records on the performance of PAG system are very limited. However, the experimental study conducted by United States Air Force (USAF) shows good performance of the system when used for an airfield subject to C-17 aircraft operations. At the time of site inspection, no sign of cracking or damage to the slabs was observed. However, the C-17 aircraft did break the welded loops. In 2003, the other experimental investigation was undertaken on the system optimized by using enriched limestone materials as a concrete component for the production of panels. The optimized panels were used as reusable temporary access roads for building construction, often in terrible muddy conditions under heavy truck traffic with no complaint of inadequate performance or slab failure. So far, only issues associated with minor concrete cracking and loop separation have come up [6]. Based on the summary of other field testing [16], projects, where precast concrete panels with slots at the bottom (Fort Miller Super Slab system) are used, are usually in very good conditions. In some cases only a few cracks were noted on panels, but it is not considered as concern as steel reinforcement is used in each panel (Tappan Zee Toll Plaza, New York State Jointed Continuous Project; I-66 Ramp, Virginia Jointed Continuous Project). Rarely, dowel slot grout in the joints got separated from the joint face (I-295, New Jersey Jointed Intermittent Repair Project; TH 62, Minnesota Jointed Continuous Project). On the contrary, when precast concrete panels with slots at the top are used the proposed systems exhibit significant damage. For instance, after seven years of using, few panels deteriorated and had to be replaced in the Michigan Project, I-675, where Michigan system was used. The main cause lies in grout spalling at the location of slots (figure 7) which are exposed to structural and environmental loading. The same issue is associated with Uretek Stitch system. Cracking and spalling at the location of stitches belong to the main concerns the system shows [11]. Very likely such failure mode is caused by extreme temperatures during summer as the locked joints inserts enable only a limited in-plane movement of a slab and as a consequence stress concentrated at interlocking system result in crushing of the concrete in the joint area.

![Figure 7. (a) deterioration noted in the Stitch interlocking system and (b) detail of grout spalling at the I-675 project (Michigan system). [16]](image_url)

4. Conclusion
Better concrete curing conditions and quality concrete, minimal weather restrictions on precast element placement, shorter delay before opening to traffic and elimination of construction related early age failures represent decisive aspects why the PCP systems are used over cast-in-place concrete pavements for the repairs and rehabilitation of existing damaged pavements. Most of the current PCP systems have been developed in USA; namely it concerns Fort Miller Super Slab System, Michigan system and Uretek Stitch system. Their wider utilization is limited by production costs which are
estimated 1.6 to 4 times higher than the cast-in-place repair methods. On the contrary, cost savings associated with shorter time required for repairs and traffic restrictions increase significantly when PCP systems used and consequently slightly compensate the high production costs. In terms of the structural behavior and the performance of the listed PCP systems, load transfer between adjacent panels represents a crucial aspect. Concrete spalling and cracking were observed at systems using precast concrete panels with slots at the top surface. Moreover, systems with locked joints inserts enable only a limited in-plane movement of a slab and as a consequence stress concentrated at interlocking system result in crushing of the concrete in the joint area under significant temperature changes. There is also evidence of using PCP systems for entirely new airfields in the Soviet Union during the last century. However, until the latest experimental studies show that the PAG system performs very well. The only issue is associated with the interlocking system when the welded loop got separated and as a consequence the panel joint slightly opened up. The obtained findings play a key role in the ongoing development of a new PCP system for pavement construction which is supposed to be finalized in 2018. Considering the defined issues of the current PCP systems, the main objective of the proposed system is to develop precast panels with keyed joints rather than any dowel bars or dowel slots used for the load transfer between adjacent elements.

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