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<p>DOI: 10.2478/ncr-2021-0018</p>	<p>Received: Oct. 13, 2021 Revision received: Dec. 8, 2021 Accepted: Dec. 9, 2021</p>

Evaluation of Rapid Repair of Concrete Pavements Using Precast Concrete Technology: A Sustainable and Cost-Effective Solution

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ABSTRACT

Concrete and asphalt are the two competitive materials for a highway. In Sweden, the predominant material for the highway system is asphalt. But under certain conditions, concrete pavements are competitive alternatives. For example, concrete pavements are suitable for high-traffic volume roads, roads in tunnels, concentrated loads (e.g., bus stops and industrial pavement). Besides the load-carrying capacity, the concrete pavement has many advantages such as durability (wear resistance), resistance against frost heave, environment (pollution, recycling, and low rolling resistance leading to fuel savings), fire resistance, noise limitations, brightness, evenness and aesthetics.

Concrete pavements are long-lasting but need final repair. Single slabs may crack in the jointed concrete pavement due to various structural and non-structural factors. Repair and maintenance operations are, therefore, necessary to increase the service life of the structures. To avoid extended lane closures, prevent traffic congestions, and expedite the pavement construction process, precast concrete technology is a recent innovative construction method that can meet the requirement of rapid construction and rehabilitation of the pavement. This paper evaluates rapid repair techniques of concrete pavement using precast concrete technology by analysing three case studies on jointed precast concrete pavements. The study showed that the required amount of time to re-open the pavement to traffic is dramatically reduced with jointed precast concrete panels.

Key words: Jointed precast concrete panel, Concrete Pavements, Durability, Cracking, Repair, Maintenance.

1. INTRODUCTION

1.1 Background

Pavements are engineered structures and constitute an essential part of our society. They are used as roads, runways, driveways, and parking lots and are expected to withstand the load applied from a vehicle such as an aircraft or a truck. The load-carrying capacity of a road depends not only on the pavement but also on the entire pavement system consisting of several layers. Good quality pavement is vital for the smooth working of any city.

Concrete and asphalt are competitive construction materials for busy roads, especially in and close to urban areas. There are several advantages and disadvantages of both materials. For example, the compressive strength and the stiffness of concrete are higher than asphalt. In contrast, asphalt is more flexible (providing a smooth and safe ride) and less sensitive to flexural stresses compared to concrete [1]. In Sweden, asphalt is the predominant highway material, only less than 1 percent of the total Swedish road network are concrete roads, see Table 1 [2]. The lower proportion of concrete road is due to several factors, e.g., lack of experience in the design and construction of concrete roads, high construction costs and strong asphalt industry, for details see [1, 2].

Concrete roads are the best alternatives under certain conditions that is valid for high volume traffic roads (close to urban areas), high demands on wear resistance, concentrated loads (e.g., bus stops & industrial pavements), in tunnels with specific requirements on lifespan, durability,

brightness and fire safety. Damages are rare on concrete pavements, but there is a need for rapid repair if it appears. There are also solutions to replace concrete pavement after service life, like applying asphalt pavement after pre-cracking/crushing of an old concrete pavement, but asphalt pavement is not a durable and economical solution for long-lasting pavements, especially for regions subjected to harsh climate conditions. A repair technology based on using precast concrete panels exists in the United States (U.S), but the technology has to be adapted to Swedish conditions.

Table 1: Concrete roads in Sweden [3].

Section of road	Year	Length (km)	Status
E6 Vellinge	1972	13	Overlaid with asphalt
E4 Helsingborg	1978	7	Overlaid with asphalt
E4.65 Arlanda	1990	1.6	In use
E6/120 Falkenberg 1	1993	15	In use
E6/120 Falkenberg 2	1996	13	In use
E20 Eskilstuna	1999	14	In use
E4 Uppsala	2006	23	In use
Total		87	In use
In use		67	In use

Over the past 20 years, traffic volumes on the highway system have significantly increased, especially in urban areas leading in many instances to necessary rehabilitation and reconstruction of highway pavements earlier than expected. Pavement rehabilitation in urban areas is a challenge for highway agencies because of construction-related traffic congestion and safety problems. To avoid extended lane closures and prevent traffic congestions, many highway departments have started to investigate the method of rehabilitation and reconstruction that are faster and result in durable and long-lasting pavements. Precast concrete pavement systems (PCPS) have been shown the potential of promising and effective alternatives. Safety is also improved with the precast concrete pavement by reducing road users' and workers' exposure to construction traffic [4].

Previously, the use of rapid-setting concrete was a preferable option for short-closure windows [5]. A few years ago, six full-scale tests were conducted on State Route 14 near Palmdale, about an hour north of Los Angeles, to evaluate the fatigue behaviour of hydraulic cement concrete pavement. It was observed that there is variability in the performance of the slab, some slabs crack under very early traffic while others are long-lasting. The cause of variability might be that the concrete pavement has lost support from the substructure in turn due to cyclic variations of temperature that affect the structural behaviour of the slab due to the expansion and contraction of the slab [6]. The conventional cast-in-place method requires several days before the traffic is allowed, while the repair with fast track Portland cement concrete (PCC) also needs several hours before the lane can be open to operations. If time is the essence, then the precast technology is the suitable solution for the slab replacement. Existing pavement structure, location of the damaged portions of the pavement, the expected life of pavement, types of repair (temporary or permanent), and availability of experienced contractors and local manufacturing facilities are the essential factors that should be considered while using precast technology for the rehabilitation of pavement [7].

The significant use of precast technology is to reduce construction time in congested traffic corridors without sacrificing the quality or durability of the pavement. Consequently, it reduces

lane closure time in heavily-trafficked areas. Precast concrete panels are fabricated in a controlled environment (field curing time is saved and requires minimal time for the component system to achieve strength), transported to the construction site, and installed on a graded foundation [4, 8]. The installation of precast concrete panels on construction sites is shown in Figure 1.

As the precast panels are fabricated in a controlled environment, they are produced under greater control over the consistency of the concrete mix, procedures of vibration, proper curing and reduced or eliminated curling (due to moisture gradients), strength loss due to insufficient curing and air entrainment problems that are common with traditional cast-in-place concrete pavement [9]. The width of the precast panel is usually provided enough to permit multiple lanes of the existing pavement to be reconstructed simultaneously, depending on on-site access and clearance constraints. Precast panels can be used for single panel replacement or multi-panel replacement or full-width road construction. Precast concrete pavement is preferable technology for short lane closure and long-lasting pavements, short-lasting pavements are not acceptable because of economic and environmental reasons [8].

Figure 1 – Installation of precast concrete panels on construction site [10].

1.2 Research methodology

The methodology adopted for the research behind this paper is illustrated in Figure 2.

Figure 2 – Applied research methodology.

1.3 Benefits of precast concrete pavement systems

Better-quality concrete and curing conditions

The problem related to concrete delivery on construction sites and flooring equipment operations, including poor concrete quality, concrete consolidation and concrete surface finishing, are eliminated. One main advantage of precast technology is that curing of the precast panels takes place under controlled environmental conditions at the plant. Another one is that they are installed on the construction site during nighttime and ready to be opened to the traffic the next morning, which help to reduce the delay before opening to traffic [4, 11].

Speed of construction

Precast concrete pavement has the potential of rapid construction or, more importantly, the fast opening of the pavement to traffic. The rapid-setting concrete paving mixtures require 2 to 4 hours for curing. The short closure time reduces the construction activities on-site and prevents the congestion of traffic [12].

Durability or long term solution

The primary consideration of choosing PCPS is the longevity or durability of precast concrete pavement. Precast pavement panels require little, if any, additional on-site curing time since they are cast off-site, fully cured and ready for use upon arrival [13]. The precast concrete pavement also helps to ensure the uniformity of the concrete mixture because the mixtures are transported only for a short distance between batch plant and forms. The precast concrete panels can be reinforced or prestressed. Prestressed concrete pavement systems are the attractive solution of long-term service life performance, i.e., 30 to 40 years service life. But for short-term performance, other solutions are more cost-effective [12].

Safety

The essential advantage in the work zone of precast concrete pavement is safety. The constructions can be completed during short time closures if the construction is restricted to non-peak travel times. The safety of pavement users and construction workers is improved by reducing the frequency and duration of the work [12].

Sustainability

Precast concrete pavement systems are acknowledged to be a sustainable solution. They are helpful to reduce associated pollution and traffic congestion during construction. PCPS is fast to install, and these products are designed for long-term performance, reducing annual energy consumptions. Precast fabrication plants produce quality concrete mixtures with low water-to-cementitious materials ratio and a high level of uniformity [12].

2. PRECAST CONCRETE PAVEMENT REPAIRS

The precast concrete pavement repairs can be divided into two categories.

1. Intermittent repair of concrete pavement
2. Continuous applications

2.1 Intermittent repair of concrete pavement

Isolated pavement repairs are conducted using precast concrete panels under this approach. The intermittent repairs can be divided into two possible approaches [14, 15]:

- Full-depth repairs (FDRs) are used to repair deteriorated joints or cracking. This repair technique can also be used to repair punch-outs and deteriorated cracks in continuously reinforced concrete pavements (CRCP) full- panel replacement.
- Full-panel replacement are used to replace cracked slab panels.

Key features required for intermittent repair applications to ensure that the adequate load transfer between panels, proper installation of panels and base support under the panels must be achieved are listed below [4]. The variation of intermittent repair techniques is illustrated in Figure 3.

- Provide uniform support condition under the precast panels
- Ensure a load transfer at transverse joints
- Level the elevation differences between the panel and the existing pavement
- Ensure long-term performance of the repair

a) With slots of dowel bars cut in existing concrete pavement

b) Dowel bars positioned in existing pavements

Figure 3 – Variation of intermittent repair technique [16].

2.2 Continuous application

This approach includes full-scale project-level rehabilitation (reconstruction or overlay application) of asphalt and concrete pavements using precast concrete panels. For continuous applications two types of system have been used in the United States [17, 18]:

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

Jointed precast concrete pavement (JPrCP) system

JPrCP is designed so that the precast panel expands or contracts at joints. In JPrCP, the transverse joint load transfer between the precast panels or the precast panels and the existing pavement is achieved by providing standard load transfer dowels. The width of the JPrCP panel is one lane wide (typically 3.6 m) and the length is 4.8 m or less dependent on the type of application. The structural design of JPrCP (design of panel size, load transfer system, transverse joint spacing) is the same that of jointed cast in place concrete pavements; therefore, the designs can be performed confidently across the world. The key design and construction element in jointed precast concrete pavement is presented in Figure 4. The four basic requirements of jointed precast concrete pavement are [19]:

- Adjust the panels to the grade

- Install bedding material to support panels uniformly.
- Establish effective load transfer between panels
- Provide a geometrically correct pavement surface (by grinding, using nonplanar panels or other means).

Figure 4 – Schematic figure showing key design and construction elements in a jointed precast concrete pavement panel installation [19].

Precast post-tensioned concrete pavement system (PPCP)

The main advantage of the PPCP system is that the prestressing force in the PPCP increases the panel's structural capacity that leads to possibilities to reduce the thickness of the panel, which is also safe during transportation and installation. PPCP is very useful in such circumstances where thin pavement is needed due to a high subbase layer. PPCP increases the durability of pavement and significantly reduces the maintenance cost [20]. There are three different configurations of the PPCP system that are illustrated in Figure 5.

Figure 5 – Schematic view of PPCP, different design and construction options [19].

3. PRECAST CONCRETE PAVEMENT SYSTEM

Many highway departments are looking for a suitable method for the rapid rehabilitation of pavement and keeping them durable. Precast concrete technology is gaining popularity among them. Several precast systems are used for both intermittent and continuous repairs. Some of them are:

- Fort Miller Super-Slab system
- Roman Stone system
- Michigan system

3.1 Fort Miller Super-Slab system

A proprietary PCP technology called super-slab system is suitable for both intermittent and continuous paving operations. Super-slab is the most common method that is widely used around the world. It consists of precisely fabricated precast panels, installation methods, and materials for interlocking them together to create an integrated pavement system. With a super slab system, pavement repairs take less than an 8-hour roadway closure. To provide uniform slab support, precast panels with a thin layer of fine bedding material (maximum aggregate size 12.7 mm) are installed directly on a prepared subgrade [14, 21, 22]. Dowels bars are used in the Super-Slab system to transfer the load between adjacent precast panels or between the existing pavement and precast pavement. The dowel slots are positioned in the bottom side of the Super-Slab system so that slot grout is not directly subjected to the environment (possible freeze-thaw effects, moisture, deicing salts, etc.) and not directly exposed to passing wheel loads, which might cause the material to deteriorate. A Super-Slab system can be seen in Figure 6.

Figure 6 – Fort Millar Super Slab system (a) sub-grade preparation - bedding material; (b) panels installation; (c) interlock systems between adjacent elements; (d) dowel grout pumped into each inverted dovetail slot [21].

3.2 Roman Stone system

The Roman Stone construction company developed the system in 2009 for intermittent repair. The load transfer in this system is provided by the Dowel Bar Retrofit (DBR) technique after the panels are placed. The precast panels are cast less than 25 mm thinner than the existing pavement. The special feature of this system is to use expensive polyurethane foam under the cast panel to fill voids, and then panels are raised to the desired elevation as the foam expands [12, 23, 24].

3.3 Michigan system

The Michigan method is also known as a precast concrete panel for full-depth repair method and is used for intermittent repair. In October 2001 and summer 2002, this system was used to install 21 precast panels along two interstate roads of Michigan with the help of Michigan State University in cooperation with the Michigan Department of Transportation. The panels were sized 1.8 m long, 4.8 m wide and 250 mm thick. Three dowels slots were cut in the panels and 38 mm diameter dowels were used along the wheel path to transfer the load across joints. Flow able fill was used to fill the gap between the precast panel and base as a result of the slab demolition and removal process [25].

4. TECHNICAL CONSIDERATIONS FOR A PRECAST CONCRETE PAVEMENT (PCP) SYSTEM

Precast concrete pavements have common features and requirements but differ in several design aspects, i.e., panel fabrication and installation, how the load transfer is achieved at the transverse joint, and support conditions between the prepared base and the precast panel. The construction features and key design that are important for any precast concrete pavements system are as follows [4, 26, 27].

- Concrete requirement
- Support conditions
- Load transfer at joints
- Joint spacing
- Panel reinforcement and installation rate

4.1 Concrete requirements

Concrete mix requirements for cast-in-place concrete and PCP are similarly specified by highway departments. Some problems associated with cast-in-place concrete can be avoided with PCP, such as early age changes in concrete volume, placement in hot or cold weather, placement in rainfall, delays in concrete delivery and equipment failure. The panel fabrication in a controlled environment is a significant advantage of PCP. Precast concrete pavement should fulfil the following concrete requirement [26]:

- Concrete strength (at 14 or 28 days)
 - Flexural strength for design purposes—650 psi (4.5 MPa).
 - Compressive strength for acceptance purposes—4000 psi (27.5 MPa)
- Maximum water-cementitious materials ratio—0.45 for pavement exposed to cycles of freezing and thawing, 0.50 for other pavement
- Air content— Depend on maximum aggregate size used and extremity of exposure (climatic region)
- Durability— Concrete must be durable and not sensitive to material distress, such as alkali-silica reactivity, sulphate attack.
- Surface texture

The compressive strength of the prefabricated panel is also an essential factor to take into account when stripping panels. The panels are typically stripped after 16 hours of casting and compressive strength at the time of stripping should be at least 17.2 MPa (2500 psi). To achieve rapid strength gain many precasters utilize steam curing.

4.2 Support conditions

The bedding layer between the precast panel and base provides support for PCP and it depends on how the panels are installed. The panel installation is done either on grade-supported system or on grout-supported system. In a grade supported system, the bedding layer (consists of a thin layer of cemented granular material, typically 13 mm) is placed over the graded and compacted base. In the grout supported system, the panels are set over the base using Garcia levelling screws and fast setting flowable fill grout (typically 6 to 13 mm) is introduced through grout ports at the panel surface to fill the gap between the base and the panel [26]. The grade supported and grout supported panel placements are illustrated in Figure 7.

Figure 7 – Support conditions (a) Grade-supported panel placement (b) Grout supported panel placement [28].

Sub-sealing is performed in grade supported system to fill the void between panel and base. The compressive strength of both bedding material and sub-sealing material at the time of opening traffic should be 3.5 MPa (500 psi) and about 17.2 MPa (2500 psi) at 28 days [29,30]. To meet the smoothness requirement, the panel surface level can be adjusted to match with the adjacent pavement surface; therefore, surface grinding may not be necessary for grout supported systems but it is almost always required in grade supported systems [18].

4.3 Load transfer at joints

Load transfer at transverse joints is another important consideration for jointed precast concrete pavements. Dowel bars are used along the transverse direction to transfer load to adjacent panels similar to the DBR technique in existing pavement. Typically, in Jointed Precast Concrete pavement (JPCP) the dowel bars installed in slots or ducts are fabricated along one transverse side of the panel. The most common systems used in U.S associated with the dowel bar slots are (i) dowels bar slots at the panel bottom (ii) narrow-mouth dowel bar slots at the panel top surface (iii) teardrop-shaped surface slot (iv) Barra Glide load transfer system as shown in Figure 8 [26-28].

Figure 8 – Different dowel system a) Super-Slab system (b) narrow mouth slots (c) tear-drop shaped system (d) Barra Glide dowel system [28].

Due to expansion and contraction, the system must allow transverse joints for proper opening and closing to maintain load transfer efficiency (LTE). Following are the critical aspects of dowel bars in PCP system for long term performance [26]:

- Dowel bar: Dowel diameter 32 mm is recommended for precast panel less than 250 mm thick and diameter 38 mm is recommended for slab thickness between 250 and 360 mm.
- Dowel length: The location of dowel bar is sensitive in JPCP; therefore, 355- to 380-mm long dowel bars are considered adequate for a joint width of up to 12 mm, allowing for embedment of about 178 mm at each side of the joint.
- Dowel spacing: The dowel bars can be spaced at 300 mm over the entire length of joints for both intermittent and continuous repairs, but four dowel bars per wheel path are considered adequate for traffic channelization.

- Dowel patching material or grout: The compressive strength of patching material or grout for dowel bars and lifting insert ports at the time of opening to traffic should be 17.2 MPa (2500 psi) about 27.6 MPa (4000 psi) at 28 days.
- Dowel bar location and alignment: Ideally, the dowels are placed at the mid-depth of the panel and parallel to longitudinal axis of pavement to avoid horizontal translation, vertical translation, longitudinal translation (also called “side shift”), horizontal skew and vertical tilt [29].

4.4 Joint spacing

One of the main design parameters of the JPCP is joint spacing. For intermittent repair, the length of the JPCP panel is approximately 1.8 m or full length with typically single-lane width. For continuous repair, the length of the JPCP ranges from 3.3 to 4.8 m for thick panels with single or two-lane width. Shorter panels are useful for monitoring joint distress in case of intermittent repairs [18]. In Sweden, the JPCP panel length is limited to 5 m with lane width of 3.5 m [30].

4.5 Panel reinforcement and installation rate

In jointed precast concrete pavements, to avoid cracking due to lifting, transporting and installation operations, double mat (top and bottom) reinforcement is provided i.e. 0.2% of the cross-sectional area. The provided reinforcement will not have any substantial effect on the structural performance of the slab.

The panel installation rate is the most critical factor for the precast concrete technology and it depends upon the lane closure, traffic congestions and site clearance. With good lane closure requirement for intermittent repairs, typically 15-20 panels can be installed per nighttime lane closure and for continuous repair 40-50 panels can be installed per nighttime closure [24].

5 CASE STUDIES ON PRECAST CONCRETE PAVEMENT REPAIRS

Three case studies have been chosen for investigating the repair of concrete pavement using jointed precast concrete panel in more detail. The first case study is related to the highway pavement, which provides the details of PCP implementation on the rehabilitation of concrete pavement in the heavily trafficked area. The second and the third case studies are related to the airfield pavement and are based on the speed of precast concrete technology. In addition to the third case study, the cost of PCP was compared with previously used other repair types.

5.1 Case study 1: Honolulu Interstate H1 precast concrete pavement demonstration project

The Hawaii Interstate H1, a demonstration project of PCP, was conducted in 2016 by the Hawaii Department of Transportation (DOT). The Interstate H1 is located just east of the Aiea Pedestrian Overpass and parallel to Heleconia place. The eastbound lanes carry high traffic during the morning rush hour i.e. annual average daily traffic (AADT) between 90,000 and

200,000 vehicles, therefore to rehabilitate the settled section Hawaii DOT uses PCP to provide a long term solution. The project was consisted of the replacement of six lanes of settled jointed concrete pavement. The Super Slab panels were dimensioned 305 x 305 x 255 mm with Barra Glide slots and were installed using Garcie levelling lifts. The Barra Glide load transfer system can be seen in Figure 9.

Total 84 panels were cast over a period of 30 days with 3000 man-hours to complete the rehabilitation of interstate H1. Due to the limited availability of slot blockouts, only six panels were fabricated at a time and seven panels were installed per night lane closure. The panel installation included the removal of existing pavement, preparing the cement-treated base, panel setting, levelling and grouting. Saw cutting of the existing pavements was done in advance one or two nights before the panel installation. To achieve the desired compressive strength of concrete- mix ready, the delivered concrete was tested on a daily basis. Performance plus RH bedding grout was used to fill the small voids between base and precast panel while Performance Plus RH Latex fill grout was used to fill the dowel slots. Both grouting materials were rapid hardening, very free-flowing, zero bleed, sand free and cementitious grout. For details, see in [31].

Figure 9 – The Barra Glide load transfer system after the dowel [31].

5.2 Case study 2: Precast concrete paving repairs at Vancouver International Airport

In 2019, Vancouver International Airport (YVR) conducted a precast concrete panel replacement using the proprietary Super-Slab® system on Taxiway Victor to establish whether precast concrete was a viable option for a planned runway repair project. This was the first major use of precast airfield pavement in North America in nearly 20 years. The pilot project was conducted to replace twelve precast panels on Taxiway Victor, measuring 6m x7.5m with a thickness of 360 mm. To provide visual aids for aircraft operation, 5 out of 12 panels required light cans, which required significant precision for proper alignment and functioning. The new improved and innovative technologies of the 21st century of the precast concrete pavement were involved in this project.

To avoid disturbance of support layers, the precast panel's thickness was limited to 360 mm, and 20 mm bedding layer was used between the precast panel and the existing cement stabilized base. Due to precast panel thickness limitation, the structural design requirements were achieved

by reinforcing the panels with 20 and 25 mm bars with approximately 135–200 mm spacing in the top and bottom mats and additional steel around the slab perimeter and in the corners. The installation of the panels was decided to complete over three nights for more (eight hour night closure time), for details see in [32]. The installation of Super Slab panel on the construction site can be seen in Figure 10.

Figure 10 – Installation of a typical Super-Slab panel at YVR, showing dovetail edge slots to accommodate dowels anchored in adjacent panels, bottom-mounted foam grout containment gaskets, and bedding grout distribution channels [32].

5.3 Case study 3: Full-Scale field testing of precast Portland cement concrete panel airfield pavement repairs

The United States conducted research to determine the feasibility of rapid repair using precast technology in 2011. The purpose of the study was to develop a precast Portland cement concrete panel repair system to conduct expedient airfield pavement repairs for military operations worldwide. For this, three types of repairs were conducted i.e. Repair 1 (single panel), Repair 2 (two panels) and Repair 3 [Quad panels (four panels)]. The intent was to determine if precast panel repairs could be completed within a 4 to 6-hour timeframe and to support aircraft traffic i.e., minimum pass levels of 3700 passes of C-17 aircraft traffic before failing. Later, the performance, speed and cost of precast panel was compared with other repair methods.

The study focused on replacing full-slab replacement i.e. 355 mm thick PCC pavement, using precast panels with thickness 280 mm and 75 mm flowable fill between the base course and precast panel. Two types of panels were designed to enable both single repair and multi-panel repair, named standard panel and terminal panel. The standard panel had load transfer on both transverse edges, while the terminal panel had load transfer on one transverse edge, see Figure 11.

Figure 11 – Panel Schematics [33].

The size of the partial slabs were with a single panel 3m x 3m, half slab replacement with two panels 3m x 6.1m and full slab replacement with four panels was 6.1m x 6.1m. The panels were minimally reinforced with top and bottom mat 9.5 mm diameter bar and two layers of 16 mm bar all around the panels to avoid installing and storage damage of panels. The comparison of precast concrete panel with other methods is shown in Table 2. The individual installation time for each precast panel time is illustrated in Table 3. For more details see [33].

Table 2: Comparison of precast concrete panel with other methods (based on time to complete single panel) [33]

Repair type	Repair detail	Passes to failure (#)	Time to complete repair (h)	Estimated material cost (US \$)
Rapid-setting cap/aggregate	254 mm cap 102 mm compacted aggregate	5000+	3.5 h	1380
Rapid-setting cap/foam	254 mm cap 102 mm foam	1000	3.2 h	6055
Rapid-setting cap/injected foam	254 mm cap debris 102 mm foam	1000	3.8 h	6020
Rapid-setting cap/flowable fill	254 mm cap 102 mm flowable fill	5000+	3.4 h	1865
Precast panel/flowable fill	279 mm panel 76 mm flowable fill	5000+	4.8 h ^a	2500
Traditional PCC (full-depth)	356 mm PCC	5000+	28 days	555

^a Based on time to complete a single-panel repair.

Table 3: Precast panel installation time [33]

Task	Time (min) ^a		
	Single-panel repair	Double-panel repair	Quad-panel repair
Mark perimeter of distressed slab	10	15	20
Saw-cutting operations	15	35	60
Dowel slot cutting	25	50	50
Anchor drilling and installations	20	40	80
Attach crane rigging hardware	0 ^b	0 ^b	5
Lift distressed section	5	10	20
Dowel slot excavation (existing PCC slab)	30	60	60
Flowable fill placement	10	20	25
Precast panel placement	5	10	30
Compaction (if needed)	5	10	20
Removal of flowable fill from dowel slots	5	5	10
Placement of joint and dowel sealant	30	55	90
Dowel slot finishing	5	10	20
Curing	120	120	120
Total repair time(min)	285	440	610
Total repair time (h)	4.75	7.33	10.17

^a Times rounded to the nearest 5 min interval.^b Task required less than 1 min to complete.

6. SUMMARY

The issues associated with the traditional cast-in-place concrete pavement repair may be eliminated with new repair technology, i.e., precast concrete pavement. Precast concrete technology is used for any type of application where expedient pavement repairs are required. The application includes the removal and replacement of pavement or new pavement applications, intersections and ramps. The precast concrete panels are fabricated in a controlled environment which improved the repair quality of pavement as well as improved potential for long-lasting repairs. In addition, precast concrete pavement is a suitable technology for applications requiring a short pavement closure time.

Following conclusions are obtained by analysing the above three case studies using jointed precast concrete panel as repair applications. Furthermore, the comparison among three case studies i.e. Honolulu Interstate H1 precast concrete pavement demonstration project, precast concrete paving repairs at Vancouver International airport , full-scale field testing of precast Portland cement concrete panel airfield pavement repairs are illustrated in Table 4.

- The Hawaii Interstate H1 is a successful demonstration project of PCP technology which provides the detailed implementation of PCP. The interstate H1 is heavily trafficked area therefore PCP is the best alternative to minimise the traffic lane closure and provide a long-term solution. The project was extended from few weeks to several months during installation period because of shortage of bedding grout. But after the availability of bedding grout the project progressed smoothly. The concrete used in this project was able to achieve compressive strength more than 21MPa (3000 psi) at 24 hours and 41 MPa (6000 psi) at 28 days. The bedding grout achieved compressive strength of 17 MPa

(2500 psi) at 24 hours and 55 MPa (8000 psi) at 28 days while the dowel bars slots grout material achieved 21 MPa (3000 psi) within one hour and 55 MPa (8000 psi) at 28 days.

- The Vancouver International airport pilot project was the demonstration and development of a large size precast panel in 8-hours overnight work windows on an active airfield that addressed heavy anticipated load and limited the thickness of the panel. The project was conducted in 2019 and is still in use, confirming jointed precast concrete pavement's durability at least two years of performance during an 8-hours overnight work window. Dowel bar conflict, the bond between cement stabilized base and existing slab and tight constructions tolerance was major challenges in the YVR pilot project. The pilot project consists of only 12-panels replacement; therefore, the precast panel's production efficiencies and repairs cost and associated closure window time with conventional repair were not performed. The case study showed that the overall production efficiency of the precast panel can be achieved by using specially trained crew members and keep them together.
- In full-scale field testing of precast Portland cement concrete panel airfield pavement repairs, the precast repair method's time, cost, and performance were compared with other repair methods to determine the feasibility of using a new repair method against others previously tested. It was noticed that the only single panel repair might be conducted in less than 6 hours while the others might be conducted in 8 to 10 hours. All the repair types were withstood 5000 passes except the repair method with foam and injected foam. The precast slab was the third-best option to consider for rapid repair in terms of cost, performance and time; see Table 1. Traditional PCC was the least expensive option, but an immediate return to the traffic was not possible with this method.

Table 4: Comparison of jointed precast concrete pavement among three case studies i.e. Honolulu Interstate H1 precast concrete pavement, Vancouver International airport, full-scale and field testing of precast Portland cement concrete panel airfield pavement repairs

Parameters	Case study 1	Case study 2	Case study 3
Construction year	2016	2019	2011
Types of Repair	Continuous	Intermittent	Intermittent and continuous
Size	3.6m x 3.6m	6m x 7.5m	Repair 1: Single panel- 3m x 3m , Repair 2: Two panel: 3m x 6.1m & Repair 3: four panels 6.1 m x 6.1m
Thickness of precast panel	255 mm	360 mm	280 mm
Thickness with traditional PCC	230 mm	450 mm	356 mm
Application area	Highway	Air field	Air field
Considered loads	AADT	A380 bus	C-17
	Axle load spectra	Max take-off weight: 5730 kN [34]	Max take-off weight: 2600 kN [35]
Lane closure time (planned)	Day and night-time lane closure, for detailed see [31]	8 hours –night-time lane closure (3-nights)	All repairs were expected to be complete within 4-6 hours
Lane closure time (actual)	Rehabilitation was done according to the planned time	Rehabilitation was done according to the planned time	Repair 1: less than 6 hours Repair 2: 8 hours & Repair 3: 10 hours

7. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

Asphalt roads take less time to build and construction cost is low compared to concrete roads, but asphalt pavement is not a durable and economical solution for long-lasting pavements, especially for regions subjected to harsh environmental conditions. Potholes are common on asphalt roads and this leads to pavement's maintenance several times, which ultimately lead to increased costs over time. Concrete is a long-lasting or durable material and construction cost for the concrete pavement is high but has a lower maintenance cost than asphalt pavements. The pavement rehabilitation with precast concrete technology reduces the maintenance cost and overall repair time for a project. This innovative technology can be used in any weather condition (rainy or cloudy), which minimises the risk of delay of projects. The highway agencies cannot afford to close lanes in traffic congestion areas to rehabilitate pavements, as these activities can only be done during a short night-time work window with precast technology. The investigation shows that the precast concrete pavement is the suitable solution for rapid rehabilitation of pavement in terms of cost, performance (panels can be thinner than conventional cast-in-place concrete). Furthermore, the required amount of time to re-open the pavement to traffic is dramatically reduced with jointed precast concrete panels.

The recommendation for future work is to develop prototypes prefabricated concrete panels and evaluate them according to Swedish conditions that include geology, climate, weather, concrete

recipe, pavement thickness, studded tire effect, views on the environment and construction practices.

ACKNOWLEDGEMENTS

The Swedish Transport Agency (Trafikverket) is acknowledged for funding the project “The Rapid Repair of Concrete Pavements”.

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