PERFORMANCE OF PRECAST CONCRETE PAVEMENTS

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ABSTRACT: Precast pavement technology is a new and innovative construction method that can be used to meet the need for rapid pavement repair and construction. Precast pavement systems are fabricated or assembled off-site, transported to the project site, and installed on a prepared foundation (existing pavement or re-graded foundation). The system components require minimal field curing time to achieve strength before opening to traffic. These systems are primarily used for rapid repair, rehabilitation, and reconstruction of asphalt and portland cement concrete (PCC) pavements in high-volume-traffic roadways. The precast technology can be used for intermittent repairs or full-scale, continuous rehabilitation. In _intermittent repair of PCC pavement_, isolated full-depth repairs at joints and cracks or full-panel replacements 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. Key features of this application are slab panel seating and load transfer at joints. In _continuous applications_, full-scale, project-level rehabilitation (resurfacing) or reconstruction of asphalt concrete and PCC pavements is performed using precast concrete panels.

As part of the US Strategic Highway Research Program 2 (SHRP 2), a study (Project R05) is underway to develop tools for the design, construction, installation, maintenance, and evaluation of precast concrete pavements. As part of this study, field testing is in progress to obtain field performance data from selected precast concrete pavement projects constructed throughout the US. Field test data being collected to provide an assessment of the structural and functional performance of the installed/in-service precast pavement systems:

1. Condition Data (Visual condition survey)  
2. Ride - using a high speed Profiler  
3. Joint faulting/joint elevation difference  
4. Deflection testing - mid-slab testing and testing at joints

This paper summarizes the field test data collected to date from intermittent repair projects as well as from continuous application projects and presents the findings of the data evaluation. Also, issues with the performance of specific precast pavement systems are discussed.

KEY WORDS: Concrete pavement, pavement performance, precast concrete, precast concrete pavement.
1. 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 modular pavement technologies, principally precast concrete pavement systems, 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, precast concrete pavement systems 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 precast concrete pavement technology is the ability to reduce construction time without sacrificing quality or longevity, thus reducing lane closure time in heavily congested traffic corridors.

1.1. SHRP 2 Modular Pavement Study

The “Renewal” focus area of the US Strategic Highway Research Program 2 (SHRP 2) emphasizes the need to complete highway pavement projects rapidly, with minimal disruption to the users and local communities, and to produce pavements that are long-lasting. A goal of this focus area includes applying new methods and materials to preserve, rehabilitate, and reconstruct roadways. The effective use of precast concrete pavement technologies for rapid repair, rehabilitation, and reconstruction of pavements addresses this goal.

One of the projects funded under SHRP 2 is Project R05, Modular Pavement Technology. The project was awarded to Fugro Consultants, Inc. The objective of this project is to develop tools for use by highway agencies to design, construct, install, maintain, and evaluate modular pavement systems. These tools are to include, at a minimum, the following:

1. Guidance on the potential uses of modular pavement systems for specific rapid renewal applications.
2. Generic design criteria for modular pavement systems.
3. Project selection criteria for modular pavement systems.
5. A long-term evaluation plan to assess the performance of modular pavement systems and to refine these systems.

As discussed previously, modular (precast concrete) pavement technology is being considered seriously by many highway agencies in the United States for specific applications; however, the higher costs and gaps in technology prevent these systems from being readily adopted and implemented by most agencies. The development of desired tools under this project will greatly expedite the adoption of modular (precast concrete) pavement technologies by highway agencies.

The Phase I effort under Project R05 identified a serious lack of field performance data from installed precast concrete pavement systems. When field data are collected, these are not publicly reported. Because of this serious gap in available performance data, the project team contacted several highway agencies in the US and Canada to request support with the performance data collection effort, as part of Phase II effort under Project R05. The support requested was for data collection by the agency or assistance and site access for data collection by the project team. Many agencies responded positively to the request. This paper summarizes the field test data collected to date from several precast concrete pavement projects and presents the findings of the data evaluation. Also, issues with the performance of specific precast pavement systems are discussed.

2. BACKGROUND

Precast concrete pavements use prefabricated segments for quick placement of entire pavements or the replacement of pavement segments. The process allows most of the work to occur outside the traffic stream. Precast concrete pavement technology has great potential for rapid pavement repair, rehabilitation, or reconstruction. Applications include but are not limited to isolated repairs, intersection and ramp rehabilitation, pavement replacement under overpasses, and construction of longer mainline pavement segments. Precast concrete pavement technology can speed up construction without sacrificing quality while minimizing lane closures and traffic disruption. Off-site fabrication has the potential to permit lighter, thinner, and more durable pavement sections through more stringent quality control and use of design details not feasible for in-place construction.

To date, the primary use of precast concrete pavement technologies is to achieve construction time savings in high-traffic-volume highway applications and for rapid repair and rehabilitation applications at airfield pavements. Under current pricing scenarios, without the benefit of time saving, use of precast concrete pavement technologies cannot be justified economically. To be applicable to rapid renewal situations, use of precast concrete pavement technologies must result in reduced lane closures or better-managed lane closures that result in less traffic disruption and improved safety at construction zones. In addition, precast concrete pavement systems must be capable of providing low-maintenance service life for the desired duration. The applications for new construction or rehabilitation (overlay or re-construction) must be viewed as long-life pavements with the expectation of 40-plus years of low-maintenance service life.
As indicated in the previous sections, the precast concrete pavement technology (principally, the precast concrete pavement technology) is gaining wider acceptance by North American highway agencies and contractors and precasters are beginning to seriously explore business opportunities related to precast concrete pavement applications. The 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. As indicated in the previous sections, 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.

2.1. Precast Pavement Concepts

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

1. Intermittent repairs of concrete pavements.
2. Continuous concrete paving (project-level rehabilitation and reconstruction).

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.

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

2.2. Precast Pavement Systems

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)
   b. Kwik Slab system (proprietary)
   c. Roman Stone system (proprietary)
   d. Michigan system (generic)
   e. Illinois Tollway system (generic)
   f. La Guardia International Airport system (generic)

Discussion of the various systems and techniques is given elsewhere (Tayabji et al., 2009; Hall and Tayabji, 2008; Merritt and Tayabji, 2009). Brief details for the more common systems are given below:
1. Precast Prestressed Concrete Pavement (PPCP) - The PPCP system was developed at the University of Texas at Austin, under the sponsorship of FHWA and TxDOT. 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.

2. The Fort Miller Super-Slab System - The Super-Slab system is a proprietary precast concrete pavement technology suitable for both intermittent and continuous paving operations. This paving system consists of precast slabs placed on a precision-graded fine bedding material (maximum aggregate size of 13 mm [0.5 in.]) or placed over a graded existing granular base. 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. This system has the most production paving experience to date.

3. Precast Concrete Panels for Full-Depth Repair (The Michigan Method) - Referred to as the "Michigan" method, this is a nonproprietary precast concrete pavement technology, a dowelled full-depth system suitable for isolated or intermittent repair of highway pavements. This system was refined at the Michigan State University under a project sponsored by FHWA and the Michigan DOT. The repair panels are typically 1.8 m (6 ft) long and 3.7 m (12 ft) wide, fitted with three or four dowel bars in each wheelpath. The Michigan method can be used for full-depth repair as well as full-panel replacement. This method utilizes a partial or full dowel bar retrofit technique to install dowel bars at the transverse joints formed by the precast panel.

4. Other US Developed Systems - There has been increased interest shown by highway agencies to develop generic precast pavement systems and for precasters to develop their own precast pavement systems or to adopt a generic system, such as the Michigan system, for intermittent repair application. The Roman Stone Company, based in New York, is marketing such a system. In addition, the Illinois Tollway has also developed a generic precast panel repair system based on the Michigan system and implemented this systems for new full-depth, full-slab replacement projects beginning in 2009. During 2002, the PANY/NJ constructed two 61-m (200-ft) test sections at a noncritical taxiway area at LaGuardia international Airport in New York City.

2.3. 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

The following U.S. agencies have investigated or are investigating use of precast pavement:

1. Colorado DOT
2. Delaware DOT
3. Florida DOT (demonstration project planned for construction, 2010)
4. Hawaiian Agencies
5. Indiana DOT
6. Michigan DOT
7. Minnesota DOT
8. Missouri DOT
9. Texas DOT
10. Virginia DOT
11. Airport Authorities
   a. Port Authority of New York and New Jersey
   b. Metropolitan Washington Airport Authority
12. US Air Force

In addition to the North American initiatives, the Netherlands, France, Russia (previously Soviet Union), and Japan are actively investigating or are using the precast concrete pavement technologies. Also, a 32 plus km (20 plus mile) section of a tollway in Indonesia was constructed recently using the PPCP type system.

3. SHRP 2 FIELD TESTING PROGRAM

The Phase I effort of the SHRP 2 Project R05 identified a serious lack of field performance data from installed precast concrete pavement systems. When field data were collected, these were not publicly reported. Because of this serious gap in available performance data, the project team contacted several highway agencies in the US and Canada to requested support with the performance data collection effort, as part of Project R05 Phase II effort. All agencies contacted agreed to cooperate with the field data collection effort.

3.1. Precast Pavement Projects Tested

The following precast pavement projects were tested, between December 2009 and May 2010:

1. PPCP projects (all based on the Texas system)
   a. Georgetown Frontage Road, Texas
   b. I-57, Missouri
   c. Route 896, Delaware
   d. I-66, Virginia
2. Jointed continuous projects (all Fort Miller Super Slab system)
   a. Tappan Zee Toll Plaza, New York
b. TH 62, Minnesota
  c. I-66, Virginia

3. Jointed repair projects
   a. I-295, New Jersey (Fort Miller Super Slab system)
   b. I-280, New Jersey (Fort Miller Super Slab system)
   c. I-675, Michigan (Michigan system)
   d. Route 27, New York (Roman Stone system)

Additional precast pavement projects in New York State, California, and Utah will be tested during August and September 2010.

3.2. Test Program Overview

The following data were planned to be collected at each project to provide an assessment of the structural and functional performance of the installed/in-service precast pavement systems:

1. Condition Data (Visual condition survey) – Specific distresses to look for included slab panel cracking, joint spalling, poor surface condition (original or ground), joint sealant condition, dowel slot condition, PPCP prestress pocket condition, PPCP joint hardware, and joint grout material condition for the Fort Miller system. Photographs of representative distresses were obtained.
2. Ride – using a high speed Profiler to determine the section IRI values.
3. Joint Elevation Difference (Faulting) – using the Georgia Faultmeter. This measure can include the built-in joint elevation difference for newer projects as well as true joint faulting for older projects.
4. Joint Width Measurement - Joint width was measured for both the jointed as well as the PPCP systems.
5. Deflection testing – as per the falling weight deflectometer (FWD) test protocol developed for this study, as discussed in the following section;
   a. Mid-panel (basin) testing
   b. Testing at joints (wheel path) for LTE and void detection

3.3. Deflection Testing Protocols

For jointed precast concrete pavement system:

Testing was conducted at the outer wheel path (OWP) locations at transverse joints and at the midslab location of the precast panel and control slabs of the existing pavement, as shown in Figure 1. The testing sequence was as follows:

1. Intermittent Repair Projects – The sequence of testing is as follows:
   a. Precast panel test, as shown in Figure 1, locations 1 to 5
   b. Test at the first existing slab panel that is not adjacent to a precast panel, using the test locations 6 to 8 only as shown in Figure 1.
2. Continuous Application Projects – For continuous application projects, the testing was conducted for as many precast panels as possible within the allowable traffic closure period. The sequence of testing was locations 1 to 3 for each panel.
The number of load drops and the target load levels used are shown in Table 1. The LTE test was conducted with deflection sensors located approximately 152 mm (6 in.) from the center of the joint on each side and the load located tangential to the joint on the loaded side of the joint. The LTE was determined as follows:

\[
\text{LTE, } \% = \left( \frac{\text{Deflection Unloaded Joint Side}}{\text{Deflection Loaded Joint Side}} \right) \times 100
\]

(Note: The deflections are measured 152 mm [6 in.] from the joint center)

Table 1: LTE test load levels

<table>
<thead>
<tr>
<th>Drop No.</th>
<th>No. of Drops</th>
<th>Target Load, kN (lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seating</td>
<td>2</td>
<td>40.0 (9,000)</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>26.7 (6,000)</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>40.0 (9,000)</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>53.4 (12,000)</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>66.7 (15,000)</td>
</tr>
</tbody>
</table>

The interior (basin) load test was conducted at an approximate midslab location for Test Locations 3 and 6. The test loads were the same as shown in Table 1. Deflection sensors were spaced at 305 mm (12 in.) and a minimum of six sensors were used, including the load plate sensor.

The total number of precast panels that were tested at a site was governed by the site access conditions. The plan was to test at least 20 precast panels and at least 10 existing slab panels.
For precast prestressed concrete pavement (PPCP) system:

Testing was typically conducted at the outer wheel path (OWP) locations at transverse expansion joints of the outside lane and at several midslab locations of the post-tensioned segments, as shown in Figure 2. At the Missouri and the Delaware projects, similar testing was also conducted at several conventional pavement slabs.

![Figure 2 - FWD test locations](image_url)

The number of load drops and the target load levels were the same as shown in Table 1. The LTE testing was performed similar to the procedure used for the jointed precast pavements. The interior (basin) tests were conducted at Test Locations 3, 4, and 5. Deflection sensors were spaced at 305 mm (12 in.) and a minimum of six sensors were used, including the load plate sensor. It was planned to perform LTE testing at all expansion joints and to perform basin testing within all post-tensioned segments.

4. SUMMARY OF FIELD TESTING

Highlights of the field testing are presented in this section. Because of site access, field testing was typically limited to about 3 to 4 hours, daytime or nighttime. The respective highway agencies provided traffic control. In addition, the Michigan DOT and the Missouri DOT performed the deflection testing. In all cases, deflection testing was performed using a Dynatest FWD. Several agencies also provided ride data.

4.1. Georgetown, Texas PPCP Project

This is the oldest PPCP project, constructed during November 2001. Pavement details are as follows:

- Panel thickness: 203 mm (8 in.)
- Panel dimensions: length - 3 m (10 ft); Width - 5, 6, and 11 m (16, 20, and 36 ft) (two 3.7 m [12 ft] lanes and 1.2 and 2.4 m [4 and 8 ft] shoulders)
- Base: asphalt treated base
- Panel/base interface: polyethylene sheet
- No. of panels post-tensioned together, comprising a segment: 25 typical, 32 (first segment, and 22 (last segment)
- Post-tensioning method: from mid-segment location
- Total project length: 701 m (2,300 ft) (both sides of a bridge)
- Total no. of expansion joints: 11 (including one at the beginning and one at end)
- Traffic level: Light with few trucks per day; two-way traffic

The project was tested at night during December 2009 and during daytime during January 2010. Overall condition of the project is good. There was tight longitudinal cracking in a few 11 m (36 ft) wide panels. The expansion joint seals were not in good condition. The seals were torn and the expansion joints were filled with debris. The joint width at the time of the daytime testing ranged from 20 to 79 mm (0.8 to 3.1 in). The temperature during the daytime testing was about 13 °C (55 °F). The pavement condition is shown in Figure 3.

![Figure 3: Georgetown PPCP project views](image)

The LTE data for the nighttime outer wheel path test are presented in Table 2. The joint deflections ranged from about 0.102 to 0.508 mm (4 to 20 mils) for the 40.0 kN (9,000 lbf) load level. Basin testing resulted in maximum deflections ranging from about 0.051 to 0.127 mm (2 to 5 mils) for the 40.0 kN (9,000 lbf) load level. The daytime and the night-time testing resulted in similar results. The deflection testing indicates that the LTE at the expansion joints is poor.
Table 2: Load transfer efficiency data (40.0 kN [9,000 lbf] load level)

<table>
<thead>
<tr>
<th>Joint</th>
<th>Night-time Testing</th>
<th>Load Transfer Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Approach Side</td>
<td>Leave Side</td>
</tr>
<tr>
<td>1</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td>2</td>
<td>17%</td>
<td>14%</td>
</tr>
<tr>
<td>3</td>
<td>17%</td>
<td>8%</td>
</tr>
<tr>
<td>4</td>
<td>15%</td>
<td>26%</td>
</tr>
<tr>
<td>5</td>
<td>18%</td>
<td>38%</td>
</tr>
<tr>
<td>6</td>
<td>41%</td>
<td>20%</td>
</tr>
<tr>
<td>7</td>
<td>31%</td>
<td>21%</td>
</tr>
<tr>
<td>8</td>
<td>11%</td>
<td>40%</td>
</tr>
<tr>
<td>9</td>
<td>17%</td>
<td>13%</td>
</tr>
<tr>
<td>10</td>
<td>15%</td>
<td>9%</td>
</tr>
<tr>
<td>11</td>
<td>20%</td>
<td>22%</td>
</tr>
</tbody>
</table>

4.2. I-57, Missouri PPCP Project

This PPCP project was constructed during December 2005. Pavement details are as follows:

- Panel thickness: variable – 143 mm (5.625 in.) (shoulder edge) to 276 mm (10.875 in.) (at centerline) due to cross-slope
- Panel dimensions: length – 3 m (10 ft); Width – 12 m (38 ft) (two 3.7 m [12 ft] lanes and 1.2 and 3 m [4 and 10 ft] shoulders)
- Base: permeable asphalt treated base
- Panel/base interface: polyethylene sheet
- No. of panels post-tensioned together, comprising a segment: 25
- Post-tensioning method: from expansion joints
- Total project length: 302 m (1,000 ft)
- Total no. of expansion joints: 5 (including one at the beginning and one at end)
- Traffic level: Moderate with high level of trucks per day

The project was tested during daytime during March 2010. Overall condition of the project is good. The expansion joint had been reconstructed during October 2009. The sealant material was in good condition. Many panels exhibited transverse and/or longitudinal cracking. The transverse cracking was generally located within the two driving lanes and did not continue all the way to the edges of the shoulders. The joint width at the time of the daytime testing was about 51 mm (2 in.) and the temperature during testing was about 16 C (60 F). The pavement condition is shown in Figure 4. Spalling was noticed at panel joints at few locations. A spall resulting from high steel location and steel corrosion is shown in Figure 5.
The deflection data for the outer wheel path test indicated LTE at expansion joints of about 60%, compared to LTE of 80 to 85% at transverse joints of the adjacent 305 mm (12 in.) thick jointed plan concrete pavement section. The LTE at the expansion joints is considered fair. The joint deflections at the expansion joints ranged from about 0.178 to 0.203 mm (7 to 8 mils) for the 40.0 kN (9,000 lbf) load level. Joint deflections for the 26.69 kN (6,000 lbf) load at the PPCP expansion joints, the PPCP interior keyway joints (between individual 3 m (10 ft) long panels), and at transverse joints of the adjacent JPCP section are shown in Figure 6. The deflections at the PPCP expansion joints are about two times the deflections at the transverse joints of the adjacent JPCP section. Also, the deflection at an interior joint in PPCP segment PPCP 2 was very high as shown in Figure 6. There is a transverse crack in one of the panels adjacent to that joint. The LTE at this interior joint was about 30%, compared to LTE of about 90 to 95% for the other PPCP interior joints tested. The deflection data indicate that there may not be adequate residual prestress at the mid-segment location in that segment. Basin testing resulted in maximum deflections ranging from about 0.076 to 0.127 mm (3 to 5 mils) for the 40.0 kN (9,000 lbf) load level.
4.3. Route 856, Delaware PPCP Project

This PPCP project was constructed during May to July 2009 at an intersection. One section (with 7.3 m [24 ft] wide panels) comprised a left hand turn and one section incorporated through traffic and a right hand turn. Pavement details are as follows:

- Panel thickness: 203 mm (8 in.) (replacement of an existing 305 mm [12 in.] thick JRCP)
- Panel dimensions: length – 2.9 m (9 ft 10 in.); Width – 3.7 m (12 ft) (single lane) and 7.3 m (24 ft) (two lanes or lane and shoulder)
- Base: 102 mm (4 in.) thick permeable cement treated base
- Panel/base interface: geotextile fabric
- No. of panels post-tensioned together, comprising a segment: variable – 12, 13 or 14
- Post-tensioning method: from expansion joints
- Total project length: About 390 m (1,280 ft) (318 m [1,044 ft] right turn lanes and 72 m [236 ft] left turn lanes)
- Total no. of expansion joints: 9 in the right turn lane section and 3 in the left turn lanes section (including one at the beginning and one at end for each section)
- Traffic level: Moderate with few trucks per day

The PPCP project was tested during daytime during April 2010. In addition, 5 panels of the existing 305 mm (12 in.) thick JRCP were also tested. Overall condition of the PPCP project is very good. There were a few partial depth patches to repair damage to the panels during installation. The expansion joint seals were in good condition. The joint width at the time of the daytime testing was about 38 mm (1.5 in.) and the temperature during testing was about 26 C (78 F). The PPCP condition is shown in Figure 7.
The deflection data for the outer wheel path test indicated LTE at expansion joints of about 60 to 70%, compared to LTE at the existing JRCP of 50 to 70%. The joint deflections ranged from about 0.152 to 0.254 mm (6 to 10 mils) for the 40.0 kN (9,000 lbf) load level, compared to 0.102 to 0.178 mm (4 to 7 mils) for the existing JRCP. Basin testing resulted in maximum deflections of about 0.102 to 0.305 mm (4 to 12 mils) for the 40.0 kN (9,000 lbf) load level, compared to about 2 mils for the existing JRCP.

4.4. I-66, Virginia PPCP Project

This is the newest PPCP project, constructed during August to October 2009. Pavement details are as follows:

- Panel thickness: 222 mm (8.75 in.)
- Panel dimensions: length – 3 m (10 ft); Width – 3.7 m (12 ft) (two inside lanes) and 8.2 m (27 ft) (two 3.7 m [12 ft] outside lanes and 0.9 m [3 ft] shoulder). The most outside lane is a rush hour lane and has been treated with an asphaltic surfacing together with the 0.9 m [3 ft] shoulder)
- Base: existing aggregate with upto 13 mm (0.5 in.) leveling stone dust
- Subbase: 152 mm (6 in.) cement stabilized subgrade
- Panel/base interface: geotextile fabric
- No. of panels post-tensioned together, comprising a segment: 11 (end segments) or 16
- Post-tensioning method: from expansion joints
- Total project length: 311 m (1,020 ft)
- Total no. of expansion joints: 8 (including one at the beginning and one at end)
- Traffic level: Heavy commuter traffic (Washington, DC area) with large number of trucks per day (184,000 vpd with 5% trucks)

The project was tested at night during December 2009 before opening to traffic. Overall condition of the project as of May 2010 is good. The expansion joint seals are in good condition. The joint width for the I-66 project was not measured. The pavement condition is shown in Figure 8. The most outside lane and the 0.9 m (3 ft) shoulder have been treated with an asphaltic surfacing material)
The deflection testing was conducted in the inner wheel path of the third lane from the median side (inside lane of the 8.2 m [27 ft] wide panels) due to construction activity in the most outside lane. Test data for the inner wheel path test indicated LTE at expansion joints of about 75 to 90%. The joint deflections ranged from about 0.381 to 0.762 mm (15 to 30 mils) for the 40.0 kN (9,000 lbf) load level and are considered very high compared to basin test deflections. Void analysis indicated 0.127 to 0.381 mm (5 to 15 mils) of voids under the joints. Basin testing resulted in maximum deflections of about 0.076 to 0.152 mm (3 to 6 mils) for the 40.0 kN (9,000 lbf) load level. Deflection data for the 40.0 kN (9,000 lbf) load are shown in Figure 9.

(Series 1= basin test data; Series 2 and 3 = expansion joint test data)
4.5. Tappan Zee Toll Plaza, New York State Jointed Continuous Project

This is the oldest jointed precast concrete project, constructed during October 2001 and July 2002. Pavement details are as follows:

- Precast pavement system: Fort Miller’s Super Slab system
- Panel thickness: 254 mm (10 in.)
- Panel dimensions: length - 5.5 m (18 ft); Width - 3 m (10 ft) (toll plaza drive lanes; 12 lanes)
- Number of panels installed: 1,071
- Base: existing granular base (top 51 mm [2 in.] removed) with 38 mm (1.5 in.) leveling stone dust
- Joints: Doweled transverse joints; longitudinal joints tied
- Total project area: over 33,445 m² (40,000 y²) (both sides of the toll booths)
- Traffic level: Heavy commuter traffic (New York city area) with large number of trucks per day (eastbound through toll plaza - 72,000 vpd)

The project was tested during the daytime during May 2010. Overall condition of the project is very good. The joint seals are in good condition. Some very tight transverse cracking was noted on a few panels but is not considered to be of concern because of the steel reinforcement in each panel. The pavement condition is shown in Figure 10.

![Figure 10: Approach and leave views of the Tappan Zee Toll Plaza](image)

The deflection testing was conducted along two toll plaza lanes – Lanes 9 and 10. A total of 20 panels were tested. Test data for the outer wheel path test indicated LTE at transverse joints of about 85 to 90%. The joint deflections ranged from about 0.102 to 0.178 mm (4 to 7 mils) for the 40.0 kN (9,000 lbf) load level. Basin testing resulted in maximum deflections of about 0.076 to 0.102 mm (3 to 4 mils) for the 40.0 kN (9,000 lbf) load level. The deflection data indicate a well performing precast concrete pavement project.
4.6. TH 62, Minnesota Jointed Continuous Project

This jointed precast concrete project was constructed during June 2005. Pavement details are as follows:

- Precast pavement system: Fort Miller’s Super Slab system
- Panel thickness: 235 mm (9.25 in.)
- Panel dimensions: length – 3.7 m (12 ft); Width – 3.7 m (12 ft) (single lane of a two-lane roadway; existing adjacent lane – JRPC with 12 m [40 ft] joint spacing)
- Number of panels installed: 18
- Base: granular base
- Joints: Doweled transverse joints; longitudinal joints not tied adjacent existing lane
- Total project length: 66 m (216 ft)
- Traffic level: Moderate traffic (Minneapolis international Airport location) with moderate number of trucks per day (63,000 vpd)

The project was tested during the daytime during April 2010. The pavement condition is shown in Figure 11. Overall condition of the project is very good. The joint seals are typically in good condition. However, at a few locations the dowel slot grout material in the joint has separated from the panel face, resulting in the appearance of a raveled joint as shown in Figure 12.

Figure 11: Views from the Minnesota project (precast panels in right hand lane)

Figure 12: View of a transverse joint at the Minnesota project
The deflection testing along the outer wheel path indicated LTE at transverse joints of about 80 to 95%. The joint deflections ranged from about 0.152 to 0.254 mm (6 to 10 mils) for the 40.0 kN (9,000 lbf) load level. Basin testing resulted in maximum deflections of about 0.127 to 0.228 mm (5 to 9 mils) for the 40.0 kN (9,000 lbf) load level. The deflection data indicate a well performing precast concrete pavement project.

4.7. I-66 Ramp, Virginia Jointed Continuous Project

This jointed precast concrete project, along a ramp exiting off from I-66 highway, was constructed during August to October 2009. Only the outside lane of the two-lane exit ramp was rehabilitated. The precast pavement section, with typical 4.6 m (15 ft) joint spacing, was tied to the inside lane 229 mm (9 in.) thick jointed reinforced concrete pavement (JRCP) with a joint spacing of 18 m (60 ft). It should be noted that it is not considered a good practice to tie different pavement types with different joint spacing. On this project, the precaster’s shop drawings indicate the tie-in at the longitudinal joint between the two lanes. Several precast panels were custom fabricated to account for the curvatures in the ramp. Pavement details are as follows:

- Precast pavement system: Fort Miller's Super Slab system
- Panel thickness: 222 mm (8.75 in.)
- Panel dimensions: length – 4.6 m (15 ft) (a few shorter panels to accommodate ramp curvature); Width – 3.7 m (12 ft)
- Number of panels installed: 224
- Base: existing granular base with upto 6 mm (0.25 in.) leveling stone dust
- Joints: Dowelled transverse joints; inside longitudinal joint (ramp centerline joint) tied to existing JRCP
- Total project length: 1083 m (3,552 ft)
- Traffic level: Moderate commuter traffic (Washington, DC area) with low level of truck traffic (55,000 vpd)

The project was tested during the nighttime during December 2010 before opening to traffic. The pavement condition during May 2010 is shown in Figure 13. Some very tight transverse cracking was noted at 52 panels before opening to traffic, but this is not considered to be of concern because of the steel reinforcement in each panel. About 50% of the cracking in the precast panels was associate with a joint or patch in the adjacent JRCP lane and the tying of the two lanes with different joint spacing and different joint/slab behavior. Such a crack is shown in Figure 14.
The deflection data for the outer wheel path test indicated LTE at transverse joints of about 85 to 95% for the 45 panels tested. The joint deflections ranged from about 0.203 to 0.381 mm (8 to 15 mils) for the 4082 kg (9,000 lb) load level. Basin testing resulted in maximum deflections of about 0.076 to 0.127 mm (3 to 5 mils) for the 40.0 kN (9,000 lbf) load level. The deflection data do not indicate any potential for structural performance issues for the precast concrete pavement project.

4.8. I-295, New Jersey Jointed Intermittent Repair Project

The precast panel repairs were installed during late 2007 to mid-2008. Panel details are as follows:

- Precast pavement system: Fort Miller’s Super Slab system
- Panel thickness: 222 mm (8.75 in.) (existing JRCP thickness – 229 mm [9 in.])
- Panel dimensions: length – variable (2.4, 3.0, 3.7 m [8, 10, 12 ft]); Width – 3.7 m (12 ft)
- Number of panels installed: 277
- Base: existing sandy granular base
- Joints: Doweled transverse joints; longitudinal joints not tied
• Traffic level: Heavy freeway traffic with heavy truck volume (140,000 vpd)
• Existing JRCP joint spacing: 24 m (78 ft)

The project was tested during the daytime during April 2010. A total of 20 precast panels and 20 existing pavement slab panels (adjacent to each precast panel) were tested. Overall condition of the project is good. However, the precast panels exhibited settlement (as measured along the outside longitudinal joint) of up to 25.4 mm (1 in.). This slab settlement also corresponded to a transverse crack in the leave side of the existing slab panel, about 2.4 to 3.7 m (8 to 12 ft) from the end of the repair. The pavement condition is shown in Figure 15. The joint sealing in the repair area was not consistent as some of the joints appeared not to have been sawed or sealed. Also, the dowel slot grout in the joint had separated from the joint face and many of the repair joints, as shown in Figure 16.

![Figure 15: Views of the I-295 precast panels](image1)

![Figure 16: View of a transverse joint at the I-295 project](image2)

The deflection data for the outer wheel path test indicated LTE at transverse joints of the precast panels of about 65 to 85%, compared to LTE of about 70 to 85% in the 50-year old existing JRCP slab panels. The joint deflections at the precast panel joints ranged from about 0.102 to 0.178 mm (4 to 7 mils) for the 40.0 kN (9,000 lbf) load level, compared to about 0.102...
to 0.127 mm (4 to 5 mils) for the existing JRCP joints. Basin testing resulted in maximum deflections at the precast panels of about 0.102 to 0.178 mm (4 to 7 mils) for the 40.0 kN (9,000 lbf) load level, compared to 0.076 to 0.127 mm (3 to 5 mils) at the interior of the existing JRCP panels. The deflection data indicate a well performing transverse joint system for the precast panels. However, the panel settlement indicates that a better technique may be warranted to upgrade the bedding when granular bases are used as these bases cannot be effectively re-compacted as part of the precast panel installation process.

4.9. I-280, New Jersey Jointed Intermittent Repair Project

The precast panel repairs were installed during mid-2008 to mid-2009. Panel details are as follows:

- Precast pavement system: Fort Miller's Super Slab system
- Panel thickness: 222 mm (8.75 in.) (existing JRCP thickness – 229 mm [9 in.])
- Panel dimensions: variable (2.4, 3.0, 3.7 m [8, 10, 12 ft]); Width – 3.7 m (12 ft)
- Number of panels installed: 281
- Base: existing sandy granular base
- Joints: Doweled transverse joints; longitudinal joints not tied
- Traffic level: Heavy commuter traffic with large volume of trucks
- Existing JRCP joint spacing: 24 m (78 ft)

The project was tested during the nighttime during April 2010. A total of 10 precast panels and 10 existing JRCP slab panels (adjacent to each precast panel) were tested. At the time of testing the project had been milled in anticipation of an asphalt concrete overlay. Overall condition of the repair panels tested appeared to be good, considering the surface had been milled. The joint condition could not be determined because of the milling and the nighttime condition. The pavement condition is shown in Figure 17.

![Figure 17: Views of the precast panels at the I-280 project](image)

The deflection data for the outer wheel path test indicated LTE at transverse joints of the precast panels of about 70 to 95%, compared to LTE of about 70 to 90% in the 50-year old existing JRCP slab panels. The joint deflections at the precast panel joints ranged from about 0.203 to 0.279 mm (8 to 11 mils) for the 40.0 kN (9,000 lbf) load level, compared to about
0.102 to 0.203 mm (4 to 8 mils) for the existing JRCP joints. Basin testing resulted in maximum deflections at the precast panels of about 0.076 to 0.127 mm (3 to 5 mils) for the 40.0 kN (9,000 lbf) load level, compared to 0.076 to 0.102 mm (3 to 4 mils) at the interior of the existing JRCP panels. The deflection data indicate good performing transverse joint system for the precast panels. The slab settlement, similar to that noticed at the I-295 project, could not be assessed as the project had been milled.

4.10. Route 27, New York State Intermittent Repair Project

The precast panel repairs were installed during November 2009. Panel details are as follows:

- Precast pavement system: Roman Stone’s Roman Road system (first project)
- Panel thickness: 203 mm (8 in.) (existing JRCP thickness – 229 mm [9 in.])
- Panel dimensions: length – variable (1.8, 2.4, 3.0 m [6, 8, 10 ft]); Width – 3.7 m (12 ft)
- Number of panels installed: 35
- Base: existing granular base (sandy loam)
- New bedding material: about 25.4 mm (1 in.) thick polyurethane foam injected under each panel
- Joints: Doweled transverse joints; longitudinal joints not tied
- Traffic level: Moderate traffic with moderate truck volume
- Existing JRCP joint spacing: 18.4 m (60.5 ft)

The project was tested during the daytime during May 2010. A total of 12 precast panels, 2 cast-in-place (CIP) full-depth patches, and 12 existing pavement slab panels (adjacent to each precast panel and a CIP patch) were tested. Overall condition of the repair panels is good. The repair panels are shown in Figure 18. The joint sealing in the repair is good.

![Figure 18: Views of the precast panels at the Route 27 project](image)

The deflection data for the outer wheel path test indicated LTE at transverse joints of the precast panels of about 70 to 90%, compared to LTE of about 60 to 90% in the 30-year old existing JRCP slab panels and 70 to 90% at the CIP patches. The joint deflections at the precast panel joints ranged from about 0.152 to 0.203 mm (6 to 8 mils) for the 40.0 kN (9,000 lbf) load level, compared to about 0.102 to 0.178 mm (4 to 7 mils) for the existing JRCP joints, and
about 0.127 to 0.178 mm (5 to 7 mils) at the CIP patch joints. Basin testing resulted in maximum deflections at the precast panels of about 0.152 to 0.203 mm (6 to 8 mils) for the 40.0 kN (9,000 lbf) load level, compared to 0.127 to 0.203 mm (5 to 8 mils) at the interior of the existing JRCP panels, and 0.127 to 0.178 mm (5 to 7 mils) in the interior of the CIP patches. The deflection data indicate good performing transverse joint system for the precast panels.

4.11. I-675, Michigan Project

The precast panel repairs were installed during 2003. Panel details are as follows:

- Precast pavement system: Michigan generic system (demonstration project)
- Panel thickness: 254 mm (10 in.) (existing JPCP thickness – 229 mm [9 in.])
- Panel dimensions: length – 1.8 m (6 ft); Width – 3.7 m (12 ft)
- Number of panels installed: 8 (a 9th panel was not installed due to poor fit)
- Base: re-graded existing dense granular base
- Bedding: fast setting flowable fill concrete (2 panels) or injected polyurethane (6 panels) (both 25.4 mm [1 in.] thick)
- Joints: Doweled transverse joints (3 dowel bars/wheel path); longitudinal joints not tied
- Traffic level: Light freeway traffic with moderate volume of trucks (10,400 vpd with 6% trucks)
- Existing JRCP joint spacing: 22 m (71 ft)

The project was tested during the daytime during April 2010. A total of 5 precast panels (remaining of the 9 installed) and 6 existing pavement slab panels (adjacent to each precast panel) were tested. Overall performance of the repairs is mixed. A few of the panels had deteriorated and were replaced and one, shown in Figure 19, was planned to be replaced. However, the remaining five panels are still considered to be performing well, as shown in Figure 20.

Figure 19: Views of a deteriorated panel at the I-675 project (planned for replacement)
The deflection data for the outer wheel path test indicated LTE at transverse joints of the precast panels of about 75 to 85%, compared to LTE of about 65 to 90% in the 25-year old existing JRCP slab panels. The joint deflections at the precast panel joints ranged from about 0.178 to 0.254 mm (7 to 10 mils) for the 40.0 kN (9,000 lbf) load level, compared to about 0.152 to 0.279 mm (6 to 11 mils) for the existing JRCP joints. Basin testing resulted in maximum deflections at the precast panels of about 0.102 to 0.152 mm (4 to 6 mils) for the 40.0 kN (9,000 lbf) load level, compared to 0.076 to 0.127 (3 to 5 mils) at the interior of the existing JRCP panels. The deflection data indicate good performing transverse joint system for the remaining precast panels.

5. DISCUSSION OF FIELD TEST DATA

Only a limited summary of the data related to performance of older and recently constructed precast concrete pavements are presented in this paper. Detailed data analysis is in progress. Evaluation to date of the field data, as summarized here, indicate that precast pavements that are designed and installed well have the potential to provide long term service for both repair and continuous applications. Both the PPCP and the jointed precast pavement systems can be considered as equally viable candidates for rapid rehabilitation of concrete as well as asphalt pavements and for overlay applications. The service life expectations in the US for continuous applications would be about 40 years, similar to what is currently being designed for new conventional concrete pavements. For intermittent repair applications, both the proprietary systems, such as the Fort Miller's Super Slab system, and generic systems, such as the Michigan system, appear to have the potential to provide service life ranging from 10 to 20 years.

The following specific observations can be made on the basis of the evaluation of the performance of the field tested precast concrete pavements:

- PPCP systems
  - The wider joint opening of the expansion joints is resulting in variable LTE. Limiting the length of the post-tensioned segments may allow reduction in the expansion joint width and improve the LTE at these joints. Based on the
experience of the authors, good LTE (greater that 85%) is necessary in new construction for highways that carry higher truck traffic.

- Even though some PPCP panels exhibited cracking, this cracking is not considered of concern as the reinforcement used in each panel and the “bonded” prestressing will keep the cracks tight. However, it is necessary that there be adequate prestress available in the panels in the mid-segment area. The low LTE measured at an interior joint at the Missouri project, between adjacent 3 m (10 ft) long panels, will be analyzed further to determine the cause for the low LTE.

- The spalling over the reinforcement indicates a need to re-design the reinforcement details. Reinforcement should be epoxy-coated and at least 51 to 64 mm (2 to 2.5 in.) below the panel surface to minimize the potential for surface spalling.

- The Virginia I-66 project indicated higher deflections and loss of support at the expansion joints. This may be a result of night-time slab curling over the full length of the post-tensioned segments and/or the use of the stone dust bedding/leveling material.

- The Delaware project shows potential for use of PPCP systems for specific applications, such as, high volume intersections.

Jointed systems for continuous applications

- The jointed Super Slab system for continuous applications has performed well. The oldest project, the Tappan Zee project, and the Minnesota project indicate good structural performance – low deflections at joints and at panel interior and good LTE values.

- Similar to the cracking in PPCP panels, the tight cracking observed in the jointed panels at the Tappan Zee and the Virginia ramp projects are not considered of concern because of the reinforcement used in these panels. For long-term service, it is important that the top layer of the reinforcement in the panels be at least 64 mm (2.5 in.) below the panel surface.

- For the Super Slab system, the joint sawing detail needs improvement. Joint sawing that leaves a sliver of the dowel slot grout material (possibly not bonded to the joint face) at the surface can result in non-effective joint sealing, begging the question whether these joints should be sawed and sealed or not.

Jointed systems for repair applications

- For full-depth or full-slab repair applications, there is a critical need to ensure that there is adequate LTE at joints and that there is good support under the repair, irrespective of whether the repairs involve precast panels or cast-in-place concrete. The Super Slab system, with dowel slots at the bottom, appears to provide good load transfer at joints. The systems incorporating dowel slots at the surface, similar to conventional dowel bar retrofit method, are also capable of providing good LTE at joints. However, these systems require care with the installation of the dowel slot patch material.

- The use of dowel bar caps is strongly recommended to minimize failure of the dowel bar slot patches, especially when the repairs are used for repairs of joints in JRPC.

- The panel settlement at the New Jersey I-295 project indicated that more attention needs to be paid to improve the bedding support under precast panels.
placed over “disturbed” granular bases. This is weakness in the full-depth repair technique that is a major cause of the failure of cast-in-place full depth patches. The use of precast panels is not a warrant to pay any less attention to making sure the support under the precast panels is not compromised during existing concrete removal and panel installation.

Overall, there does not appear to be any concern about the quality or the durability of the concrete used for the precast panels. For most of the precast applications, repair or continuous, there is a requirement to grind the surface of the completed project and therefore any joint elevation differences during placement of the precast panels can be addressed and a desirable surface texture can be obtained.

To summarize, the precast concrete pavement technology for rapid repair and rehabilitation of high volume highways is an evolving technology, with many highways agencies having implemented it for production use, some investigating it, and some waiting on the sidelines before moving forward with it. The need for the technology is obvious – rapid construction and longer-lasting solutions. Because of the newness of the technology, there is a need to assess current technology and develop refinement to provide confidence to highway agencies that the precast pavement technology can play a critical role in addressing repair and rehabilitation of their high volume highway network. Project R05 is addressing these needs by assessing the performance of precast concrete pavement applications to date, identifying gaps in technology, providing guidance to address these gaps in proprietary systems, and developing refinements in non-proprietary systems and non-proprietary system components. Some of the findings presented in this paper and additional work underway in the SHRP 2 Project R05 will provide improved guidance for the application of precast concrete pavements for rapid repair and rehabilitation of distressed pavements.

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7. REFERENCES

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