Precast concrete pavements: Technology overview and technical considerations

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- Precast concrete pavement is an emerging technology in the United States for rapid repair and rehabilitation of high-volume, congested roadways.
- This paper summarizes the results of a study aimed at developing the necessary information and guidelines to encourage the successful adoption of this new technology.
- The performance of demonstration projects in the United States indicates that sufficient advances have been made to reliably achieve the four key attributes of precast concrete pavement: constructability, concrete durability, effective load transfer at joints, and effective panel support conditions.

Pavement rehabilitation and reconstruction are major activities for all U.S. highway agencies. These activities place a significant demand on agency resources and disrupt traffic with extensive and lengthy lane closures. Traffic volumes on the primary highway system, especially in urban areas, have significantly increased over the past 20 years, leading in many instances to an earlier-than-expected need to rehabilitate and reconstruct highway pavements. Pavement rehabilitation in urban areas is a challenge for highway agencies because of construction-related traffic congestion and safety problems. Many agencies also continue to wrestle with the dilemma: longer delays now and longer service life or shorter delays now but shorter service life.

In recent years, many agencies have started investigating strategies for pavement rehabilitation and reconstruction that are faster but can produce durable pavements. Expedient rehabilitation that results in a shorter pavement life is no longer considered acceptable by most highway agencies. A promising alternative is the effective use of modular pavement technologies, principally precast concrete pavement systems, which provide for rapid repair and rehabilitation of pavements that last. Rapid construction techniques can minimize disruptions to the driving public because lane closures and traffic congestion are kept to a minimum. Safety is also improved by reducing road users' and workers' exposure to construction traffic.

Precast concrete pavement technologies have been investigated sporadically over the past 40 years. In the early years, the technology was explored either as a matter of curiosity, that is, to learn whether precast concrete pavements were technically feasible, or as an emergency repair technique with minimal concerns regarding longevity. No serious attempts had been made until more recently to fully develop the technology as a cost-effective strategy or to implement it on a production basis. Today, the maturing highway system in heavily traveled urban corridors makes the need for timely pavement repair and rehabilitation urgent, and highway agencies are looking at innovative technologies. Over the past 10 years, new precast concrete pavement technologies are becoming technically feasible and economically justifiable on a project-by-project basis.

Background

Precast concrete pavements use prefabricated concrete panels for rapid repair of concrete pavements and for rehabilitation of concrete and asphalt pavements. Precast concrete pavement may also be used for reconstruction or as an overlay. Precast concrete pavement applications include isolated repairs, intersection and ramp rehabilitation, urban street rehabilitation, and rehabilitation of longer mainline pavement sections. Precast concrete pavement systems are fabricated or assembled off site, transported to the project site, and installed on a prepared foundation (existing pavement or regraded foundation). The system components require minimal field curing or time to achieve strength before opening to traffic.

The specific advantages of using precast concrete pavement versus cast-in-place concrete pavements include the following:

- Better-quality concrete: problems related to concrete delivery or paving equipment operation, including poor concrete quality, concrete consolidation, and overfinishing of the concrete surface, are eliminated.

- Better concrete curing conditions: curing of the precast concrete panels takes place under controlled conditions at the plant.

- Minimal weather restrictions on placement: the construction season can be extended because panels can be placed in cool weather or during light rainfall.

- Reduced delay before opening to traffic: on-site curing of concrete is not required. As a result, precast concrete pavements can be installed during nighttime lane closures and be ready to be opened to traffic the following morning.

- No joint raveling: Early-age failures due to late or shallow joint sawing are eliminated.

Precast concrete pavement systems are used in highway corridors with high traffic volume and where lane closures are problematic. The precast concrete pavement work is performed during the night and with short closures, typically from about 8 p.m. to about 6 a.m. The production rate per lane closure is about 15 to 20 repair locations or about 300 to 600 ft (90 to 180 m) lengthwise for continuous rehabilitation. The key concerns about precast concrete pavement are constructability, concrete durability, and pavement performance as primarily affected by joint load transfer and panel support condition. Sufficient advances have been made in precast concrete pavement technology to reliably achieve the following four key attributes:

- Constructability: techniques and equipment are now available to ensure an acceptable production rate for rapid installation.

- Concrete durability: plant fabrication of the precast concrete panels can result in excellent concrete quality, strength, and durability.

- Load transfers at joints: reliable and economical techniques are now available to incorporate effective load transfer at transverse joints of jointed precast concrete pavement systems.

- Panel support condition: the techniques to provide adequate and uniform support conditions continue to be improved.

However, it must be emphasized that precast concrete pavements are not "super pavements" and should not be expected to perform significantly better than cast-in-place concrete pavements. Once installed, precast concrete pavements can be expected to behave similarly to cast-in-place concrete pavements under traffic and environmental loading. The primary difference between the two technologies is how each system is constructed. The main advantage of precast concrete pavement is that it is a truly rapid rehabilitation technology that is also durable. In addition, as discussed later, prestressing allows the precast concrete panels to achieve higher load-carrying capacity within a constrained pavement cross section when reconstructing existing pavements.

Precast concrete pavement concepts

The application of precast concrete pavement technology can be divided into two categories: intermittent repairs of concrete pavements and continuous applications.

Intermittent repairs of concrete pavements

With this approach, isolated pavement repairs are conducted using precast concrete slab panels. The two types of possible repairs are full-panel replacement of severely cracked

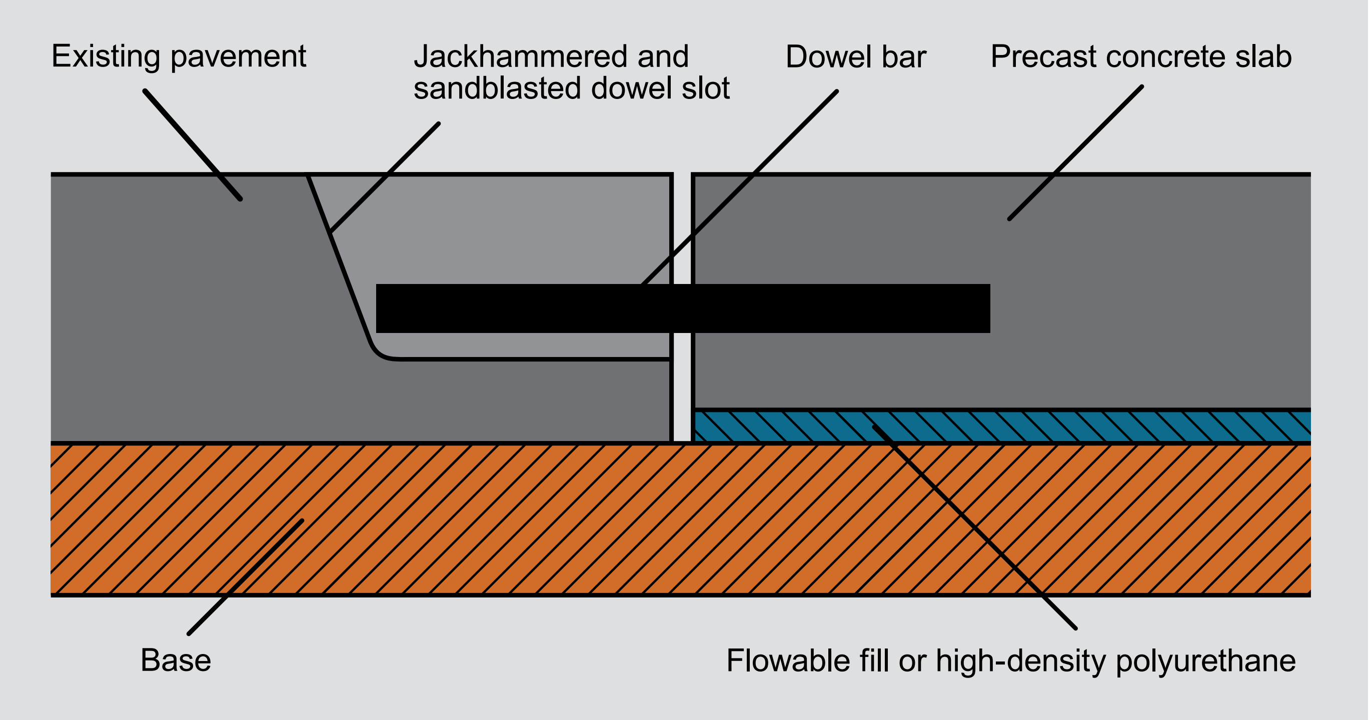

Figure 1. Schematic of the intermittent repair application. Source: Data from Hall and Tayabji (2008).

or shattered slab panels and full-depth repairs of deteriorated joints or cracking. Also, as discussed later, full-depth repairs can be used to repair punch-outs and deteriorated cracks in continuously reinforced concrete pavement.

The repairs are always full-lane width. The process is similar for full-depth repairs and full-panel replacement, except for the length of the repair area. **Figure 1** shows a schematic of the repair in which dowel bars are embedded in the precast concrete panel[1] and slots for dowel bars are cut into the existing concrete pavement, similar to the dowel bar retrofit method (**Fig. 2**). The dowel slots are then filled with fast-setting patching material. In a variation of this scheme, no dowel bars are embedded in the precast concrete panel and dowel bars are installed after panel installation using the dowel bar retrofit technique (**Fig. 3**).

In another scheme for intermittent repairs, the dowel bars are positioned in the existing concrete pavement by drilling and epoxy grouting, similar to cast-in-place concrete full-depth repairs or full-slab repairs, and the slots for the dowel bars are fabricated in the repair panels along the bottom of the transverse sides (**Fig. 4**). The slots and the joint perimeter gap are then filled with fast-setting grout.

Each of these methods of panel installation, with respect to the load transfer provisions, has certain advantages and disadvantages that are discussed later. In addition, the actual panel installation and the base support under the panel can be achieved using several techniques as follows:

- panel placed directly over the prepared base
- panel placed and raised to proper elevation using expandable polyurethane foam
- panel held in place using strongback beams and bedding material injected under the panel
- panel positioned at the proper elevation using setting bolts and bedding material injected under the panel

Following are key features required of the intermittent repair applications:

- good support condition under the panels
- adequate load transfer at transverse joints
- minimization of elevation differences between the panel and the existing pavement
- acceptable long-term performance of the repair area

Continuous application Under this approach, full-scale project-level rehabilitation (reconstruction or overlay application) of asphalt and concrete pavements is performed using precast concrete panels. Two types of systems, discussed later in detail, have been used in the United States, jointed precast concrete pavement systems with either reinforced or prestressed concrete panels and precast, prestressed concrete pavement systems.

As part of this study, a third category of continuous systems has been established. This category is referred to as the incrementally connected precast concrete panel

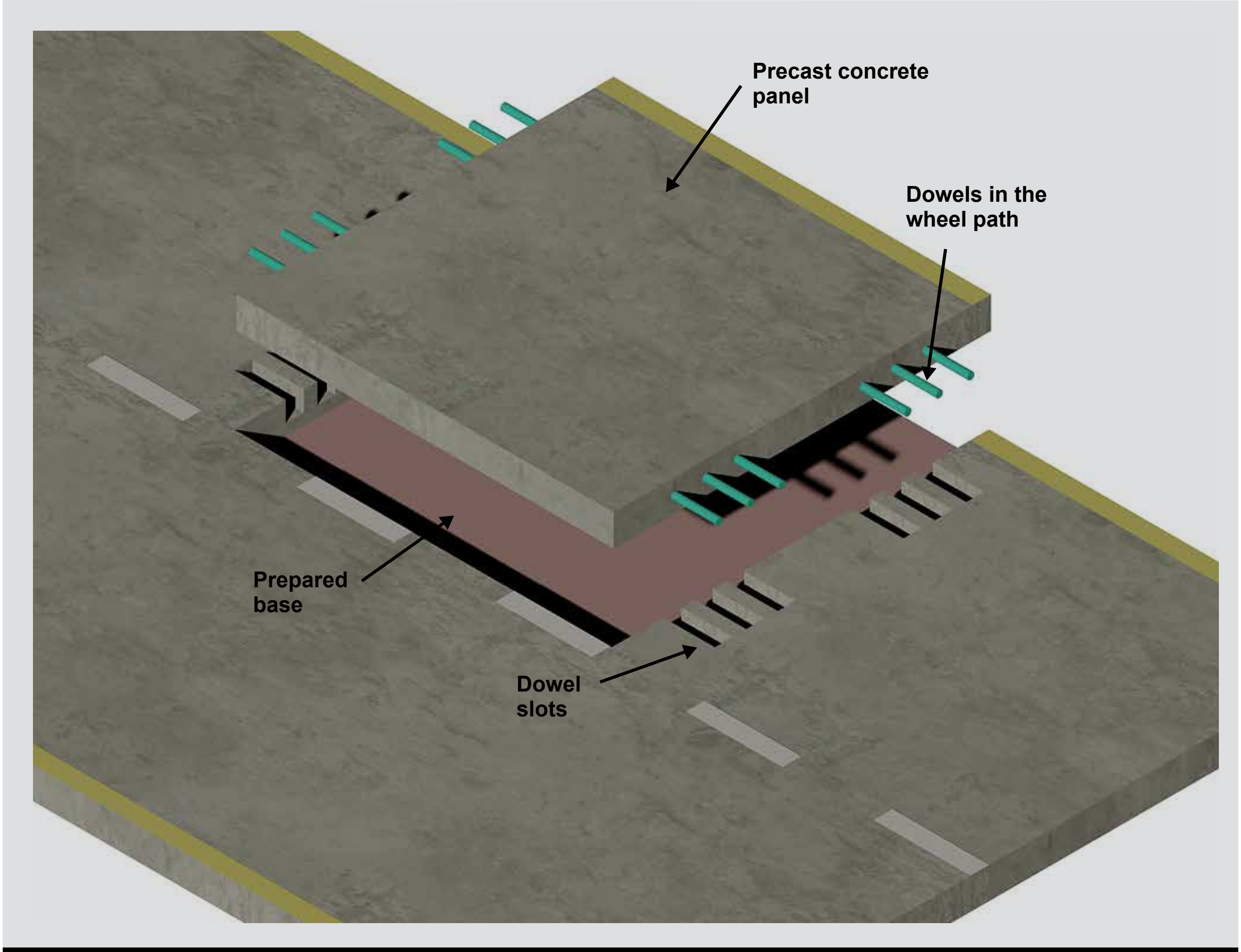

Figure 2. One scheme for intermittent repairs.

systems and includes systems that simulate the hinged jointed reinforced concrete pavement behavior. Incrementally connected precast concrete panels may be reinforced or prestressed.

Jointed precast concrete pavements Jointed precast concrete pavements are similar to cast-in-place jointed concrete pavements. Once installed, jointed precast concrete pavements behave similarly to cast-in-place jointed concrete pavements. Some specific differences that influence the performance of the jointed precast concrete pavements are as follows:

- The panels are installed flat. As a result, they do not exhibit construction-related curling or warping.
- The panels incorporate steel reinforcement. Therefore, any in-service cracking that may develop over time due to traffic loading can be maintained tight.
- The panel transverse joint faces are smooth (cast surfaces); therefore, aggregate interlock cannot be counted on for load transfer at these joints.

Jointed precast concrete pavements used in the United States incorporate load transfer at transverse joints. In fact, it is necessary that load transfer provisions be incorporated in all jointed precast concrete pavements. Jointed precast concrete pavements use round dowel bars, typically steel bars, for load transfer. **Figure 5** shows one scheme that

Figure 3. A variation for installing dowel bars using dowel bar retrofit.

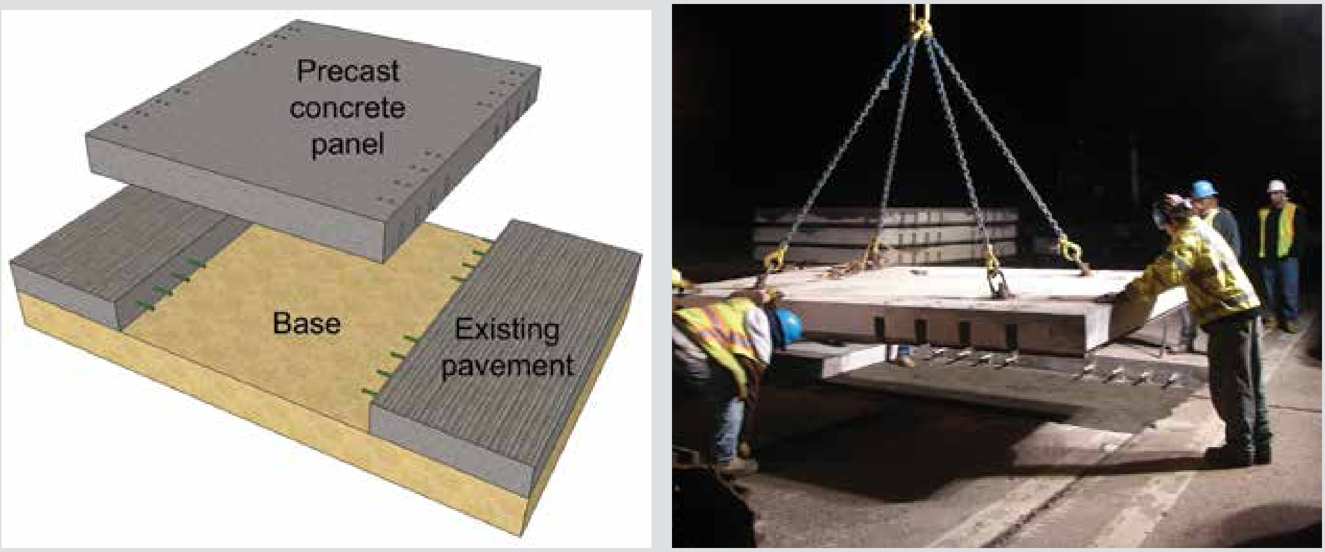

Figure 4. Another scheme for intermittent repairs.

is used to effect the load transfer, similar in concept to the system in Fig. 4 for intermittent repairs. Under this scheme, one side of the panel has slots along the bottom to accommodate the dowel bars, and the other side has embedded dowel bars at locations that match the slot locations. After installation, the slots and the joint perimeter gap are filled with fast-setting grout.

A simpler scheme using a dowel bar retrofit can also be used for jointed precast concrete pavements. Such a scheme requires patching of the dowel slots during the same lane closure as the panel installation because of use of wide-mouth dowel slots. The primary reason for not using this scheme is not related to performance but to avoid leaving open, wide-mouth slots exposed to highway traffic for a day or two. The retrofitted dowel bar scheme was used at an airfield demonstration application.[2] Under this scheme, the dowel bars were embedded along one transverse side of the panel, and dowel bar slots were placed at the top of the panel along the other transverse side. The panels were then interconnected by positioning one panel with the embedded dowels adjacent to another panel with the dowel slots (**Fig. 6**). At this demonstration project, reinforced panels and thinner prestressed panels were used.

A scheme developed under this study, and discussed in this report, allows use of dowel bar retrofit by using narrow-mouth dowel bar slots. In this scheme, the narrow-mouth dowel slots can be left open to traffic until the next lane closure (within a day or two), when the slots are patched.

Precast, prestressed concrete pavements

Precast, prestressed concrete pavements simulate cast-in-place posttensioned concrete pavements. These systems incorporate longer posttensioned sections and expansion joints between sections. The posttensioned sections are

Figure 5. A scheme for providing load transfer in jointed precast concrete pavement.

Figure 6. Alternative scheme for providing load transfer in jointed precast concrete pavement.

formed by posttensioning together a series of panels. The section length may vary from 150 to 250 ft (46 to 76 m). The individual panel width may be single-lane or multiple-lane, and panel length can vary from 8 to 10 ft (2.4 to 3 m) for multilane panels to 10 to 30 ft (9 m) or more for single-lane panels. A project in California is using panels up to 36 ft (11 m) long.[3]

Three types of precast, prestressed concrete pavement systems have been developed. **Figure 7** illustrates the three versions of precast, prestressed concrete pavement. **Figure 8** shows the second and third versions of precast, prestressed concrete pavement.

In the original version, used in the first precast concrete pavement project in Texas,[4,5,6] base, central stressing, and expansion joint panels were used:

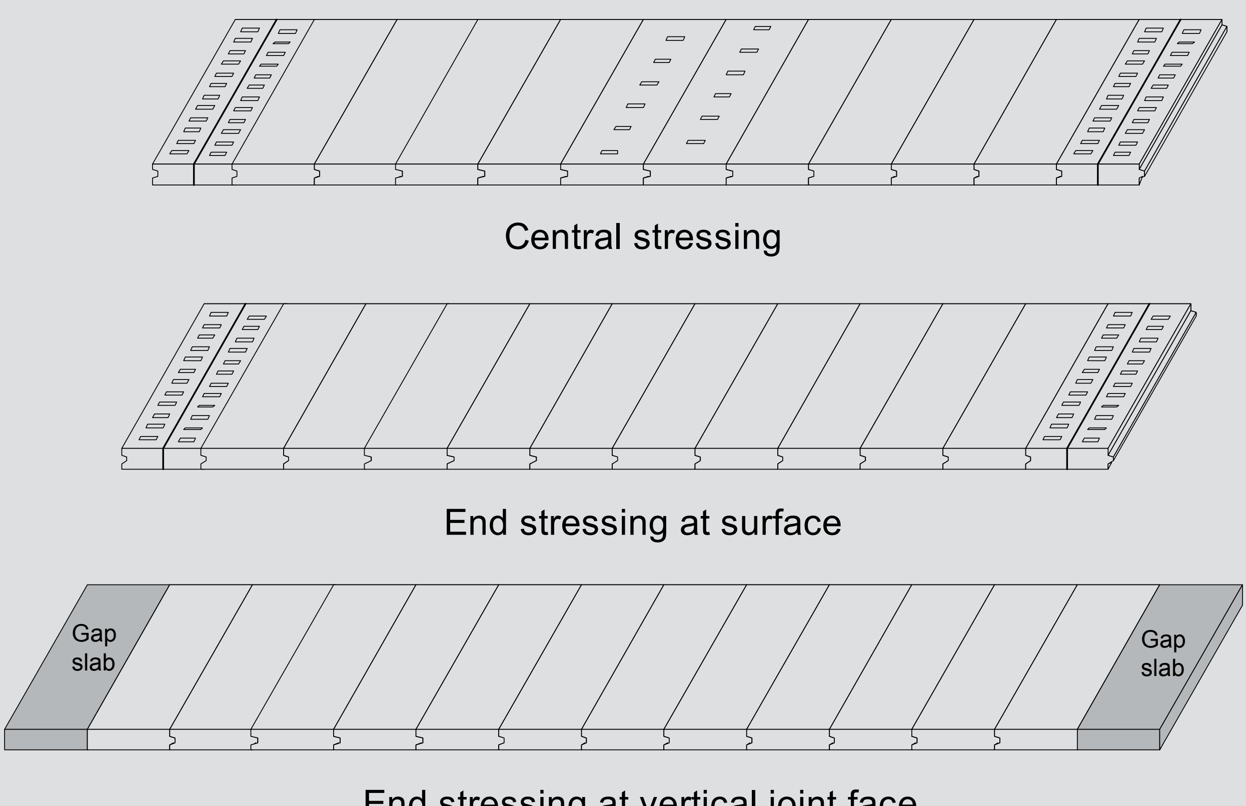

Figure 7. Schematic of three precast, prestressed concrete pavement systems.

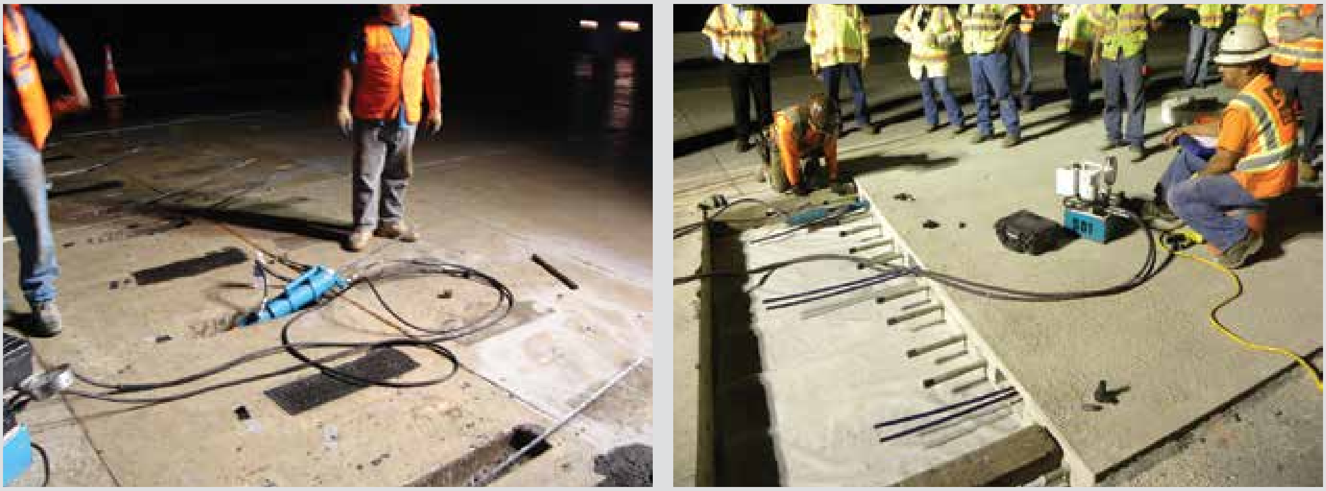

Figure 8. Views of the installation of two current versions of precast, prestressed concrete pavement systems.

- Base panels: the majority of the connected (posttensioned) panels.

- Central stressing panels: to apply posttensioning from the midportion of the connected panels using slots prefabricated in the panels.

- Expansion joint panels: one at each end of the posttensioned sections. These panels include dowel bars for load transfer and provisions for joint sealing.

In the second version of the precast, prestressed concrete pavement system, used on the Delaware, Missouri, and Virginia projects,[7] only base and expansion joint panels were used:

- Base panels: the majority of the connected (posttensioned) panels.

- Expansion joint panels: one at each end of the posttensioned sections. These panels include dowel bars for load transfer, provisions for joint sealing, and provisions for applying posttensioning using slots prefabricated in the panels.

In a third version of the precast, prestressed concrete pavement system, which was used on Interstate 680 in California, base, end joint, and expansion joint gap panels were used:

- Base panels: the majority of the connected (posttensioned) panels.

- End joint panels: one at each end of the posttensioned sections. These panels include dowel bars for load transfer, provisions for joint sealing, and provisions for applying posttensioning from the face of the panel using anchorage system pockets prefabricated in the end panels.

- Expansion joint gap panels: one expansion joint gap panel, about 4 ft (1.2 m) long, to fill the gap between adjacent panels to accommodate the posttensioning. For new construction where lane closure is not a concern, the gap panel may be cast in place. The gap panel includes provisions for dowel bars for load transfer and for joint sealing.

The gap slab concept has been successfully used in cast-in-place prestressed concrete pavements constructed during the 1970s and 1980s.[8] These cast-in-place prestressed concrete pavements were posttensioned from the joint face, and a cast-in-place concrete gap slab was constructed between adjacent posttensioned sections after posttensioning.

The posttensioning of the series of panels induces compressive stress in the connected panels, which allows for reduction in the panel thickness by 2 to 4 in. (50 to 100 mm) compared with an equivalently designed cast-in-place jointed concrete pavement or jointed precast concrete pavement. This results in the need for less concrete, making precast, prestressed concrete pavement a more sustainable alternative with respect to material consumption and carbon dioxide production. Based on a small number of demonstration-type precast, prestressed concrete pavement projects constructed in the United States, precast, prestressed concrete pavement costs are comparable to costs for jointed precast concrete pavement. In any case, well-designed and well-constructed precast, prestressed concrete pavement systems can be considered long-life concrete pavements with little need for major repairs or rehabilitation during their service life.

Incrementally connected precast concrete pavements Incrementally connected precast concrete pavements simulate jointed reinforced concrete pavement with hinged joints and incorporate panels of varying lengths, typically 15 to 30 ft (4.5 to 9 m), which are connected to achieve a continuous section length of 60 to 100 ft

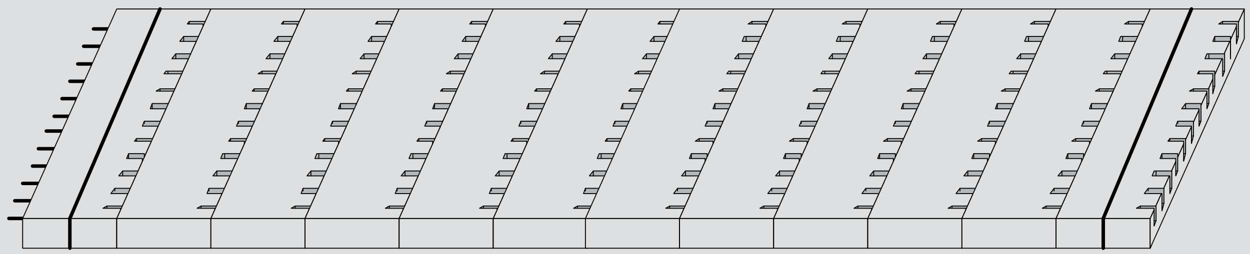

Figure 9. Incrementally connected precast concrete pavement.

(18 to 30 m). The panels are connected using deformed dowel bars that lock the joint and also provide the required load transfer. A narrow expansion joint is provided between connected panels.

The advantages of incrementally connected precast concrete pavement are fewer active joints and narrower expansion joints. Both nominally reinforced and prestressed concrete panels can be considered for use. **Figure 9** illustrates the incrementally connected precast concrete pavement system. The prestressed concrete panels allow use of thinner panels but require good support similar to that needed for precast, prestressed concrete pavements.

Precast concrete pavement systems in the United States

Many precast concrete pavement systems are available for production or have been used on an experimental basis in the United States.

Precast, prestressed concrete pavement

The precast, prestressed concrete pavement system in Fig. 7 and 8 is well suited for continuous paving. The basic precast, prestressed concrete pavement system consists of a series of individual precast concrete panels that are posttensioned together in the longitudinal direction after installation. Each panel may also be prestressed in the transverse and/or longitudinal direction. Ducts for longitudinal posttensioning are cast into each of the panels during fabrication. The posttensioning and pretensioning offset some of the tensile/flexural stress that develops in the precast concrete panels under traffic and environmental loadings.

The compressive stress introduced by the longitudinal posttensioning varies along the length of the posttensioned section, with a maximum prestress developing at the ends and a minimum (effective) prestress developing near the midsection. The reduction in the prestress is due to the panel-base friction and other prestress losses. Also, the effective prestress in the concrete allows for a reduction in the thickness of the panel for precast, prestressed concrete pavement systems.

The basic features of the typical precast, prestressed concrete pavement system are as follows:

- Panel size: up to 40 ft (12 m) wide, 10 to 30 ft (3 to 9 m) long, and 8 to 10 in. (200 to 250 mm) thick (as per design requirements).
- Panel types:
  - — System 1: base, joint, and central stressing panels (as originally developed).
  - — System 2: base and joint stressing panels.
  - — System 3: base, end stressing, and gap panels.
- Connections: a mechanism for connecting panels at intermediate joints (for example, a keyway detail)
- Posttensioning details:
  - — Strands: 0.6 in. (15 mm) diameter, seven-wire strands, typically spaced at 18 to 24 in. (450 to 600 mm).
  - — Strand load: 75% of ultimate strand load.
  - — Applied prestress: sufficient to ensure 100 to 200 psi (700 to 1400 kPa) (effective prestress at the midpoint of each posttensioned section, after accounting for losses due to panel-base interface friction, concrete creep and shrinkage, and steel relaxation), the smoother the panel-base interface, the greater the effective prestress at the midpoint of the posttensioned section.
  - — Bonded tendons: grouted posttensioning ducts.
- Pretensioning details:
  - — Strands: 0.5 in. (13 mm) diameter, seven-wire strand.

Figure 10. Proprietary road system.

— Strand load: 75% of ultimate strand load.

— Prestressing is achieved as part of panel fabrication.

— Expansion joint spacing: 150 to 250 ft (46 to 76 m).

- Base type: stabilized base preferred because of the thinner panels used for the precast, prestressed concrete pavement systems (to minimize panel deflections under truck traffic).

- Panel-base interface treatment: a membrane, typically 6 mil (0.15 mm) polyethylene or geotextile, used to ensure low frictional resistance between the panel and the base during posttensioning.

- Seating of panels: injection of bedding grout to firmly seat panels (after posttensioning).

Proprietary slab system

The system in Fig. 4 and 5 is a proprietary precast concrete pavement technology suitable for both intermittent and continuous paving operations. This paving system consists of precast concrete panels placed on a graded and compacted bedding material or placed over an existing graded granular base. This particular technology lends itself to the construction and rehabilitation of freeway entry and exit ramps and along curved sections because the panels can be produced with varying cross slopes (nonplanar panels).

The Michigan method

The Michigan method, a nonproprietary precast concrete pavement technology, is a doweled full-depth repair system that can be used for intermittent repairs.[9] The repair panels are typically 6 ft (1.8 m) long and 12 ft (3.6 m) wide, fitted with three or four dowel bars in each wheel path. The Michigan method can be used for full-depth repair as well as full-panel replacement. This method uses a partial or full dowel bar retrofit to install dowel bars at the transverse joints formed by the precast concrete panel (Fig. 1).

Proprietary road system

The road system was introduced in 2009 for intermittent repairs (**Fig. 10**). In this system, dowel bars are not embedded in the panels but are installed using dowel bar retrofit after the panels are placed. The slots for dowel placement are cut in the existing concrete as well as in the panel after the panel is set in final position (elevation). The unique feature of this system is the use of polyurethane foam as a bedding material. The panel is cast about 1 in. (25 mm) thinner than the existing pavement. The panel is placed in the prepared hole after removal of the deteriorated portion of the existing pavement and sits about 1 in. (25 mm) below final elevation. The polyurethane material is then injected under the panel, raising it to the desired elevation and providing uniform seating over the existing base.

Proprietary joint-interlock slab system

The proprietary slab system, which includes patented joint steel couplers, interlocks reinforced precast concrete panels, allowing reinforcement continuity throughout the length of the connected section (**Fig. 11**). The system essentially simulates jointed reinforced concrete pavement sections. As such, there is a limit to the total length of panels that can be connected, and there is a need to provide expansion joints between connected sections. Use of active or expansion joints has not yet been incorporated into this system.

Airfield system

In 2000, the Port Authority of New York and New Jersey investigated the use of precast concrete pavement to rehabilitate taxiway A at New York's La Guardia International Airport. Two 200 ft (61 m) test sections were constructed at a noncritical taxiway in 2002.[2] One test section used nominally reinforced concrete panels 16 in. (400 mm)

Figure 11. Proprietary joint interlocking slab system.

thick and 12.5 × 25 ft (3.8 × 7.6 m), and the second test section used prestressed concrete panels 12 in. (300 mm) thick and 12.5 × 25 ft. The two systems were developed as generic systems. A unique feature of this system is that the panel elevation was controlled using threaded setting bolts, and a 0.5 to 1 in. (13 to 25 mm) gap was maintained under the panels. The gap was then filled with fast-setting cementitious grout. Another unique feature was that the dowel slots were fabricated at the plant. Figure 6 shows the panels used and the installation process. The performance of the two test sections is still under evaluation as they are subjected to aircraft loadings.

Highway agency–developed systems

Highway agencies have shown increased interest in developing generic precast concrete pavement systems because many states prohibit procurement of proprietary products and also to encourage competitive bidding. In such cases, the highway agencies have developed end-product specifications or plans and specifications for nonproprietary systems. The following agencies have developed nonproprietary systems.

Illinois Tollway The Illinois Tollway began specifying the tollway-developed intermittent repair system or equivalent for projects beginning in 2010. This system uses standard panel details for panels 6 ft (1.8 m) long and 12 to 14 ft (3.7 to 4.3 m) wide. **Figure 12** shows a drawing for one of the standard panel designs and a trial installation of the system.

Utah Department of Transportation The Utah Department of Transportation developed a nonproprietary precast concrete pavement system. The precast concrete panels in this system are positioned at the desired elevation using a threaded setting bolt system, similar to the Port Authority of New York and New Jersey system. The gap between the panel and the base is filled with fast-setting cementitious grout. Also, the dowel bar retrofit is used for joint load transfer after the panels are set. A 600 ft (183 m) long section of Interstate 215 was rehabilitated using this technique in June 2011.

Performance evaluation of precast concrete pavement systems

Only a limited amount of field monitoring has been conducted by highway agencies. When field data were collected, they were typically not publicly reported. The lack of well-documented data on the performance of installed precast concrete pavements results in many questions related to field performance and detracts from wider implementation of this technology.

Several U.S. highway agencies agreed to support this study with field testing of the installed precast concrete pavements. A detailed documentation of the field testing for each project tested is given in a supplemental report.[10,11] Field testing occurred at various locations in California, Texas, Missouri, Minnesota, Illinois, Michigan, New York, New Jersey, Delaware, and Virginia. Of the 15 projects tested, two were about 10 years old, one was a few weeks old, and the remaining were from 2 to 6 years old.

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

- Condition data: visual condition survey.
- Ride (smoothness): using a high-speed profiler to determine the section's International Roughness Index.
- Joint elevation difference: using an electronic digi-

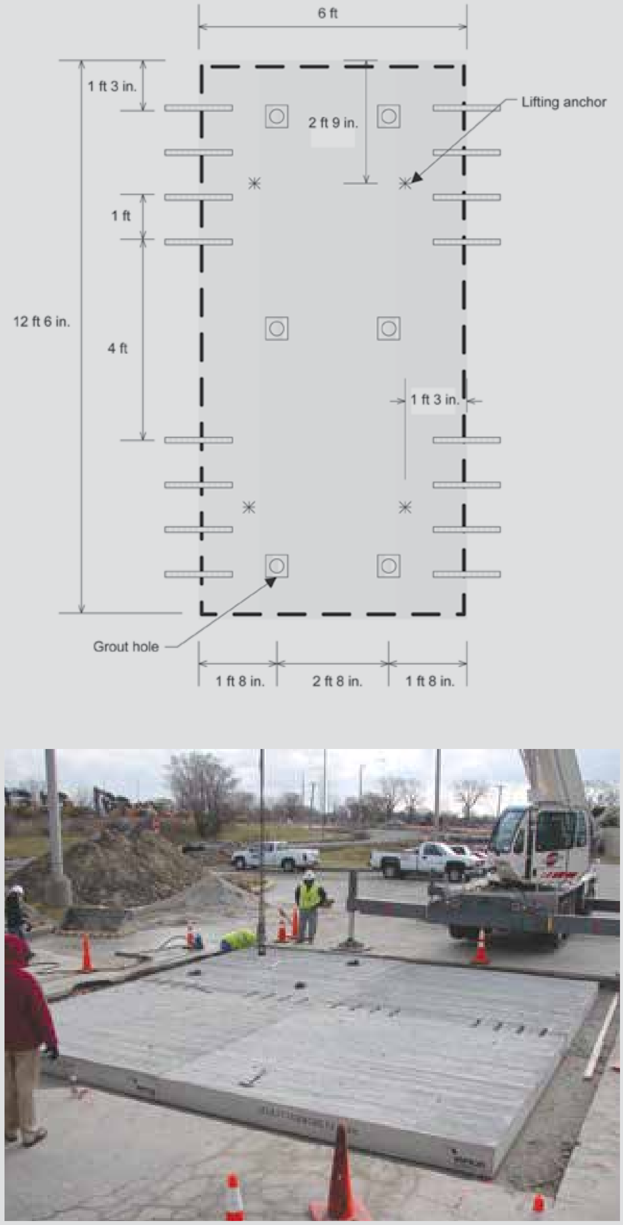

Figure 12. Illinois Tollway intermittent repair system. Note: 1 in. = 25.4 mm; 1 ft = 0.305 m.

tal faultmeter, in accordance with AASHTO R36-12 *Standard Practice for Evaluating Faulting of Concrete Pavements*.[12] This measure can include the built-in joint elevation difference for newer projects as well as traffic-related faulting for older projects.

- Joint width measurement: joint width was measured for the jointed precast concrete pavements as well as the precast, prestressed concrete pavements.

- Deflection testing: using a falling-weight deflectometer in accordance with ASTM D4694–09 *Standard Test Method for Deflections with a Falling-Weight-Type Impulse Load Device*.[13]

  — midpanel (basin) testing

  — testing at joints (wheel path) for load transfer effectiveness and void detection

The field testing indicated that once installed, precast concrete pavements behave similarly to cast-in-place concrete pavements. The precast concrete pavements evaluated did not exhibit any unusual distress or failure mechanisms. However, there is concern about the risk of panel cracking in the jointed precast concrete pavement used for continuous applications. A primary cause of such early cracking is considered to be the use of a thick layer (>¼ in. [6 mm]) of fine-grained granular bedding material over the existing base. Therefore, care must be exercised in specifying the type and thickness of the bedding material for precast concrete pavements subjected to heavy truck traffic. Overall, there does not appear to be any concern about the long-term performance of the precast concrete pavements that are properly designed and installed. The quality of the concrete used for the precast concrete panels appears to meet the expectations for durable concrete, and there is no evidence of early-age concrete failures.

Technical considerations for precast concrete pavement systems

Concrete requirements

Concrete requirements need to be similar to those specified by the highway agency for cast-in-place concrete pavements. However, because the precast concrete pavements are used for highways with high traffic volumes where lane closures are at a premium, concrete durability is of great importance. Concrete must not fail because of materials-related distress or poor-quality construction. The fabricator may optimize the aggregate size and grading to achieve an economical and sustainable concrete mixture that is workable for fabrication of the panels. An added benefit of using precast concrete panels is that the concrete strength that is typically achieved is higher than that of the concrete used for cast-in-place concrete pavement.

Panel reinforcement

A double mat of epoxy-coated reinforcement is typically used for precast concrete panels to mitigate cracking due to lifting and transport. The amount of reinforcement is typically at least about 0.20% of the panel cross-sectional area in both directions, depending on the panel dimensions. The reinforcement is not necessary for pavement performance unless the panels are designed as reinforced concrete pavements. Some agencies require heavier reinforcement if the installed panels are subjected to traffic before panel subsealing is completed. An advantage of panel reinforcement is that if the panels develop cracking over the long term due to traffic loading, the cracks can be expected to remain tight without affecting pavement serviceability.

Production rates

The panel installation rate is one of the most critical factors in considering precast concrete pavement. The panel installation rate determines productivity and lane closure requirements. Panel installation includes all activities that are conducted during a given lane closure, as listed:

- Existing pavement removal, including a portion or all of the base material, may require milling of a stabilized base, as per design requirements.

- The dowel bars are drilled and grouted for repair applications (based on system design).

- Base preparation includes regrading the existing base or placing a new base and bedding material to achieve a proper base grade. The base is compacted if granular or placed and finished if cementitious (rapid-setting lean concrete base). The bedding material may be granular, fast-setting flowable fill or polyurethane foam material.

- The panel-base interface treatment, typically polyethylene fabric or geotextile membrane, is placed.

- Panel is placed.

- There is a temporary transition to existing pavement at the end of the precast concrete pavement installation for a given lane closure.

For intermittent repairs within a given lane closure area, the typical production rate is about 14 to 18 panels in a 6- to 8-hour lane closure, or about one panel per 20 to 25 minutes. Ideally, two crews would be used for repair installations: one crew prepares the repair area, including drilling and epoxy-grouting the dowel bars, and the second crew installs the panels.

For continuous applications, a higher panel installation rate can be achieved because work is performed along a longer rehabilitation area. The typical production rate for panel installation is about 30 to 40 panels for jointed systems, or about 400 to 600 ft (122 to 183 m) of installation length per 6- to 8-hour lane closure. The production rate can vary for precast, prestressed concrete pavement systems and is dependent on the panel width and length. Greater production can be achieved using longer panels because fewer panels need to be set and temporarily posttensioned. The precast, prestressed concrete pavement panel installation can range from about 200 ft to more than 600 ft (61 to 183 m) per 6- to 8-hour lane closure, depending on the panel length and width.

The joint load-transfer system

Jointing and load-transfer provisions at transverse joints are two important design features for precast concrete pavement. The joint spacing must be optimized for intermittent repair and continuous applications by considering constraints on panel size fabrication, shipping, and structural performance requirements. In addition, it is necessary to ensure that adequate load transfer will be available at all active transverse joints, including expansion joints, over the long term. Precast concrete pavements with poor or no load-transfer provisions at active transverse joints cannot be expected to perform adequately under truck traffic. Precast concrete pavement joints incorporate smooth joint faces and are typically wider than the joints in cast-in-place jointed concrete pavement. As a result, there is no aggregate interlock at the joints.

Typically, load transfer at transverse joints of concrete pavements is provided by dowel bars. Dowel bars in highway pavement construction are smooth, round, solid steel bars conforming to ASTM A615/A615M-12 *Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement*.[14] In addition, corrosion protection is typically provided in the form of a fusion-bonded epoxy coating, about 0.008 to 0.012 in. (0.203 to 0.305 mm) thick, which acts as a barrier against moisture and chloride intrusion. In recent years, because of concerns about the long-term effectiveness of epoxy coating and with the movement toward longer-life pavement designs, a number of agencies have started specifying alternative dowel bar materials. These are materials that either are constructed of a corrosion-resistant material or contain a corrosion-resistant cladding for protection against degradation caused by moisture and deicing chemicals. Examples of alternative dowel bar materials include the following:

- fiber-reinforced polymer constructed with a range of composite materials and manufactured in solid form

- stainless steel of varying grades (most commonly SAE grades Type 304 and Type 316) manufactured as a hollow tube that is filled with cement grout (in some cases, stainless steel may also be used as a cladding on a conventional carbon-steel bar)

- microcomposite steel, a more corrosion-resistant steel material than conventional carbon steel, used to produce solid dowel bars

- rolled zinc alloy used as a cladding over conventional carbon steel for corrosion protection

Dowels are typically placed at a spacing of 12 in. (300 mm). However, the middle dowels do not contribute to the load transfer at a joint. Therefore, a cluster of four to five dowels per wheel path, spaced at 12 in. (300 mm), is considered adequate for intermittent as well as continuous applications. For jointed precast concrete pavement, the incorporation of a well-designed load transfer system at active transverse joints is critical to long-term performance. The practice for providing load transfer at active transverse joints should be similar to the well-established and well-performing practices used for cast-in-place jointed concrete pavement. If a practice has not been successful for cast-in-place jointed concrete pavement or has not yet been used, it should not be considered for precast concrete pavement without additional investigation or field verification. The risk of failure of the load-transfer system should be minimized.

Panel support condition

For new construction as well as for repair, pavement support is critical to long-term performance. Proper seating of the panels on the base is critical. The support under the panels needs to be firm (strong) as well as uniform.

For most precast concrete pavement repair or rehabilitation (reconstruction) applications, the following support alternatives may need to be considered:

Existing base

- A granular base may be reworked, graded, and compacted. The panel is placed on the compacted granular base.

- A granular base may be reworked, trimmed, graded, and compacted; additional bedding material is then used to make up the difference in the base grade needed. The bedding material may be the following:

  — a thin layer of finely graded granular material or sand

  — fast-setting flowable cementitious grout or flowable fill

  — polyurethane foam material, applied after the panel is placed or set in position (for repair application, a foam thickness of up to 1 in. (25 mm) may be used)

- The stabilized base, if not damaged in the removal of the existing slab, may be used as is. A thin layer of finely graded granular material or sand may be used to provide a level surface for setting the panel.

- The stabilized base may be trimmed as necessary to accommodate the panel thickness. A thin layer of finely graded granular material or sand is then used to provide a level surface for setting the panel.

New base A new base may be used if the existing base will not serve the long-term needs of the new precast concrete pavement. Because of time constraints, the new base material must be of good quality and placed, graded, and compacted, if granular, fairly quickly within the same nighttime closure as the panel installation. This option is common when precast concrete pavement is used to rehabilitate asphalt pavements. The new base type may include a dense-graded, free-draining granular base or a rapid-setting lean concrete base. Cement-treated or asphalt-treated bases are not considered viable options for precast concrete pavement installed during nighttime lane closures but may be considered if full-lane closure is available and the duration of lane closure is not a concern.

For both repair and continuous applications, the granular bedding should be kept as thin as possible (not greater than 0.25 in. [6 mm]) because thicker granular bedding can lead to poor support under the panels. If thicker bedding is necessary, then consideration should be given to the use of a fast-setting cementitious fill material. In addition, for lane replacement applications, the use of a new base should not result in a detail that traps moisture under the panels.

Little testing has been performed on site to ensure that the granular base used for precast concrete pavement is adequately compacted. Poor compaction of the granular base or the fine-grained bedding layer can lead to excessive nonuniform settlement and distress in the precast concrete pavement. As indicated, the support conditions for precast concrete pavements should be as good as or better than those required for cast-in-place concrete pavements. **Figure 13** shows an example of poor support condition. At this project, a 0.5 to 1 in. (13 to 25 mm) thick layer of manufactured sand was used over a trimmed existing cement-treated base. The bedding material is not stable and will most likely not provide uniform support under the precast concrete panels.

It is recommended that agencies specify quality control/quality assurance testing of the granular bases to monitor the level of compaction using the lightweight deflectometer. The lightweight deflectometer was introduced in the United States during the 1990s, and several agencies use it for acceptance testing of granular paving material (base, subbase, and subgrade).[10,15]

Prestressed concrete pavement–related considerations

The use of prestressed concrete pavement requires the consideration of a number of features related to prestressing. These features include the following:

- prestressing strands

- prestressing accessories

- prestressing methods

Figure 13. Poorly compacted fine-grained bedding layer.

- prestress losses for posttensioned system
- pretensioning considerations if needed to facilitate longer or wider panel lifting
- expansion joint system
- load transfer at expansion joints

Ye and Tayabji discuss these features in detail.[11] The experience with precast, prestressed concrete pavement in the United States is based on use of the bonded strand technique. This is considered a safer approach for highway applications and allows localized repairs to be performed without concern for prestress loss in the system. Prestressing results in use of thinner panels to achieve a desired structural capacity.

Panel structural design

The design of precast concrete pavement is based on the recognition that, once constructed (installed), its overall behavior under traffic loading and environmental loading is not significantly different from that of a similar cast-in-place concrete pavement. Thus, a jointed precast concrete pavement is expected to behave similarly to a cast-in-place jointed concrete pavement, and a precast, prestressed concrete pavement is expected to behave similarly to a cast-in-place, posttensioned concrete pavement. Concrete pavements are typically designed, constructed, and rehabilitated to provide long-life performance. The definition for long-life concrete pavements, generally used in the United States, is as follows:

- Original concrete will have a service life of 40 or more years.
- The pavement will not exhibit premature failures or materials-related distress.
- The pavement will have a reduced potential for cracking, faulting, and spalling compared with conventional 20-year-life concrete pavements.
- The pavement will maintain a desirable ride and surface texture with minimal intervention to correct for ride and texture, joint resealing, and minor repairs.

Although precast concrete pavements are of recent use and in-service performance information of the oldest U.S. projects is available for less than 10 years, precast concrete pavements can be designed to provide long-term service.

In fact, the warrant for use of precast concrete pavements is rapid repair and rehabilitation with recognition of the need for long-term service. Specific design procedures have not been developed for precast concrete pavement. Development of reliable pavement design procedures requires a sound understanding of the pavement's behavior and validation of the design concepts on the basis of field performance. At this time, there are not sufficient projects available with long service to allow field validation. Precast concrete pavements can be designed for long-term performance using design procedures currently used for design of cast-in-place concrete pavements. The use of these design procedures requires some refinements to allow consideration of some of the specific characteristics of the different precast concrete pavement systems.[16]

A significant advantage of precast concrete pavement is that the panels are either reinforced or prestressed. As a result, if cracking develops prematurely or due to traffic loading, the panels can be expected to perform well because the cracking will be held tightly and not contribute to deterioration. The performance of the thinner prestressed concrete systems, whether jointed or precast, prestressed concrete, is greatly dependent on support conditions. The support for such systems should ensure that joint deflections under loading remain low.

Conclusion

This paper presents an overview of precast concrete pavement technology as it is practiced in the United States. The paper also addresses some technical considerations related to the design of precast concrete pavements. The load transfer provision at transverse joints and the support condition under the precast concrete panels are two critical design features and must be properly addressed for any precast concrete pavement. Precast concrete pavement technology is maturing and continues to evolve. It is expected that innovations in this technology will ensure a permanent place for the application of the precast concrete pavement technology for durable, rapid repair and rehabilitation of existing pavements and will help reduce the cost of panel fabrication and installation.

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Abstract

The use of precast concrete pavement is an emerging technology in the United States for application to rapid repair and rehabilitation of existing pavements. The technology is being applied in high-volume, congested roadways where lane closures and work windows are constrained. Several U.S. highway agencies have begun to implement this technology in demonstration projects. The implemented precast concrete pavement systems include proprietary and nonproprietary systems and components. A study on modular pavement technology was aimed at developing the necessary information and guidelines to encourage the successful adoption of this new technology.

The performance of projects indicates that sufficient advances have been made to reliably achieve the four key attributes of precast concrete pavement: constructability, concrete durability, effective load transfer at joints, and effective panel support condition.

This paper presents a summary of the work performed under the study and reports on potential refinements to the precast concrete pavement technologies.

Keywords

Constructability, durability, load, panel, pavement, road.

Review policy

This paper was reviewed in accordance with the Precast/Prestressed Concrete Institute's peer-review process.

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