PRECAST CONCRETE PAVEMENT FOR SUSTAINABILITY AND TRAFFIC MANAGEMENT

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ABSTRACT

Important aspects of sustainability and traffic management are being achieved through the use of precast concrete pavement for the repair and rehabilitation of existing pavements. Precast concrete pavement offers a solution which permits rapid construction during nighttime and other off-peak hours with minimum disruption to traffic, while providing high-quality durable concrete pavement that offers long-life performance with little or no maintenance. Precast prestressed concrete pavement and jointed precast concrete pavement applications for repair and rehabilitation projects throughout the United States during the last ten years have firmly established the ability of precast pavement to deliver these important aspects of sustainability and traffic management. Several projects constructed to date that have been in service for as much as ten years, have required no maintenance to date, providing initial support for the competitive life cycle cost of the precast pavement that was anticipated during design and construction. A project recently completed in Virginia utilizing both precast prestressed and jointed precast concrete pavement demonstrated the viability of precast pavement for nighttime construction, minimizing traffic disruptions and returning all traffic lanes to service the following morning. This paper will provide a brief overview of the precast pavement technology utilized in Virginia, and elsewhere in the United States, and will discuss the aspects of sustainability and traffic management what were addressed with this project.

1. INTRODUCTION AND BACKGROUND

The combination of a rapidly deteriorating pavement infrastructure (which has far outperformed initial lifespan expectations), rising prices and reduced availability of raw materials, and the continued pressure on transportation agencies to reduce the impact of construction activities on the travelling public is forcing most state highway agencies in the U.S. to seek new methods for rapid renewal and reconstruction of existing pavement. Over the past decade, a number of projects in the U.S. have demonstrated the viability of precast concrete pavement systems (PCPS) for rapid pavement reconstruction in urban areas. These projects have utilized both precast prestressed concrete pavement (PPCP) as well as jointed precast pavement systems (JPPS).

One such project was completed in 2010 by the Virginia Department of Transportation (VDOT). This project utilized a combination of rapid reconstruction techniques, including

PPCP, JPPS, as well as high early strength cast-in-place concrete pavement to achieve the objectives of providing a long-lasting pavement constructed with minimal disruption to the travelling public.

2. BENEFITS OF PRECAST CONCRETE PAVEMENT

The benefits of precast concrete have been recognized for more than a half century in the bridge and commercial building industries. However, within the past decade these benefits have also been realized for pavement construction. While the benefits of PCPS have been described in more detail elsewhere,[1,2,3,4] a summary of these benefits as they pertain to sustainability and traffic management is provided below

2.1. Sustainability

2.1.1 Design

A number of sustainability benefits are realized through the design of PCPS. PCPS utilize full-depth precast panels installed over the existing subbase and subgrade whenever possible. Full-depth panels eliminate the need for any additional paving operations on-site, such as for placement of an asphalt or concrete overlay. By utilizing the existing subbase and subgrade whenever possible, the additional step of subgrade and/or subbase reconstruction and the new materials, construction processes, and disposal of existing materials associated with it are eliminated.

Additionally, when prestressed panels are used (for PPCP) the slab thickness required for the specified design life can be greatly reduced. PPCP projects completed to date have utilized precast panels up to 40 percent thinner than that which would have been required for a non-prestressed cast-in-place pavement. Typically, this means that the existing pavement can be replaced with PPCP of equal thickness but greater load-carrying capacity. This results in savings in concrete materials as well as shipping costs due to a reduction in the weight of the panels.

Finally, PCPS panels are typically designed in “standard” types and sizes for a given project as much as possible. Standardization of panels permits a much more efficient process for the fabricator by allowing the panels to be mass-produced to the extent possible. Standardized panels also facilitate efficient storage and shipping procedures since all panels of a particular type can be interchanged.

2.1.2 Manufacture

The precast concrete manufacturing process also presents a number of sustainability benefits for PCPS. Supplementary cementitious materials, such as fly ash recycled from coal combustion, are commonly used in precast concrete elements. PCPS projects completed to date have been produced using concrete mixtures containing up to 25 percent fly ash replacement of cement. The use of fly ash also provides enhanced durability by reducing the potential for destructive alkali-silica reaction.

PCPS panels are produced in existing precast plants which produce a variety of precast elements. This eliminates the need to set up batch plants at or near the project site specifically for the paving concrete. Established precast plants with diverse product lines also readily reuse formwork for various types of precast elements. Manufacturing of new formwork for PCPS panels is generally restricted to only the side forms, which in turn can be re-used for other precast elements.

Finally, while all concrete batch plants generate a certain percentage of waste material, precast plants seek to minimize any waste and readily reuse waste that is generated. It has been estimated that approximately 2 percent of concrete generated at a precast plant is waste, but approximately 95 percent of this waste is beneficially reused elsewhere in the plant or separated back into constituent materials for use in fresh concrete.[5]

2.1.3 Construction

The sustainability benefits of PCPS as it pertains to construction are primarily realized through the reduction in traffic congestion during construction. This benefits the contractor, owner agency, and the travelling public. PCPS permit construction to be completed during non-peak travel times, such as at night or over weekends, thereby greatly reducing or even eliminating construction-related traffic congestion. This reduces the pollution associated with idling or slowly-moving traffic. Additionally, by limiting construction to off-peak times, any pollution generated by construction occurs when pollution from other sources is minimal. Finally, PCPS generally requires less construction equipment on-site than conventional pavement construction. This reduces the environmental impact of construction equipment throughout construction.

2.1.4 Life Cycle

Life cycle sustainability benefits of PCPS are realized through the durability of the finished product. PCPS is utilized as a long-lasting, low-maintenance product, and not as a temporary fix. Minimal maintenance over the lifespan of the pavement reduces the environmental impact of maintenance operations, and the anticipated longevity of the product greatly increases the reconstruction cycle time.

2.2. Traffic Management

The traffic management benefits of PCPS are primarily realized through the ability to complete pavement reconstruction (including removal of the existing pavement and installation of the new pavement) during short, overnight lane closures. This provides a number of benefits in terms of requirements for traffic control devices and traffic control plans.

Depending on the type of closure, whether full, single lane, multiple-lane, only temporary traffic control devices, such as drums, cones, or tubular markers are typically required for precast pavement construction. While movable concrete barrier may provide a more impenetrable screen between traffic and the work area, this may significantly increase the set up and tear down time for traffic control at the beginning and end of each night's closure, and is typically not required for the traffic volume anticipated during overnight closures.

By permitting all lanes to be open during peak travel times, traffic control plans can be simplified to focus only on the conditions during off-peak travel times, typically at night. Unless a full closure is required for reconstruction of the full pavement width, detours will typically not be required, and special traffic control scenarios such as narrowed lanes, head-to-head traffic on divided highways, etc. will not be necessary.

3. PRECAST CONCRETE PAVEMENT SYSTEMS

3.1. Precast Prestressed Concrete Pavement

Many of the underlying features of the PPCP concept are adapted from experience with both cast-in-place prestressed concrete pavement and segmental and full-depth precast bridge deck panels. The details of the PPCP concept are described elsewhere.[1,2] The key aspects of the PPCP concept as implemented in projects in the U.S. to date are described below.

3.1.1 Two-Way Prestressing

Prestressing in both directions of the pavement is essential. Prestressing not only provides the desired long-term compressive stresses in the pavement slab to reduce thickness and ensure satisfactory pavement performance over time, but also counteracts lifting and handling stresses during precast panel fabrication and installation. Prestressing is generally incorporated into PPCP through a combination of plant pretensioning in the transverse pavement direction (perpendicular to traffic flow) and on-site post-tensioning in the longitudinal pavement direction (parallel to traffic flow). Pretensioning is in the direction of the longer axis of the precast panels to help counteract lifting and handling stresses, while post-tensioning is in the direction of the shorter axis of the precast panels, and serves to tie a section of precast panels together on-site.

Grouted post-tensioning systems have been used for PPCP projects constructed to date. Grouting provides additional corrosion protection for the post-tensioning tendons, an important consideration for pavements in saltwater environments or where deicing chemicals are used. Additionally, if it were necessary to remove an individual precast panel during the lifespan of the pavement, grouted tendons can be cut without compromising prestress in the entire pavement section (just over the section that is removed). Unbonded tendons are an option for PPCP, but have not been used to date.

3.1.2 Keyed Panel Joints

To help align adjoining precast panels during construction, and to minimize any vertical differential between panels in the finished roadway, the mating edges of the precast panels feature tongue and groove keyways.

3.1.3 Standardized Precast Panels

As discussed above, PPCP panels are standardized to the extent possible for a particular project by maintaining uniform panel dimensions, strand patterns, lifting anchor locations, etc. This greatly reduces the setup and re-tooling of the casting beds, improving efficiency and reducing the environmental impact of the fabrication process, while also making all panels of a particular type interchangeable. This includes base panels, anchor/central stressing panels, and joint panels with the exception of joint panels at the extreme ends of a particular project where they tie into the existing pavement.

A general precast panel layout for the PPCP system is shown in Figure 1. In an individual post-tensioned section of PPCP, there are essentially three types of panels: joint panels, base panels, and anchor panels. Joint panels are installed at the ends of each post-tensioned section of panels and contain expansion joints for accommodating the longitudinal expansion and contraction movement of the post-tensioned section under daily and seasonal temperature cycles. Joint panels also contain the post-tensioning anchors for the longitudinal post-tensioning tendons on either side of the expansion joint.

Base panels (Figure 2) constitute the majority of each post-tensioned section, and the number of these panels can be varied to increase or decrease the post-tensioned slab length. Anchor panels are used to anchor the center of each post-tensioned slab to the underlying base such that each post-tensioned slab will expand and contract outward from the center and not "slide" longitudinally (in the direction of traffic) over time. The original PPCP concept featured "central stressing," wherein the post-tensioning tendons were stressed from the middle of the slab at large pockets cast into the anchor panel. For PPCP utilizing this feature, central stressing panels would be installed at the center of each slab for post-tensioning, and would also serve as the anchor point for anchoring the slab to the underlying base.

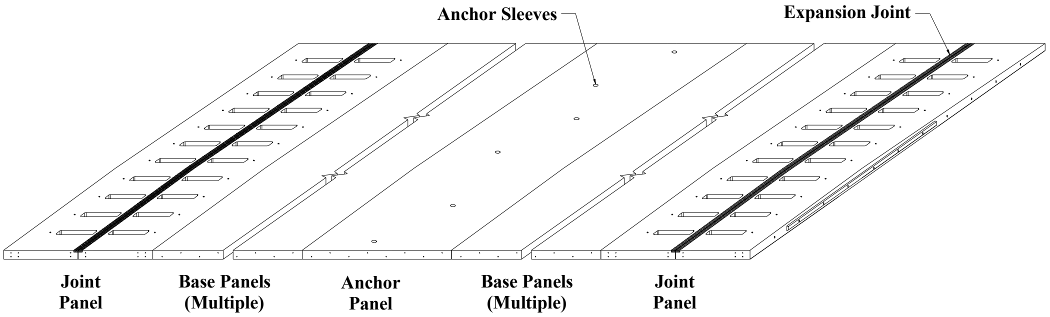

FIGURE 1 Typical Precast Prestressed Concrete Pavement Panel Layout.

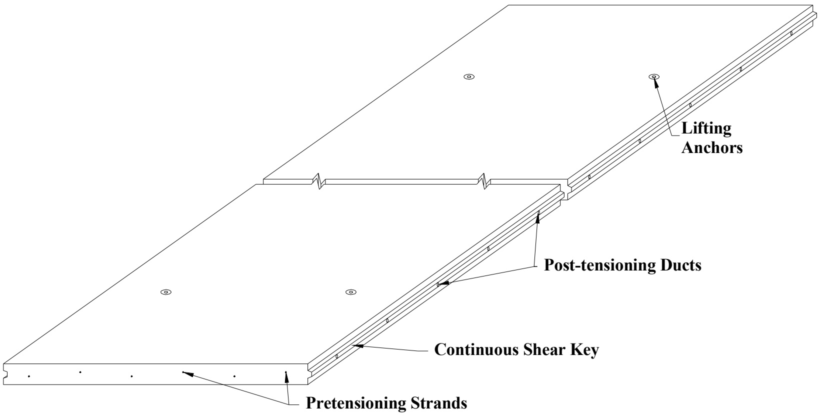

FIGURE 2 Typical Precast Prestressed Concrete Pavement Panel (Base Panel).

3.2. Jointed Precast Pavement Systems

3.2.1 In-Kind Slab Replacement

Jointed precast pavement systems essentially replace the existing pavement with precast pavement slabs with similar characteristics [3,4]. Slab thickness, for example, is typically the same as the pavement slab being replaced. In some cases it is necessary to use precast panels 6 to 13 mm (0.25 to 0.5 in.) thinner in order to provide a bedding layer between the new precast panels and remaining underlying subbase. Slab widths are typically one lane wide, and slab lengths will generally match the existing 3.7 to 6 meter (12 to 20 ft) joint spacing. If the existing pavement has significantly longer slab lengths (e.g., greater than 6 m [20 ft]), the new precast pavement will typically feature more conventional joint spacing of 3.7 to 6 meters (12 to 20 ft) to reduce the anticipated thermal movement at joints between panels.

For new construction or reconstruction where thicker pavement slabs are permitted (i.e., additional slab thickness will not adversely affect drainage, overhead clearance, or matching adjacent pavement) JPPS are designed in a similar manner to conventional cast-in-place pavement. Thickness will be determined based on design life, traffic characteristics, climate, and pavement support. Joint width and spacing will typically follow standard practice for cast-in-place pavement.

3.2.2 Dowelled Joints

Rather than keyways between individual precast panels, JPPS typically utilize dowel bars to provide load transfer between panels, similar to cast-in-place concrete pavement. Dowel sizing and spacing will generally match typical dowel configurations for conventional cast-in-place concrete pavement, and may be provided across the full width of each transverse joint, or just in the wheelpaths. Figures 3 and 4 show a typical precast panel layout for a JPPS and the dowelled joint configuration.

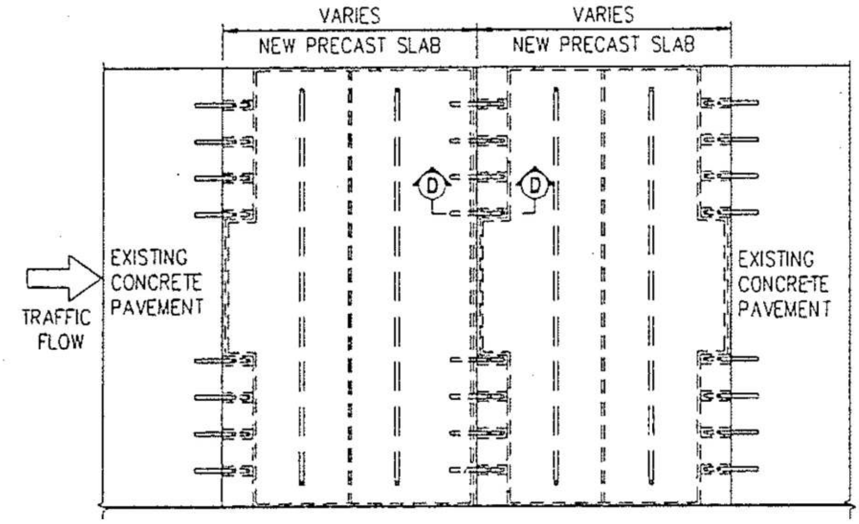

FIGURE 3 Panel layout of JPPS showing dowelled joints between panels [6].

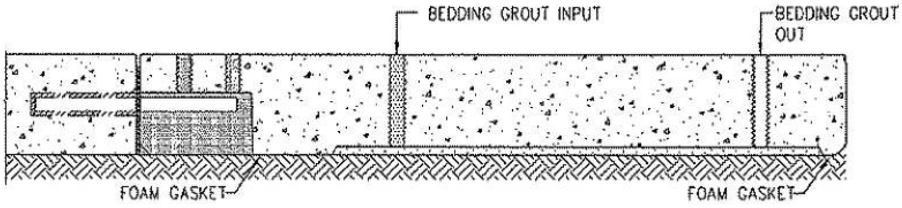

FIGURE 4 Cross section of JPPS showing dowelled connections between panels [6].

3.2.3 Reinforced Panels

JPPS panels are typically heavily reinforced in order to account for lifting and handling stresses as the panels are removed from the forms during fabrication, transported to the project site, and installed on site, typically using cranes. Reinforcement also serves to hold any cracks that may form in the panel over time from opening. Reinforcement typically consists of a double mat of steel with a reinforcement ratio similar to that which would be used for continuously reinforced concrete pavement. Reinforcement and dowels are generally epoxy coated, to minimize the risk of corrosion.

3.2.4 Warped Slabs

One of the primary challenges for any precast pavement system is reproducing the geometric features of the existing pavement, namely horizontal/vertical curves and superelevations. One of the proprietary JPPS used most commonly in the U.S. accommodates these geometric features with “warped” precast panels. Warped panels have a non-uniform thickness, with one corner of the panel typically thicker than the other three, which creates the proper superelevated geometric profile in the top surface of the panel.

4. VIRGINIA INTERSTATE 66 PROJECT

In November 2009, the Virginia Department of Transportation (VDOT) completed construction of a major pavement rehabilitation project near Fairfax City, Virginia which utilized both PPCP and JPPS, as well as high early strength cast-in-place concrete pavement.

4.1. Project Overview

The project involved reconstruction of the travel lanes of westbound Interstate 66, just east of the interchange with U.S. Highway 50, and the connector ramp from westbound I-66 to westbound U.S. Highway 50. For the mainline pavement on I-66, all four lanes of the existing pavement were reconstructed with PPCP. Much of the existing jointed concrete pavement was more than 45 years old, and had required continual maintenance under extremely high traffic volumes (184,000 vehicles per day). For the two-lane connector ramp from I-66 to U.S. 50, the entire right lane was reconstructed with JPPS and selected slabs of the left lane were reconstructed with high-early strength cast-in-place concrete pavement. The use of the various types of pavement reconstruction techniques permitted VDOT to evaluate the differences between them, specifically cost, productivity, and over time, performance.

Due to the very high traffic volumes, reconstruction could only be completed during nighttime work windows between 10:00 pm and 5:00 am. Excluding traffic control set-up and removal, this provided approximately six hours each night for construction. For the mainline pavement on I-66 only two lanes could be reconstructed at a time, to ensure at least one lane remained open to traffic during the nighttime closures. For the connector ramp, a full closure of the ramp was permitted during the nightly work windows.

Figure 5 shows the locations of the two areas of reconstruction along I-66 and the U.S. 50 connector ramp. Area A consisted of reconstruction of approximately 1,083 m (3,552 ft) of the right lane of the connector ramp using JPPS and isolated slab replacements of the left lane using high early strength cast-in-place concrete, as shown in Figure 6. Area B consisted of reconstruction of approximately 310 m (1,020 ft) of mainline pavement PPCP, as shown in Figure 7. For the mainline pavement, the two 3.7-m (12-ft) inside lanes were reconstructed simultaneously with adjoining panels, and the two outside lanes, 3.7-m (12-ft) and 4.6-m (15-ft) widths, were reconstructed with a full-width panel.

FIGURE 5 Precast Panel Layout for Virginia DOT PPCP Project.

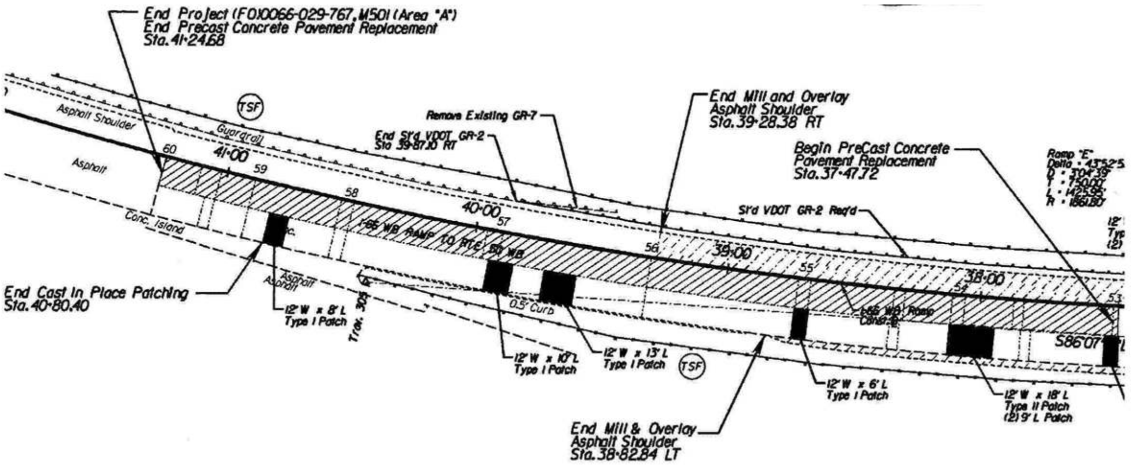

FIGURE 6 Typical reconstruction layout for the connector ramp utilizing JPPS (cross-hatched) and high early strength concrete (solid black).

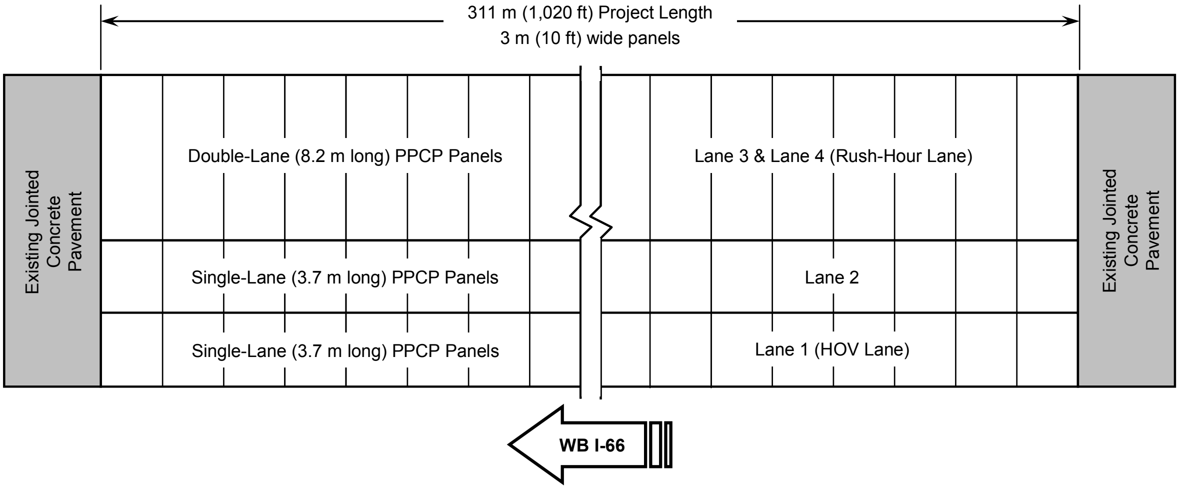

FIGURE 7 Precast panel layout for the mainline reconstruction using PPCP.

4.2. Reconstruction Technique Selection

VDOT selected the various reconstruction techniques based on the advantages each technique provided for the overall project. PPCP was selected for the mainline pavement because it is a low-maintenance solution intended for very heavily trafficked pavements. Prestressing gives the pavement high load carrying capacity while also permitting the existing pavement to be replaced in-kind. Additional excavation of base/subbase was not required as the existing 230 mm (9 in.) and 280 mm (11 in.) pavement slabs could be replaced with 222 mm (8.75 in.) thick PPCP.

JPPS was selected for the complete right lane reconstruction of the connector ramp primarily due to the ability of JPPS to accommodate various superelevations in the ramp geometry. The connector ramp had multiple changes in superelevation over its length and JPPS utilizing warped slabs was able to match this geometry. The existing slab thickness was deemed suitable for the traffic levels on the ramp, and therefore the existing 230 mm (9 in.) pavement was reconstructed with JPPS of the same thickness.

High early strength cast-in-place concrete was selected for the isolated slab reconstruction of the left lane of the ramp due to the flexibility in accommodating varying quantities during reconstruction. While all of the slabs that were replaced were identified in the initial project plans, additional portions of the left lane could have been added if necessary during the construction process. While JPPS would have required new panels to be fabricated for these areas, cast-in-place provided the potential to add them on an “as needed” basis. The high-early strength concrete was required in order to open the pavement to traffic after each nightly closure of the ramp.

4.3. Traffic Management

Due to extremely high traffic volumes at the project location, traffic management was a critical component of this project. Precast pavement provided a solution that ensured all lanes of the mainline pavement and ramp would be open to traffic during peak travel times. To make the construction operation as “invisible” as possible to the travelling public during normal daytime operation, the contractor utilized temporary traffic control measures and carefully planned access to the work zone. Self mobilizing equipment that could be staged nearby but off-site was utilized for all pavement removal and installation. The on-site construction crew size was kept to a minimum, and advance preparation was utilized as much as possible for items such as sawcutting the existing pavement, drilling holes, etc. Prior to beginning actual construction, the contractor practiced their traffic control and mobilization operation in the nights leading up to the start of construction.

For the mainline pavement, the contractor was permitted to close two lanes at 9 pm each night in order to begin equipment mobilization. At 10 pm the contractor could close a third lane and begin removal of pavement. The third lane provided a one-lane buffer between live traffic and the dropoff where pavement was being removed. The third lane also provided a staging area for trucks bringing precast panels to the site and provided additional room for maneuvering panels as they were removed from the trucks.

For the ramp reconstruction, a full closure of the ramp was permitted in order to provide adequate area for staging the installation. Although construction could have been completed with a single-lane closure, the lack of a one-lane buffer between traffic and the edge drop-off during pavement removal would have required a more substantial barrier.

4.4. Design Features

For the mainline PPCP pavement, the precast panel dimensions were selected to optimize fabrication, transportation, and installation, while also considering geometric constraints. A primary geometric constraint was the crowned cross slope between the two inside lanes, set at approximately 1.5 and 2 percent cross-slope in opposing directions. To achieve this crowned cross-section, separate 3.7-m (12-ft) wide panels were used for each lane and set to the proper cross-slope on either side of the crown. The two outside lanes were reconstructed with a single precast panel, 8.2 m (27 ft) in length (perpendicular to the direction of traffic). A panel width of 3 m (10 ft) (parallel to the direction of traffic) was specified to minimize the number of precast panels to fabricate and install. A total of 306 panels were required for the project.

Beneath the PPCP, a fine-graded aggregate base was specified for the 6-mm (1/4-inch) “level-up” layer beneath the inside three lanes, and 57 mm (2 1/4 inches) of granular material was used to build up the base beneath the outside lane, which was originally 280 mm (11 in.) thick. The base materials were graded by hand using a straightedge to ensure the top surface was at the appropriate elevation and cross-slope.

The post-tensioned slab lengths were limited to a length of approximately 49 m (160 ft) to minimize expansion joint movement, such that a plain dowelled expansion joint detail could be utilized. Final slab lengths varied from 30 m (100 ft) up to 49 m (160 ft) in order to match the project limits, resulting in up to 16 precast panels per post-tensioned slab. Because de-icing salts are used on this section of pavement, epoxy was applied to the mating vertical faces of the keyed panels prior to joining, and all post-tensioning tendons (strands and bars) were epoxy-coated.

For the JPPS on the connector ramp, a proprietary precast pavement system was selected by the contractor. An off-site trial installation of this system was required in order to validate the features and constructability of the system prior to beginning construction on site. The system selected by the contractor consisted of dowelled joints between panels, with dowel slots cast into the bottom of the panels to receive dowels from adjoining panels, similar to that shown in Figure 4. A precision grading device was used to grade a fine-graded bedding material to the proper slope and elevation prior to installing the panels. After the panels were installed, the dowel slots were grouted to encase the dowel bars, and grout was also pumped beneath the panels to provide full support.

The JPPS featured 4.9 m (16 ft) long precast panels to replace the existing pavement which had 18.7 m (61.5 ft) joint spacing. Each panel spanned the full 3.7 m (12 ft) lane width. Tie-bars drilled and epoxied into the pavement remaining in the left lane were used to tie the two lanes together.

4.5. Construction Features

Saw-cutting of the existing pavement for removal was completed several nights in advance of PCPS installation for both the mainline and ramp. Each night, the existing pavement was lifted out and removed from the site for recycling, the base material was placed, compacted, and screeded the proper elevation and cross-slope, and the precast panels were set over the prepared base. For the PPCP, a woven geotextile fabric was placed over the prepared base to serve as a bond-breaker/friction reducing membrane. The precast panels for each night’s installation were hauled to the project site nightly and installed directly from the haul truck. JPPS panels were typically stockpiled near the project site and hauled from the storage area as needed.

For the PPCP section, high-strength threaded bar tendons were used for temporary post-tensioning of each section of panels. The bars provided the necessary clamping force for the joint epoxy, and provided temporary post-tensioning force for the pavement to be opened to traffic each day. The two bars for each panel were coupled to the bars from the panels already in place, and tensioned simultaneously after the installation of every two panels. Any gap remaining between the end of each night's installation and the existing pavement was filled with a temporary precast panel. After the post-tensioning strands for each section (between joint panels) were installed and stressed, the stressing pockets where filled with a rapid-strength-gain concrete patch material. The post-tensioning tendons were then grouted, followed by grouting beneath the slabs using ports cast into each of the precast panels. Tie-bar slots were cut into the existing pavement at the beginning of the section to receive tie-bars from the first precast panel, and closure pours were required at the end of the section to transition back to the existing pavement. After completion of installation of all panels, the pavement was diamond ground for smoothness, and the expansion joints and longitudinal joints between lanes were sealed.

For the JPPS section, after an adequate number of panels had been installed, the dowel slots were grouted, encasing the dowels in the slots and filling the joint between the panel and adjacent panels and existing pavement around the perimeter of each panel. During a separate operation, grout was pumped beneath the panels to provide full support. Gaskets attached to the bottom of the panels prior to installation served to contain the grout around the perimeter of the panels and within the dowel slots.

Figure 8 shows photos of panel fabrication, existing pavement removal, base construction, panel installation, and post-tensioning of the bar tendons for the PPCP portion of the project, and Figure 9 shows a similar sequence for the JPPS portion of the project. A typical production rate of 10 to 12 precast panels per night was achieved for both the PPCP and JPPS portions of the project. This equated to up to 37 lane-meters (120 lane-ft) or 134 m2 (160 SY) per night for the PPCP portion and up to 58.5 lane-meters (192 lane-ft) or 214 m2 (256 SY) per night for the JPPS portion. By comparison, the production rate for the high-early strength cast-in-place pavement on the connector ramp was only 12.2 lane-meters (40 lane-ft) or 44.3 m2 (53 SY) per night. The lower productivity was attributed to the 2-3 hours of cure time required for the cast in place concrete prior to opening to traffic as well as the wider spacing of the repairs along the ramp.

Following completion of both the mainline and connector ramp pavement reconstruction, all lanes were diamond ground for rideability. While ride quality for both precast pavement techniques was adequate for "temporary" opening to traffic each day, diamond grinding was necessary to meet VDOT ride quality specifications for high speed facilities such as these.

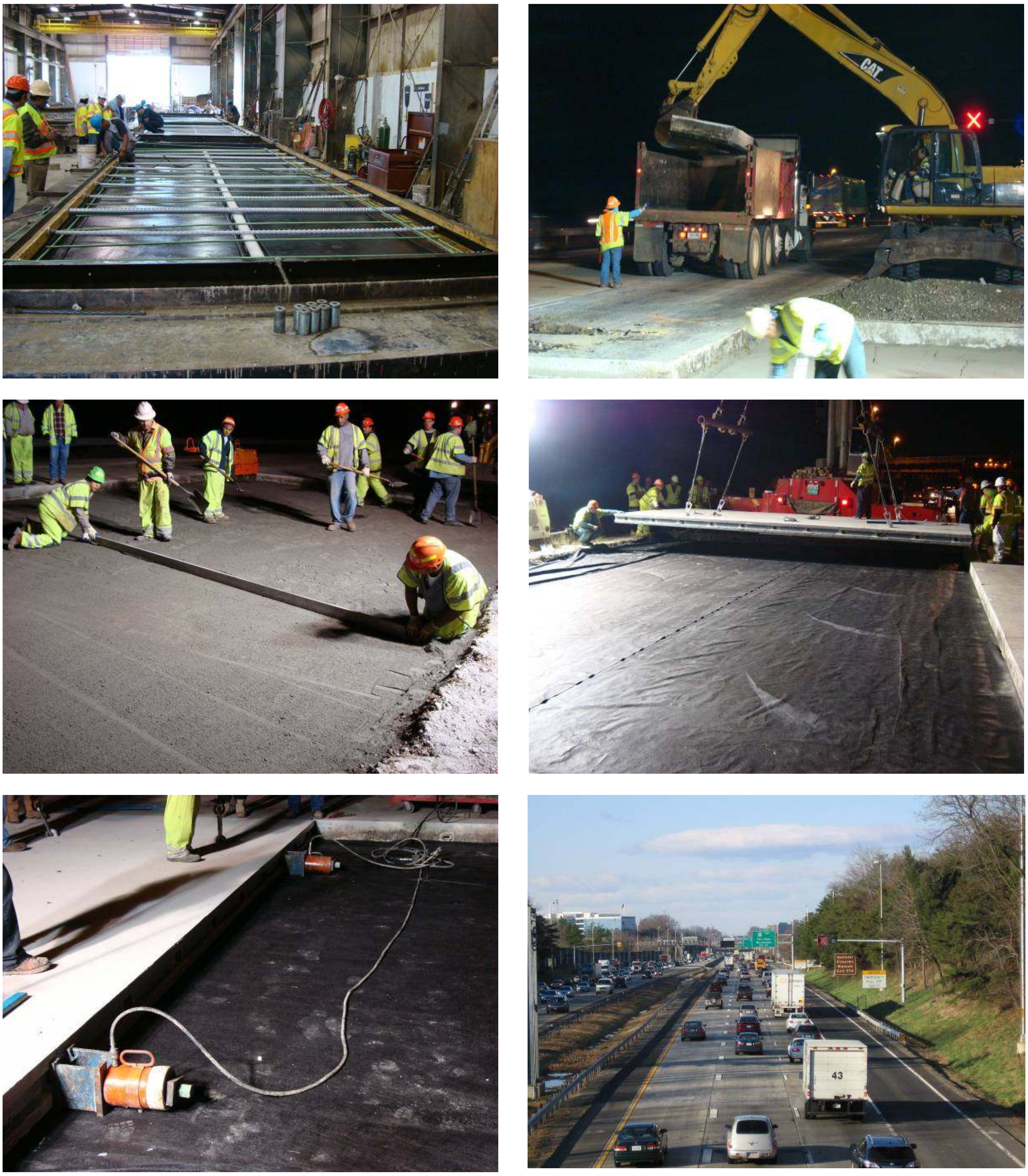

FIGURE 8 Virginia DOT PPCP Project (from top left: precast panel fabrication bed, removal of existing pavement for recycling, base preparation, panel installation, post-tensioning of bar tendons, and completed project open to traffic).

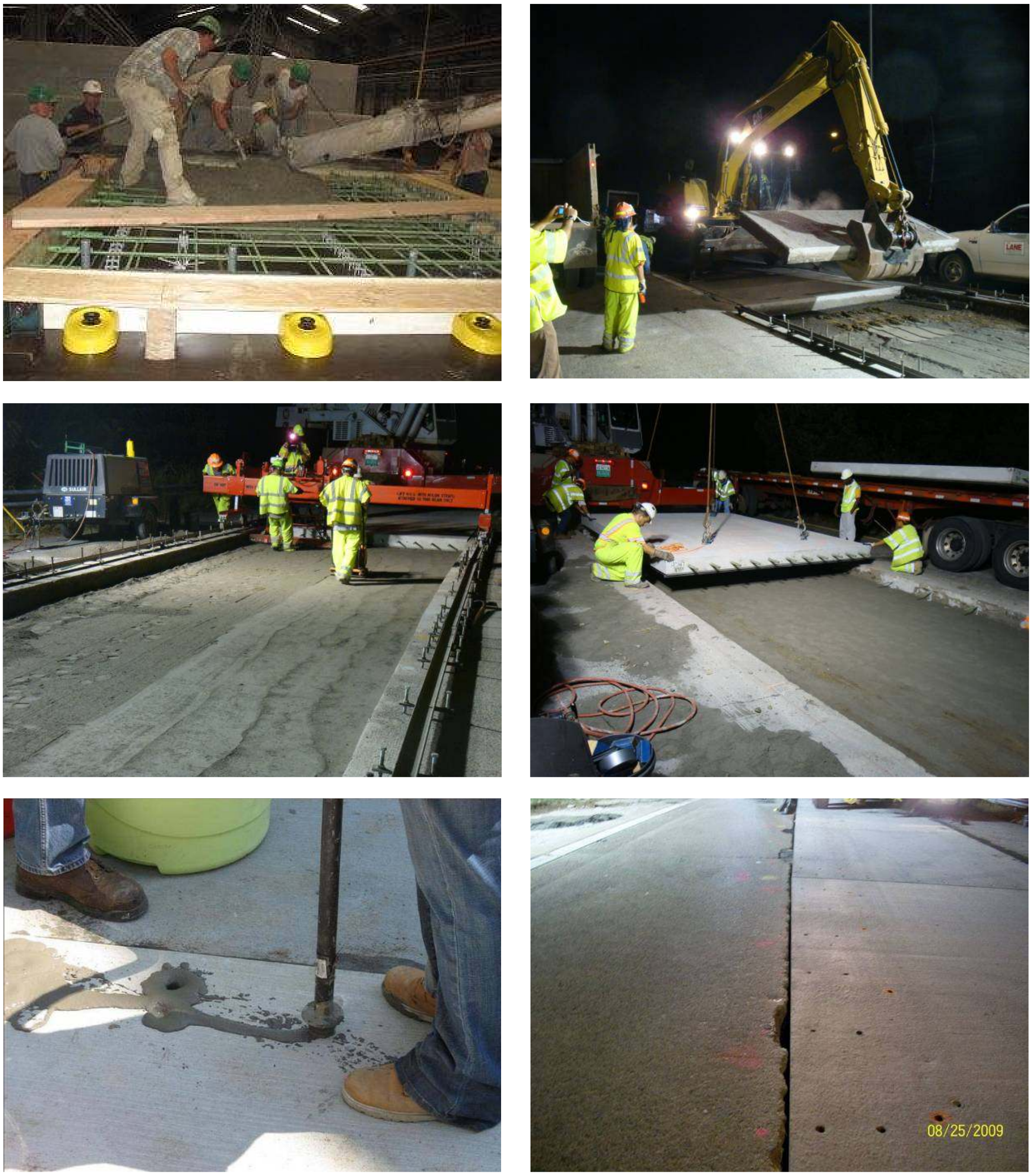

FIGURE 9 JPPS installation on connector ramp (from top left: precast panel fabrication, removal of existing pavement for recycling, grading of base, panel installation, grouting of dowel slots/underslab, and installed panels next to existing left lane).

CONCLUSION

Precast concrete pavement systems have been demonstrated to provide a unique solution for rapid pavement reconstruction in the U.S. These techniques provide agencies a tool for reconstructing existing pavement with a highly durable new pavement with minimal impact to the travelling public. Through the projects constructed to date, including the Virginia project discussed above, the benefits of precast pavement for traffic management in urban areas are clear. Moreover, as realized through reducing the impact of construction on traffic and better utilization of materials in both the fabrication and installation operations, PCPS offer a number of sustainability benefits for pavement reconstruction and rehabilitation.

As highway agencies are continually pressed to find more sustainable solutions for reconstruction of a deteriorating pavement infrastructure, while minimizing disruption to the motoring public, it is anticipated that PCPS technology will become a widely utilized alternative to cast-in-place concrete. The precast concrete industry in the U.S. is fully capable of supplying this new market for precast products, and with the support of contractors and agencies that have utilized PCPS for repair and rehabilitation of high-volume roadways, it will quickly become a more commonly used solution.

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