NATIONAL PRECAST CONCRETE ASSOCIATION

Manual for
Jointed Precast Concrete Pavement

3rd Edition

National Precast Concrete Association

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Manual for Jointed Precast Concrete Pavement
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Chapter 1: **INTRODUCTION**

Figure 1-1. Photo of deteriorated concrete pavement.

Figure 1-2. Precast pavement repair underway on heavily trafficked Interstate H1 in Hawaii.

Pavement Repair: A Worldwide Necessity

The need for rapid repair and replacement of concrete pavement is evident in every large metropolitan area in the U.S., Canada and other parts of the world. Many aging pavements are exhibiting alarming deterioration as the volume of traffic they carry increases to an all-time high (Figure 1-1). In many locations, pavements must be repaired under traffic because traffic cannot be diverted for any significant length of time (Figure 1-2). Right-of-way for building new roadways is scarce and difficult to obtain, and the availability of viable detours is often non-existent. As a result, agencies are forced to rehabilitate roadways with rapid-repair materials that can be installed effectively without adversely affecting traffic flow.

Making matters worse, money for repair and replacement is limited. Agencies are often forced to choose the cheapest repair material available, even though it may not last for more than a few years. Over time, agencies must repair newly deteriorated areas and replace previous repairs that have failed.

A more sustainable approach is to select durable materials that will last for decades, even if the initial costs are slightly higher. Precast concrete pavement systems are durable and reliable alternatives to traditional rapid-repair techniques for concrete pavements.

What Is a Precast Concrete Pavement System?

A precast concrete pavement (PCP) system is a set of specific panel details, materials and associated installation methods used in concert to rapidly create a fully functioning concrete pavement. High-quality materials are used in a carefully controlled manufacturing process to produce durable precast panels. Effective and rapid methods of placing, bedding and connecting those panels in the roadway complete the system, creating a concrete pavement.

Well-designed PCP systems enable rapid replacement of concrete pavement with minimal impact on traffic flow and provide pavement that offers the potential for decades of service. These attributes are especially valuable in meeting pavement maintenance and repair needs in heavily trafficked areas.

Figure 1-3. String line controlled slip-form paver approaching dowel basket (note vibrators for consolidation).

Figure 1-4. Plastic concrete extruded to correct grade and cross-slope behind slip-form paver.

Similarities to Cast-In-Place Systems

Precast paving is a process where a precast panel or series of panels is installed on a properly prepared foundation. The panel or series of panels must be fully supported and properly connected to perform as a completely functional concrete pavement system. Although the PCP construction process differs from conventional concrete paving, it must still provide key features of successful cast-in-place paving operations to produce a finished pavement that behaves and performs comparably to good cast-in-place concrete pavement. It is beneficial to recognize those features to better understand their importance in PCP systems.

Consider the slip-form paver system shown in Figures 1-3 and 1.4. Low-slump concrete is extruded to the correct grade and cross slope over a carefully prepared base. The paver consolidates the plastic concrete, ensuring that full contact with and support by the base is achieved. At the same time, placement and consolidation processes allow the concrete to fully encase load transfer dowels (Figure 1-3).

Finally, the paver uses pre-placed string lines or laser-based stringless paving systems to control the concrete extrusion and screeding and to produce a pavement surface with the correct grade and cross slope (Figure 1-4).

The four key elements of the slip-form paving process are:

1. Providing full contact between the concrete pavement and the properly prepared base.
2. Completely encasing the load transfer dowels at transverse joints.
3. Placing extruded concrete to the correct elevation and grade.
4. Producing a smooth pavement surface with the correct cross slope.

These same key elements must be achieved or developed in the precast paving process to ensure comparable pavement behavior and performance. In other words, the results of the precast pavement construction process must emulate those of the slip-form pavement construction process to achieve a comparable finished product. The primary differences are that rigid precast panels, rather than plastic concrete materials, are used in the construction process and that the same key elements must be achievable in short work windows (typically overnight work windows of eight hours or less) to be viable for rapid repairs. A well-developed jointed precast concrete pavement (JPrCP) system will offer this capability.

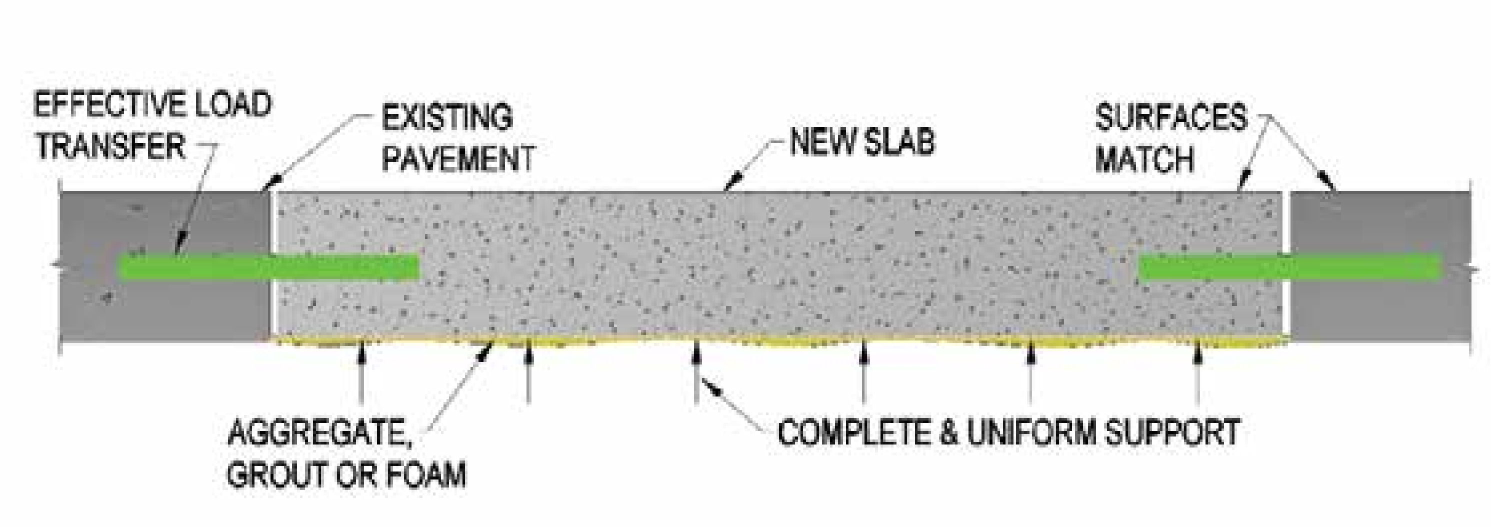

Figure 1-5. Schematic showing key design and construction elements in a jointed precast concrete pavement panel installation.

Precast Concrete Pavement Systems

As stated previously, a PCP system is a set of specific panel details, materials and associated installation methods used in concert to create a fully functional concrete pavement. To be effective and to emulate cast-in-place paving, the installation of jointed PCP systems must include the four basic requirements listed in Table 1-1. Note that these four requirements correspond directly with the four key elements of slip-form paving described previously.

Table 1-1. The Four Basic Requirements of Jointed Precast Concrete Pavement (JPrCP)

1. Place or adjust panels to the correct grade.
2. Install bedding material to uniformly support panels.
3. Establish effective load transfer between panels.
4. Provide a geometrically correct pavement surface (by grinding, using nonplanar panels or other means).

These four basic requirements are shown schematically in Figure 1-5, which is a drawing of a single, generic precast concrete panel installed in an existing pavement. Not shown in Figure 1-5 is a specific mechanism or technique for positioning the precast panels at the correct vertical grade to "generally" match adjacent pavement surfaces. Bedding material – shown in yellow – is introduced, by various means, as an interlayer of grout, fine aggregate, polyurethane foam or a combination of these materials. Efficient joint load transfer, typically required for pavements subjected to a significant volume of heavy traffic loads, must be achieved with mechanical devices such as dowels because the formed edges of precast concrete panels provide no aggregate interlock load transfer. Load transfer dowels, shown spanning both transverse joints in Figure 1-5, must be installed in grout-filled slots either fabricated in the precast concrete panels or saw cut into the existing pavement. Finally, the top surface of the panel must be fabricated or diamond-ground to conform to and reasonably match the surfaces of adjacent panels or pavement.

These basics are referenced repeatedly throughout this manual as the many different aspects of precast paving – including system approval – are presented.

Every proposed JPrCP system should be evaluated in terms of how well it achieves the four basic requirements listed in Table 1-1. Successful JPrCP systems already in use accomplish these basic criteria differently and all provide a pavement structure equal to (and sometimes better than) conventional cast-in- place concrete placed in similar, abbreviated work windows. Details of these systems are presented in the following chapters so designers, fabricators and contractors may determine which, if any, of these systems best meet their needs.

It is possible that new systems will be developed as the industry grasps the challenges and advantages associated with precast pavement. However, a system is more than a sketch or a set of procedures shown on a piece of paper and no system should be considered for use until it has been demonstrated to meet the four basic requirements listed in Table 1-1.

General Categories of Precast Pavement Systems

PCP systems can generally be grouped into two broad families: precast prestressed concrete pavement (PPCP) and jointed precast concrete pavement (JPrCP). While this manual deals primarily with the latter, both families are briefly described below.

Precast Prestressed Concrete Pavement (PPCP)

Typical Characteristics of PPCP

PPCP can be characterized as precast pavement built by post-tensioning a series of transversely prestressed precast panels together to create much longer pavement slabs (typically 150 to 250 feet in length) that are effectively "jointless" due to the effects of post-tensioning. The resulting assembly is a pavement slab that is prestressed in two directions. Prestressing forces enhance the structural characteristics of the slab in both directions, counteract load- and temperature-related stresses, and keep joints within the slabs tightly closed.

Figure 1-6 illustrates three different configurations commonly used for PPCP systems. The first two configurations feature post-tensioning from the top of the pavement through surface slots. Provision for thermal expansion is provided by doweled (for load transfer) expansion joints or expansion dams sandwiched between two precast slabs, at least one of which is included in the PPCP slab arrangement. In the third configuration, post-tensioning is accomplished through the vertical faces at the ends of the slab. A doweled expansion joint panel – a gap panel not included in the post-tensioned assembly of panels – is installed between the post-tensioned slab and the existing pavement or the next PPCP slab. In all cases, the panels are constructed on polyethylene sheeting or a similar low-friction surface to facilitate slab movement during the post-tensioning operation. While a bedding material may be placed and graded on the foundation to provide reasonably uniform support prior to panel placement, injectable void-filling materials (e.g., grout, urethane, etc.) are not always used in the construction process.

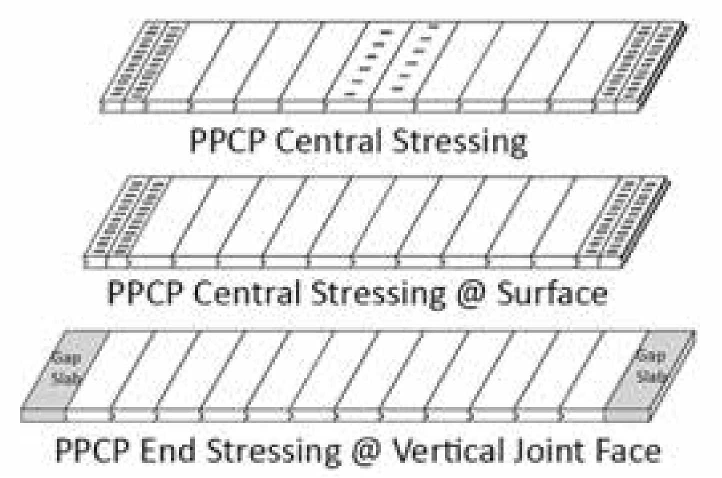

Figure 1-6. Schematics showing alternate PPCP design and construction options.

Principal Benefits and Advantages of PPCP

The primary benefit of PPCP is that prestressing forces increase the structural capacity of the panels, allowing panel design thickness to be reduced and providing for safe handling of longer panels. This results in savings in concrete material costs and is especially beneficial in situations where thin pavements must be used due to high underlying subbase layers or overhead clearance issues. Additionally, prestressing also helps compensate for nonuniformities in support which may be present prior to the installation of cement-based grout or other bedding material used to fill small voids under the slabs.

Another benefit of PPCP is that field-applied prestressing forces act to keep joints between precast panels tightly closed, essentially converting each assembly of panels into a single "jointless" slab. When appropriate design and

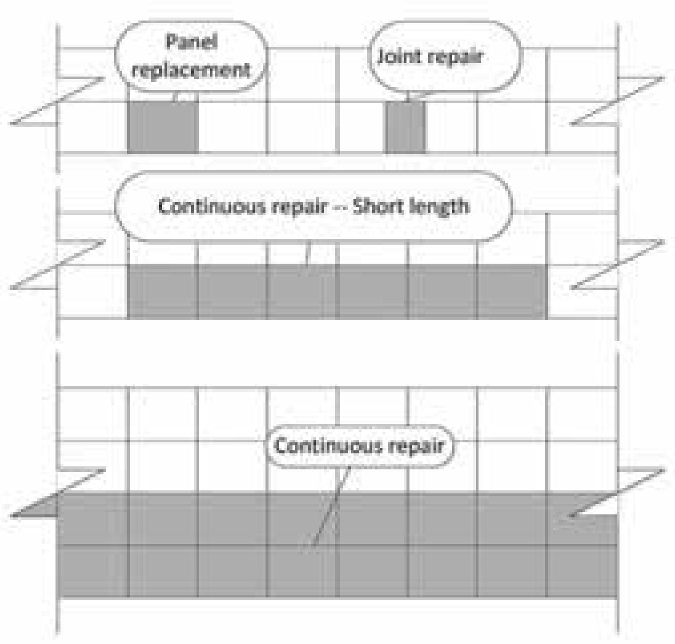

Figure 1-7. Illustrations of the three most common categories of application for PCP systems. Single panel and joint replacement panels are typically not post-tensioned.

construction features are provided to produce good vertical alignment between precast panels (e.g., "tongue-and-groove" systems), the reduced number of effective joints can result in improved ride quality over each assembled slab length. In addition, prestressing forces applied at the plant and in the field typically hold tight any cracks that may develop during or after installation, preventing their deterioration under typical traffic loads.

Suitable Applications for Post-Tensioned PPCP

The most common applications for post-tensioned PPCP systems can be grouped into two categories: short-length continuous repairs (less than 150 feet in length, typically within a single lane) and continuous repairs (greater than 150 feet in length and in one or more contiguous lanes), as illustrated in Figure 1-7. While some forms of PPCP can be used in any of these applications, PPCP is best suited for longer, continuous repairs where the full structural and ride quality benefits of post-tensioning can be realized. Much more information on the design, fabrication, installation and efficiency of PPCP may be found in PCI (2012) and Tayabji, et al (2013).

Jointed Precast Concrete Pavement (JPrCP)

Typical Characteristics of JPrCP

JPrCP is designed to expand and contract at every panel joint; that is, panels are not post-tensioned together and each panel expands and contracts independently. Transverse joint load transfer between precast panels and other precast panels or between precast panels and existing pavement is achieved with standard load transfer dowels.

JPrCP panels are typically sized to be one lane wide (typically about 12 feet) and about 16 feet or less in length. Panel thickness varies with the application. For example, intermittent repair (patching) panels are typically specified to approximately match the thickness of the surrounding pavement. JPrCP panels placed in continuous applications may be equivalent in thickness or thicker than the adjacent pavement, as dictated by design.

Precast panels in different lanes are typically tied across the longitudinal joints, although short runs of panels (less than 45 feet in length) are often not tied to adjacent lanes. Some designers choose to isolate long stretches of new precast lanes from adjacent existing lanes.

JPrCP is designed to function similarly to jointed cast- in-place pavement, so no structural reinforcing is required for service loads. However, precast panels do need to be reinforced for handling and transportation conditions. A minimum amount of conventional reinforcing (typically taken as the amount required by ACI 318 for temperature and shrinkage requirements in structures) is used. Some system manufacturers use additional reinforcing (often double the previously mentioned ACI requirements) placed in two layers, as shown in Figure 1-8, to provide additional resistance to temporary stresses that may be induced when traffic is allowed to use grade-supported panels before they are fully supported by grout. This is discussed in more detail in later chapters.

Figure 1-8. Two layers of reinforcing steel in each direction in a JPrCP fabrication.

Figure 1-9. Photo of JPrCP fabrication in a prestressing bed.

Alternatively, JPrCP panels can be reinforced by prestressing, as shown in Figure 1-9. These panels can be produced very efficiently when several panels are fabricated and cast in a single, long-line prestressing bed. Prestressing may also be used to reduce panel thickness, making it the reinforcing method of choice when thinner planar panels are required.

Benefits and Advantages of JPrCP

One major benefit of JPrCP is that the structural design is generally accomplished using the same thickness design procedures used for jointed cast-in-place concrete pavements. Since these procedures are well understood by concrete pavement engineers across the world, the designs can be performed with confidence and are easily verified. The design of panel sizes (transverse joint spacing) and load transfer systems is essentially the same for both cast-in-place and JPrCP systems.

Another major benefit of JPrCP is that the panels are more easily fabricated than are PPCP panels because there are no post-tensioning blockouts and prestressing ducts, which must be placed with great precision to ensure constructability. Additionally, JPrCP panels are often more easily transported due to their smaller size. Because JPrCP panels are typically sized and jointed to match the surrounding pavement, they expand and contract and generally behave similarly to the surrounding pre-existing concrete panels; thus, they are easily integrated with, rather than isolated from, the surrounding pavement. In addition, JPrCP is useful in a wide range of applications, as described below.

Suitable Applications for JPrCP

The most common applications for PCP systems can be grouped into three categories (as shown in Figure 1-7): intermittent repairs and panel replacements, short-length continuous repairs (less than 150 feet in length, typically within a single lane) and continuous repairs (greater than 150 feet in length and in one or more contiguous lanes). JPrCP is the best option for intermittent repair applications, but is also highly useful and widely used in continuous repairs of all lengths. JPrCP systems have also been successfully used in intersection and plaza replacements, airfield applications, bridge approach panels and almost every other application where jointed cast-in-place pavement is used. These applications are discussed further in Chapter 3.

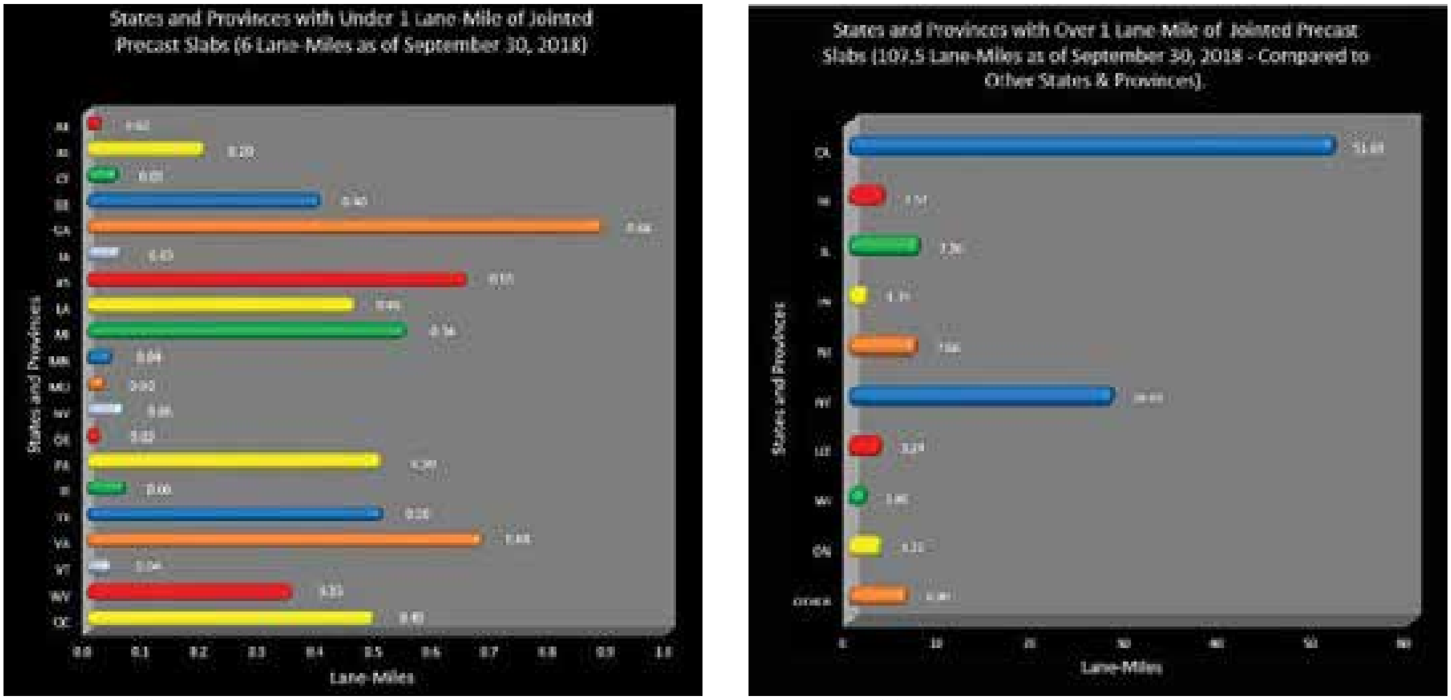

Figure 1-10 (a)

Figure 1-10 (b)

Figure 1-10. Precast pavement use in the United States and Canada as of Sept. 30, 2018. Figure 1-10 (a) shows states and provinces with installations totaling less than one lane-mile. Figure 1-10 (b) shows states with installations totaling more than one lane-mile compared to usage in states and provinces in Figure 1-10 (a).

Experience and Performance Expectations

Fabrication and Installation Experience to Date

More than 113 lane-miles (approximately 185 projects and over 53,000 panels) of JPrCP have been installed in 26 states and two Canadian provinces since the first major JPrCP project was installed in 2001 at the Tappan Zee Bridge Toll Plaza in Tarrytown, N.Y., as illustrated in Figures 1-10 (a) and 1-10 (b). The vast majority of these slabs were installed in 8-hour (or shorter) work windows and at night, proving that replacing existing distressed concrete pavement with JPrCP is an effective method for rapidly repairing concrete pavement. On some projects, work windows were limited to five hours and workspace was restricted to one lane and an adjacent shoulder.

The number of projects in so many states is a strong indicator the technology associated with JPrCP has been successfully transferred to more than half of the states in the U.S. It is important to notice most of the lane-miles were installed in eight states and one Canadian province, a likely indication that this technology is deemed valuable enough (in those states) to be used repetitively on many projects. Significant use in at least nine other states and one Canadian province suggests those states may be on track for similar repetitive use.

Applications to date include:

- Intermittent repair (patching)
- Continuous installations on mainlines and ramps
- Intersections
- Underpasses at bridges
- Bridge approach slabs
- City streets
- Bus pads
- Airfield runways, taxiways and aprons
- Removable/replaceable pavement (to allow access to underlying utilities)

Figure 1-11. Falling weight deflectometer.

Figure 1-12. Heavy vehicle simulator testing jointed precast pavement panels in Fontana, Calif.

This wide range of applications in so many states demonstrates the versatility and constructability of JPrCP.

More than 20 fabricators in 28 states and provinces have been involved in successfully manufacturing and shipping JPrCP panels of various sizes and shapes (including rectangular, trapezoidal and nonplanar panels of various sizes) for the projects described above. Precast panels have been fabricated within specified tolerances and successfully installed on their respective projects in all locations, indicating that this technology can be transferred to precasters anywhere in North America.

Early contractor fears (including being unable to complete repairs due to incorrectly produced panels, potential delivery problems over long distances and weather-related construction delays) have seldom been experienced. In instances where project delays occurred, they were minimal.

Over 100 different contractors have been involved on the JPrCP projects constructed to date, and most have readily embraced the technology and met or exceeded all specification requirements. This is a good indication that, while this method of rapid repair is very different from conventional concrete pavement repair and construction, it is readily implemented and widely accepted.

On a few projects, some hairline cracks have been observed during or shortly after installation (in fewer than 2% of all installed panels). While most cracks have been caused by incorrect installation procedures that resulted in nonuniform panel support, a few were the result of design-related errors (as discussed in later chapters of this manual). However, because the cracks were hairline and most were arrested at the top layer of reinforcing (or were full-depth cracks that were held tight by the relatively high reinforcing steel content), replacement of these panels has not been necessary. This reveals that JPrCP design principles (presented in Chapter 4) and generally accepted fabrication and installation techniques (discussed in Chapters 7, 8 and 9) are highly effective.

Performance Indicators

Falling weight deflectometer (FWD) testing, as shown in Figure 1-11, has been performed on numerous projects (beginning with the first Tappan Zee Bridge project in 2001), not only at time of installation, but also after a number of years of use. Deflection measurements across transverse joints have been used to compute load transfer efficiency (LTE) values, and they have been found to fall well above the generally accepted minimum acceptable level of 70% in all but a few isolated cases.

A significant accelerated fatigue test on a series of Super-Slab JPrCP panels was performed in 2005-2006 in Fontana, Calif., using a heavy vehicle simulator, as shown in Figure 1-12. The conclusion drawn from that test was that it is “reasonable to expect long life from adequately designed and constructed precast concrete pavements.” Specifically, it was estimated that the service life of the JPrCP system used for that test – 8-inch grade-supported panels placed on a 4-inch lean concrete base – was 140 to 240 million 18-kip equivalent single-axle loads (ESALs), providing an estimated service life of up to 37 years on a portion of Interstate 15 in San Bernardino County, Calif. (Kohler et al., 2007).

Testing and evaluation was more recently performed on 10 of the JPrCP projects evaluated in the Strategic Highway Research Project R05 Report (Tayabji, et al., 2013). The report states, in part, that “The experience to date with use of PCPs in the United States indicates that different PCP systems can be fabricated and installed successfully in most regions of the country, given the wide range of projects constructed to date using different precasters and different contractors.”

Topics Covered in This Manual

The foregoing description of precast pavement systems, the benefits associated with their use and experience with fabrication, installation and performance to date is a basis for giving more serious consideration to specific details that will play a role in successful implementation of PCP. This manual includes the following topics that may be beneficial to agencies, owners, program managers, designers, fabricators and contractors:

Chapter 2 – Criteria and Considerations for Using Precast Pavement Systems

Chapter 3 – Applications for Jointed Precast Pavement Systems

Chapter 4 – Design of Jointed Precast Concrete Pavement Systems

Chapter 5 – Developing Plans, Specifications and Cost Estimates

Chapter 6 – Shop Drawings and Other Submittals

Chapter 7 – Fabrication of Precast Pavement Panels

Chapter 8 – Pre-Installation Procedures Common to All Systems

Chapter 9 – System-Specific Installation Procedures

Chapter 10 – Organizing and Managing a Project for a Quality Installation

Chapter 11 – After Panel Installation – The Finishing Touches

Chapter 12 – Precast Concrete Pavement Maintenance Requirements

Chapter 13 – Future Applications for Precast Concrete Pavement

Summary

The need for viable and durable methods of rapid repair and replacement of heavily traveled concrete pavement is staggering. JPrCP has emerged as a technology that can meet that need.

A PCP system is set of specific panel details, materials and associated installation methods used in concert to rapidly create a fully functioning, long-life concrete pavement. To qualify as a legitimate, fully functioning system, it must be demonstrated that any given JPrCP system meets the following four basic requirements: 1) it must provide for placing or adjusting panels to the correct grade; 2) it must provide for the uniform support of installed panels; 3) it must establish effective load transfer between panels; and 4) it must provide geometrically correct and smooth pavement surfaces.

A few precast pavement systems have been used to install more than 113 lane-miles of JPrCP in at least 28 states and provinces on more than 185 different precast projects, proving that precast pavement technology is successful and transferrable. Full-scale testing and evaluation indicates that precast pavement offers the potential for many years of service under heavy traffic loading conditions.

Chapter 2:
CRITERIA AND CONSIDERATIONS FOR USING PRECAST PAVEMENT SYSTEMS
A GUIDE FOR DESIGNERS, AGENCIES AND OWNERS

Designers and project developers should consider many factors in identifying feasible candidate projects for the use of precast concrete pavement (PCP) systems in the repair or reconstruction of concrete pavement. The primary criteria that drive the use of PCP systems include the necessity for short work windows (typically overnight) due to high traffic volumes and the desire for a durable, high-quality product that will provide long-term pavement performance in the area to be repaired.

However, many other factors may impact the design, fabrication and installation of the precast panels, which may influence the decision to use PCP. These factors include: available work space on or adjacent to the pavement; vertical clearance restrictions at the project site; site access issues for large or heavy equipment and panel haul trucks; availability of certified, qualified and properly equipped precast concrete plants; existing pavement condition (including the nature, extent and severity of distress present); the need for increased structural capacity; accommodation of existing utilities; pavement geometry and planarity requirements; and more.

The information provided in this chapter is intended to aid project developers and designers in determining the feasibility of using PCP systems on any given project and in identifying the specific factors that need to be considered and addressed to ensure that panels are installed effectively.

Principal Criteria for Using Precast Pavement

Short Work Windows and/or Heavy Traffic

When travel lane reconstruction or repairs can be accomplished during lengthy closures, many options are available for constructing durable repairs. In these cases, PCP systems may not be the most productive and cost-effective option. However, as work windows become shorter, fewer suitable repair options are available. When work windows shrink to eight hours or less (e.g., because of the need to maintain traffic flow capacity on heavily traveled roads or other essential routes – see Figure 2-1), repair options become much more limited. Work window activities typically include setting up (and removing) traffic control/protection devices, locating and marking the repair area(s), sawing and removing deteriorated concrete, preparing the repair area(s) (including performing foundation repairs and installing dowels and tie bars), placing or installing the repair product and allowing the product to come to a strength or condition that will support traffic (e.g., concrete curing).

Figure 2-1. Example of a heavily trafficked route that may be subject to short repair work windows.

The time required to achieve required strength for opening to traffic limits the usefulness of most conventional concrete repair products. It may take several hours to accomplish all other work window activities, leaving very little time for concrete curing and strength gain, particularly in cool weather or under adverse construction conditions. Adjustments can be made to traditional concrete mixtures (e.g., by using high cement content, set-accelerating admixtures and/or warmed mixture components) and specialty materials that are also available for achieving rapid strength gain (e.g., calcium aluminate cements, rapid-set cements, various polymer cements and epoxy-based materials, and other proprietary materials). While these approaches have been used successfully on one or more projects, many are prone to premature cracking and durability problems (Janssen and Snyder, 1994). Additionally, the rapid strength gain characteristics of some of these materials make them very difficult to handle and use under certain field conditions.

On the other hand, PCP units can be fabricated with high-quality materials and cured under controlled conditions, resulting in durable repair products that can be placed in short work windows. This allows the pavement to be reopened to traffic almost immediately,[1] sometimes with significantly higher production rates than for typical cast-in-place operations and less chance of delayed opening due to typical repair construction and curing problems. Hossain and Ozyildirim (2012) documented precast panel installation rates that were more than double the rate of cast-in-place repair installations in a seven-hour work window on a Virginia demonstration project.

While PCP systems offer the best option for reliably constructing durable concrete pavement repairs during relatively short work shifts, every effort should be made to maximize the length and effectiveness of project work windows. These factors will drive installation rates and unit costs for most products, including PCP systems (with higher rates and lower unit costs resulting from longer, more effective work windows). Typical installation rates and unit costs are discussed in Chapter 5.

Long-Term Durability Required

Assuming the use and production of durable materials at the precast plant, PCP systems offer the potential for service life that will match or exceed that of any cast-in-place pavement repair/replacement material. When the expected service life of the repaired pavement is relatively short, other less costly materials and repair techniques may be preferred. However, consideration should be given to the possibility that repair construction efforts may need to last longer than anticipated due to reallocations of resources or other factors. In addition, the use of long-life repairs may facilitate “incremental reconstruction,” where additional long-life repairs are placed adjacent to existing installations during future rehabilitation activities, effectively resulting in pavement reconstruction in stages. This concept is discussed in more detail under “Addable Precast Concrete Pavement” in Chapter 13 and in Tayabji et al., (2013).

Project Suitability: Other Factors for Consideration

While work window duration and durability requirements may drive design and construction decisions toward the use of precast pavement systems, there are many additional factors that must be considered in both the decision-making process and in project planning and design. These considerations can be grouped into two major categories: general constructability and site-specific factors impacting design and construction.

General Constructability Considerations

Constructability may be a concern when construction must take place in difficult locations, such as on ramps and other narrow facilities with only one or two travel lanes and limited shoulder space, the inner lanes of multi-lane facilities, beneath bridges and overpasses with limited shoulder space, or inside of tunnels (Tayabji et al., 2013). In addition, providing access to the site for large, heavy construction equipment and for the transport of precast panels can require special permitting and even temporary roadway and traffic control modifications along the access route, particularly in urban areas. The following sections discuss these considerations in more detail.

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[1] Grade-supported, urethane-supported and similar systems can be opened to traffic within minutes of satisfactory placement until the next closure, at which time bedding grout (if necessary) and hardware grout around dowels and tie bars must be installed to complete the repair. Other support systems may require additional time to gain sufficient strength for opening to traffic.

Figure 2-2. Example use of two lanes to perform repairs in a single lane.

Figure 2-3. Example installation of PCP in a single-lane closure.

Balancing Work Space and Traffic Maintenance/Protection Requirements

PCP systems are installed most efficiently (i.e., with the highest installation rates) when an adjacent lane is available for delivering the precast panels to the work site and for the panel lift equipment. In this manner, a single-lane repair requires a minimum two-lane closure (or one lane plus a shoulder), and three lanes (or two lanes and an adjacent shoulder) are required for placing repairs in two lanes, etc. Figure 2-2 shows the installation of precast panels using one outside lane and an existing 10-foot shoulder. Split-traffic configurations may be necessary for maintaining adequate traffic flow and worker safety when repairing the interior lanes of some multi-lane facilities.

Precast panels can also be installed using a single-lane closure while allowing some traffic use of at least one adjacent lane. Delivery trucks approach the installation site with traffic in the adjacent lane. Upon reaching the off-loading site, the traffic is stopped just long enough for the crane, which is set up in working lane, to remove the panel from the delivery truck in the adjacent lane – typically five minutes or less. The crane lifts the panel from the delivery truck and swings 90 degrees to install the panel in the prepared area. If the area has been prepared correctly for full grade support, as is discussed in detail in Chapter 9, the crane moves forward over the panel to the proper location for setting the next panel. This single-lane closure installation process can be seen in Figure 2-3.

Sometimes, it is necessary to remove existing pavement and install and deliver new panels within a single lane. This is the case with two-lane interstate pavement, where traffic must always be maintained in at least one of the two lanes. In this scenario, new panels must be delivered over recently placed (and un-grouted) panels. This process requires an accurately graded or finished bedding area (to support delivery and installation equipment, as discussed in Chapter 9), and will almost certainly require smaller panels and lighter installation equipment, both of which will reduce the overall installation rate and add to the project cost.

While single-lane closures can be used for successful precast panel installations, installation rates drop significantly when compared to what is possible with multi-lane closures. Therefore, when only one or two lanes exist in each direction, it may be preferable to close the lane(s) in one direction and manage traffic entirely on the lane(s) in the opposite direction, using pilot vehicles if necessary. Single-lane ramps are typically closed to traffic during panel installations.
In all of these cases, traffic plans will need to be carefully developed to ensure safe passage of vehicles and safety of construction workers.

Figure 2-4. Sources of potential vertical clearance issues during installation.

Figure 2-5. Example use of an excavator placing PCP panels beneath an overpass. Traffic is maintained on the lane to the right of the excavator.

Vertical Clearance Requirements

Typical PCP placement operations involve the use of a crane to pick the panels from the delivery vehicle and move them into position for placement. The required crane size varies with the weight of the panels being placed and the reach required to place them. Larger cranes require more space (width) to accommodate the crane stabilizing outriggers and longer pick distances typically require higher booms. While the presence of bridges and overpasses can present special construction challenges, it is important to identify and address other potential installation clearance restrictions, such as potential conflicts with overhead signs, lighting standards and power lines (Figure 2-4). It may be necessary to temporarily remove these conflicts or to use special installation equipment in these locations.

The installation of PCP systems beneath bridges and overpasses or within tunnels represents a good potential alternative to the placement of overlays that would reduce vehicle clearances after rehabilitation. However, these installations present special construction challenges because vertical height restrictions can provide very little room for panel handling and placement equipment. Contractors have successfully met these challenges on various projects by using loaders, excavators, fork trucks and similar low-clearance lift equipment, often in combination with smaller panel sizes, as shown in Figures 2-5 and 2-6. It is typically beneficial to keep the specified panel size to a minimum in these instances to avoid the difficulties that accompany the use of equipment sized for installing larger panels.

Installation and Panel Handling Equipment: Size/Weight and Site Access Considerations

The project site must be accessible for the heavy construction equipment that is necessary for removing the existing pavement and installing the new PCP panels. While the question of site access is usually not an issue on most major highways and truck routes, urban applications may require special evaluation of the strength and thickness of the existing mainline and/or shoulder pavement to determine if it is adequate for handling heavy construction equipment and highway truck loads. In some cases, shoulders may need to be replaced with thicker pavement before the project begins to handle temporarily diverted traffic. Consideration should also be given to pavement adequacy as it may relate to possible damage to underlying utilities and associated structures.

The size of equipment that must be accommodated typically varies with the sizes of the panels that are to be placed. Larger panels require larger equipment (often cranes – see Figures 2-2 and 2-3), resulting in heavier wheel and outrigger loads. It may be beneficial for the designer to give the contractor panel size options – within specified limits – so that the contractor can

Figure 2-6. Example use of a fork truck to install PCP panels beneath an overpass.

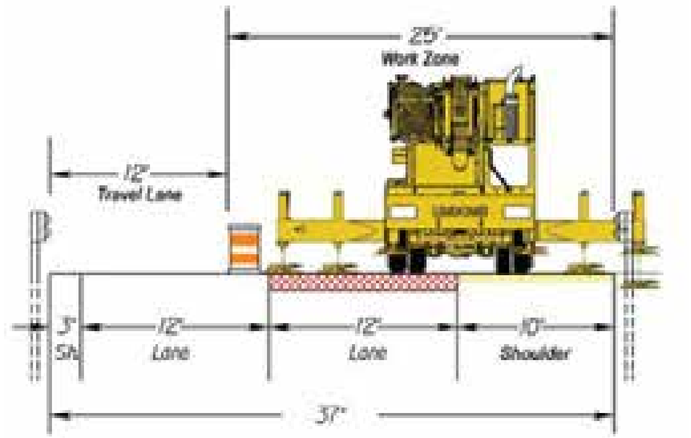


Figure 2-7. Illustration of crane footprint on Virginia DOT project.

minimize overall installation costs. Smaller panels that can be placed with rubber-tired-type excavators are often preferred, especially on intermittent repair projects where the equipment can also be used to remove the existing pavement. Contractors frequently offer lower installed prices if the same equipment can be used to remove existing pavement and place new panels.

Work space configuration must be able to accommodate the footprint of the properly positioned lift equipment, which may include outriggers (supporting legs that typically extend a few feet on either side of the lift equipment for added stability). The fully stabilized position of the lift equipment (i.e., with outriggers down and fully extended) may result in some encroachment of adjacent lanes or shoulders, as shown in Figure 2-7.

Panel Transport to the Project Site

One of the keys for successful PCP system installation is the ability to deliver the correct panels to the project site in the most efficient manner possible. Delivery directly from the precast plant to the project site, often referred to as "just-in-time" delivery, is generally more efficient and is usually preferred because there is no need for a storage or staging yard. However, when this technique is used, it is important to determine what limitations, if any, may affect panel delivery operations, including local freight regulations (e.g., weight, width and night delivery restrictions), permits, limitations on turning movements (intersection geometry), overhead restrictions, etc.

Staging yards are sometimes preferred and even necessary on large projects and on projects where over-width shipping is prohibited overnight. The designer should always consider these factors, as they may drive the necessity of arranging a nearby staging area before the project bids.

Shipping weight and width restrictions highly impact the sizes of panels that can be efficiently transported and placed. Contractors typically prefer panel sizes that best match placement equipment and simultaneously minimize freight cost because more panel area can be placed on any given hauling vehicle. Panel sizing to meet width limitations must consider not only the panel but also any protruding reinforcing steel or dowel bars.

Contractor Experience with PCP Systems

PCP systems represent a relatively new technology. Because of this and the recent increase in the number of available precast paving and repair systems, it is not uncommon for contractors with little or no prior experience with PCP systems to perform installations. Despite this lack of experience, almost all precast paving projects executed to date in the U.S. have been completed successfully within both budget and time constraints (Tayabji et al., 2013).

The key to successful installations appears to involve the use of proven or well-developed PCP systems, the availability of well-developed project plans and specifications, the availability and use of system-specific installation training for both contractors and inspectors, and diligence in the application of that training during the installation process. As with any new technology, there is sometimes a steep learning curve at the beginning as contractors first put training into practice, but sound installation techniques can be rapidly developed with good oversight and inspection.

It is recommended, especially for larger projects, that the contractor be required to construct a test or demonstration section to exhibit mastery of all necessary PCP construction techniques and the availability of all necessary installation equipment prior to scheduling a production lane closure and panel installation operation, as is discussed in detail in Chapter 10.

Availability of Certified and Qualified Precast Concrete Plants

Another important factor in deciding whether to use PCP systems is the availability of at least one National Precast Concrete Association (NPCA)- or Precast/Prestressed Concrete Institute (PCI)-certified precast plant within a reasonable distance – generally around 200 miles – of the project site. State department of transportation certifications and plant approvals may be required in addition to NPCA/PCI certification in some states. The use of a certified plant is important in helping to ensure the production of high-quality precast panels.

If prestressed panels will be produced, the plant will need to have those capabilities as well as associated certification and plant approvals. In addition, if agency specifications require the use of steam curing, the candidate precast plant will need to have those capabilities.

Panels have been transported by truck over distances greater than 300 miles, requiring up to six hours of travel. However, three to four hours of travel over 200 miles is a more typical maximum haul distance since overall costs generally increase with travel distance (Tayabji et al., 2013). Alternate modes of transportation with lower costs (e.g., barge transport) have been used successfully on some projects. Transport of panels over long distances presents the potential for travel-related disruptions in delivery, which can affect installations at the job site. In such cases, on-site storage of panels in a staging area will permit reliable, on- time delivery and buffering of delivery-related delays, but will also require the use of additional crews and product handling equipment.

Site-Specific Factors That May Impact Design and Construction

There are many site-specific factors and conditions that may affect the feasibility of using a PCP system. These include: the condition of the surrounding pavement and existing foundation materials; drainage issues and the roles that they may have played in the deterioration of the existing pavement (and may play in the performance of the PCP system); the presence of utilities beneath the pavement surface and the presence of penetrations (e.g., manholes, outlets, etc.) through the pavement surface; the presence of stabilized base/subbase layers and their repair and/or grading; and the need to match the surface geometry of the existing and surrounding pavement (i.e., nonplanar surfaces and the need for nonplanar or “warped” precast panels).

Some of these factors must be considered in laying out and constructing cast-in-place repairs as well as PCP systems, but some present unique challenges for PCP systems. The potential impacts of some of the key site-specific factors on PCP system design and construction are presented below.

Existing Pavement Condition

The condition of the existing pavement should inform decision makers concerning the use of precast pavement, as well as the need for additional types of repairs or rehabilitation, such as drainage improvements and foundation repairs. As with any pavement repair project, it is essential that the designer determines the causes of any distress and ensures that the selected repair strategies not only repair the distress, but also prevent it from reoccurring.

Figure 2-8. Deteriorating transverse crack on concrete pavement.

Figure 2-9. Joint failure on concrete pavement.

The pavements shown in Figures 2-8 and 2-9 are examples where it appears the distress is primarily panel cracking and joint spalling, issues that can be addressed with full-depth repairs and little foundation repair work. These types of pavement may be good candidates for precast pavement solutions, assuming that they meet other previously discussed criteria. However, Figures 2-10 and 2-11 are examples of cases where there appears to be foundation settlement and drainage issues that cannot be properly addressed using PCP systems unless work is also performed to address the root causes of the problems. Undercutting and backfilling with new select aggregate subbase material, with (see Figure 2-12) or without geotextile fabric, can be done in conjunction with overnight installation of PCP panels, but installation rates will likely be slightly reduced.

Figure 2-10: Longitudinal crack (possibly due to foundation support issues).

If the existing pavement is in relatively good condition, the use of intermittent precast repairs may be appropriate. If the existing pavement is not in good condition, one can consider repairing the worst areas first, leaving open the option to add on to those repairs later (i.e., “incremental” repair or reconstruction, as mentioned earlier in this chapter and in Chapter 13). If most of the existing pavement is in poor condition, then full lane replacement should be considered.

Figure 2-11: Joint and crack faulting with severe pumping, indicating drainage and erosion problems.

Surrounding Pavement Condition

The condition of the surrounding pavement may indicate the need for additional repair work or, without additional repair

Figure 2-12. Undercutting foundation prior to placing PCP panels on Route 7 near Rotterdam, N.Y.

Figure 2-13. Precast panels placed next to cracked panels on Interstate 395 near Reno, Nev.

work, a limitation to the support that will be provided to the precast repair. For example, if the surrounding pavement doesn't support the effective use of dowel bars and tie bars for anchoring the repair, the repair may experience higher stresses and movements under traffic loads, possibly resulting in a shorter performance life (Figure 2-13).

Even if the surrounding pavement condition appears to be good, there may be modest amounts of slab curl/warp or localized heaves in adjacent lanes, settlements or other movements that will necessitate the use of nonplanar precast panels and/or diamond grinding to ensure a smooth final surface. If the entire roadway will be diamond ground for smoothness or surface texture (e.g., to reduce built-in curl/warp of surrounding slabs, remove repair-related roughness or to provide improved surface friction), it may not be necessary to provide a turf drag or rake/tined finish on new panels at the precast plant.

Structural Design Considerations

It is sometimes desirable to provide PCP panels with increased structural capacity without increasing panel thickness (e.g., as a part of the incremental reconstruction of badly damaged pavement or to bridge soft foundation areas where short intermittent work windows do not allow proper repair and replacement of the underlying layers). In these cases, prestressing and/or post-tensioning of the precast panels can provide the necessary load-carrying capacity without increasing panel thickness.

The fabrication of panels that are prestressed through pre-tensioning of strands requires special forms, equipment and fabrication techniques. Experience in pre-tensioning is also valuable. The availability of these capabilities should be confirmed before proceeding with project compilation and bidding. The structural design of prestressed concrete panels is discussed in Chapter 4.

Base/Subgrade Support Issues

As with any concrete pavement rehabilitation effort, the type and condition of the existing base materials must be considered in developing plans for rehabilitation using PCP systems. The adequacy and uniformity of structural support should be considered in determining whether to use the existing base/subbase materials or to replace or reconstruct them. The use of PCP alone is not a remedy for foundation problems, although precast will probably perform better than cast-in-place repairs because precast panels are typically heavily reinforced and/or prestressed.

The type, condition and thickness of base and subbase layers can be determined through original construction documents and verified through pavement coring. The functionality

Figure 2-14. Water standing in a core hole several minutes after retrieval, indicating poor drainage of underlying layers.

Figure 2-15. Removal of cement-treated base using a skid-steer-mounted milling machine on Interstate 210 in Tarzana, Calif.

of drainage layers should also be evaluated (Figure 2-14). Materials that are substandard must be repaired, modified or replaced in a manner that maintains any necessary drainage capabilities.

In addition, it is not uncommon for some stabilized base materials to be partially attached to the bottom of original pavement slabs when they are removed. This is particularly true for drainable asphalt- and cement-treated and open-graded aggregate base materials. The development of project plans should include provisions for the rapid repair or replacement of base and subbase layers that may be damaged or partially removed during pavement removal and repair operations.

The partial or complete removal of asphalt and cement-treated base materials can be costly and time-consuming and may result in reduced repair productivity. However, it may be necessary in some situations.

An additional challenge with stabilized base materials left in place is the potential need to do unplanned trimming or removal of those materials at the time of precast panel installation. Precast panels typically are fabricated to be slightly thinner than the slabs they are replacing. This is done to allow room for some bedding material underneath the panel. However, sometimes the slabs that are removed are unusually thin due to variances in the original construction or due to profile grinding such that the new panel cannot be placed until additional base material is removed (Figure 2-15). Because of this problem, California now typically replaces existing cement-treated base (on lane replacement projects) with new "lean concrete base, rapid-setting." This material is placed at the correct elevation to allow for placement of the precast panels of the specified thickness. More information on this topic is provided in Chapter 9.

Drainage Issues

Most pavement distresses are either caused by water or are accelerated in the presence of water. In concrete pavements, the presence of excessive amounts of water can play a role in the development of pumping and faulting (Figure 2-11), foundation movements and resultant panel cracking (Figure 2-10), joint deterioration (Figure 2-9), freeze-thaw damage (D-cracking and popouts), alkali-aggregate reactions and many other distresses. Therefore, it is important – if not essential – to determine the need for providing a means of removing water from the pavement structure.

Determining the need for improved pavement drainage often begins by considering whether moisture-related distresses (e.g., pumping, faulting and corner breaks) are present in the original pavement. Pavement location (e.g., beneath

Figure 2-16. Installation of pavement drainage prior to the use of PCP panels.

Figure 2-17. Urban intersection requiring repair with numerous utility access points.

bridges, at the bottom of vertical curves, or in areas of deep cut on one or both sides of the roadway) may also suggest the potential for water collection or flow through the project area. The presence of water at the bottom of core holes (Figure 2-14) in the pavement is another indicator of poor drainage, excess water or both.

When pavement drainage is required, it is essential that the function of existing drainage systems be maintained or restored, (i.e., the preservation of permeable base material and maintenance of the edge drain system and outlets) or that a new drainage system be installed. New installations should be installed prior to the installation of precast repairs, if possible (Figure 2-16). However, undercuts and drain installations have been installed successfully and concurrently with precast repairs in some instances (Figure 2-12). When installing new drainage materials, be sure that the water is both collected and removed from the pavement structure. Do not create a "bath tub section" where water is collected and trapped in storage within the pavement drainage system.

Accommodating Existing Utilities

The presence of utility facilities, such as drainage structures, water and sewer pipes, natural gas and electrical pipes, and conduits is common in many types of pavements, particularly urban arterials and intersections (Figure 2-17). Some of these utilities require penetrations in the pavement surface for easy or regular access, such as manholes, inlet grates and valve covers. Others are not intended to be accessed but sometimes must be reached through excavation for repair (e.g., water and natural gas delivery systems). Precast pavement features and systems exist that can accommodate these situations as easily as cast-in-place pavements, and in many cases with greater ease.

The need for relatively frequent access to underground utilities for repair and maintenance can be addressed in an efficient and sustainable manner with removable/reusable urban pavement (RUP) systems. RUP systems are manufactured with PCP and are designed to allow for temporary removal and replacement/reuse, which allows access to underlying utilities and rapid replacement of the pavement without consuming or wasting paving and foundation materials. Figures 2-18 and 2-19 present two examples of RUP systems. More detailed information on RUP systems is presented in Chapter 13.

Manholes, Inlets and Other Slab Penetrations

Utility access can be accommodated in PCP systems by using "blockouts" – properly located holes in the new panels that will fit around existing manholes, grates and other in-place castings and utility access points (Figure 2-18). Accurate surveys and location of the castings and utility access points


Figure 2-18. Numerous utility blockouts in precast panels temporarily filled with asphalt to maintain traffic.


Figure 2-19. French hexagonal interlocking RUP system.

is essential for both proper fabrication and reinforcing of the panel, as well as for the layout of the panel joints. This will ensure that blockouts are not located too close to panel edges and corners, where they can facilitate the formation of panel cracks. These panels may also require special design, detailing and fabrication considerations to ensure that they have adequate strength and reinforcement for shipping, handling and service loads. Existing inlets, manholes and other in-place castings must typically be adjusted to the proper grade elevation prior to or during installation of the precast panels.

Geometry and Planarity of the Pavement Surface

The use of PCP systems to replace flat, rectangular cast-in-place panels on tangent (straight) pavement sections is relatively straightforward and can be accomplished with standard panel fabrication processes and installation procedures. Flat precast panels typically compose the majority of work on many precast pavement installation projects.

Many projects, however, include the placement of precast panels in horizontal curves and transitions to super-elevated areas, where trapezoidal panels and nonplanar pavement surfaces (Figure 2-21) may be required. In addition, there may be modest amounts of slab curl/warp or localized heaves, settlements or other movements that have produced nonplanar surfaces in the adjacent existing pavement, even though they may appear to be flat.


Figure 2-20. Super-Paver RUP system.

The presence of planned nonplanar surfaces (i.e., vertical and horizontal curves and their transitions) can be identified on original project plan sheets. The actual in-service surface shape of both planned and developed surface nonplanarity can be easily identified and measured using modern surveying techniques, including high-speed 3-D noncontact profiling.

Figure 2-21. Schematic of non-planar pavement surface where opposite sides always have different slopes.

Fabrication of nonplanar, trapezoidal and other shaped panels requires special precasting forms. It is important that project plans and specifications clearly indicate the need for, or at least the possibility of the need for, such special panels. Most certified precast plants should be able to obtain the necessary forms for successfully fabricating precast pavement panels of any reasonable shape.

The need for nonplanar panels often requires additional consideration in planning, fabrication and installation. To produce custom-shaped panels that will match field surface needs, accurate surveying of the existing pavement is essential for determining panel dimensions and the degree of nonplanarity or warp that is necessary in the finished precast panel surface. The fabrication of nonplanar panels requires precasting techniques that typically require special precasting beds, forms or both. Some nonplanar panel fabrication processes are covered by patents that require licensing agreements for use. Special care must be taken to mark or label each unique slab during fabrication so that the proper slabs are transported to the project site and installed in the correct sequence and location, thereby ensuring the best possible fit.

An alternative to producing nonplanar panels is to use flat panels and then diamond grind the entire pavement area to the desired profile. This can be done on most precast pavements if the amount of grinding does not exceed approximately 1/4 inch. Panels that have been intentionally fabricated with extra thickness (“sacrificial” concrete) may be ground a greater amount without compromising the structural integrity of the panel. While profile grinding may be acceptable to produce the desired surface profile, multiple grinding passes can add significant expense and time to the project and may result in structurally significant reductions in slab thickness. Therefore, this approach may not be practical or suitable when the amount of nonplanarity in any given panel is much more than 1/4 inch. The designer should be aware that it is not uncommon to encounter warps of up to 2 inches in a single, 12-foot-by-15-foot precast panel and that it is unacceptable to grind away that amount of precast panel thickness unless that magnitude of sacrificial thickness has been provided in the panel.

The use of warped surfaces is discussed in more detail in Chapter 3. Design-related discussions of nonplanar precast panel surfaces are included in Chapter 4 and Chapter 6. Finally, forms for fabricating nonplanar panels are discussed in Chapter 7.

Summary

Many factors should be considered in identifying feasible candidate projects for the use of PCP systems in the repair or reconstruction of concrete pavements. The primary criteria that drive the use of PCP systems are the necessity of short work windows (typically overnight) and the desire for a high-quality, long-lasting and durable product. However, there are many other factors that may play a role in the decision process or that may impact the design, fabrication and installation of the precast panels.

Chapter 3:
APPLICATIONS FOR JOINTED PRECAST PAVEMENT SYSTEMS

A GUIDE FOR DESIGNERS, PROJECT OWNERS AND PRECASTERS

While there is not an abundance of published information on the design, construction and performance of jointed precast concrete pavement (JPrCP), there are more than 185 completed projects in the U.S. and Canada that can be used as examples of where, why and how JPrCP has been used in specific locations. The National Precast Concrete Association and the Precast/Prestressed Concrete Institute both maintain repositories of data that contain each project's location, owner, size and type as well as specifics regarding traffic volume, type of work window, contractor and special features.

This chapter provides brief overviews of several types of "typical" completed projects that illustrate the versatility, usefulness and implementation of JPrCP systems in a wide range of applications. Agencies, designers, project developers, and even precasters and contractors may find this information useful as they contemplate the use of JPrCP.

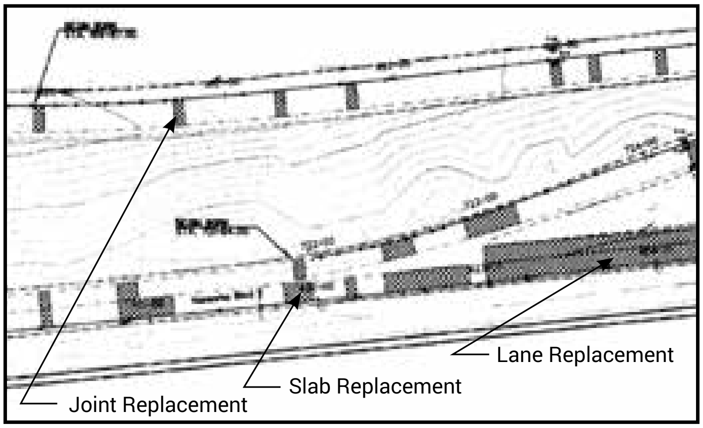


Figure 3-1. Plan view of a typical repair project showing intermittent joint and slab repairs and lane replacements.

Types of Repair

Precast repairs are sometimes loosely classified as intermittent, continuous intermittent or continuous, but all three are similar in detail and frequently are used on the same project, as shown in Figure 3-1. However, there are some distinctions between the different types of repair, as described below.

Intermittent Repairs

Approximately 2/3 of precast pavement projects constructed to date in the U.S. and Canada can be categorized as intermittent repairs, where "isolated" areas of the roadway have been replaced. This is a cost-efficient and sustainable practice because it allows owners to rapidly restore concrete pavements with localized distresses to serviceable conditions by repairing only the areas that are distressed.

Precast concrete pavement (PCP) is a good repair material in these cases because it is durable, and, if properly installed, may provide a service life of 38 years or more (Kohler et al., 2007). Less durable materials, such as asphalt and some high early-strength concrete products, may last only 5 to 10 years (or less). The costly consequence of using less durable materials is that they fuel a maintenance program that must include a "fix the fix" component (Tayabji et al., 2013).

Another reason JPrCP is a good choice for intermittent pavement repairs is that durable, previously placed panels may be left in place and added to when surrounding pavement areas fail. This long-term maintenance technique is a relatively new concept that helps to delay replacement of the entire roadway and is discussed in detail in Chapter 13.

Figure 3-2. Eight-foot-long, full lane-width joint repair panel placed in a single lane.

Figure 3-3. Six-foot-long, full lane-width joint repair panels in adjacent lanes.

Joint Repairs

Joint replacement is the most common type of intermittent repair because joints are typically the first concrete pavement feature to fail. Transverse joints are commonly subject to spalling, load transfer failure and materials-related durability problems.

Pavement deterioration in most joints is typically localized within 1 or 2 feet of the original joint, so short precast repair panels can be used effectively. Joint replacement panels, typically 6 to 8 feet long and the width of the lane, are usually centered over or placed in close proximity to the existing failed joint, resulting in the introduction of two new doweled joints to replace the one that failed (Figure 3-2).
This restores load transfer between the existing slabs and replaces the deteriorated joint pavement at the same time. If deterioration around the joint is more extensive, single panels with lengths of up to approximately 15 feet (and additional panels if necessary) may be used as required.

Figure 3-3 shows the replacement of just the deteriorated concrete at the existing joints in adjacent lanes, effectively preserving most of the original pavement between the original joints. The original joints were spaced 62 feet apart on this project.

Short Panels in Other Locations

Short panels may be used to repair cracks and general deterioration at any location within a slab or a series of slabs. Short rectangular panels are also useful on curved alignment, as seen in Figure 3-4. The design and use of precast panels on curved alignment is discussed in more detail in Chapter 6.

While judicious use of short panels allows designers to make the most out of project budgets by “preserving” short sections of good existing pavement (as shown in Figure 3-5), it may be more cost-effective to use longer precast panels in these areas (as shown in Figure 3-7) rather than to leave short sections of the good existing pavement, which are likely to need replacement within a few years.

Figure 3-4. Use of precast panels for joint and mid-slab crack repairs in 62-foot-long slabs.

Figure 3-5. Construction of precast panel repairs for joints and mid-slab cracks in 40-foot-long panels.

Figure 3-6. Long interior repair area prepared for installation of JPrCP panels.

Figure 3-7. Example use of multiple JPrCP panels in a single repair.

Longer Intermittent Repair Areas

JPrCP can also be used to replace larger distressed areas (e.g., encompassing one or more complete slabs.) In such cases, it is generally most efficient to use longer panels (up to about 15 feet in length), as shown in Figures 3-6 and 3-7, depending on the length of the damaged area being replaced.

On large intermittent repair projects, common practice is to establish a standard "menu" of panel lengths for the project (e.g., 6 feet, 9 feet and 12 feet) that can be used individually or in various combinations to replace distressed areas of any length. This concept, established to standardize panel sizes for reduced fabrication cost, is discussed in more detail in later chapters.

Continuous Lane Replacement

Continuous full-lane replacement is appropriate when long stretches of any given lane have failed beyond the reasonable use of intermittent repair techniques. The far-right travel lanes of many heavily traveled routes are frequently the first lanes to fail, especially on interstate-type highways with high volumes of heavy truck traffic. This was the case on a section of a project on Interstate 15 near Ontario, Calif., where a high volume of trucks traveling from a nearby container terminal caused early deterioration of the two right-hand lanes of I-15 near its intersection with Interstate 10. This section of I-15 carried about 200,000 vehicles per day, so replacement activities had to be limited to eight-hour night work windows.

During each eight-hour work window, existing pavement was removed, the existing cement-treated base was milled to depth (when necessary), bedding material was installed and graded, and precast panels were placed and grouted. An average of about 250 lane-feet of pavement was replaced in this manner each night, with replacement rates reaching as high as approximately 500 lane-feet on some nights. All the I-15 travel lanes were open to traffic right up to and immediately following each eight-hour night work window. Approximately 1.5 miles of the two right-hand lanes were replaced in these short work windows during a portion of one construction season (Figures 3-8 and 3-9), demonstrating that long sections of deteriorated pavement can be replaced efficiently with JPrCP panels during overnight work windows.

Intermittent and Continuous Replacement in Adjacent Lanes

While intermittent and continuous JPrCP repairs are frequently made in a single lane, they may also be made in two or more adjacent lanes such that new precast panels may abut new precast panels or existing pavement in adjacent lanes. The precast panel installations seen in Figures 3-3, 3-4, 3-5, 3-8 and 3-9 all involved placement of new precast panels in two or more adjacent lanes.

New precast panels in adjacent lanes are typically tied together across longitudinal joints. New precast panels may or may not be tied to adjacent existing pavement, depending on how long the repair is and the design standards relating to longitudinal joint ties in the state in which the repairs are being made. Longitudinal joint ties are discussed in more detail in Chapters 4 and 9.

Figure 3-8. Tangent lane replacement of a portion of Interstate 15 near Ontario, Calif., using JPrCP.

Figure 3-9. Lane replacement of a curved portion of Interstate 15 near Ontario, Calif., using JPrCP.

Precast Repairs in Interior Lanes Only

JPrCP may be used advantageously for the repair of interior lanes only – for example, on three-lane interstate highways where traffic may not be easily diverted from the middle lane for the extended periods of time often required for the use of conventional cast-in-place repairs. Precast panels are especially useful in such locations because they can be installed in short work windows, when traffic is lightest, so that traffic can be restored to all lanes during periods of peak traffic flow. Even in these cases, precast panels may be tied to adjacent existing pavement, as discussed above, if required by the designer.

Precast Repair for Other Locations

While most projects described so far have involved intermittent repair and full-lane replacement, JPrCP has been used in other locations that may be of great interest to designers and project developers. Some of these locations require special types of panels, such as:

- The use of specially shaped panels for ramps and intersections
- Heavy-duty panels for bridge approaches, airport pavements and bus pads
- Panels designed to accommodate utilities
- Instrumented panels for toll plaza replacement, open tolling panels
- Panels that are cast with electronic scale equipment for weigh-in-motion stations

These applications are discussed below.

Ramps

Closing ramps for repairs can be problematic because ramps typically provide vital links between interstate-type highways and intersecting primary, secondary or other roadways. JPrCP panels have been used successfully to keep ramp closures to a minimum on many projects in New York, Virginia, Illinois, Utah and Ontario.

Single-lane ramps, such as the one shown in Figure 3-10, have been replaced during a single weekend closure, while multi-lane ramps, like the one shown in Figure 3-11, were replaced during overnight closures, with traffic being fully restored during daytime hours.

The required duration and extent of work closures for ramp replacement depends on the timing of traffic flow and the work that needs to be done within the lane. For example, the installation of the right-hand lane of the two-lane ramp seen in Figure 3-11 (photo taken before the pavement was replaced), required longitudinal joint ties between lanes, so time and work space consideration were given to that operation. Even so, the nearly 1-mile-long ramp was replaced during several eight-hour night closures of the entire ramp.

Figure 3-10. “Tight-radius” single-lane ramp in Chicago, Ill., that was replaced during a single weekend closure.

Figure 3-11. The right-hand lane of a high-speed exit ramp in Fairfax, Va., that was replaced during overnight full ramp closures.

Project developers may be reluctant to consider the use of JPrCP for use on ramps because they frequently involve tight horizontal curves, pronounced vertical grade changes and pavement widenings, especially at the beginnings and ends of ramps. Designers may be assured that precast panels can be designed to fit almost any pavement geometry if geometric parameters can be developed or captured by appropriate surveying operations. The project shown in Figure 3-10 demonstrated that precasters are capable of fabricating precast panels to meet complex geometric requirements.

Urban Arterials

Precast panels are especially useful in rehabilitating aging, heavily traveled urban arterials, where local commerce considerations often demand minimal disruption of traffic flow. Even though horizontal and vertical geometries of many such arterials may be complex, with relatively "tight" horizontal curves, significant vertical grade changes, and frequent lane widenings and turning lanes, JPrCP panels can be designed for overnight installation. JPrCP panels can also be designed to accommodate utility appurtenances, such as manholes, catch basins, valve boxes and communication structures, which are commonly located in such roadways.

One example of JPrCP use for replacement of a heavily traveled urban arterial pavement is the 2010 four-lane Rockaway Boulevard project in Queens, N.Y., where JPrCP panels were used to replace all four lanes of Rockaway Boulevard continuously over about 1/2 mile (Figure 3-12). All the work was completed during eight-hour night work windows because of heavy daytime traffic. The roadway was sharply curved in some areas, as can be seen in the background in Figure 3-12. The project also included several variable-width turning lanes at intersections, which are discussed later in this chapter. The panels were placed between existing curb (which was preserved) on both sides of the roadway and around many utility structures, such as catch basins, water and gas valves, and underground telephone service boxes.

JPrCP panels were also used effectively to rehabilitate Interstate 680 in Philadelphia, Pa., in 2010. At the project site, there was little room for staging traffic for the installation of conventional cast-in-place concrete (Figure 3-13). Despite the heavy traffic on this arterial, the precast concrete repairs were successfully installed in the specified eight-hour night work windows.

Intersections

Intersection pavement is often difficult to maintain because of high levels of traffic from two or more directions. Because of this traffic, asphalt intersection pavement frequently ruts and shoves due to vehicle stops, starts and turning movements.


Figure 3-12. Precast concrete lane replacement on Rockaway Boulevard in Queens, N.Y.


Figure 3-13. Intermittent precast repairs on Interstate 680 in Philadelphia, Pa.

JPrCP panels offer an ideal solution for these areas because of their superior durability and immunity to rutting and shoving. JPrCP panels can also be placed in such locations in very short work windows – usually during off-peak traffic hours – minimizing the impact on traffic patterns and work-related congestion.

While project developers typically embrace the benefits of precast pavement for intersections, they may be reluctant to

Figure 3-14. Aerial view of the intersection of Route 7 and Nott Street in Rotterdam, N.Y.

Figure 3-15. Street view of pavement replacement operations at the intersection of Route 7 and Nott Street in Rotterdam, N.Y.

use it because of complexities in intersection alignment and surface geometries. The two projects described in the next few paragraphs may allay these concerns.

The 2006 Route 7 project in Rotterdam, N.Y., demonstrated that JPrCP panels can be designed and installed in geometrically complex locations (Figures 3-14 and 3-15). Surface geometry at this location was complicated because the intersection resides within a super-elevation transition (requiring the use of non-planar panels) at the approach to a horizontal curve in mainline Route 7. The intersecting Nott Street meets the mainline at two significantly different angles (Figure 3-14), necessitating the use of severely shaped trapezoidal panels. Left turn lanes on Route 7, also seen in Figure 3-14, required JPrCP panels of varying widths. Despite these complexities, custom panels were designed, fabricated and placed to fit without exceeding the specified transverse and longitudinal joint tolerances of 1/2 inch.

The installation process was also challenging because the panels had to be installed at night (in 10-hour work windows) under "live" traffic conditions. In other words, traffic had full use of the intersection during work hours – except for the immediate work area – necessitating creative maintenance-of-traffic techniques. Installation was further complicated because it was necessary to undercut the existing pavement and backfill it with a 1-foot layer of new dense-graded base material (Figure 3-15). Even with these complexities, approximately 260 panels were installed in 10-hour work windows over a period of 18 nights under live traffic conditions.

The Route 7 project was also unique in that costlier JPrCP panels were used only in the critical area of the intersection to keep traffic flowing around the clock. Conventional cast- in-place pavement was used outside of the critical intersection area where traffic could be diverted long enough to allow conventional placement and curing techniques. This approach demonstrated that precast and cast-in-place pavement can be used together on the same project if proper attention is paid to joint layout and tie bar details between the two types of pavement. This concept kept overall project costs to a minimum while satisfying the needs of businesses in the immediate area.

Another intersection project of note is the previously mentioned Rockaway Boulevard-Farmers Boulevard intersection project in Queens, N.Y., shown in Figures 3-16 and 3.17. The existing full-depth asphalt approaches to four major intersections (outside of the previously mentioned 1/2-mile continuous section) along a 6-mile stretch of Rockaway Boulevard were replaced with JPrCP panels. Located adjacent to John F. Kennedy International Airport, the asphalt pavement in this area was heavily rutted due to the stopping and turning movements of heavy local truck traffic (Figure 3-17). All approaches and the previously

Figure 3-16. Aerial view of the Rockaway Boulevard-Farmers Boulevard intersection in Queens, N.Y.

Figure 3-17. Heavily rutted asphalt pavement on Rockaway Boulevard in Queens, N.Y.

described 1/2-mile section of four-lane pavement on Rockaway Boulevard were replaced with JPrCP panels in eight-hour night work windows during one construction season.

City Streets

While many city streets carry high volumes of traffic and may, therefore, seem like good candidates for the use of precast pavement, conventional concrete paving is typically more cost-effective because adjacent city streets can usually be used as detours. However, there are some locations where this is not the case and repairs must be made in short night work windows under live traffic conditions.

A good example of this is the 2013 Broad Street project in Winder, Ga., where approximately 3/4 of a mile of Broad Street was replaced with JPrCP under live traffic conditions. Multiple layers of old pavement, installed over a period of several decades, were completely removed and the subgrade was replaced and upgraded prior to placing the new precast panels to new cross-slopes and grades. Numerous variable-width panels in turning lanes and other widenings (Figure 3-18), and non-planar panels (to accommodate changing cross-slopes) were required. The success of this project is an indication that JPrCP panels can be designed for almost any city street geometry.

Figure 3-18. New precast panels on Broad Street in Winder, Ga.

Another example of the successful use of JPrCP panels on a geometrically complex city street is the Brooklyn Bridge project in New York City, where precast panels were used to replace the pavement on both 1,000- foot bridge approaches in 2013-2015. These approaches included diverging access ramps and numerous heavily skewed bridge overpasses (to accommodate streets below the approaches), as seen in Figure 3-19, and required many custom-designed precast panels. The JPrCP panels on this project (except for the header portions at the skewed joints) were overlaid with asphalt for improved ride quality, as shown in Figure 3-19.

Figure 3-19. Only the header portions of the skewed precast approach slab panels used on this Brooklyn Bridge project in New York City are visible in this photo. All other precast panel exposures were overlaid with asphalt to provide a smoother riding surface.

This project is a prime example of the benefit of using JPrCP in situations where a street or bridge cannot be shut down for maintenance or rehabilitation for more than a few off-peak hours. Closures on this project were necessary to allow installation of new JPrCP and were arranged on a nightly basis over a period of approximately two years while the entire bridge was open to traffic for peak day-time flow. The successful execution of this project should give designers and project developers confidence that JPrCP technology can be used for very complex pavement repair or replacement situations.

Toll Plazas

JPrCP is especially useful for replacing pavement at toll plazas because using it minimizes adverse effects to traffic flow while maintaining (as much as possible) incoming revenue and level of service provided to toll-paying customers. As a result, the New York State Thruway Authority chose JPrCP in 2000 to replace aging pavement on the 13-lane Tappan Zee Bridge toll plaza in Tarrytown, N.Y, which serviced approximately 140,000 vehicles per day.

Figure 3-20. Rush hour traffic at the Tappan Zee Bridge toll plaza near Tarrytown, N.Y., in 2000 before the plaza was replaced with new JPrCP panels.

Figure 3-21. The expanded Tappan Zee Bridge toll plaza after precast panel installation was completed in 2002 (photo taken during off-peak hours to highlight the expanse of precast panels).

Reconstruction of the plaza was staged during off-peak hours (Figure 3-20) so that heavy traffic during peak hours was not adversely affected. Many toll plaza users were unaware that approximately four acres of existing pavement was being replaced over about a 6-month construction period (Figure 3-21). The success of this project led to the subsequent use of precast panels on at least one other toll plaza project in New York, four in Illinois and three in New Jersey.

Bridge Approaches and Bridge Approach Slabs

JPrCP is currently attracting the interest of bridge and roadway engineers as a potential solution to failed bridge approaches and bridge approach slabs, which is a common problem throughout the United States and other countries. Bridge approach slab failures often arise due to a loss of

Figure 3-22. Replacement of bridge embankment material below approach slabs on the Route 46 Bridge in Clifton, N.J.

Figure 3-23. New precast concrete bridge approach panels at the Route 46 Bridge in Clifton, N.J.

foundation support resulting from the gradual erosion of bridge abutment backfill material and/or movement of restraining wingwalls and backwalls (White et al., 2005; Smith, 2011). Replacing these approach panels is frequently problematic because room to divert traffic for extended periods of time at these locations is often very limited.

Repair and replacement using JPrCP works well at these locations because precast panels can be installed during off-peak hours (usually at night) without major interruption to highway traffic. In addition, JPrCP can be designed to fit almost any bridge approach slab geometry (including heavy skews) and for any structural capacity that may be needed to bridge anticipated future backfill material erosion or settlement.

A good example of precast approach slab installation is the 2011 weekend replacement of the Route 46 Bridge and approach slabs in Clifton, N.J. Renewal of the underlying abutment embankment is shown in Figure 3-22. The open excavation provided a good opportunity to incorporate state-of-the-art materials and methods, such as select granular backfill, geo-fabric and proper compaction techniques. The new precast panels were fabricated with a significant skew, as shown in Figure 3-23, which illustrates a feature that is common to many bridges. This project demonstrates that precast bridge approach slabs can be – and have been– designed and fabricated to accommodate bridges with significant skews.

When existing backfill material can't be re-compacted or removed and replaced, as shown in Figures 3-22 and 3-23, it may be necessary to stabilize the existing backfill in situ using deep-placed urethane injection techniques, or to design the panels to bridge the backfill material altogether. The latter technique requires structurally adequate panels and full panel support at both ends of the slab. This is typically accommodated at the bridge by providing a supporting shelf on the backwall of the bridge abutment. At least one agency has designed and installed pile-supported sleeper slabs to support the other (land-side) ends of the slabs.

Bus Pads

Engineers in California, Connecticut and New York have recently used JPrCP panels to replace badly deteriorated bus pads (pavement at bus stops). Bus pad pavement failure (Figure 3-24) is common because the road surface is subjected to heavy loads and stresses related to repeated stopping, sitting and starting of heavy bus traffic. This problem is exacerbated because bus stops cannot be easily moved to other locations, even for short periods of time. Precast panels have proven to be an effective solution in these locations because they can be installed during brief overnight or weekend closures when bus schedules can be more easily modified.

An example of the use of JPrCP in a bus pad application is a 2012 project in North Hollywood, Calif., where the

Figure 3-24. Bus pad pavement prior to replacement in North Hollywood, Calif.

Figure 3-25. New precast bus pad pavement in North Hollywood, Calif.

two bus pads were replaced in overnight closures. The new precast panels shown in Figure 3-25 were placed in service immediately following a nighttime installation. Inconvenience to bus patrons was minimized while a long-term solution to a serious pavement problem was provided.

However, bus pad installations on city streets are not without challenges, because they sometimes involve appurtenances to underlying utilities, some of which may be visible before construction begins and others that may not be. For the project shown in Figures 3-24 and 3-25, a water valve visible before construction was easily accommodated by casting a hole at the proper location in the panel during fabrication. A buried gas valve not visible before construction was discovered during installation at another location, making it necessary to core a matching hole in the solid precast panel on site before placement. Fortunately, the contractor obtained appropriate equipment in time to perform the work without appreciable delay to the installation schedule.

Pavement Under Low-Clearance Bridges

JPrCP has recently emerged as an effective solution for pavement restoration under low-clearance bridges because it can be installed as a full-depth replacement of the existing pavement during a series of overnight closures – all without reducing clearance under the bridges. This is especially beneficial on heavily traveled interstates where extended traffic detours cannot be easily arranged to allow cast-in-place techniques.

An example of such a project is the replacement of pavement under three bridges on the Interstate 94 Business Loop in Kalamazoo, Mich., in 2013 and 2014. New JPrCP panels were placed to the same grade as the original pavement, thus maintaining the required clearance under the bridges (Figures 3-26 and 3-27). This allowed the Michigan Department of Transportation to retain the original concrete shoulder and, in some areas, to "save" one of the two original travel lanes that was still in good condition.

Work space on this project was limited because the roadway in each direction consisted of two 12-foot travel lanes bounded by a 10-foot shoulder on the right and a 4-foot shoulder on the left. Traffic during work closures was confined to the shoulder and part of the lane that was not being replaced during that closure. This configuration left a work area that was significantly smaller than the preferred two-lane working width, especially when traffic was diverted to the left 4-foot wide shoulder. Despite these limitations, the old pavement beneath the overpasses was successfully replaced with JPrCP panels in a series of eight-hour night work windows. Both lanes and adjacent shoulders were made available to the traveling public, without restriction, during daytime travel hours. More installation-related information on this project is presented in Chapter 9.

Figure 3-26. Placement of repair panels beneath an overpass on westbound Interstate 94 (Business Loop) near Kalamazoo, Mich.

Figure 3-27. Completed repairs beneath an overpass on eastbound Interstate 94 (Business Loop) near Kalamazoo, Mich.

Weigh-In-Motion Stations

Precast weigh-in-motion (WIM) panels are effective for installing weigh stations on heavily traveled truck corridors where there is no room for conventional off-highway weigh station areas. Like precast pavement in other locations, WIM panels can be placed during overnight work closures with minimal disruption to heavy truck traffic. Additionally, complex embedments and instrumentation can be installed in a precast plant with greater precision than with cast-in-place installations because of factory-controlled fabrication conditions (Figure 3-28). The high durability of PCP also provides greater long-term protection to the sensitive WIM instrumentation embedded within it.

Figure 3-28. Frame for weigh-in-motion scales positioned in a precasting form.

The placement of sophisticated precast WIM units takes only a few minutes in the field (Figure 3-29) because most of the critical work is done in the precast plant. Also visible in Figure 3-29 is a conduit that will allow rapid attachment to adjacent power and recording equipment when the unit is in its final position.

Precast Repairs for Composite Pavement

Most JPrCP panels placed to date in North America have been installed to repair concrete pavement that has not been overlaid with asphalt. However, a few projects have advantageously included the use of precast panels to

Figure 3-29. Weigh-in-motion precast unit being lowered into position in the field.

Figure 3-30. Milled composite pavement on Route 21 in New Jersey.

rehabilitate existing concrete pavement underneath asphalt pavement (e.g., the Brooklyn Bridge project shown in Figure 3-19). Precast panels are useful in these cases because the cure time typically associated with conventional fast- track concrete repairs is not required before the pavement is re-opened to traffic.

Composite pavements are typically "milled and filled" periodically – typically every 5 to 15 years, depending on traffic and climate conditions – to eliminate surface rutting or to replace an otherwise failed asphalt layer. While some short sections of composite pavements are milled and filled in only one or two work shifts, others require additional time to make repairs to the underlying concrete pavement. During the time required to complete those repairs, construction and/or service traffic must drive on the milled surface (Figure 3-30), resulting in a noisy and rough-riding experience that needs to be minimized. JPrCP panels can be installed rapidly, thereby reducing the amount of time the milled surface is open to traffic.

The time-saving advantage of using JPrCP repair panels for composite pavements was demonstrated on the 2013 Interstate 495 (Long Island Expressway) project in Long Island, N.Y., where standard-width precast panels were used for all repair locations. Rather than wait until the asphalt was milled to measure required widths for each panel, a "standard" width (i.e., one that would fit most repair locations) was agreed upon in advance so that all precast panels could be fabricated prior to removal of the existing asphalt overlay. The new standard-width precast panels were installed immediately after milling, enabling the contractor to get the milled surface covered with new asphalt within the specified seven-day time limit.

Repairs to Airport Pavement

Airport taxiways, runways and aprons may also be good candidates for JPrCP because airport managers must provide continuous service and access to their client air carriers. JPrCP repair is especially beneficial when acceptable alternate facilities (e.g., alternate runways, taxiways and gates) are not available.

JPrCP repair panels offer the same benefits to airport agencies that they do to highway agencies in that they can be installed overnight and offer the promise of long service life. One major difference between the two applications is that existing airport panels (as originally constructed) are typically as large as 25 feet in each direction and often up to 24 inches thick (for commercial and military airports). Panels of this size and thickness are nearly impossible to transport over the highway because of their size and weight. Therefore, they must be fabricated on-site or transported to the site by alternate routes. Alternatively, panels may be divided into smaller component panels (e.g., 12.5-foot square or 12.5 foot by 25 foot) for easier transport and handling. However, this may increase fabrication, handling and placing costs.

Figure 3-31. Installation of precast taxiway panels with leveling bolts at LaGuardia Airport.

Figure 3-32. Installation of precast taxiway panels on precision-graded base at Dulles International Airport.

Two pilot projects in the U.S. where precast panels have been used successfully to replace airfield taxiway panels are the 2002 LaGuardia Airport project in Queens, N.Y., and the 2002 Dulles International Airport project in Chantilly, Va. The LaGuardia panels, shown in Figure 3-31, were fabricated in full size off site, but were shipped by barge rather than by truck because the taxiway was adjacent to navigable waters. The panels were successfully installed during weekend closures, during which time the existing asphalt pavement was milled to the proper depth. The new panels were adjusted to grade with embedded leveling bolts and were then undersealed with injected bedding grout.

The second project, shown in Figure 3-32, involved intermittent repairs to two taxiways at Dulles International Airport. Two 25-foot-by-12.5-foot panels, shipped by truck, replaced each 25-foot-by-25-foot existing slab. While this project was successful, the cost was understandably high because two panels were required to replace each existing airport slab, requiring additional dowels to connect them.

Thick JPrCP airport panels are not likely to be cost-effective if they must be shipped over the highway by truck, and most airports are not located next to navigable waterways. A more practical solution is to cast full-size precast panels (slabs) at or near the airport site, thereby reducing or eliminating the high cost of shipping over roadways. The cost of equipment required to lift and place such heavy panels also needs to be considered.

Summary

The projects presented in this chapter demonstrate that JPrCP can be used effectively in many different applications where traffic is intense and time to repair or replace concrete pavement is limited to very short (typically overnight) work windows.

In addition to intermittent repair patches and mainline lane replacements, JPrCP panels have been used successfully in geometrically complex locations such as superelevation transitions, intersections, ramps and bridge approaches. They have also been successfully installed at critical locations, such as bus pads and airport taxiways, which demand installation of heavy-duty pavement in similarly abbreviated work windows. The use of instrumented JPrCP panels for weigh-in-motion stations is included in this chapter to introduce the broader concept of using instrumented panels for other applications, as is discussed in Chapter 13. Designers contemplating the use of JPrCP in similar applications may use the information presented in this chapter and contact the specific project experts referenced in precast pavement data repositories maintained by NPCA and PCI.

Chapter 4:
DESIGN OF JOINTED PRECAST CONCRETE PAVEMENT SYSTEMS

Today's concrete pavements are typically selected and designed with an expectation of long service life (e.g., 30 or more years). Some agencies have developed designs and construction specifications that are intended to produce "long-life concrete pavements" having service lives of 40 years or more with no premature failures and reduced potential for cracking, faulting and spalling. While modern precast concrete pavement (PCP) technology in the U.S. is less than 20 years old, experience and testing to date indicates that jointed precast concrete pavement (JPrCP) systems can also be designed (and constructed) for service lives of 40 years or longer. Several factors in the fabrication of PCP panels contribute to the potential for good performance:

- Precast panels typically do not develop significant curl or warp during fabrication and storage, which reduces total curl/warp stresses present during pavement service.
- The strength of precast concrete panels typically exceeds design requirements before the panels are installed. As a result, there is no potential for additional structural damage due to the application of early-age traffic loads.
- Precast panels typically include substantial amounts of reinforcement for transport and handling conditions (and sometimes for structural considerations as well). Any panel cracks that might develop generally remain tight and do not deteriorate.

The design of PCP systems is based, in part, on the expectation that the behavior of the installed precast pavement should not be significantly different from that of a cast-in-place (CIP) pavement under the same traffic, environmental and support conditions, and that the performance of the PCP should be comparable to (or, perhaps, somewhat better than) that of CIP pavement in the same application. The system design must also address mechanical and functional details that are not present in CIP pavement.

Therefore, the design of PCP systems must address many considerations and features, including:

- Determination of the structural design criteria (i.e., service life and performance requirements)
- Joint layout and selection of panel sizes
- Selection of the slab support system
- Thickness design
- Slab reinforcing design
- Joint design (including load transfer systems, tie bars and other details)
- Slab surface geometry (flat vs. non-planar)
- Slab surface texture
- Other details, including grout ports, lifting mechanisms, utility openings, bedding grout distribution systems, etc.

The interaction of many PCP design features (e.g., the impact of panel dimensions on slab thickness and reinforcing requirements) requires a holistic design approach.

This chapter presents information on all these considerations and design features.

Structural Design Criteria

The structural design criteria for any pavement system are based on the types of structural distresses that might be expected to develop under service conditions. The distresses that are most commonly considered directly in CIP jointed concrete pavement (JCP) design are transverse cracking, joint faulting and joint spalling. The structural design of JPrCP should be performed with consideration of these same factors. In addition, direct consideration must be given to transportation and handling conditions, which can impart stresses that are very different from service conditions and are not considered in conventional pavement design thickness procedures. These conditions generally drive minimum panel reinforcing requirements for safety in transportation and handling, but typically do not impact pavement thickness design.

There are other distress types that may indicate a structural failure of JCP systems (e.g., corner breaks, longitudinal cracking, blowups and some forms of materials-related distress). These are generally not considered directly in pavement structural design because they are related to the same mechanisms that cause transverse cracking, faulting and spalling, or because they are handled through materials and construction quality specifications.

There are often additional design criteria that reflect pavement function, such as ride quality, surface friction and others. These are sometimes at least partially a reflection of structural conditions as well (e.g., ride quality is strongly influenced by the development of structural distresses such as joint and crack faulting, spalling, etc.).

Pavement design procedures that are specific to PCP have not yet been developed; therefore, the design of JPrCP is currently based on available procedures for CIP concrete pavement systems. The AASHTOWare Pavement ME Design software is generally acknowledged as the most sophisticated pavement design system currently available. It was developed for use with asphalt and CIP concrete pavements, but is considered suitable for use with many PCP systems as well. The design criteria typically considered for JCP in the AASHTOWare Pavement ME Design software are: transverse cracking, joint faulting, spalling and International Roughness Index (IRI, a measure of ride quality).

Service Life and Performance Criteria

The service life for PCP should be selected with consideration of the intended use for the precast panels. For repairs, the service life of the precast units should generally match or slightly exceed the remaining service life of the surrounding pavement, taking into account any extension of the overall pavement service life that is to be expected with the precast repair. For repairs of relatively new pavement, the precast pavement service life should match or exceed that of the surrounding new pavement (e.g., 20 to 40 years or more). For repairs of older pavement with relatively little remaining service life, the precast pavement service life may be less than 20 years unless the repairs are being used for incremental reconstruction (see Chapter 13), in which case they should be designed for the service life of a new pavement.

The selected service life impacts the structural design of the pavement by dictating the number of service loads and environmental cycles that must be accommodated without panel cracking or crack deterioration, with acceptable levels of joint faulting, etc. It can also affect aspects of the pavement design that impact functional performance.

Typical functional requirements for any pavement system include ride quality (typically indicated by IRI for higher speed facilities), surface friction (safety) and tire-pavement noise. These are discussed further below.

Strength and Reinforcing Considerations

Most highway agencies use concrete design compressive strengths at 28 days (f’c-28 days) of 3,000 to 4,000 psi, which results in average required compressive strengths of 4,000 to 5,200 psi to ensure that design strength is achieved with a high degree of statistical reliability. PCP can easily be produced with this level of strength and often with less variability in strength than for CIP concrete.

PCP panels must also be reinforced to resist temperature and shrinkage stresses during curing and yard storage – as required by ACI specifications – and to prevent cracking or catastrophic

Table 4-1. Recommended Design Criteria for JPrCP Systems (after Fugro Consultants, 2012 and Tayabji et al., 2013)

Criterion	Value (after Fugro Consultants, 2012)	Value (after Tayabji et al., 2013)
Structural		
Cracked Slabs, percent	< 20	25 – 30
Joint Faulting, in.	< 0.10	< 0.15
Joint Spalling	Minimal length, only low-severity	Minimal
Materials-related Distress	None	None
Functional		
International Roughness Index, in./mile	< 160	150 - 180
Surface Texture – Friction	SN > 35, long-lasting	FN (SN) > 35
Surface Texture – Tire-Pavement Noise	No criteria available, but tire-pavement noise levels should be acceptable for the specific application and location	No criteria available, but surface should produce accepted level of tire-pavement noise

and dangerous panel failures during lifting and handling. Conventional steel reinforcing is typically included at a rate of at least 0.2% (by area of concrete) in one mat in the lower half of the panel to satisfy both requirements. A second mat of temperature and shrinkage reinforcing steel is frequently added to the top half of the panel as further protection against cracking in panels that are opened to traffic before they are fully grouted. Conventional steel reinforcing should be protected from corrosion when used in environments with deicing chemicals or other corrosive agents.

It should be recognized that conventional steel reinforcing provides very little structural (load-carrying) capacity to most PCP systems because the pavements are relatively thin when compared to structurally reinforced beams and columns, and cover requirements typically result in the placement of steel away from the surfaces and close to the neutral axis of the system, where they contribute little to the bending stiffness. When additional structural capacity is required, the pavement must be made thicker, the individual panels must be prestressed, or both. The design and benefits of prestressing systems using pretensioned strand are discussed later in this chapter.

The use of structural fibers in concrete may also provide some additional structural capacity (Bordelon and Roesler, 2009), but this benefit has not been widely considered in PCP system design.

Typical Thickness Design Criteria

The design criteria presented in Table 4-1 have been recommended for JPrCP systems that are intended to provide long service life (Fugro Consultants, 2012; Tayabji et al., 2013):

The above criteria represent values for each distress or condition that are not to be exceeded within the service life of the pavement. Periodic corrective action (e.g., diamond grinding) may be required over the pavement service life for some functional criteria (e.g., IRI and friction).

The tabulated values are similar to those that would be applicable to any long-life concrete pavement with the exception of the cracked slabs criterion, for which much lower values (5% to 15%) would be typical in jointed, unreinforced CIP concrete pavement. As noted previously, the reinforcing typically provided in JPrCP panels for transport and handling is usually sufficient to ensure that most precast panel cracks remain tight and do not deteriorate over the pavement service life. Therefore, a higher value can be applied to this criterion for JPrCP to account for cracks that might develop during transport, handling or placement of the panels, but that will not deteriorate.

The above criteria can be modified based on owner/agency experience with precast pavement systems or policy. For example, Caltrans has adopted a criterion of 10% maximum cracked slabs (Fugro Consultants, 2012). Modifications to the design criteria may impact the design thickness or other aspects of the PCP system. For example, decreasing the value for allowable slab cracking for any given design reliability level will increase the design pavement thickness unless other design modifications are made (e.g., reducing panel dimensions, providing panel prestressing, etc.).

Typical Thickness Design Constraints

Maximum and minimum PCP panel thickness may be limited by the thicknesses of existing pavement layers, overhead clearances, fabrication and constructability concerns, or pavement behavior considerations. Examples include:

- Panel thickness may be limited if the pavement profile is to be maintained and excavation of foundation material is either difficult (e.g., cement-treated or lean concrete base is present) or the use of thicker replacement panels may result in drainage problems, differential frost heave or other soil movements.
- The use of bedding material or mandated slab leveling material (e.g., grout-supported panels) will further reduce precast panel thickness if a preexisting pavement profile is to be maintained and foundation materials cannot be excavated to accommodate a thicker slab.
- Minimum panel thickness may be limited by cover requirements for embedded steel, minimum web thickness over (or under) load transfer dowel or tie bar slots, etc.
- Minimum panel thickness to control slab deflections (even when stress requirements are met through prestressing).

Maximum thickness limitations may drive the need for prestressing and/or higher-strength concrete, depending on structural and service life requirements.

Panel Size Selection and Joint Layout Considerations

Panel size impacts many aspects of the production, installation and performance of the precast panel and surrounding slabs, including:

- Fabrication efficiency (given a finite number of casting beds) and unit costs (reflecting both production efficiency and the need to purchase new forms for unusual panel sizes)
- Ability to transport via truck (typically a 12-foot maximum trailering width, including any protruding reinforcement or other features) without special permitting (see Chapter 7 for more information)
- Efficiency in transport (i.e., selection of panel sizes that can be shipped in combinations that fully use load-carrying capacity, thereby minimizing the number of trucks and trucking costs required for any given project; see Chapter 6 for more information)
- Impact of panel size on required installation equipment (e.g., size of crane or other lifting equipment and job space requirements to accommodate the equipment and delivery trucks) and location (see Chapter 9 for more information)
- Number and location of embedded lifting anchors
- Impact of panel size on panel transport and lifting stresses
- Impact of panel size on joint layout with respect to the joint layout of adjacent panels (repair applications)
- Impact of panel size and dimensions on resulting load placements and service stresses (both curl/warp and load-related)

Some of these factors are self-evident or are project/manufacturer-specific (e.g., fabrication efficiency, truck width restrictions, etc.) and are not discussed further here. Others are discussed later in this chapter. This section discusses more general panel size and joint location considerations.

Panel Dimensions: Limiting Maximum Size and Aspect Ratio

Panel dimension requirements for jointed precast pavement systems are typically considered to be the same as for conventional jointed plain (unreinforced) cast-in-place concrete pavement (JPCP) systems in similar applications. Panel widths are typically for the full paving lane (i.e., 10 to 14 feet) and panel lengths typically vary from a minimum of 6 feet for intermittent joint and mid-slab cracking repairs to 15 feet or more.

These dimensions are rooted in conventional panel dimensioning guidance for cast-in-place JCP, which suggests that the maximum panel dimension in feet should not exceed 1.5 to 2 times the slab thickness in inches and that the ratio of the panel length and width should not exceed 1.5 in order to prevent uncontrolled cracking. For an 8-inch-thick slab, for example, the maximum panel dimension would be limited to 12 to 16 feet (with lower values for placement on stabilized foundation materials and higher values for placement on softer, lower-friction granular materials). The corresponding ratio of panel length to width for 12- to 16-foot panels in a 12-foot lane width would be 1.0 to 1.33, a range lower than the 1.5 limit. Using these "rules of thumb," thicker pavements could have significantly longer panels, especially when placed on softer, lower friction foundations, but performance records in many states have resulted in a cap of 15 feet on JCP panel length (and JPrCP panel length, by extrapolation) in most states to prevent panel cracking. Improved prediction of potential cracking can now be performed using the AASHTOWare Pavement ME Design software, which may result in length/width combinations that fall outside of the guidelines described here and still provide good performance without panel cracking.

The above guidelines were developed to prevent uncontrolled cracking in unreinforced CIP concrete pavement, and it should be noted that the AASHTOWare Pavement ME Design software prediction models are also developed for unreinforced concrete pavement. Jointed precast pavement typically contains a significant amount of panel reinforcing (often 0.2% or more by cross-sectional area of concrete, in each direction, sometimes in conjunction with structural fiber reinforcing) that is provided primarily for transport and handling considerations and is not considered in the pavement structural or service design. This reinforcing has been shown to hold tight most – if not all – cracks that develop in service due to improper installation, service loads and environmental conditions (i.e., curl/warp stresses), provided the pavement is uniformly supported, similar to the way that the reinforcing in continuously reinforced concrete pavement (CRCP) holds tight the cracks that develop routinely in that type of pavement. Examples of this are shown and discussed in detail in Chapter 11.

Therefore, a case can be made that neither the panel dimensioning guidelines above nor the cracking performance criteria provided for JPCP in the AASHTOWare Pavement ME Design software are directly applicable to JPrCP, and longer panels with higher aspect ratios may provide acceptable service when needed, provided that the owner understands that panel cracks may develop (but that they will not deteriorate rapidly as they would in conventional JPCP). Longer panel lengths (up to 20 feet and possibly longer) can be used with reduced risk of cracking and crack deterioration if individual panels are prestressed (Tayabji et al., 2013).

Matching Transverse Joint Locations in Adjacent Lanes

It is generally recommended that precast panel transverse joint locations be matched as closely as possible with the transverse joints of adjacent panels, particularly if the precast panels are to be tied to adjacent lanes. This ensures that joint movements in either lane are not restrained by the adjacent lanes. When transverse joints are not aligned across adjacent lanes, cracks often propagate from working joints across the adjacent lane panels (Figure 4-1) unless the panels are isolated from each other (typically by eliminating tie bars and providing Styrofoam sheeting or other isolation material along the longitudinal joint) between the two transverse joints to allow unrestrained movement due to thermal expansion and contraction along the longitudinal joint (Figure 4-2). In addition, it is common to eliminate longitudinal lane tie bars and provide isolation material along the longitudinal joints for all intermittent repairs

Figure 4-1. Transverse sympathy cracking due to mismatched transverse joints.

Figure 4-2. Use of isolation material between mismatched transverse joints.

Figure 4-3. Concrete pavement with widened outside lane construction.

and whenever the lane repair length is 15 feet or less (see Chapter 9).

Considerations for Retaining the Existing Longitudinal Joint Layout

For both CIP and precast concrete pavement, longitudinal joints are generally placed to coincide with (or be very close to) designated lane lines because it is commonly believed that this minimizes the potential for driver error in mistaking a longitudinal joint for a lane line. It is sometimes necessary or desirable to locate longitudinal joints away from the pavement lane lines. Examples of this include:

- The use of widened outside travel lanes that are striped at the lane line but which extend 1 to 2 feet beyond that stripe to reduce load-related edge stresses (Figure 4-3).
- The addition of longitudinal joints down the center of ramps and other paving elements with widths that are significantly greater than 12 feet (Figure 4-4).
- The use of small pavement panels is common with concrete pavements that are 6 inches or less in thickness. For slab thicknesses of 5 to 6 inches, the panels are typically 6 feet square. Smaller panels have been used for thinner pavements, which typically places a longitudinal joint in the middle of the travel lane.
- Construction staging requirements sometimes dictate the placement of longitudinal joints within travel lanes in tightly constrained work areas.
- For precast concrete installations, it may be convenient to cast and place wider single panels that extend over more than one travel lane. For example, Figure 4-5 shows the placement of a single panel that extends over a travel lane and an adjacent parking lane in an urban setting. In this case, the precast panel was sawed at

Figure 4-4. Wide precast concrete ramp pavement in Long Island, N.Y., with a longitudinal joint in the center of the lane.

Figure 4-5. Installation of wide panels (travel lane plus shoulder) in Winder, Ga.

the lane line location to develop a weakened plane that would control the location of any eventual cracking (due to the large width and unusual aspect ratio of the precast panel) and to provide a visual lane line cue for traffic.

When longitudinal joints are placed within the travel lane, an effort should be made to avoid placing them within or near the primary wheel paths to avoid creating critical panel edge loads. Midlane longitudinal joint placement is the best first alternative to lane line placement. When longitudinal joints are placed within or near wheel paths, special attention must be paid to the structural design of the system (i.e., thickness and/or edge support provided by dowels, tie bars, keyways or other provisions).

Misaligned longitudinal joints also offer the same potential for sympathy cracking that misaligned transverse joints do. This problem can sometimes be avoided in a similar manner by using isolation material in the area between the mismatched joints so that they can move without being restrained by the adjacent panels. Alternatively, additional reinforcing can be placed transversely near the face of the panel edge that abuts the intersecting longitudinal joint to resist the propagation of any sympathy cracking.

Impact of Utility Access on Joint Layout

Utility structures and access points (manholes, drainage structures, etc.) can cause panel cracking problems if they are located too close to concrete pavement joints.
It is generally best to adjust joint patterns so that utility "knockouts" are as far as possible from panel joints, or, when they must be located close to a joint, locate a perpendicular joint between the knockout and the nearby joint at the closest point between the two.

The American Concrete Pavement Association has published guidance on jointing around utility structures that is generally applicable to both cast-in-place and precast concrete pavements (ACPA, 2007). Some example joint layouts for these situations that are taken from this reference are shown below (Figure 4-6). Note the use of isolation material around each embedded structure.

Consideration of Existing Expansion Joints

Expansion joints are constructed in new pavements to accommodate potential excessive slab expansion or movement without developing high compressive forces in the pavement that might otherwise result in joint spalling and blowups or damage to adjacent structures (e.g., bridge decks and approach panels). Potential sources of excessive

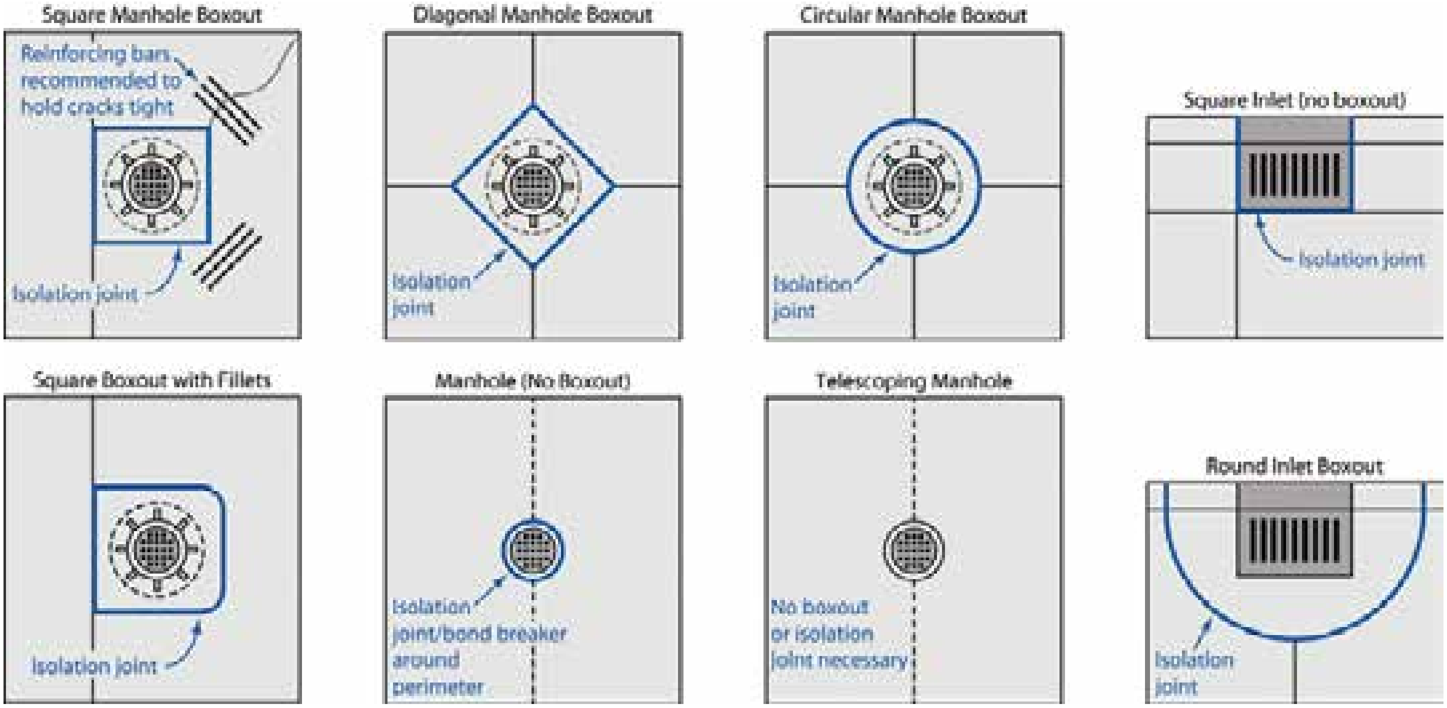


Figure 4-6. Examples of jointing adjustments to accommodate utility access points without inducing panel cracking (ACPA, 2007).

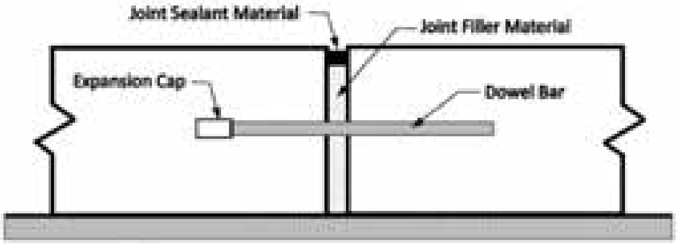


Figure 4-7. Example expansion joint schematic.

slab expansion and movement include alkali-silica reactivity, infilling of joints in cold weather followed by slab expansion in warm weather, and slab movement down steep grades. Good design practices, proper material selection and the maintenance of contraction joints have virtually eliminated the need for expansion joints, except at fixed objects such as bridges and other structures.

When an expansion joint is present in adjacent lanes within the boundaries of a precast panel installation, an expansion joint of similar width should be placed transversely at one end of the new precast panel, as close as possible to the existing expansion joint in the adjacent lane. If an expansion joint is not provided, the transverse joints on either side of the precast panel will close first and the panel will be subjected to very high compressive forces as it restrains the expansive forces of the adjacent lanes, resulting in the likelihood of joint spalling and/or a blowup.

When expansion joints are used, the pavement often moves to close the unrestrained expansion joint over a period of a few years. As this happens, several of the preceding and following contraction joints may open, eliminating the effectiveness of their seals (and any contribution of aggregate interlock to joint load transfer at joints in cast-in-place pavement). Therefore, the overuse of expansion joints should be avoided because it may result in sealant or filler failure, infiltration of water and incompressibles, and loss of load transfer.

Unlike isolation joints, which allow fully independent movement of adjacent structures, expansion joints typically include dowels or other load transfer devices and allow independent movement only in the direction of expansion (Figure 4-7). Expansion joint dowel systems typically have the same design, placement and alignment requirements

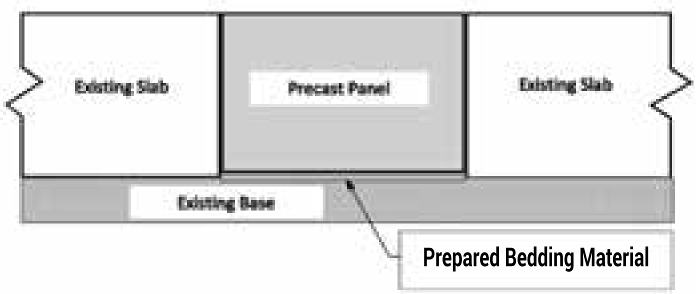


Figure 4-8. Schematic of grade-supported placement.

as are used for contraction joints, including size, spacing, location (vertically and laterally across the joint), corrosion protection and lubrication prior to paving. In addition, each expansion joint dowel must have a specially fabricated expansion cap on at least one end to allow the pavement to move freely as the joint expands and contracts. The expansion cap creates a space to accommodate the dowel as the joint closes. At the time of installation, the cap should provide the dowel with at least 1/4 inch more space than the width of the expansion joint; i.e., 1.25 inches of space for a 1-inch expansion joint (ACI, 2002). Expansion joints are typically constructed with initial widths of 3/4 inch or more using an expansion joint assembly. Joint sealant may be placed over the filler material after installation to help prevent the infiltration of water and incompressibles, but the sealant must be recessed sufficiently to prevent it from being pushed above the pavement surface as the joint closes.

Selection of Slab Support System and Impact on System Design

Uniform, durable support is crucial to the long-term performance of any concrete pavement system and the provision of full contact between the precast panel and the prepared foundation is one of the four critical elements in the precast paving process described in Chapter 1 and listed in Table 1-1. There are two general approaches to achieving this uniform panel support: grade-supported systems, where the panel is placed on a precisely graded foundation, and grout- or urethane-supported systems, where the panel eventually rests on a relatively thick (approximately 1/2-inch) layer of cementitious grout or urethane that is injected between the slab and prepared foundation.

Figure 4-9. Placement of grade-supported precast panel for overnight use prior to installation of bedding grout at Tappan Zee Toll Plaza in New York.

Each of these systems offers specific advantages and drawbacks during installation, and each has implications for the design of the JPrCP system. These aspects of slab support system selection are described below.

Grade-Supported JPrCP Systems

Grade-supported systems feature the construction of a precisely graded foundation that allows JPrCP panel placement to the proper elevation and with reasonably complete support, thereby allowing immediate opening to short-term traffic (Figures 4-8 and 4-9). This allows more effective use of short construction windows because installation activities do not need to be stopped to allow bedding grout to harden before opening to traffic – a second crew can perform that task during the next closure.

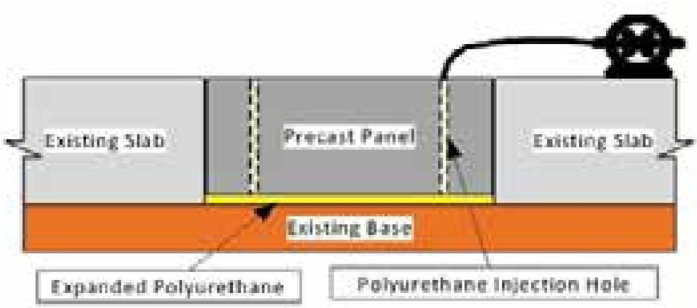
The primary disadvantage to grade-supported systems is the time and expense required for precise grading and trimming of the subbase and bedding material – a process described in Chapter 9.

The selection of a grade-supported system requires special design details. There will still be small, intermittent support gaps, even with the most precisely graded and bedded foundation materials. These small gaps must be filled with low-viscosity, high-strength material – typically a specialized

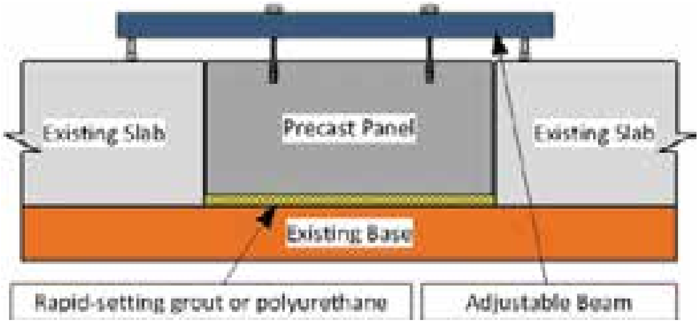
Figure 4-10. Proprietary grout distribution channels and gasket material on a Super-Slab JPrCP panel.

rapid-setting, cementitious grout – to ensure full contact with and uniform support of the slab. This requires the design, fabrication and use of some sort of bedding grout delivery, distribution and retention system. Bedding grout delivery is typically accomplished through ports from the panel surface to the bottom of the slab. Distribution of the grout can be achieved by using several delivery ports located using a sufficiently close pattern to allow complete distribution beneath the panel, or through a series of channels on the panel bottom that connects to the grout ports (Figure 4-10). This latter detail is a proprietary feature developed by The Fort Miller Co., Inc.

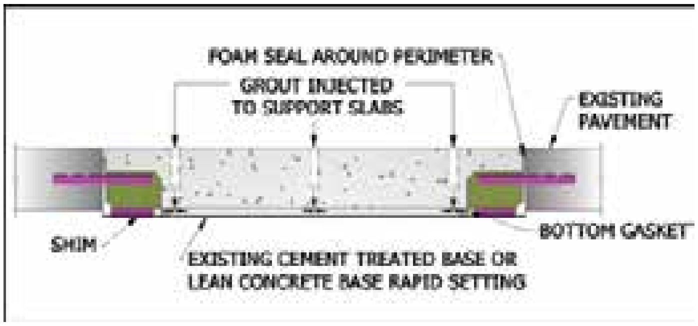
There must also be some means of confining the grout under the slab to ensure the development of enough grout pressure to fill all interface gaps, and to prevent the grout from flowing out from beneath the slab and filling surrounding joints. The Fort Miller Co., Inc., uses a proprietary approach involving the use of closed-cell "gasket" material that is glued to the bottom of each panel in the precast plant to define grout distribution bays (Figure 4-10). Non-proprietary approaches include the use of Styrofoam backer rod or similar materials placed at strategic locations on the graded surface prior to slab placement.



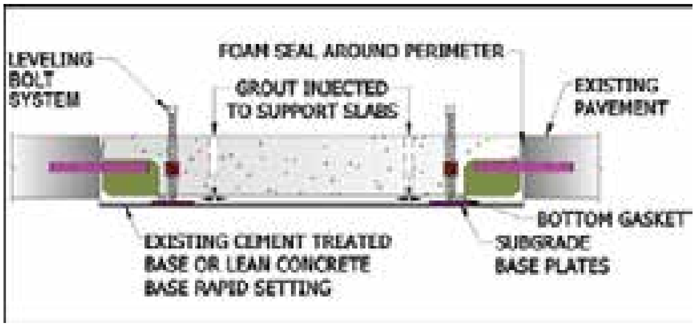
a. Pressure injection lifting using urethane.



b. Panel profile control using "strong-back" adjustable beam before grout injection.



c. Panel profile control using shims before grout injection.



d. Panel profile control using leveling bolt system before grout injection.

Figure 4-11 Illustrations of several variants of grout- and urethane-supported JPrCP systems.

Grout- and Urethane-Supported JPrCP Systems

Grout- and urethane-supported systems involve the support of the JPrCP panel by a layer of rapid-setting structural grout or expansive urethane foam approximately 1/2 inch to 1 inch thick. There are several options for establishing the desired pavement profile and gap for the grout or foam. The gap can be established by constructing the foundation to grade and using a slightly thinner panel, or by leaving the finished grade slightly low and using a full-thickness panel. In either case, the finished pavement surface profile can be established by using strategically placed support shims (typically stacks of thin, high-durometer rubber or high-density plastic), a screw-down bolt leveling system embedded in the panel or by "slab-jacking" – the repeated injection of grout or mortar through ports to gradually lift the panel into the desired position. Illustrations of several of these techniques are shown in Figure 4-11.

Grout- and urethane-supported systems offer the presumed advantage of reduced time and costs for precision-grading the foundation (precision-grading may be unavoidable if panels are to be opened to traffic before they are fully grouted, as discussed in more detail in Chapter 9), which can result in higher precast panel installation rates. The disadvantages of these systems include:

- Increased cost of panel fabrication for some systems (e.g., for installing lift device hardware)
- Need to cure the grout (typically 1 to 3 hours) or urethane (typically 15 to 60 minutes) before opening to traffic, thereby shortening the installation work window and reducing production rates
- High cost of the much greater volume of grout or urethane that must be used to fill the gap between the panel and the foundation
- Potential for slab cracking during installation – especially for the slab-jacking and leveling lift approaches – if the leveling process is not performed correctly

The selection of a grout- or urethane-supported system may also require special design and construction details. Panel lift and support mechanisms (e.g., lift devices, shim systems, strong-back beams, embedded slab connections, etc.) must be selected, designed and located in the as-constructed pavement to minimize stresses in the slab until it is fully and uniformly supported by grout or urethane. Similarly, slab-jacking ports should be considered physical support points during injection and must be located in a manner that does not induce excessive stresses in the panel during proper lifting operations. Finally, it is important to determine the size of the base plate for the lifting device. Base plate size (area) is a function of the type of base upon which the panels are being placed (e.g., concrete, dense-graded aggregate, etc.) and the size and weight of the panel. Base plate sizes may vary from as small as 4 inches by 4 inches by 1/4 inch (for placements on concrete base) to as large as 12 inches by 12 inches by 3/4 inch for large panels on aggregate base.

All operations that involve bringing the panel to profile (i.e., slab-jacking, operation of embedded lifting devices, etc.) must be performed according to a predetermined sequence that prevents the lifting or jacking of any one location more than 1/4 inch out of plane with the other panel support points at any time. This can involve repeated adjustments or injections at each lift or port. Over-jacking or over-lifting at any location can result in slab cracking. Techniques for controlling panel lifting range from sophisticated techniques, such as the use of high-precision survey equipment, to the use of simple string lines and tape measures. Many of the techniques used for slab stabilization and slab-jacking of settled CIP concrete pavement are useful for controlling the installation of grout and urethane beneath precast panels and are described in the National Concrete Pavement Technology Center's Pavement Preservation Guide (Smith et al., 2014).

All grout- or urethane-supported systems also require the design, fabrication and use of some sort of grout or urethane delivery and retention system using ports and closed-cell Styrofoam or other materials, as described previously for grade-supported systems. Grout distribution channels are typically not required to ensure coverage because the gap between the slab and foundation will not impede the flow of material. Steps should still be taken to ensure that adequate distribution is taking place (e.g., visual observation of material flow in adjacent ports). After hardening, nondestructive testing devices (e.g., ground-penetrating radar and ultrasonic tomography) can be used to verify coverage if there is any reason to believe that coverage may not be complete.

Thickness Design

Considerations and Design Procedures for Lane Replacements and Reconstruction

Design Procedures and Inputs

As noted at the beginning of this chapter, thickness design procedures that are specific to JPrCP have not yet been developed, so the design of JPrCP is currently based on available procedures for CIP concrete pavement systems.

While any agency-approved design approach for CIP concrete pavements can be used for designing JPrCP, the AASH-TOWare Pavement ME Design software is the most sophisticated pavement design system currently available and is recommended for use with JPrCP with appropriate inputs and performance criteria (AASHTO, 2014).

Recommended structural and functional performance design criteria for JPrCP systems are presented in Table 4-1. In addition, an assumed initial service life of 40 or more years is appropriate for most JPrCP installations. It is anticipated that only routine maintenance and preservation activities (e.g., joint resealing, diamond grinding to restore ride quality and friction, etc.) will be performed during this time.

Most other aspects of performing a design using the AASHTOWare Pavement ME Design software are identical to what is done or assumed for conventional CIP concrete pavement. However, the following design inputs deserve some additional consideration:

- The default value for permanent (built-in) curl/warp temperature difference for conventional JCP is -10 degrees F, which implies that the pavement surface sets and hardens in a condition that is similar to being cooler or drier on the top surface than the bottom surface. Since PCP panels are fabricated in rigid forms in a plant and usually stored on dunnage with free flow of air above and below the panels, they likely have very little built-in curling due to fabrication. However, it can be assumed that some permanent moisture gradient (warping) will develop after the panels are in contact with the ground after installation. Therefore, it is recommended that the Pavement ME Design default value of -10 degrees F be used for JPrCP thickness design until sufficient field data has been collected and analyzed to justify the use of a different value (Tayabji et al., 2013).
- Up to 50% ultimate shrinkage can be used in JPrCP thickness design because it is reasonable to assume that a large amount of the anticipated concrete shrinkage occurs during panel storage and before installation.
- Contact friction time is the time over which full contact friction between the slab and underlying base is assumed to exist. The Pavement ME Design default value for this parameter for conventional concrete pavements is 136 months (more than 11 years). The smooth, formed bottoms of precast panels are not believed to support much bond strength to the underlying layers and the presence of bedding material further isolates the two layers, so there is likely very little bond between the slab and subbase in most cases. The time to reduce that minimal bond is likely irrelevant to the thickness design. Despite this, Tayabji et al. (2013) recommend using the default 136-month contact friction period.

A sample thickness design analysis performed using an early version of the AASHTOWare Pavement ME Design methodology is presented in Tayabji et al. (2013).

Thickness Design Adjustments

Some agencies assume that two diamond grinding operations will be performed during the initial 40-plus-year service period, and that each grinding operation will remove up to 1/4 inch of pavement thickness. Therefore, it is not uncommon to increase the initial pavement thickness by up to 1/2 inch to compensate for future grinding activities. A greater increase may be necessary if planar slabs are ground to create non-planar surfaces, as discussed in Chapter 11. However, it should be noted that Rao et al. (1999) found that concrete pavement can be diamond ground up to three times "without significantly compromising its fatigue life" because the loss of thickness to diamond grinding is compensated for by long-term strength gains in the concrete.

When widened outside lanes are used (i.e., the outside lane width is increased by about 2 feet, but the lane stripe position doesn't change) or tied concrete shoulders are used, critical panel edge stresses are reduced, often making it possible to reduce panel design thickness by an inch or more without sacrificing expected service life. Most current concrete pavement design procedures can consider the effects of improved panel edge support (i.e., widened lanes and tied shoulders) on panel thickness design.

A minimum slab thickness of 10 inches should be considered for JPrCP on major highways, with even greater thicknesses (up to 14 inches) being commonly designed for heavy truck routes. The use of prestressing techniques can produce up to 200 psi compression in JPrCP panels to offset load- and environment-related critical tensile stresses, allowing thickness reductions of 3 to 4 inches relative to the thickness of conventional JPrCP panels (Tayabji et al., 2013). The design of panel reinforcement, including prestressing, is discussed later in this chapter.

Considerations for Intermittent Repairs

JPrCP panel thickness for intermittent repairs should generally be based on the thickness of the surrounding existing concrete pavement, the type of panel support selected and the type of underlying base material. Tayabji et al. (2013) make the following recommendations:

Grade-supported systems:

- For granular base, the JPrCP panel thickness should be at least 1/4 inch less than that of the surrounding concrete pavement to allow for the use of bedding material without over-excavating the existing base material. This practice may still result in the need to over-excavate the base if existing pavement is actually thinner than what was assumed in design.
- For stabilized base, the JPrCP panel thickness should be at least 1/2 inch less than that of the surrounding concrete pavement to account for any variability in the thickness of the existing pavement at the panel replacement location. If the existing pavement is much thinner than the nominal thickness, the replacement panel may be too thick, necessitating a time-consuming adjustment of the stabilized base profile or diamond grinding of a high repair, as discussed in detail in Chapter 8.

Grout- and urethane-supported systems:

- The JPrCP panel thickness should be about 1 inch less than that of the existing pavement to account for any variability in the thickness of the existing pavement at the panel replacement location and to leave a sufficiently large gap to allow free movement of the more viscous (sanded) cementitious grouts and urethane used.

It is always good practice to determine the thickness of the existing concrete pavement at all intermittent repair locations (e.g., by coring or excavating along the pavement edge) when stabilized bases are present. If the repair panel is even slightly thicker than the concrete being removed, the replacement panel surface will be too high and will result in poor ride quality, which could result in reduced repair service life. A conservative approach is to design slightly thinner panels (using a higher-strength concrete or prestressing, if necessary) to avoid this problem.

Impact of Slab Reinforcing on Thickness Design

Conventional JPrCP is typically designed with up to 0.2% (by area of concrete) deformed steel reinforcing in both the transverse and longitudinal directions (often in two layers, near the top and bottom of the panels). This reinforcing is intended primarily to meet ACI's requirement for resisting temperature and shrinkage stresses and to prevent catastrophic panel failures in shipping and handling (e.g., when being lifted by cranes in close proximity to workers). The relatively small quantities of reinforcing used and the position of the reinforcing in the panel (at or near mid-depth of the slab) make its contribution to panel structural capacity relatively small for typical panel thicknesses. Thus, the structural contribution of this reinforcing in structural thickness design is usually ignored, resulting in slightly conservative thickness designs.

Synthetic structural fiber reinforcing and steel fiber reinforcing have been used to supplement or partially replace conventional steel reinforcing in JPrCP. While research suggests that some increase in structural capacity (or decrease in slab thickness for the same capacity) is possible with sufficient quantities of structural fibers (Bordelon and Roesler, 2009), the results of this research have not yet been put into widespread practice for concrete pavement thickness design.

Prestressing techniques (either pretensioned strand embedded during fabrication or post-tensioning strands in embedded ducts) are effective in increasing the structural capacity of pavement slabs of any given thickness or in reducing the panel thickness required to achieve a given structural capacity. The design of prestressed JPrCP systems is presented in the next section of this chapter.

JPrCP Panel Reinforcing

The Need for Panel Reinforcing

Precast panels typically include substantial amounts of reinforcement to resist the stresses mentioned earlier in this chapter.

Conventional deformed steel reinforcing does little to prevent the development of PCP panel cracks because concrete cracks at relatively low strain levels – before the steel carries much load. Properly dimensioned and located deformed steel simply prevents the cracks from opening easily. The use of structural fiber reinforcing (as a partial replacement of or supplement to conventional steel reinforcing) generally serves the same purpose, but may also slow crack propagation.

Both conventional steel reinforcing and fiber reinforcing offer the added benefit of arresting the opening and deterioration of panel cracks under service conditions (whether those cracks formed prior to or after installation), thus helping to ensure superior long-term performance and ride quality.

Slab Reinforcing Techniques

Planar (flat) JPrCP panels are typically reinforced using one or more of the following materials:

- Deformed “mild” steel reinforcing bars
- Synthetic or steel structural reinforcing fibers in the concrete mixture
- Pretensioned steel strand installed at the time of panel fabrication

While fiber reinforcing can be used in conjunction with either mild steel or prestressing strands, prestressing strands should generally not be used in the same direction as mild steel reinforcing because the mild steel would resist the prestressing, reducing the effectiveness of that technique. Mild steel is sometimes used around the perimeter of prestressed panels; mild steel that is oriented parallel to prestressed steel should be located far enough away to avoid reducing the effectiveness of the closest prestressing strands.

Individual panels may be reinforced using different techniques in the transverse and longitudinal directions (i.e., mild steel in the 12-foot transverse direction and prestressing in the longer longitudinal direction).

Concrete prestressing (placing the concrete in compression to offset anticipated tensile stresses due to structural and environmental loads) can be accomplished in two different ways:

- “Pretensioning” refers to the installation and tensioning of prestressing strands in special fabrication forms prior to placing the concrete. After the concrete has been placed and has achieved sufficient strength to resist the initial prestressing forces (the release strength), the strands are cut or released and the bond between the concrete and the strand resists the relaxation of the strand, leaving the embedded portion of the steel in tension and the surrounding concrete in compression. Pretensioning in long-line beds works well for planar (flat) panels since the strands reside in a single plane during fabrication. It is sometimes impractical to reinforce non-planar (warped) panels by pre-tensioning since reinforcing for these panels needs to be placed in a non-planar configuration (see Chapters 6 and 7).

- "Post-tensioning" refers to the installation of narrow tubes or ducts in the concrete panel forms at designed locations. The concrete is cast around these ducts and other embedded panel components. Prestressing strands are threaded through these ducts after the panels have been placed and are tensioned on-site. Tension is maintained with special locking devices at the joint faces. The ducts may also be grouted after tensioning is complete. When multiple panels are to be connected and drawn together by the post-tensioning process (as they are in precast post-tensioned concrete pavement, mentioned in Chapter 1), the ducts must be maintained in very precise locations during fabrication to allow the strand to be threaded through all the panels.

Pre-tensioning is the most common form of prestressing for JPrCP systems. Post-tensioning is rarely used.

Design of Slab Reinforcing

Deformed Bars

Conventional steel reinforcing is typically included at a rate of at least 0.2% (by area of concrete), as described earlier in this chapter. The 0.2% reinforcing quantity appears to be based on experience and typical American Concrete Institute requirements for minimum steel content to resist temperature and shrinkage in structural concrete members (ACI, 2014). Panels are typically reinforced in each direction to prevent catastrophic and dangerous panel failures during lifting and handling operations. Long, narrow panels can be reinforced in only the long direction if there is no risk of panel failure in the short direction.

Some agencies require that conventional steel reinforcing be protected from corrosion (typically with a 5- to 10-mil coating of epoxy meeting the requirements of ASTM A775/A775M, "Standard Specification for Epoxy-Coated Steel Reinforcing Bars," or ASTM A934/A934M, "Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars") when used in environments with deicing chemicals, salt water exposure or other corrosive agents. Additionally, non-corrosive reinforcing bars meeting the requirements of ASTM D7957/D7957M, "Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement" or CAN/CSAS807, "Specification for Fibre-Reinforced Polymers," may be considered for design with approval of the owner agency. However, bare steel embedded in concrete is protected from corrosion through passivation and will not corrode, except where there is insufficient cover or at cracks, so epoxy coating is often not necessary.

Structural Fiber Reinforcing

Structural steel and synthetic fibers are increasingly being used in concrete pavement mixtures to enhance the fracture toughness and postcracking behavior of the concrete. Recommended dosages range from 3 to 7 pounds or more of synthetic fibers per cubic yard of concrete. Steel fiber dosages are significantly higher (25 to 50 pounds or more per cubic yard of concrete) because of the higher density of steel. These products should be used with careful consideration of the manufacturer's recommendations and after preparing trial batches to ensure that the resulting fiber-reinforced concrete has uniformly distributed fibers, acceptable workability and finishing characteristics, and good hardened properties. The use of steel fibers should be considered carefully if a tined surface texture is specified because the texturing process may pull some surface fibers into a vertical orientation. This may be perceived as a tire puncture hazard by some agencies.

Table 4-2. Immediate and Long-Term Effective Prestress Levels
for Various Panel Thicknesses and Strand Spacings – 1/2-inch-diameter, low-relaxation strand, 202,000-psi initial strand stress
(after Tayabji et al., 2013).

Panel Thickness (in)	Immediate Effective Prestress Level (psi) for Strand Spacing of:			Long-term Effective Prestress Level (psi) for Strand Spacing of:		
	24 in	30 in	36 in	24 in	30 in	36 in
8	161	129	108	131	105	88
9	144	115	96	117	94	78
10	129	103	86	105	84	70
11	117	94	78	96	77	64
12	108	86	72	88	70	58

Pre-tensioned Strand

The use of embedded, pretensioned strand is the method most commonly used in JPrCP to offset the additional slab stresses that are developed when unusually long or wide panels must be fabricated. Pretensioning can also be used to provide adequate structural capacity while reducing panel thickness (e.g., in areas where overhead clearances must be maintained or improved and additional foundation excavation is not feasible).

Pretensioning is typically accomplished using 1/2-inch-diameter 7-wire low-relaxation strands. These strands are tensioned to a stress of approximately 202,000 psi (75% of the 270,000-psi yield stress) using a force of 31,000 pounds per strand. There are some immediate and longer-term prestress losses after panel fabrication due to concrete creep, drying shrinkage and steel relaxation, so the net long-term strand stress is often assumed to be about 165,000 psi, or 25,300 pounds per strand. This level of stress is usually assumed to be available for concrete stress reduction at locations 25 inches or more from the joint face (the prestress transfer length); a linear reduction of available prestress force can be assumed over the prestress transfer length (from approximately 25,000 pounds/strand at 25 inches to zero at the joint face).

The reduction in slab tensile stress in the direction of pre-stressing at any given point can be estimated as the effective prestress force (a function of the strand tension, the spacing of the strands and the distance of the point of

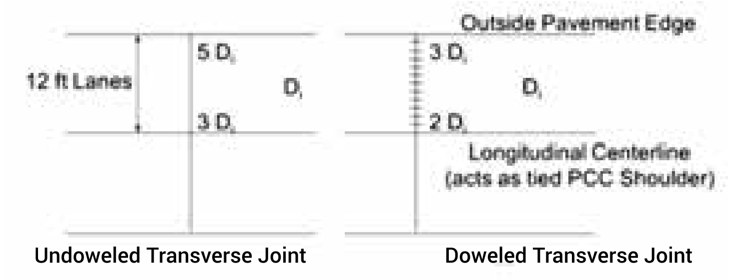


Figure 4-12. Illustration of relative concrete pavement deflections under loads placed at the slab interior and corners for un-doweled and doweled transverse joints. D_i = deflection due to interior loading.

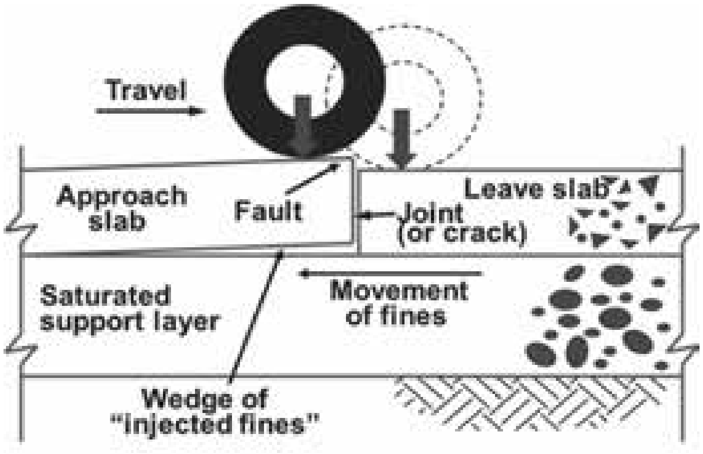


Figure 4-13. Illustration of pumping mechanism in jointed concrete pavement.

a.

b.

Figure 4-14. a. A typical falling weight deflectometer (FWD); b. Close-up of a load plate positioning near transverse joint for assessment of load transfer system.

interest from the panel edge/end of the strand) divided by the cross-sectional area of affected concrete. For example, for an 8-inch slab with strands spaced 24 inches apart, the affected area of concrete for each strand is 8 x 24 = 192 square inches. Therefore, the immediate effective prestress at a distance of more than 25 inches from the panel edge is 31,000 pounds/192 square inches = 161 psi and the long-term effective prestress is 25,300 pounds/192 square inches = 131 psi. Immediate and long-term effective prestress values for common panel thicknesses and strand spacings are presented in Table 4-2.

Tables of this sort can be very useful in design. For example, suppose that a 9-inch-thick JPrCP panel has a flexural strength, f’r, of 700 psi and that design criteria require that flexural stresses be limited to no more than 50% of strength (i.e., 350 psi) to prevent the development of fatigue cracking. The engineer may be constrained to use a 9-inch panel thickness and may desire to use an unusually long panel size to optimize production rates or to reduce unit shipping costs, but finds that the critical longitudinal stress in this panel (due to combined temperature, curl/warp and vehicle load effects) is 450 psi. A 100-psi reduction in stress is required in the long-term, and Table 4-2 indicates that this can be accomplished using 1/2-inch-diameter strand on 24-inch centers (117-psi stress reduction). Other options for reducing the stress to acceptable levels include the use of shorter and/or thicker panels.

It is possible to use pre-tensioned strand to reduce critical stresses in thin precast paving panels to acceptable levels, but the thin pavement may still exhibit unacceptable deflection characteristics that can be addressed only with added pavement thickness or increased panel support.

Load Transfer Systems

“Load transfer” refers to the action or ability of a joint to share a portion of applied loads across the joint. This is most reliably accomplished using mechanical devices like smooth dowels, but can also be achieved to varying degrees with deformed reinforcement bars (i.e., tie bars), formed keyways in the joint faces and aggregate interlock (the irregular texture that exists when a crack forms below the sawed joint in CIP concrete pavements). This section describes factors that should be considered in the design of load transfer systems, another of the four critical elements for JPrCP systems listed in Table 1-1.

Importance of Joint Load Transfer

Concrete pavement slabs deflect in response to applied vehicle loads. The magnitude of the deflection depends on many factors, including the magnitude and position of the load, the slab thickness and stiffness, and the overall stiffness of the foundation system. Loads applied in the interior of the slab – away from panel edges – produce the lowest deflections (shown as D_i in Figure 4-12) while loads applied at unsupported pavement edges and corners produce much higher deflections because they are effectively supported by only 1/2 or 1/4 of a slab (for example, see the much higher deflections shown for the slab corners in the undoweled example in Figure 4-12). When load transfer devices are used to support the edge or corner of the loaded panel through connections with the adjacent panel, edge and corner deflections can be greatly reduced (see the doweled transverse joint example in Figure 4-12).

Load-related stress develops in concrete pavements roughly in direct proportion to the magnitude of the slab deflection, so load transfer devices play an essential role in reducing slab stresses (and, therefore, eventual panel cracking) at critical locations. Reducing differential or relative deflections across joints (i.e., the difference in deflections on either side of a loaded joint) is also beneficial because these deflections promote the movement of free water and fines in the pavement foundation layers (see Figure 4-13), which can result in erosion of the foundation, loss of panel support, and eventual joint faulting (a difference in panel elevations on either side of the joint) and corner cracking. Therefore, load transfer devices play a crucial role in the performance of jointed concrete pavements.

Load Transfer Measures and Evaluation Criteria – LTE vs. Relative Deflection

The effectiveness of any given load transfer system is typically tested in the field using a falling weight deflectometer (FWD), a sophisticated piece of trailered equipment that drops a mass package through a fixed distance onto a 12-inch-diameter load plate positioned adjacent to the joint (to simulate the passage of a 9,000-pound single wheel load) and then determines the deflection directly beneath the load and the corresponding deflection on the other side of the joint (Figure 4-14).

Historically, the load transfer system effectiveness has been assessed by computing the deflection-based load transfer efficiency as follows:

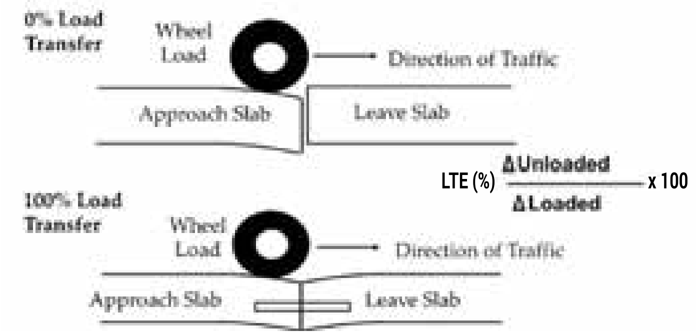


Figure 4-15. Illustration of load transfer efficiency calculation for a range of joint behaviors.

$$\text{LTE }(\%)=100(\Delta_{UL}/\Delta_{L})$$

Where LTE is the load transfer efficiency of the joint in percent, Δ_L is the deflection at the center of the load plate and Δ_{UL} is the deflection 6 inches from the joint on the unloaded side of the joint. LTE values theoretically range from 0 (corresponding to no deflection on the unloaded side) to 100 (corresponding to equal deflections on both sides of the joint – see Figure 4-15). In practice, LTE values rarely approach 0 and are usually slightly less than 100 but can slightly exceed 100 due to testing anomalies with certain pavement structures.

Unfortunately, deflection-based LTE reflects the effects of many pavement design factors, including soil stiffness, foundation stiffness, slab thickness, joint opening, dowel design, temperature and moisture gradients in the slab at the time of testing (and more), so it cannot be used alone to assess the quality of the load transfer system (Snyder, 2011). Furthermore, LTE measures alone can lead to incorrect assessments of load transfer system quality.

A more reliable and pure measure of load transfer system effectiveness is relative or differential deflection (D_{rel} or DD), which is expressed simply as:

$$\text{DD or } D_{rel} = \Delta_L - \Delta_{UL}$$

An example use of deflection measurements for JPrCP load transfer acceptance is presented later in this chapter.

Figure 4-16. Half-embedded dowels in a JPrCP panel.

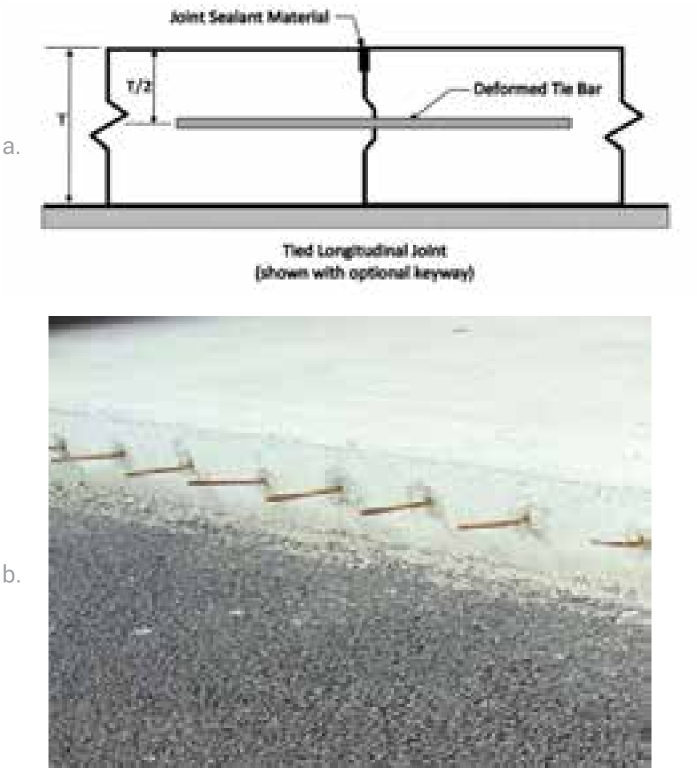


Figure 4-17. Schematic of a tied longitudinal construction joint with optional keyway and photo of tie bars along longitudinal joint. Sources: a. American Concrete Pavement Association; b. Pavement Engineering and Research Associates, LLC

Dowels, Tie Bars and Keyways – Uses and Limitations

The devices and mechanisms most commonly relied upon for load transfer in concrete pavements are dowel bars, tie bars, keyways and aggregate interlock. The uses and limitations of the first three are discussed here; aggregate interlock is not present at the formed faces of PCP systems so it is not discussed further.

Figure 4-18. Keyways on longitudinal joints of precast pavement panels.

Dowel Bars

Dowels are smooth-surfaced mechanical devices that are installed parallel to the direction of primary slab expansion and contraction (usually the longitudinal axis of the highway) to provide vertical load transfer while also allowing longitudinal movements to take place at contraction and expansion joints (usually transverse joints). Dowels are most commonly made from cylindrical carbon steel (with or without a corrosion-protective layer, such as epoxy) and are typically 18 inches long, 1.25 to 1.5 inches in diameter and are spaced on 12-inch centers across the joint (Figure 4-16). Other materials, shapes and sizes have also been used, as is discussed later.

When properly designed and installed, dowels provide the most reliable form of mechanical joint load transfer for concrete pavements.

Tie Bars

Tie bars are devices placed across pavement joints to provide restraint in both the vertical and horizontal directions. Deformed reinforcing bars are most commonly used for this purpose, with a diameter of 1/2 to 3/4 inch (#4, #5 or #6 bars), placed on 24- to 48-inch centers and with sufficient length to allow the transfer of tensile forces (to prevent joint opening) from the bar into the concrete slabs on either side (Figure 4-17).

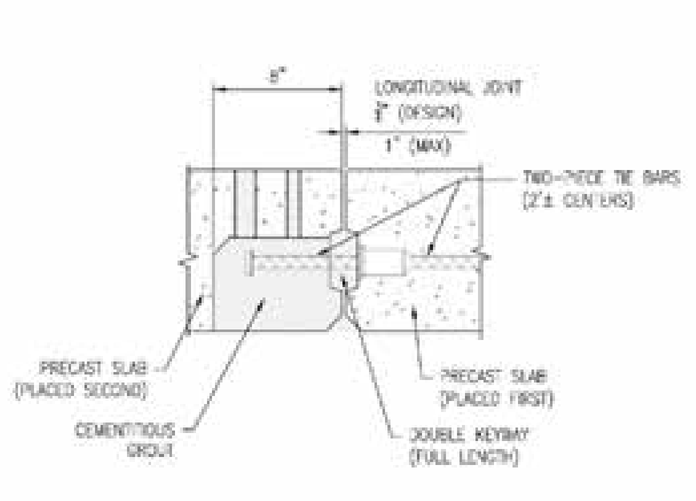


Figure 4-19. Schematic of typical double-keyway load transfer system for longitudinal joints in JPrCP systems.

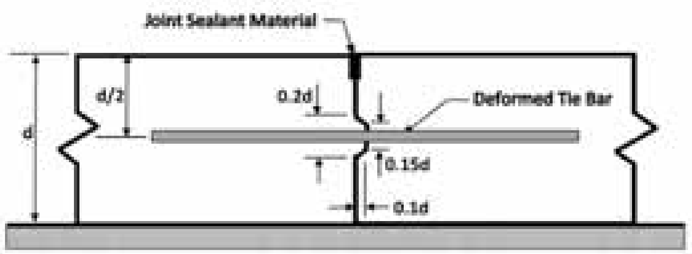


Figure 4-20. Recommended keyway dimensions for highway pavements ≥ 10 inches thick.

Tie bars alone provide very little vertical load transfer capacity because of their wide spacing and relatively small diameter. They are typically used to enhance the load transfer effectiveness of aggregate interlock (which is not present at formed JPrCP joint faces) and keyways, which are most effective if the joint remains tight. Tie bars with diameters and spacings like those used for dowel bars can provide both joint restraint and load transfer, but this type of tie bar design is rarely used.

Keyways

Keyways (or "keyed joints") are formed during the slab fabrication process for both CIP and precast paving slabs. A designed slot (indentation) or key (extrusion) is formed along the length of the vertical surface of the joint to provide vertical interlock with slots or keys formed in adjacent slabs (Figure 4-18). JPrCP panels are often constructed with keyway slots on the joint faces of slabs on either side of the longitudinal joint. The key or load transfer mechanism is then formed by filling this double-slot with cementitious grout during construction (Figure 4-19).

Recommended keyway dimensions for CIP concrete pavements greater than 10 inches thick are shown in Figure 4-20 and are also appropriate for typical JPrCP applications. Keyway height (shown as 0.2d in Figure 4-20) can be up to 1/3 the slab thickness and should not be less than 2 inches to avoid keyway shear failure problems. Most JPrCP panels are less than 10 inches thick; in these cases, keyway depth is typically held at 0.75 inches (rather than 0.1d). Keyways should also be located near mid-depth of the slab to maximize strength of the keyway and supporting concrete above and below the keyway. Note that the top and bottom of the slot or key are usually chamfered to facilitate form stripping and the consolidation of concrete or mortar in the forming process and in the interlock process. When the slots and keys are chamfered, the keyway is only effective while the joint remains tight and the key is fully engaged in the slot. When the joint opens, a vertical gap will open between the key and the slot, greatly reducing vertical load transfer capacity. For this reason, keyways are typically used in conjunction with tie bars to form a more complete and reliable load transfer system.

Another common problem with keyways is that they are subject to shear damage – the key may be sheared off due to poor key design (inadequate key depth), excessive loads, poor consolidation of concrete or other mechanisms. Load transfer will be lost when this type of damage develops.

Dowel Load Transfer System Design

The design of dowel load transfer systems is discussed at length by Snyder (2011). The discussion below summarizes portions of that document.

Dowel Diameter or Size

"Dowel bar diameter [or size] is an integral part of the design of the rigid pavement structural system [cast-in-place or precast] and should be determined as a part of the overall pavement design/evaluation process because it directly affects pavement performance … Dowel diameter should not be selected independently of pavement design, nor even as a simple function of pavement thickness" (Snyder, 2011).

Dowel load transfer systems must be designed to prevent foreseeable failures due to shear, bending and dowel bearing stress on concrete, and excessive joint movements.

Dowel bars transfer load through both shear and moment mechanisms, but it has been shown that the primary load transfer mechanism is shear. Moment can be ignored, especially for joint widths of 1/4 inch or less.

The amount of load carried in shear through any dowel can be estimated by considering the legal wheel load (typically considered to be 9,000 pounds for a single wheel of a single axle) placed adjacent to the transverse joint and directly over the dowel closest to the pavement edge (Figure 4-21). The load will be transferred across the joint by all dowels within a certain distance of the applied load – the "radius of relative stiffness," ℓ, which is calculated as:

$$\ell = (E_C h^3/12k(1-\mu^2))^{0.25}$$

where E_C is the elastic modulus of the concrete (psi), h is the slab thickness, k is the composite modulus of subgrade stiffness (psi/in) and μ is the Poisson's ratio of the concrete. In other words, the radius of relative stiffness varies with the thickness and stiffness of the slab and varies inversely with the stiffness of the foundation and has a value between 24 and 36 inches for most concrete pavement structures. Therefore, the edge load is typically shared by 3 to 4 dowels, which carry the load in inverse linear proportion to their distance from the applied load (i.e., less load is carried by dowels that are further away from the load), as is shown in Figure 4-20. In this example (taken from Appendix B of Snyder, 2011), the dowel directly beneath the load carries almost half of the load that is transferred across the joint.

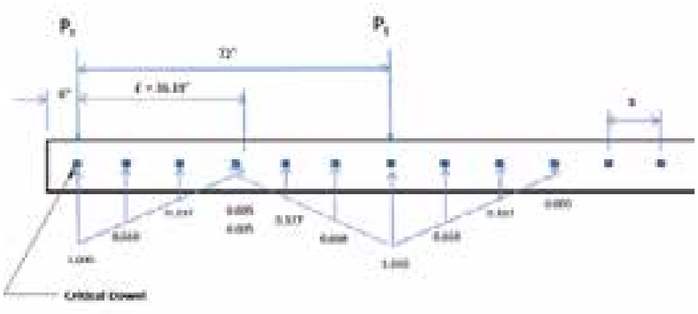


Figure 4-21. Sample computation of individual dowel shear loads within a dowel group. P_t is the transferred wheel load and S is the dowel spacing.

If the dowels are properly anchored or embedded in the concrete and the load is placed directly adjacent to the joint, the dowels will transfer 40% to 45% of the applied load to the adjacent slab, with the rest being carried by the loaded slab and transferred into the foundation. For a 9,000-pound wheel load, 45% transfer is slightly more than 4,000 lbs. If half of that is carried by the dowel beneath the load, that is approximately 2,000 pounds, and all other dowels will carry less than that. This is a typical paving dowel design load. The value varies with dowel design and spacing, slab stiffness, foundation stiffness and other factors, but rarely exceeds 3,000 pounds.

The design load for the critical dowel can be used to check the shear and bending capacity of the dowel. Allowable shear stress is often assumed to be 40% of the yield (24,000 psi for Grade 60 steel) while bending stress can be limited to 80% of the yield (48,000 psi for Grade 60 steel). By inspection, a load of 2,000 to 3,000 pounds applied to even a 1-inch-diameter

Figure 4-22. 2013 photos of conventional paving (left) and precast repairs (right) using only wheel path dowels on Illinois Tollway projects.

dowel over a 1/2-inch joint width produces shear and bending values that are far below these numbers. Of more significance is the bearing stress between the dowel and the concrete and the relative deflections of the two sides of the joint.

Bearing stress, σ_b, can be estimated using the following equations:

$$\sigma_b = KP_t(2+\beta z)/4\beta E_d I_d$$
$$\beta = (Kd/4E_d I_d)^{0.25}$$

where P_t is the transferred load carried by the critical dowel, K is the modulus of dowel-concrete interaction (typically assumed to be 1,500,000 psi/in), z is the joint width at the dowel bar, E_d is the modulus of elasticity of the dowel, I_d is the moment of inertia of the dowel ($\pi d^4/64$ for round dowels, where d is the dowel diameter in inches) and β is the relative stiffness of the dowel embedded in the concrete. Details concerning the calculation of dowel-concrete bearing stress are presented in most standard pavement design texts as well as Appendix B of Snyder (2011).

Bearing stress is typically limited to some multiple of the concrete compressive strength. The only widely accepted and published guideline on bearing stress limited values to $f'_c(4-d)/3$ (d=dowel diameter, inches) and was reported to provide a factor of safety of 2.5 to 3.2 against bearing stress-related cracking. This guideline was withdrawn soon after publication, but is still commonly cited today. Indirect consideration of bearing stress is included in the current AASHTOWare Pavement ME Design software, which models joint faulting as a function of dowel size and stiffness parameters.

Relative deflection of the joint is most easily determined using finite element analysis programs to model specific pavement structures or through FWD testing of trial installations (as discussed later in this section). LTE has been used to evaluate load transfer system behavior and values of 70% to 80% are often considered thresholds for corrective action. However, LTE is not currently considered to be an ideal measure of load transfer system effectiveness, as discussed earlier in this section, and it is not recommended for further use.

Bearing stress and relative deflection values can generally be improved by one or more of several approaches, including: larger dowels, stiffer dowel materials, closer dowel spacing and reduced joint width.

Dowel Length (Embedment Requirements)

The lengths of conventional cylindrical steel dowels in the U.S. have converged to a standard practice of 18 inches in new pavement construction. This length reflects a minimum accepted embedment length of 6-to-7 inches and a tolerance

Figure 4-23. Precast panels with dowels translated vertically downward to provide thicker concrete over slots.

Figure 4-24. Dowels retrieved from Minnesota pavements after 17 years or more of service.

on placement of joint saw cuts within 2 to 3 inches of the centers of the embedded dowels.

Since the 1950s, research repeatedly indicates that only about 4 inches of cylindrical steel dowel embedment is necessary to achieve adequate load transfer in concrete pavements and it is increasingly recognized that there is little to no variability in joint location relative to the dowel centers in precast panels, dowel bar retrofits and other repair applications. This information has led some agencies to reduce dowel length requirements to 12 to 14 inches for these types of applications. For JPrCP systems, this offers the added benefit of shorter dowel slots, which reduces fabrication costs and grout costs during installation and results in shorter zones of possible panel weakness.

Dowel Location

Common practice is to place 11 or 12 dowels on 12-inch centers across the entire transverse joint (starting either 12 or 6 inches, respectively, from the pavement edge, assuming a 12-foot-wide panel). If traffic loads are expected to be highly channelized over most of the life of the pavement, dowels near the middle of the panel can be eliminated because they carry very little load. Many agencies use 3 to 5 dowels per wheel path in both conventional paving and precast paving (e.g., Illinois Tollway, Utah DOT and others), as shown in Figure 4-22.

If long-term traffic shifts will place wheel loads at locations other than the normal wheel path (e.g., during construction phasing or at variable-width access ramps and intersections), then dowels should be used across the entire joint to avoid the development of longitudinal stress cracks due to wheel loads in undoweled locations.

Vertical Dowel Placement

Dowel load transfer systems have traditionally been installed at mid-depth of the pavement to maximize the concrete cover and associated shear resistance above and below the dowel. However, studies have shown that there is no apparent adverse effect on joint behavior or pavement performance when the dowels are shifted vertically (in either direction) within limits (Khazanovich et al., 2009; Odden et al., 2003; Popehn et al., 2003).

There is a benefit to be gained in shifting dowels vertically within JPrCP panels when using dowel slots. Moving the dowels (up for top slots or down for bottom slots) to provide the minimum required concrete (grout/mortar) cover (typically considered to be 2.5 to 3 inches) reduces the depth of the required slot. This strengthens the precast panel near the slotted joint (particularly in combination with the use of shorter dowels and slots, as described previously) and reduces the costs of fabrication and filling the slots with

Figure 4-25. Examples of available corrosion-resistant dowel products.

high-strength grout during installation. This approach has been used successfully on several projects (Figure 4-23).

Alternate Dowel Materials and Shapes

Solid, cylindrical carbon steel dowels (often epoxy-coated for corrosion protection) are most commonly used in both CIP and precast concrete pavements. However, other types of dowel materials and shapes are seeing increased use, particularly for pavements with longer service life expectations.

Corrosion-resistant and Non-corroding Dowels

Conventional epoxy-coated dowels provide good protection against dowel corrosion if the epoxy layer remains intact. Unfortunately, normal manufacturing processes often leave small defects in the coating (called "holidays"). Coatings can also be damaged in normal shipping, handling and construction operations. When defects or damage is present, water, oxygen and chemicals (such as deicers and salt spray from marine environments) can enter pavement joints and travel along the dowel-concrete boundary to find points for attacking the steel, resulting in corrosion and possible joint restraint, loss of load transfer and pavement damage (Figure 4-24).

Dowel corrosion has been identified as one of the problems that must be addressed to successfully design and construct "long-life [or high-performance] concrete pavements" (which have been defined as concrete pavements with a design life of 40 or more years with no premature failure and no further required construction activity other than normal maintenance (Tayabji and Lim, 2006). Several manufacturers have developed dowels that are intended to address this need (Figure 4-25). Available products include solid and tubular stainless steel, stainless steel-clad carbon steel dowels, epoxy-coated carbon steel that has been press-fit into a stainless steel tube, zinc alloy-clad carbon steel dowels (both solid and tubular), epoxy-coated galvanized tubular carbon steel, solid and tubular fiber-reinforced polymer (FRP), FRP-encapsulated carbon steel, microcomposite steel, carbon steel with thicker epoxy coating, carbon steel with a special hardened epoxy layer over the ASTM A775 epoxy coating, and more.

These products are all reported to have unit costs that range from "slightly more" to "two to three times more" than those of conventional epoxy-coated carbon steel dowels, but those costs have been deemed worthwhile by many agencies for projects where high volumes of heavy traffic make frequent maintenance and repair operations highly undesirable (e.g., urban freeways and similar routes). Since JPrCP systems are used in similar applications with similar long-life performance expectations, the use of corrosion-resistant or non-corroding dowels should be considered any time the expected JPrCP service life exceeds 20 years.

Extractable Dowels for Utility Cuts and Incremental Reconstruction

It is sometimes beneficial or necessary to add new PCP panels adjacent to panels that were placed intermittently several years before as the existing concrete roadway around the originally placed precast panels continues to deteriorate. It is also reasonable to expect that PCP panels placed over utilities in urban areas may need to be removed and replaced periodically for future utility access. In both cases, top slots and solid conventional (or longer-life) dowels can be used to accomplish the tasks. However, most JPrCP placements in the U.S. to date have used bottom-slot construction and a different approach must be taken to preserve the clean surface of these panels.

To accomplish this, The Fort Miller Co. developed and patented the "Super-Dowel" concept, which involves the use of hollow dowels (with epoxy-coating or other corrosion-resistant material) and embedded threaded nuts in each end. The hollow design facilitates sawing through the dowel to remove the precast panel (or the adjacent concrete) and the embedded dowel half that remains in the pavement can be extracted with a threaded rod and air wrench or cordless drill. The remaining dowel hole is cleaned and a new "Super-Dowel" can be installed prior to replacement of the cleaned-up panel (or a new bottom-slot panel for incremental reconstruction). This concept is discussed and illustrated in more detail in Chapter 13.

Plate Dowels

Plate dowels are flat steel plates that are commonly used as dowels in industrial paving and are beginning to show up in some roadway and parking lot paving projects (particularly those associated with industrial facilities, such as truck loading terminals, warehouses, etc.). Plate dowels of various thicknesses and shapes (e.g., rectangular, tapered, diamond-shaped, etc.) are available for different purposes. Plate dowels typically provide larger bearing surface at the joint, so bearing stresses are lower. They are also typically designed to allow some movement in all horizontal directions, so they are especially useful for paving large areas where lateral restraint provided by dowels and tie bars near panel corners sometimes causes slab corner cracking.

The use of plate dowels in PCP systems has not yet been reported, but is possible in applications like those where they are being used in conventional CIP paving.

Dowel and Tie Slot Systems – Design, Fabrication and Construction Considerations

Dowels and tie bars can be incorporated in PCP systems in several ways:

- Half-slots, where the dowel or tie bar is half-embedded in one panel and inserted in a slot in the other panel
- Full slots, where both panels are either fabricated with top or bottom slots or where top slots are cut in both panels after panel placement and the dowels or ties are placed on chairs in the slot or on grade
- Dowels can be placed in deep cylindrical holes in one slab and slid into receiver holes in the adjacent panel after panel placement

In all cases, the dowels or tie bars must be fully embedded or encapsulated on both sides of the joint before opening to permanent service traffic. Photos of typical slot system configurations are presented in Figure 4-26.

Figure 4-26 also shows that there are several variants of these slot systems, especially the top slots. Half-slot tie bar installations sometimes use two-part threaded tie bars, often with headed designs to reduce slot length. These are described in a subsequent section of this chapter and in Chapter 9. The pros and cons of each type of system are summarized in Table 4-3.

Approval of New Load Transfer Systems

PCP load transfer systems can be developed using many dowel materials, sizes, shapes, lengths, spacings, slot systems, and locations, and even different materials for filling the slots after the dowels have been installed (including a variety of cementitious grouts and mortars, polymer concrete and more). While some agencies have preapproved certain load transfer systems, innovative contractors and manufacturers are constantly striving to develop and use systems that may offer improved performance, more rapid installation and/or lower costs. There are several approaches to determining whether any given proposed system is likely to produce acceptable results, including proven use in service in PCP field installations at other locations, demonstration of acceptable behavior in field trial installations and demonstration of acceptable behavior in accelerated load testing (field or laboratory). Each of these


(a)

(b)

(c)

(d)

(e)

Figure 4-26. Photos and schematics of typical slot systems used for JPrCP dowels and tie bars: (a) conventional wide-mouth full top slot; (b) narrow-mouth top-slot sliding dowel; (c) Illinois Tollway top-slot system; (d) Fort Miller Super-Slab bottom slot; (e) Barra-Glide center slot.

Table 4-3. Pros and Cons of Various Dowel and Tie Bar Slot Designs

TECHNIQUE	PROS	CONS
WIDE TOP SLOT (GENERIC)	• SAME AS DOWEL BAR RETROFIT • CONTRACTORS FAMILIAR WITH EQUIPMENT AND METHOD	• SANDBLASTING OF SLOT SIDES REQUIRED – BOND IS CRITICAL • SLOTS MUST BE FILLED BEFORE SLABS MAY BE USED • DOWEL GROUT EXPOSED TO ROAD SALTS
NARROW TOP SLOTS (IL TOLLWAY METHOD)	• SLOTS NEED NOT BE FILLED TO OPEN SLABS TO TRAFFIC • DOVETAIL SHAPE OF SLOT PROVIDES MECHANICAL AS WELL AS BOND RESISTANCE TO DOWEL POP-OUT • GENERIC – NON-PROPRIETARY	• MAY BE DIFFICULT TO ENSURE PROPER EPOXY-ANCHORING OF DOWELS IN ADJACENT SLABS • DOWELS MUST BE FIELD-INSTALLED – CAN NOT BE CAST IN SLABS • LONGER DOWEL SLOTS REQUIRED
BOTTOM SLOT (FORT MILLER)	• VERY EFFECTIVE LOAD TRANSFER – NO SANDBLASTING REQUIRED • FULLY TESTED • DOWEL GROUT PROTECTED FROM ROAD SLOTS • CLEAN TOP SURFACE	• PROPRIETARY • ACCURATE CASTING IN SHOP REQUIRED – CANNOT BE CHANGED IN FIELD
BARRA GLIDE (RAPID ROADWAY)	• CLEAN TOP SURFACE • QUICK OPENING (LATEX GROUT) • LESS "WEAKENING" OF SLAB THAN DEEP SLOTS • FEWER CONFLICTS WITH SLAB REINFORCING	• MAY BE DIFFICULT TO ENSURE PROPER EPOXY-ANCHORING OF DOWELS IN ADJACENT SLABS • DOWELS MUST BE FIELD-INSTALLED – CANNOT BE CAST IN SLABS • LONGER DOWEL SLOTS REQUIRED • PROPRIETARY

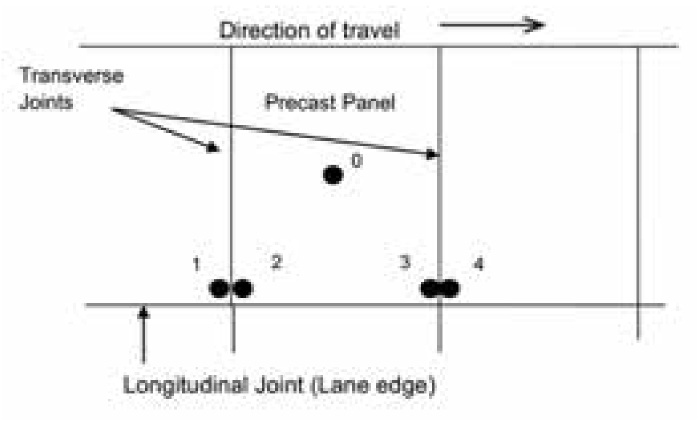


Figure 4-27. FWD test locations for field evaluation of proposed load transfer systems (after Caltrans, 2015).

techniques is discussed below.

Proven Performance in Field Installations by Other Agencies

It may be acceptable to submit proof of performance of a proposed PCP load transfer system that has been approved for use or installed in a trial by another agency (either field testing or service performance), provided that the test protocol was sufficiently rigorous and/or that the field service is documented over a sufficiently long period of service (time or accumulated traffic loads). In such cases, an agency may require submittal of the following types of documentation of the system and the proven performance:

- Description of the new load transfer system components/features
- Properties of the materials proposed for use, along with relevant specifications for acceptance tests (e.g., tests that were used to determine material strength, elasticity, etc.)
- Complete layout and installation plans for the proposed system, including elevations and sections of both sides of joints, with all dimensions
- Proposed instructions for installation
- Quality control and quality assurance plans
- Proposed instructions for field inspections of the proposed system
- Expected service life of the proposed feature or system and supporting calculations or results of modeling to support the service life estimate
- Results of lab or field tests of the proposed feature or system

Field Trial Installations

When a system is being proposed for use for the first time and has not previously been approved or installed elsewhere, a field trial installation may be the fastest way to demonstrate the potential for acceptable performance of a new or innovative load transfer system. As an example, the following options and protocols are based on recently proposed revisions to the current Caltrans protocol for approval of new load transfer systems (Caltrans, 2015). It is emphasized that what follows is not currently an approved Caltrans protocol.

- When an existing installation that includes the proposed Load Transfer System (LTS) exists:
    a. Ensure that the section has a support condition similar to that of the proposed use.
    b. Ensure that the proposed section has been in service (open to public traffic) for at least six months.
    c. Test the load transfer system at a minimum of six joints
        i. Transverse joints selected for testing must have a width of 1/4 inch or more.
        ii. Conduct Falling Weight Deflectometer (FWD) testing with the load placed on the approach and leave sides of each joint, for a total of at least 12 tests.
- When a new section is built to evaluate the system (trial installation):
    a. Ensure that the trial installation will be constructed over support conditions similar to those of the proposed use.
    b. Construct the trial installation using transverse joint spacers to ensure that the transverse joint widths are no less than 1/4 inch.

Table 4-4. LTE Test Load Levels for Field Evaluation of Proposed Load Transfer Systems (after Caltrans, 2015).

Drop Sequence No.	No. of Drops	Target Load (pounds)	Acceptable Load Range (pounds)
1 (seating)	2-3	6,000	5,500 to 6,500
2 (test)	3	9,000	8,500 to 9,500

c. Test the load transfer system at a minimum of three joints (between four consecutively placed panels).

d. Conduct FWD testing with the load placed on the approach and leave sides of each joint, for a total of at least six tests. Prior to testing each location, precondition the location with up to 1,000 drops of an FWD that has been configured for standard highway testing (i.e., a 9,000-pound simulated load impulse). Pre-conditioning at any test location can be terminated any time after the completion of 100 FWD drops if the relative deflection (defined below) increases by less than 0.1 mils over the previous 50 FWD drops.

- For both existing installations and pre-conditioned new trial installations, conduct the tests as described below:

a. Conduct FWD tests at air temperatures between 40 degrees F and 85 degrees F.

b. Perform all tests (and pre-conditioning, if necessary) directly over the dowel located closest to the lane-shoulder joint. Testing is to be performed with the load placed on each side of each joint, as well as at the center of the panel, as shown in Figure 4-27.

c. Deflection tests at the transverse joints should be done with deflection sensors located approximately 6 inches from the center of the joint on each side and the load located tangent to the joint on the loaded side of the joint. Recommended positions for the deflection sensors are shown in Figures 4-28 and 4-29. The recommended number of load drops and the target load levels are shown in Table 4-4.

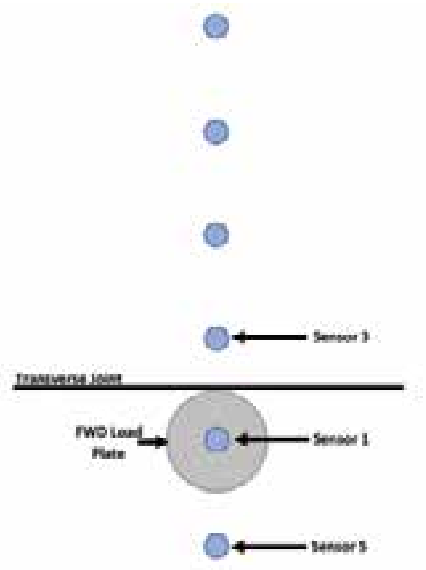


Figure 4-28. FWD sensor configuration example for Test Location 1 in Figure 4-27 (after Caltrans, 2015).

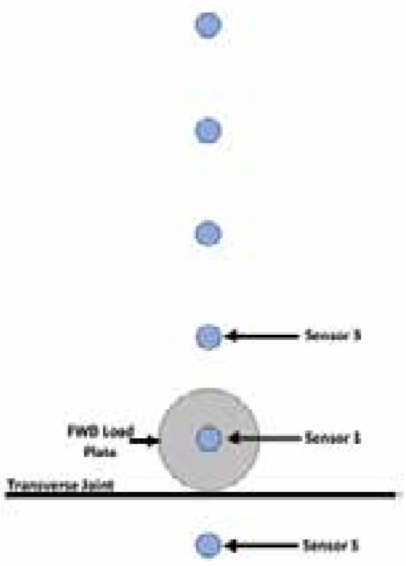


Figure 4-29. FWD sensor configuration example for Test Location 2 in Figure 4-27 (after Caltrans, 2015).

d. The centers of the panels on each side of the tested joints shall be tested to characterize the deflection basin associated with the slab-foundation system without any joints. This will be done using a series of FWD drops at location 0 in Figure 4-27 (using the load sequence described in Table 4-4, without any preconditioning load drops) and then determining the difference in deflection between the center of the load plate and the sensors located 6 inches away on either side of the load plate. The average

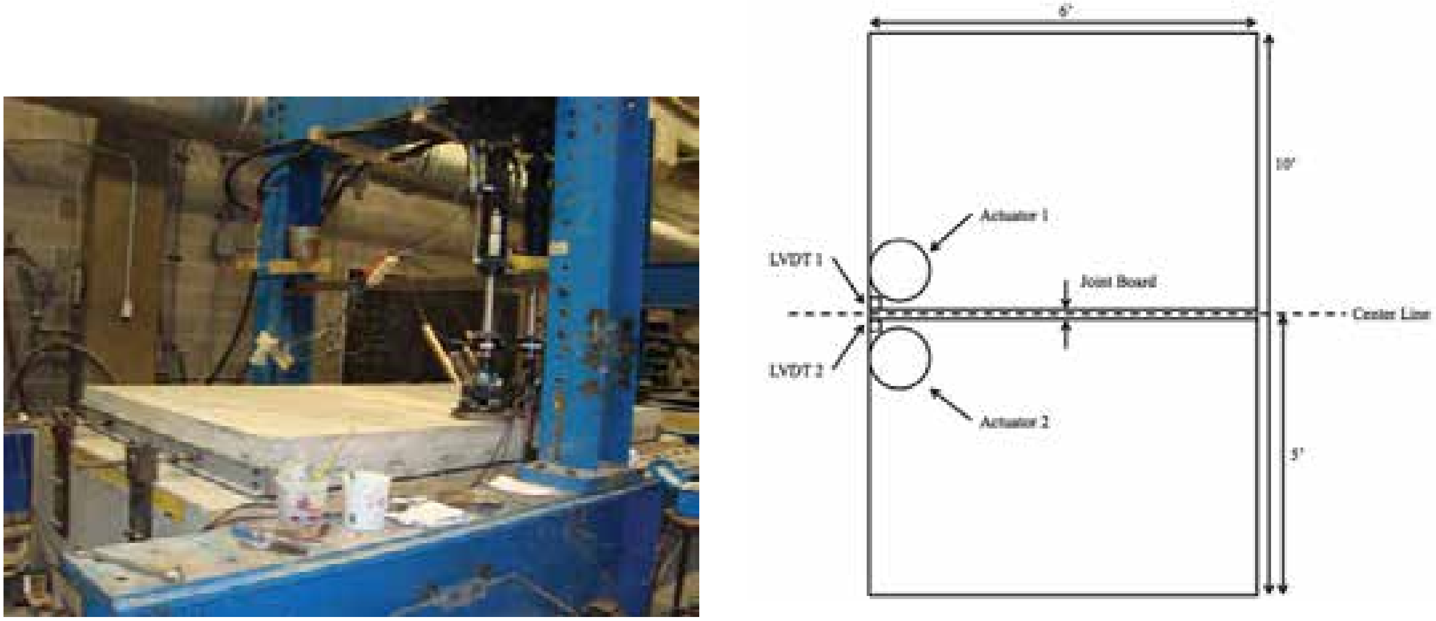


Figure 4-30. Photo and schematic of University of Pittsburgh lab-based accelerated loading pavement test stand.

of these differences for all slabs in the test section will represent the baseline against which relative deflections at the joints will be compared.

- Calculate the relative deflection (d_{rel}) at the joint for each test location. This is simply the deflection at the joint of the loaded side minus the deflection at the joint of the unloaded side. In Figure 4-28 (showing approach side loading):

  $$d_{rel} = d_1 - d_3$$

  where d_1 = deflection under the load plate and d_3 = deflection at location 3, 6 inches from the joint on the unloaded side.

  Similarly, for Figure 4-29 (showing leave side loading):

  $$d_{rel} = d_1 - d_5$$

  where d_1 = deflection under the load plate and d_5 = deflection at location 5, 6 inches from the joint on the unloaded side.

- For both existing installations and pre-conditioned new trial installations, perform a visual inspection of the load transfer system components using the protocol described below. This should be done after the completion of the FWD testing described above.
  a. One 4-inch-diameter core should be drilled from each side of each tested joint (i.e., 2 cores per joint) at a minimum of three randomly selected representative test locations for visual inspection. Cores should be drilled directly over and through the dowel bar closest to the lane-shoulder joint. The center of the core should be located between 4 to 5 inches from the transverse joint.
  b. Examine each cored load transfer installation to document any voids around the bar, any sign of cracking in the grout or damage to the grout, any sign of debonding between the grout and the slot walls, any visually apparent dowel misalignment, and the minimum and maximum thickness of grout around the bar on each side of joint.
- The following criteria shall be applied for acceptance of the proposed load transfer system:
  a. FWD testing:
     i. Average (d_{rel} - $d_{rel\text{-}0}$) does not exceed 3.0 mils for installations placed on lean concrete base or 5.0 mils for installations placed on granular base.
     ii. No values of (d_{rel} - $d_{rel\text{-}0}$) exceed 3.5 mils for installations placed on lean concrete base or greater than 6 mils for installations placed on granular base.
  b. Visual inspection of cores:
     i. No voids are observed around dowel bars.
     ii. No debonding between the grout and slot walls is observed.

iii. No signs of cracking in or damage to the grout.
iv. No apparent dowel misalignment.

It must be emphasized that the preceding is an example that is currently being considered (and is not yet adopted) in California. Other state agencies may consider different or additional factors, such as verification that bedding grout fills all voids under the panels. More information about trial installation procedures is presented in Chapter 10.

Accelerated Loading using Field or Lab Apparatus

Accelerated load facilities (both lab- and field-based) have been developed to simulate the passage of thousands or millions of vehicle loads – representing years of service – in a matter of days, weeks or months. Such tests are very time-consuming and expensive, but do offer an option for evaluating long-term fatigue and behavior of entire precast pavement systems or system components.

An example of a field-based accelerated load facility was described in Chapter 1, which documented fatigue tests (simulating nearly 40 years of traffic loading) performed on a series of Super-Slab PCP panels in Fontana, Calif. (Kohler et al., 2007).

Laboratory-based systems, such as the one shown in Figure 4-30, have also been developed and used at the University of Pittsburgh and other research institutions to evaluate many of the alternative long-life dowels described previously using relative deflection data and other criteria measured after the application of up to 10 million load cycles.

Tie Steel System Design

Tie bars are typically deformed steel reinforcing bars that are placed across pavement joints to provide joint restraint in both the vertical and horizontal directions. In PCP roadway systems, they are typically placed across longitudinal joints (most often in combination with a grout-filled keyway of some type) to provide edge support to the precast panel. Considerations for the proper design and use of tie bars in PCP systems are described below.

Where to Use (and Not Use) Tie Systems

Properly designed and constructed tie bar systems will hold adjacent pavement lanes together and prevent longitudinal joints from opening. Conventional tie bar designs (e.g., #5 bars spaced 30 inches apart) will not provide adequate load transfer across longitudinal joints unless they are used in conjunction with a well-designed keyway or aggregate interlock (which does not exist for formed PCP joint faces). When only tie bars are used without keyways or aggregate interlock, they must be designed (sized and spaced) like dowel load transfer systems to provide load transfer across the longitudinal joint

Guidance for using tie bars in PCP systems generally follows the same recommendations for using tie bars with CIP concrete pavement systems, including:

- There is typically no need to use tie bars in the longitudinal joints of intermittent repairs or lane repairs with lengths less than 15 to 60 feet (values vary among agency specifications).
- When transverse joints in adjacent lanes are mismatched, do not tie a precast panel to more than one panel in the adjacent lane. Use isolation material (e.g., 1/4-inch foam board) in the joint between the precast panel and adjacent panels that it is not tied to. Consideration should be given to completely leaving out the tie bars along affected longitudinal joints, especially if the repair length is short (as described above).
- It is commonly recommended that no more than three lanes (including the concrete shoulder) be tied together (ACI, 2002). ACPA (1992) recommends limiting the width of tied roadway to about 48 feet, but notes that there has been good field performance in some instances with up to 70 feet of tied pavement. Mallela et al. (2009) concluded that concrete stresses do not increase significantly when three or more lanes are tied together, and experience in some states suggests that at least four lanes can be tied together without inducing uncontrolled longitudinal cracking. If a very wide section must be placed and local experience with very wide placements is not available, consider using a doweled contraction or construction joint near the centerline of roadway sections that exceeds 48 feet.

Tie Steel Diameter, Length and Placement

Tie bar size, spacing and length can be designed in consideration of pavement thickness, the number of lanes being tied together, the location of the joint in question and its distance to the nearest free (or untied) pavement edge, the foundation stiffness, the properties of the concrete and steel, and the environment in which the pavement is being constructed. AASHTO (1993) and NCHRP (2004) provide relatively simple approaches to tie bar system design (bar diameter and spacing) that are based on the force required to pull the pavement across the foundation. ACPA (Mallela et al., 2009) provides a more complex mechanistic-empirical approach to tie bar system design that considers the physical and mechanical properties of the pavement system components and the effects of local temperature and moisture conditions on stresses in the steel.

Although tie bar size and spacing requirements can vary significantly for different longitudinal joints on a given project (joints that are closest to free edges require less tie bar reinforcing than those that are further away), the design for the joint furthest from a free edge is commonly used for all longitudinal joints to simplify construction. A typical tie bar system design may include Grade 40 or 60 steel and #4, #5 or #6 bars (1/2 inch, 5/8 inch or 3/4 inch, respectively, in diameter) on 24-inch or 30-inch centers, which results in 4 or 5 ties per 15-foot panel.

ACPA (2015) recommends that tie bars in cast-in-place concrete pavement should not be placed within 6 inches of the ends of transverse joint dowels (i.e., within 15 inches of transverse joints when 18-inch long dowels are used) to avoid corner spalling and other potential interference effects For JPrCP, tie bars should be placed at least 24 inches from transverse joints to reduce local restraint stresses near dowel slots. Depending on panel length and required tie bar spacing, it may be necessary to reduce tie bar spacing slightly to provide the required number of tie bars in each panel while avoiding conflicts with transverse joint dowels. See Chapter 7 for more on this topic.

Figure 4-31. Typical two-part threaded tie bar and splice coupler system.

Tie bar length is generally selected to develop the allowable working strength of the tie bar using equations such as those in AASHTO (1993) and ACI (2002). These equations typically result in the use of tie bar lengths of 24 to 30 inches. Shorter lengths may provide acceptable service if the design does not require the full working strength of the steel.

Like dowel bars, tie bars are generally installed at mid-depth to maximize concrete shear capacity above and below the bar. However, some deviation in placement depth may be desirable to reduce slot depths, which strengthens the PCP panels and reduces the volume and cost of grout or mortar required to fill the slots. Experience indicates that placement within 2 inches of mid-depth will result in good performance provided at least 3 inches of cover is maintained and the bars are not tilted (Khazanovich et al., 2009). Even greater deviations from mid-depth may be possible, particularly in thick pavements, but the shear capacity of critical concrete above or below the tie bar should be evaluated with respect to the tie bar capacity or expected tensile load.

Use of Two-part Tie Steel to Maximize Panel Shipping Widths

The over-the-road shipping width of PCP panels (without special permitting) is typically limited to 12 feet or less. The presence of embedded and protruding tie bars in PCP panels can further reduce the width of concrete that can be shipped when the impact of the protruding tie bars on shipping widths is considered. One solution is to use a two-part threaded tie bar and splice coupler system (Figure

Figure 4-32. Threaded, headed "dowel-in" tie bar anchor system by Dayton Superior.

Figure 4-33. Panel being moved with four-point lift using lift inserts.

4-31) where the coupler component is embedded in the PCP during fabrication so that it can be shipped without any protruding tie bars. The threaded portion is then installed in the field after the panel has been placed. Another important advantage of this concept is that panels with embedded tie bar splice couplers can be placed in one lane of multi-lane projects with no protruding tie bars that might otherwise interfere with adjacent maintained traffic. The remainder of the tie bar can be installed when the next lane is placed.

Use of Headed Tie Bar Anchor Systems to Minimize Slot Volume

Typical tie bar designs feature embedment lengths of 15 inches or more and require slots of similar length. Long slots have high fabrication and construction costs (because of the large volume of grout required to fill them) and can significantly weaken the panel. The use of headed tie bar anchors (Figure 4-32) can reduce embedment requirements to as little as 7 inches (thereby reducing required slot length and grout requirements) while providing pullout forces that meet typical tie bar requirements (i.e., 75% of yield strength).

Alternate Lane Tie Materials

Alternatives to carbon steel (plain and epoxy-coated) tie bars are available and have been used in conventional concrete paving and can be considered for PCP system tie bars as well. These products are generally produced to provide superior corrosion resistance, although some also provide additional tie bar strength (e.g., the ChromX series of products by MMFX Steel). Other tie bar products include various grades of stainless steel, carbon steel with galvanizing, galvanizing and an epoxy coating, and fiber-reinforced polymer rebar.

Additional Slab Design Features and Considerations

Embedded Features: Lifting and Jacking Hardware

PCP panels are typically lifted (from the yard to transport vehicles and from the vehicles to installation) using four lifting anchors that are embedded in each panel at locations that are symmetric with respect to the panel axes and are selected to minimize bending stresses in the slab (Figure 4-33). PCI (2004) provides guidelines for determining concrete bending stresses that result from four-point lifting. Examples of lifting stresses computed for various sizes of panels using the PCI procedures are presented in Table 4-5, which shows that lifting stresses are very small for conventional single panels up to 12 feet wide and up to 15 feet long. Lifting stresses for wider or longer panels can be substantial and may merit the use of pre-tensioned reinforcing strands in the longer panel direction to offset the lifting stresses. Alternatively, more than four lifting inserts

Table 4-5. Maximum Concrete Stress for Four-point Lifting

Panel Length (ft)	Panel Width (ft)	Panel Thickness (in)	Maximum Concrete Lifting Stress (psi)
10	12	9	39
10	24	9	154
10	36	9	347
10	12	10	35
10	12	11	32
10	12	12	29
12	12	9	39
12	24	9	154
12	36	9	347
12	12	10	35
12	12	11	32
12	12	12	29
15	12	9	60
15	24	9	154
15	36	9	347
15	12	10	54
15	12	11	49
15	12	12	45

per panel may be used in conventionally reinforced panels if rolling sheaves are included (and properly designed) in the rigging equipment used to lift the panels.

Many styles of lifting anchors are available, including conventional threaded coil inserts and some that serve combined functions as both lifting anchor and slab-jack for grout-supported installations (Figure 4-34). Each lifting anchor product and size is rated for the load that can safely be carried for a given stripping strength, slab thickness and edge distance. A detailed analysis should be conducted to ensure that the lifting anchors are compatible with the panel's weight and dimensions as well as the strength of the concrete at the time of the first lift (typically about 18 hours after casting when panels are stripped from the form bed). Manufacturers of many lifting anchors often provide recommendations for supplemental reinforcing near the anchor installation points to ensure that the anchors do not pull out under load.

It is important to note that there are different manufacturing tolerances on the threads of coil inserts, nuts, rods and bolts produced by different manufacturers. Using lift components from different manufacturers (e.g., a coil insert from manufacturer "A" and a coil bolt from manufacturer "B") could result in a catastrophic failure under lifting or handling conditions. Thus, it is strongly recommended that users of

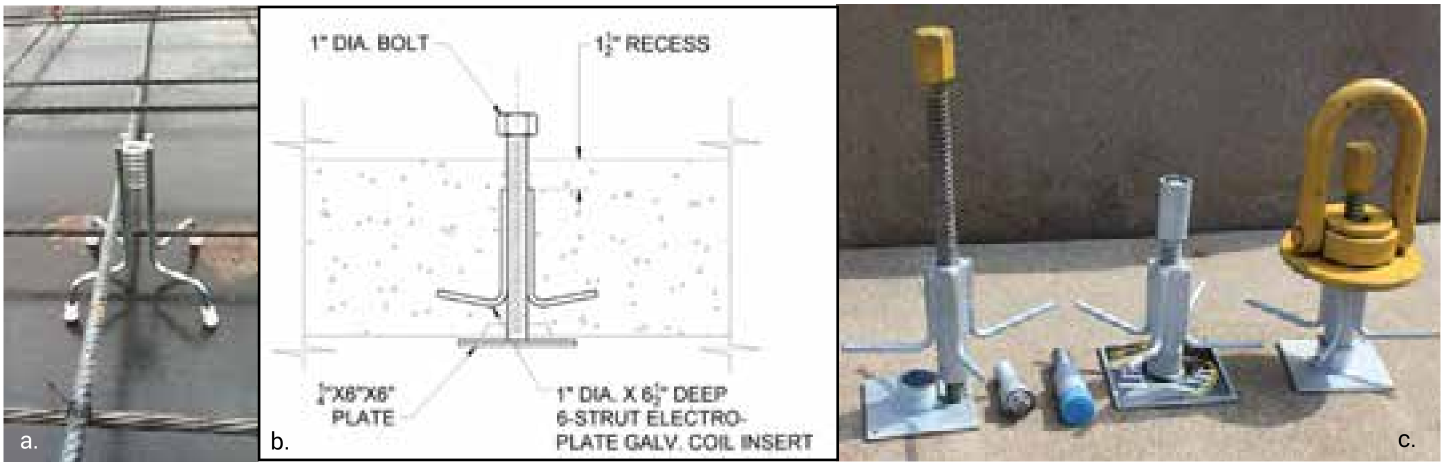


Figure 4-34. Photos and schematic of (from left to right) conventional coil lifting insert, generic lifting/adjusting insert and Gracie-Lift lifting/adjusting device.

these products purchase all coil lift-related components from a single manufacturing source or have a system in place to validate proper engagement of these threaded devices.

Lifting anchors that are left in place after use must have sufficient top and bottom cover after installation to ensure they do not corrode and cause surface spalling of the PCP panel and to ensure they do not interfere with future profile grinding of the pavement.

Embedded Features: Utility Openings

Many precast panels in urban areas must include openings for utility access (e.g., manholes, drainage inlets, etc.). The primary consideration for these openings includes adjusting joint spacing/panel length to avoid placements that may facilitate slab cracking (as discussed earlier in the jointing portion of this chapter). Additionally, avoid the use of utility openings with sharp angles that serve as stress concentration points and crack initiators. Supplemental embedded reinforcing steel can be added to the panel reinforcing in areas surrounding utility openings, especially around opening angles that are 90 degrees or less.

Slab Surface Texture, Color, Patterns

Concrete pavement surface texture affects both safety (skid resistance or friction number) and tire-pavement noise characteristics. Surface texture requirements for installed PCP panels typically match those required for new CIP pavement construction, although the texture provided during fabrication is often partially or wholly removed by diamond grinding that may be undertaken to restore the overall pavement surface profile, as discussed in more detail in Chapter 11.

The controlled conditions present at precast manufacturing facilities offer opportunities to fabricate or imprint a range of colors, patterns and textures in the PCP panels, but these features and textures will only be worth the effort if the panels can be installed within acceptable field tolerances such that diamond grinding is not necessary. It is also possible to incorporate two-lift paving concepts in precast panels using recycled concrete or other aggregates of lower quality in the lower lifts of the panel while using hard, angular, skid-resistant or uniquely colored aggregate in the top few inches of the panel.

Grout Distribution Systems (Grout Ports and Distribution Channels)

Grout ports and distribution channels that are formed into the PCP panel must be sized and located at positions that ensure the uniform distribution of the selected bedding or hardware grout.

Summary

The design of PCP systems must address many considerations and features, including: determination of the structural design criteria (i.e., service life and performance requirements); joint layout and selection of panel sizes; selection of the slab support system; thickness design; slab reinforcing design; joint design (including load transfer systems, tie bars and other details); slab surface geometry (flat vs. non-planar); slab surface texture; and other details (e.g., grout ports, lifting mechanisms, utility openings, bedding grout distribution systems, etc.). The interaction of many pavement design features (e.g., the impact of panel dimensions on slab thickness, reinforcing requirements, lift insert locations, etc.) requires that designs be performed holistically rather than feature by feature.

Thickness design for intermittent repairs often consists of nominally matching the thickness of the surrounding pavement (with some thickness reduction for bedding and support materials). For new construction and lane replacement projects, JPrCP thickness design is typically performed using available procedures for CIP concrete pavement systems because PCP-specific design procedures have not yet been developed. Design criteria for JPrCP systems are generally comparable to those used for CIP pavement, except that higher amounts of cracking are often permitted with JPrCP because of the included reinforcing. This typically results in design thicknesses that may be somewhat conservative because they do not account for the structural and functional performance benefits that generally accompany the panel reinforcing typically provided in JPrCP.

Transverse and longitudinal joint locations should closely match those in adjacent panels to avoid sympathy cracking. When this is impractical, isolation material should be placed and tie bars should be eliminated between the PCP and some adjacent panels.

Options for several other design features and construction techniques (e.g., slot locations and types, panel support systems, panel support materials, dowel materials and shapes, planar vs. warped panels, etc.) are also discussed in this chapter, along with typical advantages and disadvantages of each. Several new and innovative materials and construction techniques (e.g., removable dowels, structural fiber reinforcing, prestressing, two-part tie bars, headed tie bars, etc.) are presented.

Consideration of the fundamental concrete pavement design concepts and precast pavement features presented here, together with the options described that help to optimize fabrication and construction efforts, will result in the production and construction of PCP systems that are as cost-effective as possible while providing the superior long-term performance and durability that are associated with quality precast concrete products.

Chapter 5:
DEVELOPING PLANS, SPECIFICATIONS AND COST ESTIMATES
A GUIDE FOR DESIGNERS, AGENCIES AND OWNERS

The development of a set of clear and coherent specifications and contract plans is an important and challenging task that every engineer faces when trying to include precast pavement in any project. These documents are important because they provide the detailed information contractors need to bid on, fabricate and install the precast panels. In that regard, they play a major role in the quality of the final installation as measured by how well the four basic requirements listed in Table 1-1 (i.e., proper grade control, effective panel support, adequate load transfer and correct surface geometry) are achieved.

Specification development may also be challenging because there is no single universally acceptable way to fabricate and install precast pavement panels. It is therefore incumbent upon the engineer to become intimately familiar with the details associated with fabricating and installing any system or product that is ultimately to be included in the specification, so those details may be clearly and accurately incorporated in the specifications. Engineers may find it helpful to refer to design details, installation procedures and other aspects of the various systems, as described in Chapters 4 and 9 of this manual, before choosing products that are appropriate for the project at hand.

Specification development is frequently made more difficult when the engineer must avoid explicit specification of proprietary products, as is often the case on Federal Highway Administration (FHWA) and state-funded projects. This restriction sometimes presents a dilemma for specifiers that want to use proven precast pavement products and features because some of the most successful and widely used precast pavement products and features are proprietary in nature. In such cases, care must be taken to develop specifications that allow the desired proprietary product but also permit nonproprietary products or approaches that provide "equivalent or better" results.

This chapter provides past and current approaches to the development of precast pavement specifications and describes how proprietary products may be managed within them. Precast specifications currently in use by state DOT's are categorized by type, ranging from product-specific specifications to completely generic performance-based specifications. FHWA's current recommendations for specification development are provided, followed by a discussion of what should be included in the contract plans for various types of projects. Guidance is also provided to aid engineers in their preparation of reasonable cost estimates, which are often required before project funding can be secured.

Specifications

Historical Perspective

The first specification for a jointed PCP project of significant size was written around the Super-Slab® system for the Tappan Zee Bridge Toll Plaza project in Tarrytown, N.Y., in the early 2000s. A "product-specific" format (restricted to the Super-Slab® system) was chosen because the Super-Slab® system was the only commercially available PCP system at the time. After the completion of the Tappan Zee project, projects in New York, Virginia, Minnesota and other states were also completed using the same product-specific specification format.

In 2007, the New York State Department of Transportation introduced a "generic," performance-based "approved product list" specification to avoid specifying a single product. That specification allowed the use of any system – proprietary or not – meeting specified requirements for system approval. It was later adopted in modified form by the Illinois State Toll Highway Authority, the Virginia Department of Transportation and the Illinois Department of Transportation, and is still in widespread use in New York and Illinois. It was also adopted in modified format by the American Association of State Highway and Transportation Officials Technology Implementation Group (AASHTO TIG) and placed on their website in 2006, where it still resides as a template or guide specification for agencies wishing to use it.

In 2010, the Utah Department of Transportation and the Ministry of Transportation of Ontario developed "approved product" (or "approved system") specifications, which allowed a contractor to choose a system for any given project from a selection of previously-approved systems. Around the same time, the California Department of Transportation (Caltrans) initiated an effort to develop "generic" specifications that allowed the use of a Caltrans-developed system or alternate systems that conformed to certain specification requirements. Since then, other forms of "generic" specification have also been developed.

It is recommended that PCP project specification writers and plan developers examine the various types of specifications (as presented in the following sections) in detail to become familiar with the pros and cons of each.

Types of Specifications in Current Use

Product-specific Specifications

Product-specific specifications are typically written around a specific system that the owner has chosen (typically because of proven experience with that system within or outside of the agency). An excerpt from a product-specific specification is shown in Figure 5-1.

439.1 General Description
This work includes the furnishing and installing of reinforced precast concrete pavement slabs (Super-Slab®) as shown on the Plans and in accordance with this Specification. This work includes the removal of the existing concrete pavement; repair and re-compacting the existing subgrade …

Figure 5-1. Excerpt from a "product-specific" PCP specification.

Writing this type of specification for a given agency or project is typically straightforward because the system developer can provide descriptions of all the materials and methods required to install the system. In addition, specifications that have previously been written for the selected PCP system may serve as guides or templates in developing a special provision that is specific to the agency or project. The use of proven, clear specifications of materials, construction procedures and project submittals generally leaves little room for confusion or interpretation as to what is expected in the fabrication and installation processes.

Another advantage of specifying the use of a particular system is that it implicitly – if not explicitly – enlists the design, fabrication and installation assistance of the system developers and designers. Such assistance is invaluable in a world where expertise and experience with precast pavement is limited.

One disadvantage of this type of specification is that "sole-sourcing" of any product is discouraged by FHWA and some state agencies, unless there are compelling reasons why it should be used. However, FHWA has recently revised its guidelines on the use of sole-source products (23 CFR 635.411), making it easier for state agencies to receive FHWA approval and financial aid for projects that include product-specific specifications in certain situations. Answers to frequently asked questions concerning this guidance can be found at: https://www.fhwa.dot.gov/programadmin/contracts/011106qa.cfm.

Allowable Systems Specifications

This type of specification is written around two or more PCP systems that the owner/agency considers acceptable for the project. Materials, fabrication, construction and submittal details are prescribed in detail for each of the approved systems in the body of the specification. This eliminates the need for a formal "system approval" process since the systems chosen for the project are already "preapproved." This places the responsibility for providing a set of clear and coherent specifications for each approved system directly upon the specification writer. An example of the beginning portion of this type of specification is shown in Figure 5-2.

PRECAST CONCRETE PAVEMENT SLAB REPAIR – Item No. 13
Special Provision
363.01 SCOPE

This specification details the requirements for repairing rigid pavement with precast concrete slabs using either the Fort Miller Super-Slab Method or the Michigan Method. The work may include both continuous and intermittent slab repairs.

Figure 5-2. Example excerpt from the beginning of an "allowable systems" specification.

With this type of specification, care must be taken to ensure that all allowable PCP systems are treated equitably so that bidders are not "steered" to a particular system. For example, the specs or other contract documents must include a complete set of fabrication and installation instructions for each allowable system, including those required for any allowable agency-developed systems included in the specifications.

One advantage of this type of specification is that it is generally prescriptive (i.e., it contains a set of rules that a contractor must follow) in a format that is typically familiar to owners, engineers and contractors. Another advantage is that proprietary systems can be included in the approved "list" of systems since more than one system is allowed on the project. This concept introduces competition and avoids the proprietary appearance that can accompany product-specific (sole-source) specifications because the contractor can choose from two or more different systems. Yet another advantage over some performance-based and generic specifications is that all bidders know – before the bid – that any of the allowable systems will be approved for use on the project.

One disadvantage of this type of specification is that the specifier must be intimately familiar with all the details of every system that is allowed on the project to address them properly in the project specification. This type of specification may also be a deterrent to the development and inclusion of new or emerging systems and innovations that are not well known to the specifier because a provision for approving new systems is typically not included.

At least three states (California, Illinois and Utah) have written and successfully used allowable systems specifications that include an agency-developed system as one of the systems that may be chosen by the contractor.

ITEM 502.15PR-18 PRECAST CONCRETE PAVEMENT SLABS

DESCRIPTION. Install precast concrete pavement slabs in accordance with the contract documents. The precast slab system selected must appear on the Department's Approved List entitled "Precast Concrete Pavement Slabs Systems (704-15)."

MATERIALS.

Precast Concrete Pavement Slab Systems..704-15

Figure 5-3. Beginning of an example "performance-based approved product list" specification.

Generic Approved Product List (Performance-based) Specifications

Approved product list specifications allow the contractor to select a PCP system from two or more systems that meet specified performance criteria as proven through a specified system approval process, typically completed before a project bids. Systems that successfully complete the approval process are placed on an "approved products" list from which contractors may chose the system that best suits their needs and capabilities. An example of the beginning portion of this type of specification is shown in Figure 5-3. The criteria for system approval are provided in materials specification 704-15 in this example.

The remaining parts of an approved product list specification describe materials, submittals, fabrication requirements and construction details, and are typically written as generic, performance-based requirements that must be met by all approved systems.

Agency benefits from using this type of specification include stimulation of competition between alternate systems (because everyone is free to get a system approved by going through the specified approval process), preventing unproven systems from being used and avoiding the stigma associated with product-specific (sole-source) specifications. Another advantage is that the intricate details of each approved system need not be included in the body of the specification or in the contract plans because they are required of and provided by the system designer in the system approval process (e.g., Section 704-15 in the example shown in Figure 5-3). This type of specification works well for contractors because they know that systems appearing on the approved list have been proven to work before the project bids and there is no confusion among bidders as to what systems will be allowed on the project.

The primary disadvantage of this type of specification is that different performance criteria must be provided to address all elements of each of the various systems that may be used. For example, the subgrade surface tolerance may be less stringent for a grout-supported system (where the panel will be supported by 1/2 inch or more of bedding grout) than for a grade-supported system (where the panel is supported directly by the subgrade surface and relatively little grout is used), as is discussed in more detail in Chapter 9. Similarly, the criterion for allowing traffic on grade-supported systems is that the panels must be placed on and fully supported by a precisely graded subgrade surface, while traffic cannot generally be permitted on grout-supported systems until the bedding grout used under the panels develops sufficient strength. All these criteria and more must be included in a fully effective performance-based construction specification.

Generic Performance-based Specification (without an approved list of products)

This type of specification, currently in use by many states, is similar to the previously discussed "approved product list" specification in that it provides system approval criteria and performance-based requirements for materials, submittals, fabrication and construction in the main body of the specification, but system approval is obtained after the bid. This is an important distinction because contractors must factor into their bid and schedule the ramifications of conducting a product approval process after the bid.

A.2 System Requirements Provide a system that has a history of successful performance on at least three high volume public roadway projects in the last three years. The system shall have been demonstrated to achieve a load transfer efficiency, as demonstrated by falling weight deflectometer testing, of 70% or greater and a life expectancy of at least 35 years as demonstrated by a Heavy Vehicle Simulator (HVS) or similar test.

For contoured pavement surfaces, demonstrate the system can be used to fabricate and install non-planar slabs as required to match any surface of the pavement around them on the contract. Profile grinding of more than 3/8" to create the required contoured surface is not allowed.

If the proposed system does not meet these criteria, perform a pre-approval demonstration for the Department. Fabricate and install a minimum of five slabs in accordance with a complete set of fabrication and installation details that, once approved, will become the authorized fabrication and installation details for the entire project. Allow two weeks for Department review after completion of the trial installation and submittal of the details. Contract time extension due to trial installation or multiple iterations will not be granted.

Figure 5-4. Excerpt from the "System Requirements" section of an example hybrid, performance-based generic specification.

Some states have mitigated the negative impact of having to perform a system approval process after the bid by allowing the use of systems that "have a history of successful performance on at least three high volume (Mainline ADT > 25,000) public roadway projects in the last three years" (2016 Special Provision for State Project No. H. 012193, Louisiana DOT). An example of this type of specification is shown in Figure 5-4.

Generic "Approved Component" Specification

In order to stimulate competition, at least one state has developed a "generic" specification that requires the contractor to develop a complete system from lists of state-approved precast pavement components listed in the specification, and then to prove that it works by performing a trial installation after the project bids. As with the other generic specifications, performance criteria are set forth throughout the body of the specifications.

The writer of this type of specification must be familiar with the components that are listed as being "approved" to be sure they will perform acceptably in whatever combination the contractor may choose to use. The contractor may expect compatibility among any products that are listed as being "approved," even though the contractor may be required to perform a formal trial installation to prove the chosen system works properly.

The advantages of this type of specification are similar to those of other generic specifications in that it stimulates competition, proprietary components may be included, and the intricate details of the system (combinations of components) the contractor ultimately chooses to use on the project do not need to be defined in the specification.

One disadvantages of this type of specification is that the trial of the selected system does not occur until after the bid. This may create contractor uncertainty at the time of bid that may result in higher bids. Another disadvantage is that system development (i.e., determining suitable combinations of approved components) and subsequent system approval (i.e., trial installation and evaluation) may consume valuable time after the project has been awarded.

Generic Specification Development - FHWA Perspective

While state DOTs can and have developed their own styles of specifications that they deem best for their particular state or project (as presented in previous sections), it is well to consider the following FHWA recommendations in developing generic specifications (Tyson, 2017):

- As the state highway agency (SHA) prepares its specification and plans for a project using precast concrete panels for repair and rehabilitation of either asphalt or concrete pavements, the SHA is responsible for specifying the structural requirements, including panel thicknesses and other panel dimensions, panel layout, and required features such as two-lane panels, and specific construction requirements such as base preparation, grout strengths and, if required, the use of leveling lifts.
- The SHA must consider the experience of the contractor and determine contractor qualifications and precast system acceptance based on a trial installation, either off-site or on the project site, at the discretion of the agency.
- The SHA must require the contractor and precast supplier to submit detailed shop drawings and a construction plan for review, comment, revision and final approval by the SHA.
- Beyond the items required by the SHA, the SHA should not tell the contractor "how" to perform the work.

Essentials for Specifications of All Types

All aspects of the fabrication and installation processes must be clearly defined and specified, no matter what type of specification format is chosen. This is especially true for PCP systems because the materials and methods used to build such systems are still relatively new.

Preparing Contract Plans

Information provided in the written specifications is typically clarified with the aid of sketches and drawings included in the contract plans. Additional information not provided in the specifications, such as cross-sections, plan views and detailed panel drawings may also be shown in the plans, as described below.

Typical Sections

Typical sections, drawn as cross-sections of the roadway at specific stations throughout the project, show the cross-sectional details and limits of precast pavement placement along the project. The label or title of each typical section drawing should include the station limits to which it applies. It may be necessary to develop several pages of typical sections to depict how precast panels are to be installed as the roadway changes in width, cross-slope and shoulder details.

It is important to ensure the information shown in the typical sections and plan sheets is consistent with information provided in any item summary tables that are included in the plans, since contractors typically examine and compare all of these sheets carefully to confirm the accuracy of their bid.

Maintenance and Protection of Traffic

This section of the contract plans is vital for ensuring the safety of the traveling public and project personnel. Details concerning the maintenance and protection of traffic (MPT) are especially important for precast paving because the work is typically performed in relatively short, off-peak work windows (usually overnight) that do not allow enough time for the use of concrete safety barrier. Alternative delineation devices and other safety measures (e.g., detailed signage plans, traffic delineation details, protective equipment details and police officer coverage) must be clearly shown for every phase, if not every hour, of the project.

The specifier should be aware that the contractor will examine this section of the plans in great detail and may present changes that they deem necessary to ensure the safety of both workers and travelers. An alternate approach is to provide bidders with general MPT requirements and allow the successful bidder to develop and submit (for approval) project- and contractor-specific MPT plans that meet the stated requirements. This approach can save the specifier significant time and expense in the preparation of plan documents.

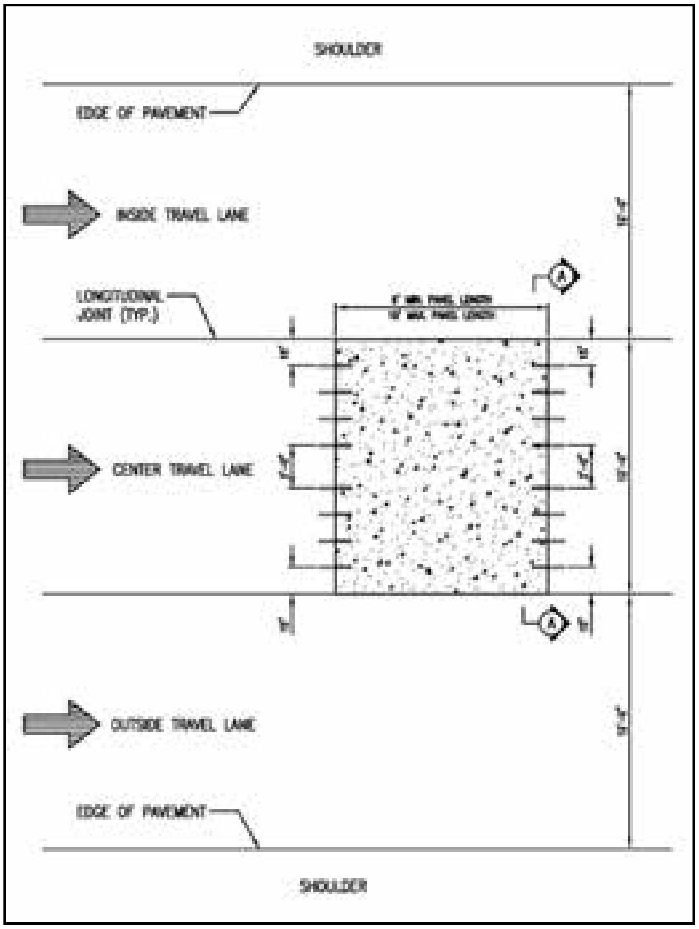


Figure 5-5. Schematic of precast panel details showing no reference to any particular precast system.

Precast Panel Details

Plan sheets should show all details of the approved precast panels or must reference system designer drawings that show such details so that bidding contractors can responsibly estimate the costs of panel fabrication and installation. The detail sheets may be generic or schematic in nature, as shown in Figure 5-5, or they may be product-specific – showing every detail of a specific system – depending on how the specifications are written.

Precast panel detail sheets should show: the range of allowable panel sizes; panel thickness(es); the number, size and spacing of dowels and tie bars (if used); reinforcement size(s) and locations; size and spacing of bedding grout ports; a schematic plan view of how the panels are to be placed (relative to existing transverse and longitudinal joints on the project); required surface finish; and details for joints between precast panels and existing pavement or other precast panels.

The detail sheets should also show the dowel and tie bar slot details and any grout ports needed for installing dowel and tie bar grout. These sheets should either depict any leveling hardware or bedding material required to provide panel grade control or make reference to other documents, such as system designer standard fabrication drawings, that show this information.

Another approach is to show all information referenced above for a specific system (e.g., the Super-Slab® system or the Roman Roads system) with a note clearly stating that "other systems may be used with DOT approval." This approach has been used successfully in conjunction with the approved product list specification used by New York and other states.

If non-planar panels are needed for the project, the panel detail sheets should include specific details concerning their dimensions and fabrication or must reference system designer standard sheets.

Installation Details

Installation sheets should show panel installation details that augment and clarify information provided in the specifications. The information shown on these sheets should be generic unless a single-product specification is used and attribution to the specified system is provided.

Section drawings should be used to provide complete information concerning the materials and methods used to fill any voids under the panels and to provide visual renderings of how dowels and tie bars between panels are installed. Additional section drawings of transverse and longitudinal joints should show joint width limits and details of how joints are to be sealed. Installation sheets should also describe how dowels are to be anchored into existing pavement at the beginning and end of precast panel installations.

Repair Locations

The locations of repairs are best shown on plan view drawings of the project that depict project stationing, mile post markers, roadway lanes, widenings, access ramps, horizontal alignment (curves) and super-elevation data. Actual locations for intermittent and continuous repairs are typically shown as cross-hatched areas with specific starting and stopping stations in each lane.

Repair locations are sometimes shown in a table that lists station numbers and quantities associated with each repair area. A table of repair locations with no accompanying project plans may be sufficient on simple intermittent repair projects (e.g., where only standard planar rectangular panels are used); this practice is not typically appropriate for more complex projects.

There is frequently an interval of one or more years between the time the repair project is designed and the time the project bids. During that time, the highway typically continues to deteriorate, so more repairs are usually needed than what is shown on the designed contract plans. Plans or specifications may address this by including a note requiring the contractor and the engineer in charge of the project – working together – to determine the actual numbers and limits of repairs needed at the time of construction.

The repair location plan should also note any possible need for non-planar panels. This will alert the contractor that a detailed "x-y-z" survey of the project may be required. Locations that may require non-planar panels include areas of cross-slope transition (e.g., at the ends of horizontal curves), tight-radius ramps with grades in excess of 3%, intersections and lane replacement areas where new panels are placed continuously next to an existing lane that undulates from the original smooth-profile grade line.

Developing Project Costs

Project scoping often requires developing cost estimates to ensure that total project costs fit within the project budget. An approximate "rule of thumb" for developing total installed cost estimates is to simply double the material cost. While this is a convenient technique because material costs are relatively easy to determine, it is not always reliable because there are many factors that impact total project costs. These factors are described in this section.

What to Include in Project Costs

PCP projects typically include a wider variety of construction activities than do conventional pavement repair projects. It is important to be aware of all these costs and to include them in the final project cost estimate. Costs that should be included in the estimate are:

a) Surveying
b) Pavement sawing
c) Excavation or lift-out of existing pavement
d) Excavation and backfill of unsuitable foundation material
e) Installation of new foundation materials, including stabilized subbase (e.g., lean concrete, cement-treated and asphalt-treated subbases)
f) Anchoring dowels and tie bars in existing concrete pavement
g) Placing and grouting precast panels and load transfer devices
h) Profile surface grinding
i) Joint sealing
j) Maintenance and protection of traffic
k) Resident engineering and inspection
l) User delay costs (if considered)
m) Life cycle costs (if considered)

Sources of Installed Cost Information

The estimation of PCP installed costs can be challenging because of a lack of extensive historical cost data in the industry. A few states and agencies have compiled "average bid prices" that reflect precast pavement costs for the limited number of completed projects in their jurisdiction. That data must be viewed and used with caution because many early demonstration-type projects were small and unique in nature, and the associated cost information is often not representative of larger "production-type" projects. Therefore, project cost estimators must often gather supplemental cost information from other sources to develop a meaningful estimate for any given job. Potential sources of cost information are described below.

Precast concrete companies that have made PCP panels for previous projects are good sources of fabrication and delivery cost data. More representative data may be obtained if the companies are first provided with details of the panels being considered for the subject project. The National Precast Concrete Association (NPCA) and Precast/Prestressed Concrete Institute (PCI) are good organizations to contact first because both organizations maintain lists of qualified and certified fabricators.

Experienced precast pavement installers are good sources of installation cost data when they are willing to share that information. However, contractors are often not anxious to share what they consider to be "confidential" cost information from previously completed projects with anyone - even agency cost estimators. In addition, they have little motivation to estimate costs for "potential" projects; their primary interest is in developing cost estimates for "real" projects that are about to be bid.

Precast concrete pavement system designers that have been involved in previous precast pavement projects may be good sources of fabrication cost data and, in some cases, installation cost information for their particular systems if they have spent adequate time in the precast plant and in the field during installation.

Compilations of average bid price data from agencies and suppliers can be useful if those agencies and suppliers have extensive experience. For example, the New York, California, Utah, and New Jersey Departments of Transportation, as well as the Illinois State Highway Tollway Authority, have built many JPrCP projects of different types and have compiled cost data that may be useful (and available for the asking) for developing cost estimates for new projects. A recent FHWA R&T Evaluation Report indicates installed costs of $317 per square yard to $625 per square yard in three of those states (Bucci, et al. 2018), primarily for intermittent repair projects. A more complete range of costs for continuous as well as intermittent installations may be obtained by contacting other high-user states.

Price ranges vary widely because of such factors as project location (which affects material, labor and freight costs), pavement thickness, project size, traffic volume and length of work window. For example, smaller projects involving smaller panels and/or intermittent repairs often have higher bid unit prices while larger projects that may include long, continuous placements typically have lower bid unit prices. The project estimator should develop cost estimates using mainly data from projects that most closely resemble the project being estimated.

Factors That Affect Project Cost

Work Window

The length of the work window is the most important factor affecting installed costs because it limits the number of panels that can be placed per shift (Table 5-1). The specifier should always attempt to maximize the length of work windows to minimize project costs.

Table 5-1 – Impact of Work Window Length on Daily PCP Installation Rates (Typical)

WORK WINDOW LENGTH	NO. PANELS -INTERMITTENT*	NO. PANELS – CONTINUOUS**
8 HOURS (NIGHT)	10 – 24	10 – 40
5 HOURS (NIGHT)	7 –17	10 – 25
WEEKEND (52 HOURS)	50 – 70	60 – 100

* Assumed panel size = 12 feet wide by 10 feet long
**Assumed panel size = 12 feet wide by 14 feet long

Figure 5-6. Example of a one-lane work area provided to replace the same lane.

The production rates shown in Table 5-1 are compiled from approximately 95 Super-Slab® projects over a period of about 15 years. The weekend production rates shown are based on projects where the contractor used a single crew placing panels only on Saturdays. Sundays were typically devoted to grouting and clean-up. Much higher production rates can be achieved if more crews are mobilized to take advantage of the available weekend hours.

Table 5-1 does not reflect recent increases in production rates that have resulted from improvements in installation processes and contractor efficiency. It is important to gather production rates from the most recent comparable projects when estimating future project costs.

Work Area

The work area is typically defined as the number of lanes that are provided for work operations during any given shift. At least two lanes are needed to make room for efficient use of excavation and placement equipment and for service and delivery trucks.

A few projects have been completed where the work area consisted of a single lane (the one being replaced), plus the adjacent shoulder in some cases (Figure 5-6). The confinement of the work area in these cases severely reduces the number of panels that can be placed during each closure. Project designers can reduce installation costs by allowing as much room as possible for the contractor's operations (to improve installation efficiency) while maintaining an acceptable flow of traffic through the project.

Project Size

The size of the project, in terms of the total number of panels, significantly affects the project unit costs (e.g., the cost per square yard or square foot of the project). Precasters and contractors must cover fixed start-up costs (such as the cost of forms, slot formers and dowel bar holders, grading or finishing equipment, grout pumps and specialized placing equipment) whether the project consists of 20 panels or 1,000 panels. Project unit costs will be reduced if these fixed costs can be amortized over more panels.

As with any product involving new and unique installation techniques, there is a learning curve that both precasters and contractors go through in PCP projects before any reasonable level of efficiency is realized. Experience suggests that most contractors become proficient at PCP installation by the time they have installed 75-100 panels, typically over a period of about one week. After this point, they will begin to achieve the higher production rates shown in Table 5-1. On larger projects involving hundreds or thousands of panels, contractors are willing to invest in more efficient labor-

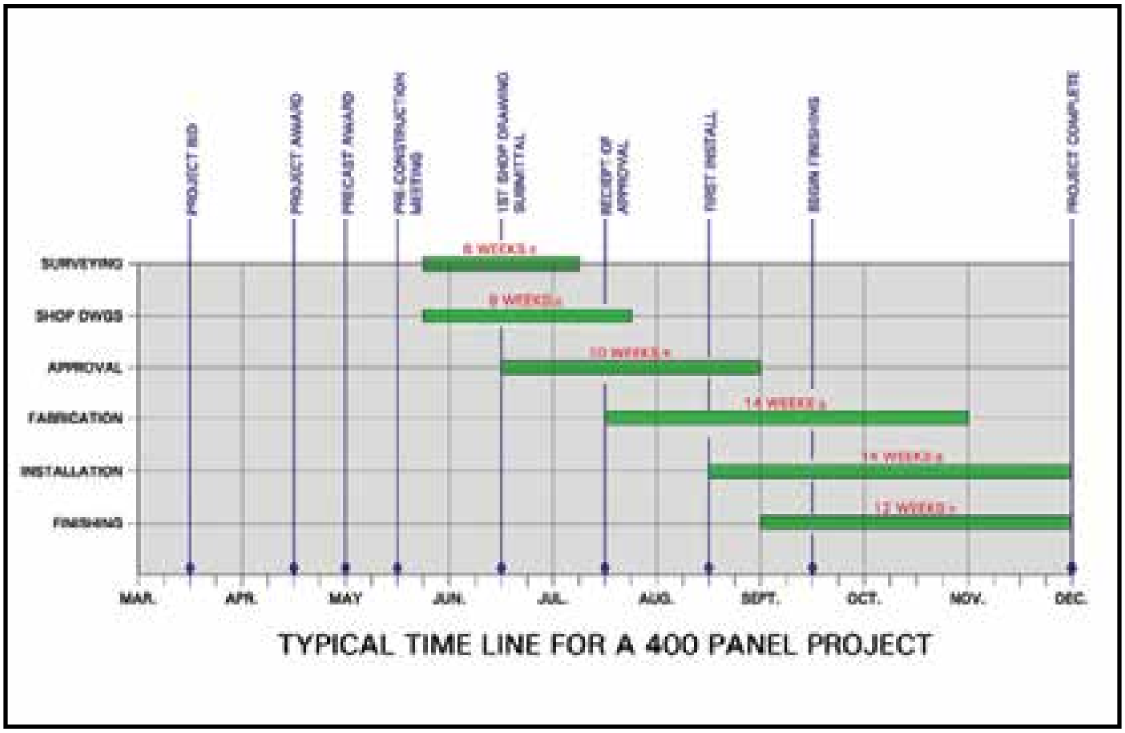


Figure 5-7. Timeline for a typical, 400-panel project showing the duration and timing of the various installation tasks.

saving installation equipment, enabling rates closer to and even higher than the upper values shown in Table 5-1.

The designer should consider these factors, as well as information from other sources, when determining the costs of installation for any new project.

Estimating Project Time Requirements

Estimating the total time required to complete a precast paving project is important because time greatly affects project costs, including contractor administration, maintenance and protection of traffic, and owner engineering and inspection costs. These costs are relatively easy to compile once the total project time is known.

To better understand how long it takes to complete a precast pavement project, one can consider the timeline of a typical 400-panel project, as shown in Figure 5-7. This graph shows the startup time and duration of each task and how the execution of the various tasks may overlap. Of particular note are the lags between startups of sequential tasks and how they add to the total time of the project. Any increase or reduction in lag time may have a significant effect on project duration.

Project Award

In most states, it takes about one month to award the project after bidding, although there are cases where this time may be abbreviated and others where it may be extended.

Contractor Mobilization and Subcontractor Awards

Figure 5-7 shows a one-month period for this to occur. The time required could be less, but time should be allowed for the contractor to identify and select the necessary subcontractors and suppliers, as well as to source appropriate equipment for the project.

Surveying

Most projects require surveying of some form before shop drawings can be developed. Surveying rarely adds more than a few days to the overall project time. For example, the required widths for 50 or more intermittent repair panels can be measured in one night. On complex projects requiring more sophisticated "x-y-z" surveys, state-of-the-art surveying equipment allows surveyors to gather large amounts of data in a single work shift. More information on surveying is provided in Chapter 6.

Development and Approval of Shop Drawings

After receiving the project surveying information, it typically takes the shop drawing engineer one to two weeks to prepare shop drawings for a typical, 400-panel project. However, keep in mind that actual fabrication cannot begin until the shop drawings are returned to the precaster and marked as "approved." Approval of the first submittal typically takes three to four weeks, depending on the complexity of the project and the efficiency of the reviewing engineers. The entire shop drawing submittal- approval process typically takes four to six weeks before any panel fabrication can begin, as shown in Figure 5-7.

Much longer approval times have been experienced in a few states, primarily because of confusing or incomplete information provided in the specifications and contract plans. This emphasizes the need for clear and coherent contract documents, as discussed earlier in this chapter.

Fabrication

The number of precasting forms required for any given project is typically determined jointly by the precaster and the contractor during the pre-construction meeting. This number depends on the number and complexity of panels needed for the project and how much time is allowed in the contract documents to fabricate and install the panels.

Approximately eight forms are typically required to fabricate the 400-panel job presented in Figure 5-7, resulting in a total production time of about 2.5 months. Note that Figure 5-7 shows a fabrication time of approximately 3.5 months, reflecting the slower "learning curve" production at the beginning of the project and slower end-of-project production to accommodate last-minute project additions and modifications.

Contractors typically give the precaster two to four weeks of lead time to produce and store panels before they schedule the start of installation to ensure they never run out of panels once installation begins. This is typically sufficient for a planned installation rate of approximately 15 panels per night. If the contractor plans to install 30 or more panels per night, fabrication will need to begin well ahead of planned installation or daily fabrication rates will need to be increased (which will require a higher number of forms).

To summarize, the time that should be allowed for fabrication will vary depending on the contractor's planned installation rate and how many forms the precaster mobilizes for production.

Time for Installation

The average installation rates presented in Table 5-2 do not necessarily reflect the lower installation rates commonly experienced at the beginning and end of a project or the lower rates that may result from unforeseen circumstances such as weather, equipment failures, traffic conditions or accidents. Therefore, it may be necessary or advisable to add extra time for installation beyond that shown in Figure 5-7.

Time for Joint Sealing, Profile Grinding and Cleanup

Joint sealing may be scheduled to begin well before panel installation is complete, but some additional time will be required to finish the task after the last of the panels have been installed. Profile grinding is usually scheduled to be done before joints are sealed, as discussed in more detail in Chapter 11. Additional time must be allotted to the overall estimated project time for completion of both of these operations. Final cleanup, including repair of small, inadvertent joint spalls, may also take additional time, as shown in Figure 5-7.

Some consideration should be given to weather conditions in determining the time needed for joint sealing, grinding and clean-up. Some project completions are pushed into colder months, which can delay temperature-sensitive operations such as spall repair and joint sealing. The project estimator should use good judgment in allotting extra time for these operations if they need to be completed in colder weather.

Some of the time periods described above and shown in Figure 5-7 may be reduced by the designer as the project is put together. For example, it may be possible to specify a shorter time for project award. Similarly, the designer may wish to commit to a shorter shop drawing review time. The designer or specification writer can also reduce project time by writing a specification that requires systems that are preapproved before the project bids. Reductions in any of the time periods described previously will have a positive effect on reducing overall project time and costs, particularly contractor and DOT overhead and administrative project costs.

Comparing PCP Costs with Other Paving and Repair Technique Costs

The cost of precast pavement should only be compared directly to the costs of those materials and techniques that can be constructed in the same work window that is specified for the subject project. For example, it is inappropriate to compare the cost of precast pavement to that of conventional cast-in-place concrete pavement unless all the costs, including traffic delay costs (for the length of time required for curing the cast-in-place concrete) are included in the comparison. It is also inappropriate to compare the costs of the two materials unless the expected service lives of the two materials are identical.

Asphalt and fast-track concretes are two classes of material that may be fairly compared to PCP because they can be installed in similar work windows. If the costs of PCP are to be compared to the costs of these materials, it is important to include all of the costs associated with each material to make a fair comparison. For example, if pavement removal is included in the precast bid item, it should also be included in the comparison cost for the other materials. Similarly, if dowels are included in the precast cost – and they usually are – they should be included in the cost for fast-track concrete as well.

Initial cost (or “first cost”) is not the only parameter that should be considered when comparing the overall costs of alternative materials. Factors such as the life cycle cost of each material, maintenance costs, user delay costs and the value of the safety associated with each installation technique should also be considered. A fair comparison will include all anticipated costs incurred over a given period of time, usually selected to be at least as long as the expected life of the longer-lived alternative, plus at least one rehabilitation activity. Since precast pavement may be expected to last longer than asphalt and fast-track concrete, with a structural life on the order of 40 years, a reasonable comparison may be to compare all of the costs associated with maintaining each type of pavement over a period of 37 or more years (Kohler et al., 2007).

An example of this type of analysis was performed by Cramer et al. (2017) for the Wisconsin Department of Transportation (WisDOT). In the cited study, real project cost data were used to estimate life-cycle costs for rapid cast-in-place concrete repairs and precast concrete repairs over various assumed service lives and using various assumed discount rates. A summary of the results of the analysis is presented in Figure 5-8, which can be used to compare the computed net present worth of agency costs of rapid cast-in-place repairs with those of precast repairs for any given assumed service life and discount rate. For example, for a discount rate of 3% and a service life of 8 years (WisDOT’s design service life for “repair and grind”), rapid repair strategies had an estimated net present cost of ~$400,000/lane mile. For the same discount rate, precast repairs had an estimated net present cost of ~$380,000 to $247,000/lane mile for service life values of 20 to 40 years, respectively. Figure 5-8 provides a basis for making comparisons using other discount rates and assumed service lives as well.

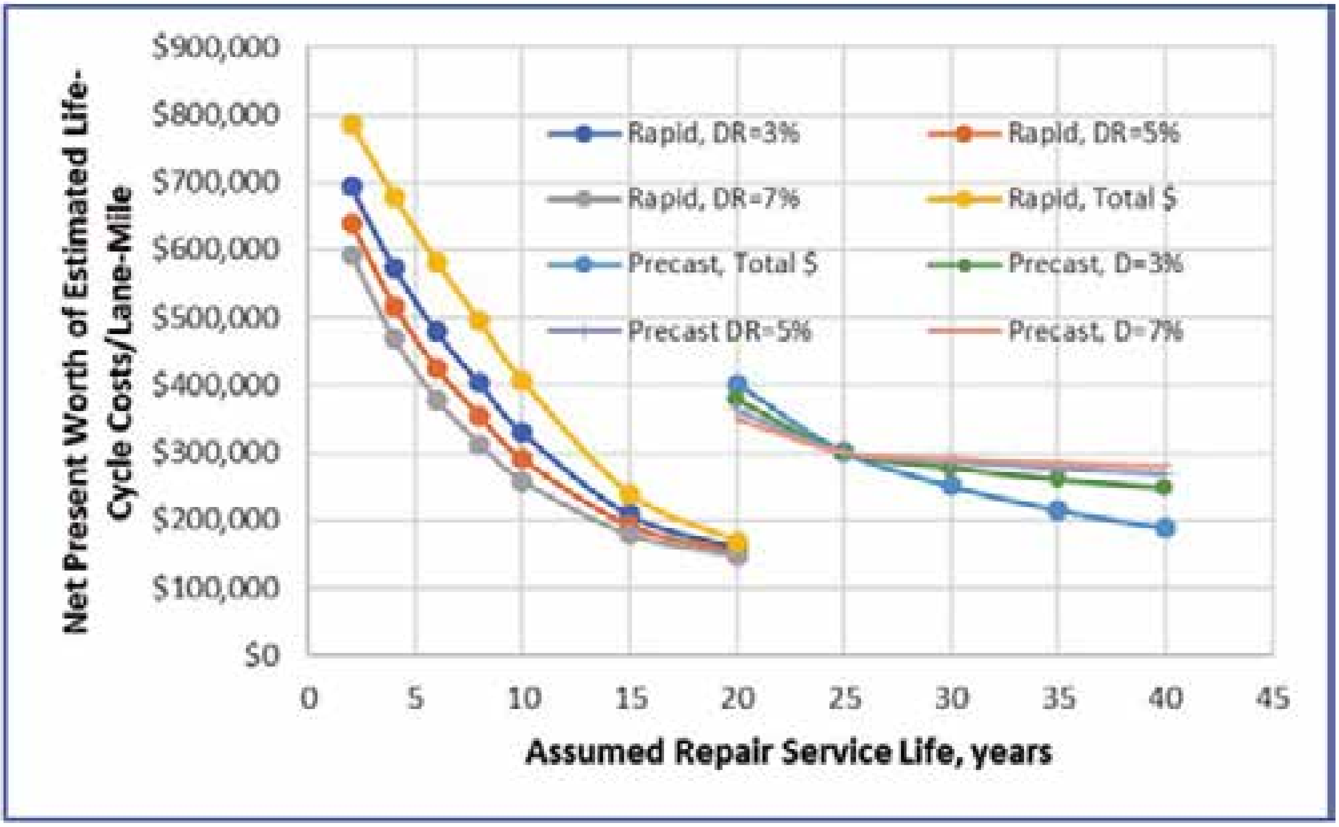


Figure 5-8. Net present worth of estimated costs vs. assumed repair service life using recent WisDOT construction cost data and various discount rates. Source: Cramer et al. (2017).

Summary

Putting a jointed precast pavement project together involves selecting the type of specification that is right for the agency and the project and developing a companion set of contract plans that includes all of the details required for successful installation.

The variety of materials and methods (systems) that may be used for installing precast pavement complicates the development of specifications. A single-product specification is easier to write, but is sometimes viewed as “sole-sourcing,” a practice that some agencies do not approve. A multiple-product specification escapes the stigma often associated with sole-sourcing, but can be difficult to write. A more reasonable approach may be to develop a performance-based specification that requires system designers to develop and test all details of a proposed system.

Contract plans are necessary to augment and clarify the specifications and to show where and how panels are installed. They are also necessary to make contractors aware of specific panel details. Panel details may be presented in a generic format or may be included as system-specific details provided attribution is given to proprietors of the systems presented. Alternatively, plans may show general panel details and reference system designer standard details for specific system details.

Project development is not complete until an estimated cost for the project is established. It is important to include all costs associated with installation in precast panels and to be aware that some factors, such as the length of work windows, work areas and project size may significantly affect the total project cost. The overall time required for project completion must also be estimated as it also affects project costs. This chapter provides a brief overview of sources that may be used to determine production rates and the time requirements for completing a project so that a realistic project cost estimate can be determined.

Chapter 6:
SHOP DRAWINGS AND OTHER SUBMITTALS
A GUIDE FOR SHOP DRAWING ENGINEERS, AGENCIES, PRECASTERS AND CONTRACTORS

Shop drawings are detailed working drawings, usually prepared by precast fabricators, to show the information needed for precast panel fabrication and installation because contract drawings and specifications typically do not include that level of detail. A complete set of shop drawings includes a production note sheet, one or more sheets of “standard” panel details, detailed drawings of each panel and/or a compilation of panel dimensions, and a panel layout drawing, when appropriate. Detailed descriptions of these sheets are provided later in this chapter.

Shop drawing engineers (SDEs), usually employed by the fabricator, use contract plans and specifications as their primary sources of information for preparing shop drawings. Other important information, such as specific panel size and connection details, need to be gathered from system designers, contractors and precast fabricators. The SDE assimilates all this information and reduces it to detailed panel fabrication drawings that are acceptable to all parties.

It is frequently necessary to resolve differences between the contractor’s desires and the owner’s specifications. While some differences may be easily resolved with a phone call, it is typically more efficient to resolve them in a pre-construction meeting – where all parties are present – before proceeding with full-scale shop drawing development. More information about pre-construction meetings is presented in Chapter 10.

This chapter focuses on developing shop drawings that are sufficiently clear and complete so that they may be reviewed in a timely manner and be subsequently followed by precast and installation personnel without intense guidance from SDEs. Shop drawings play a significant role in the quality fabrication and installation of precast panels.

Starting The Shop Drawing Process – Gathering Necessary Information

Information Gathered From Contract Plans and Specifications

Limits and Locations of Repair

Repair locations and limits, usually defined by project stations or mile post markings, are typically shown in the contract plans, as shown in Figure 6-1, and in accompanying “tables of quantities,” as appropriate for each project. Repair locations on some simple intermittent repair projects are shown only in a table (with no plan sheets), as seen in Figure 6-2.

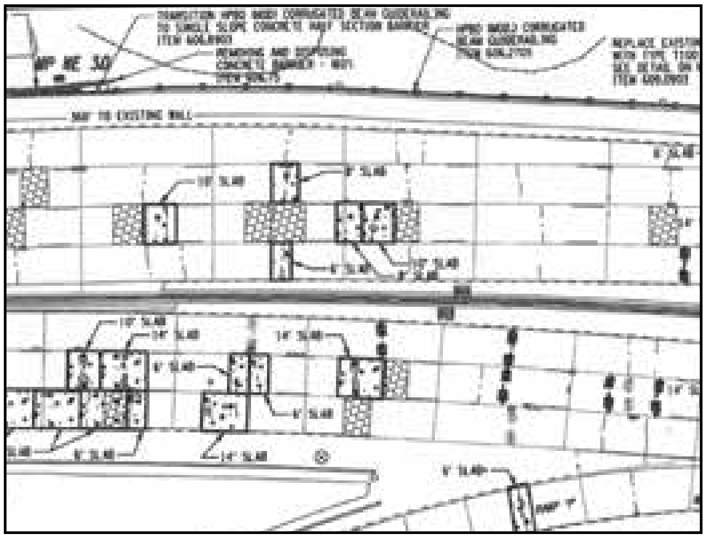
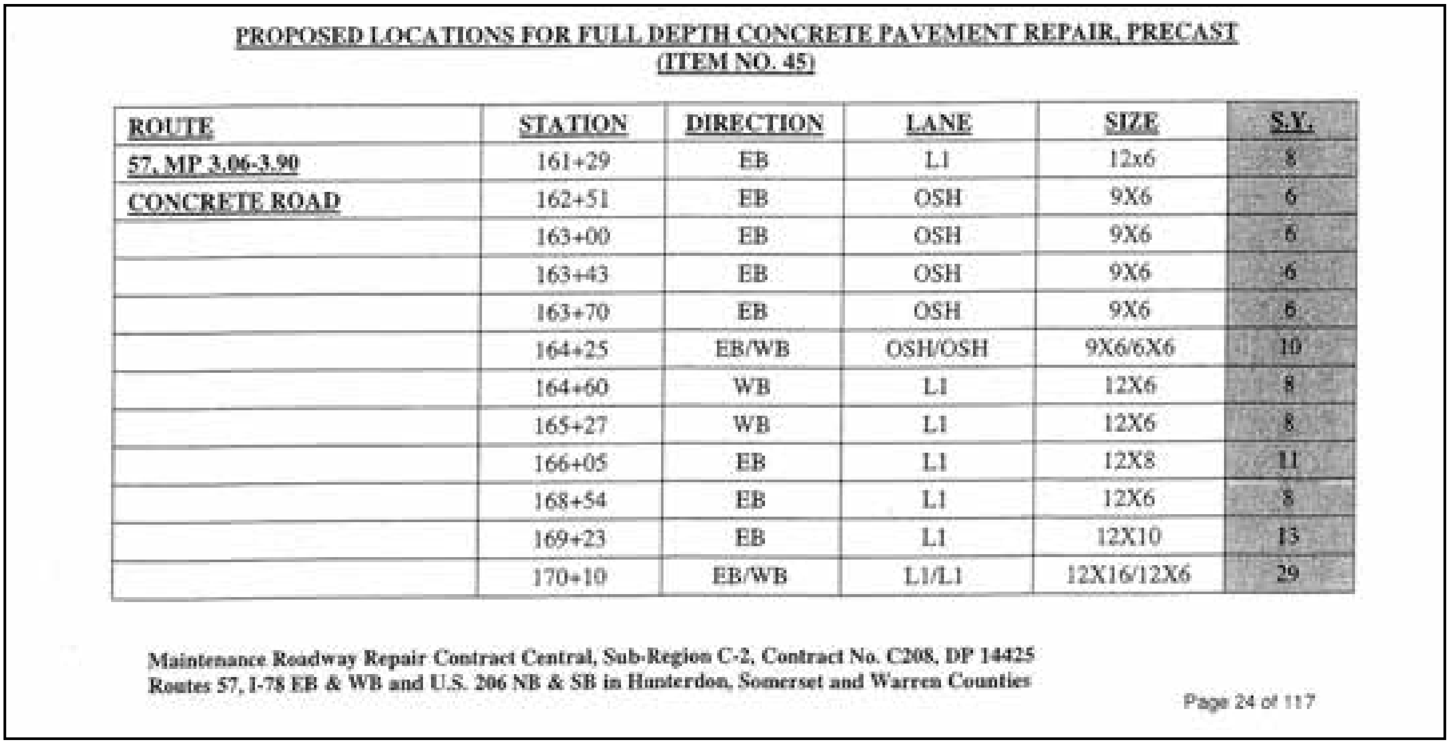


Figure 6-1. Example contract drawing showing intermittent repair locations relative to mile posts.



PROPOSED LOCATIONS FOR FULL DEPTH CONCRETE PAVEMENT REPAIR, PRECAST
(ITEM NO. 45)

ROUTE	STATION	DIRECTION	LANE	SIZE	S.Y.
57, MP 3.06-3.90	161+29	EB	L1	12x6	8
CONCRETE ROAD	162+51	EB	OSH	9X6	6
	163+00	EB	OSH	9X6	6
	163+43	EB	OSH	9X6	6
	163+70	EB	OSH	9X6	6
	164+25	EB/WB	OSH/OSH	9X6/6X6	10
	164+60	WB	L1	12X6	8
	165+27	WB	L1	12X6	8
	166+05	EB	L1	12X8	11
	168+54	EB	L1	12X6	8
	169+23	EB	L1	12X10	13
	170+10	EB/WB	L1/L1	12X16/12X6	29

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Figure 6-2. Table showing repair locations and limits that is often sufficient for construction without a set of accompanying plans.

The SDE should be aware that repair locations shown on most contract plans are approximate because additional pavement deterioration often takes place between the time the project is designed and when the work is completed. For this reason, most contract plans include a note stating that actual repair limits will be determined by the project engineer-in-charge (EIC) just prior to the development of shop drawings.

Thickness of New Panels

The SDE will usually find the thickness of the new panels in the cross-sections and, sometimes, in the panel detail sections included in the contract documents. If the specifications allow the contractor to submit different thicknesses for approval, the SDE will likely be required to submit supporting calculations. Owner review and approval of these calculations may require additional time, a factor that should be considered in the project schedule. The fastest way to get shop drawings approved is to use the thicknesses shown in the contract documents.

Nominal Lengths and Widths of New Panels

Nominal panel sizes are often shown in contract plan drawings, as shown in Figure 6-1, or in tables, as seen in Figure 6-2. Most contract specifications leave final determination of panel lengths and widths up to the contractor and precaster (subject to review and approval by the owner's engineer) because field dimensions between existing joints, shipping regulations and erection equipment influence the determination of appropriate project panel sizes.

Maximum and minimum panel length information is usually shown on standard panel detail sheets. Exact panel width, however, is shown on the contract plans only if new longitudinal joints are to be established. If existing longitudinal joints are to be preserved on an existing multi-lane interstate roadway, the SDE must determine the correct width for each panel from information obtained from the contractor's surveyor, as is discussed later in this chapter.

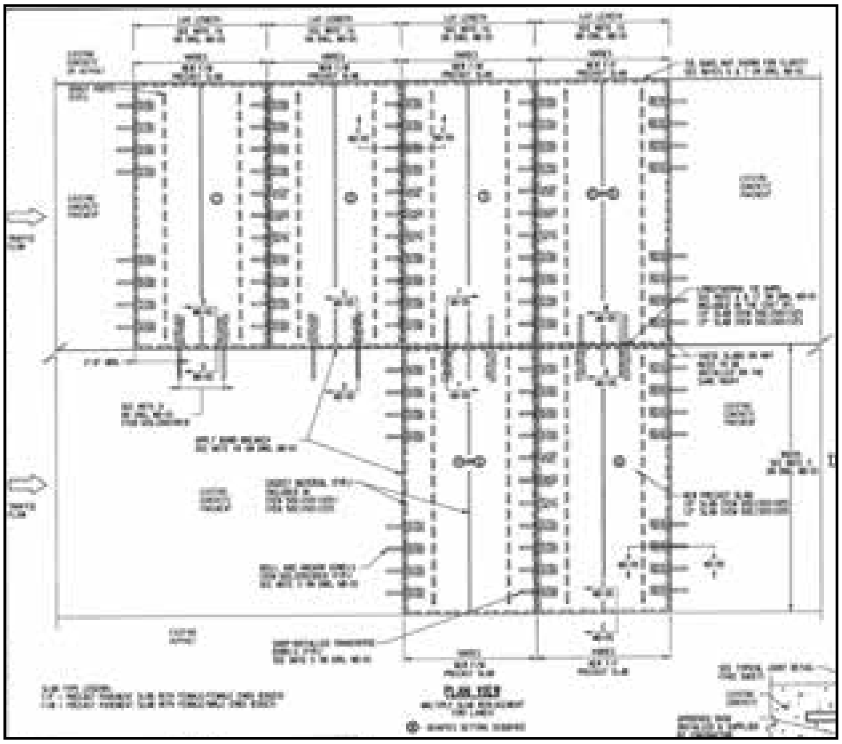


Figure 6-3. Shop drawing illustrating non-uniform spacing of tie bars to accommodate dowel bars and dowel bar slots.

Dowel Bar Size and Spacing

Dowel bar sizes and spacings are typically found or referenced on the standard panel detail sheets. Most contract drawings show only “standard spacing” of dowels (e.g., 12-inch centers when dowels are used across the entire transverse joint or when three or four dowels are spaced uniformly in each wheel path); they typically do not address variable spacing between sets of dowels when they are used in panels with varying widths. Those dimensions usually need to be determined by the SDE on a case-by-case basis.

Tie Bar Size and Spacing

Tie bar information is usually found on the standard panel detail sheets, but is typically provided for only “standard length” panels. Because new precast panels vary in length, it is the SDE’s responsibility to space tie bars in panels of each length such that they do not interfere with slots or cast-in dowels for transverse joints at the end of each panel. It is typically best practice to make the spacing of tie bars in any given panel equal to the distance shown on the standard panel detail sheet and vary only the space between the last tie bar and the end of the panel at both ends of the same panel.

If new panels are to be placed adjacent to existing pavement in an adjacent lane, as is the case with two panels in Figure 6-3, the procedure for establishing tie bar spacing should be the same regardless of possible incidence of transverse joints in the adjacent pavement. If a transverse joint in an adjacent lane abuts the new precast panel at a location away from the precast panel joints, use only the slots in the new panel on one side of the abutting joint (usually the side that offers the most slots). This concept is discussed in more detail in Chapter 9.

Reinforcing Layout

The size and spacing of reinforcing bars are sometimes shown on the standard panel detail sheets in the contract drawings. However, it is more common to find reinforcing requirements in the project specifications, usually in the form of a minimum required steel/concrete ratio. The SDE must convert that requirement to reinforcing bar size and spacing and add additional steel as necessary (e.g., around lifting inserts, around openings for utilities and as necessary for special handling and loading conditions). At least one manufacturer adds a second layer of reinforcing steel to accommodate construction or highway traffic loading before the panels are fully grouted.

Surface Finish (Texture)

The type of required surface finish or texture is typically found in the project specifications or on the sheet of standard panel details. The SDE and the owner's reviewing engineer should be aware that profile grinding of the finished surface to meet ride quality requirements, if required, will remove much, if not all, of any finish texture applied during panel fabrication. If a deeply textured finish and profile grinding are required on the same precast pavement surface, the SDE should point out the incompatibility of these two requirements to the agency's engineer and ask for official clarification. This topic is discussed further in Chapter 10.

Figure 6-4. Rubber-tire excavator placing a 12-foot-wide-by-10-foot-long panel. The same equipment was also used to excavate and remove the existing pavement.

Information Gathered From Contractors

Panel Size

The contractor typically determines panel weight and size, often during the bidding process, to match their equipment. On many intermittent repair projects, contractors limit panel length and weight to what can be easily handled by a rubber-tire excavator, as shown in Figure 6-4, because that equipment can also be used for pavement removal and excavation on the same project. Such excavators, discussed in more detail in Chapter 8, can typically handle panels up to 12 feet wide by 10 feet long by 9 inches thick and weighing up to approximately 6.75 tons. Hydraulic cranes are often used on larger continuous projects where longer and heavier panels are installed, as discussed in Chapter 9.

While placing equipment is crucial in determining panel size, maximum allowable shipping width is sometimes a governing factor. The contractor and the precaster responsible for shipping the panels must mutually determine the final dimensions of the panels to minimize freight costs and maximize the area of panels that can be placed in any given shift.

Order of Panel Placement

The SDE must determine the order in which the panels are to be placed (using information obtained from the contractor) so dowels and accommodating slots are cast in the panels correctly. Contractors usually set panels in the same direction as the traffic flows to aid in access and egress of delivery trucks, but some situations may demand placement in the opposite direction, requiring different dowel and slot locations. In some cases, it may be necessary to lay panels from each end of a repair area and meet in the middle.
The SDE must be sure to detail the panels to allow panel placement as required by the contractor.

Schedule of Panel Placement

The contractor should develop a schedule of panel placement so the SDE can prepare shop drawings in a timely manner. The contractor should also allow time for collection of field measurements, shop drawing preparation, submittal and approval when developing the placement schedule.

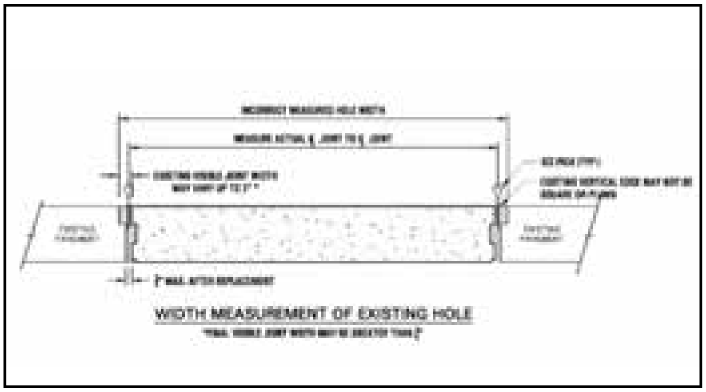


Figure 6-5. Sketch showing the use of joint probes (e.g., ice picks) to obtain correct measures of distance between longitudinal joints.

Figure 6-6. Collection of existing pavement data using a robotically controlled total station.

Field Survey to Determine Panel Widths (Intermittent Repairs)

Most specifications require that contractors gather necessary field survey information to develop accurate, project-specific shop drawings. For intermittent repair (patching) projects, the field survey may be as simple as measuring the distances between longitudinal joints at each repair location. It is typically necessary to take such measurements at each repair location because existing longitudinal joints are seldom perfectly parallel and the distance between them can vary significantly from panel to panel.

It is imperative that measurements between longitudinal joints be made perpendicular to the longitudinal joints, because even a “modest” deviation from perpendicular may result in an incorrect measurement and a panel that will not fit. It is also imperative to locate the true edges of the panels below the pavement surface when making these measurements because using the edges of the joint reservoir cuts at the pavement surface may lead to incorrect measurements. It is advisable to either remove the joint sealant before measuring or to use a probing device – such as an ice pick – to penetrate the sealant and find the true edges of the longitudinal joints (Figure 6-5).

Area Field Surveys to Gather Topographical (3-D) Information

To develop shop drawings for area placements (e.g., continuous single or multiple lanes, ramps, intersections and toll plazas), it is frequently necessary to obtain field survey information taken by the contractor’s surveyor. Such surveys are sometimes required by contract specifications, but even if they are not, it is advisable to perform detailed field surveys to ensure the new panels are designed to fit the prescribed area and create the surface required by the contract plans.

Topographical (3-D) surveys of precast pavement installation areas are performed for two reasons: 1) to determine the exact “x”, “y”, “z” coordinates of boundary features (e.g., curbs, catch basins, utility features, and existing longitudinal and transverse joints, including shoulders and ends of bridges), and 2) to capture “x”, “y”, “z” information related to the existing pavement surface, utilities and other appurtenances that may reside in the area to be replaced.

Topographical surveys of pavement areas are typically taken by qualified surveyors using conventional or robotically controlled total stations (requiring only one surveyor), such as the one shown in Figure 6-6. Area surveys of this type can also be performed using lidar (light detection and ranging) scanning equipment as long as it is sufficiently accurate to meet the precast pavement panel dimensional tolerance indicated in the specifications (typically +/- 1/8 inch).

Shots taken with total station equipment should be taken at exact boundary points (as necessary to meet existing joints) and at exact corners, edges and tops of drainage castings and other utilities. To capture the elevations of an existing pavement surface, total station shots should be taken on 10- to 15-foot centers, depending on the severity of contour change of the existing pavement. Lidar scanning equipment, on the other hand, captures all this information in the same scan, but the required information must then be extracted by surveyors trained specifically for that equipment.

It is ultimately the SDE's responsibility to reduce the topographical survey information to a digital surface model, as described later in this chapter.

Information Gathered From System Designers

System designers are individuals or entities who have developed a set of proven, panel-specific details, materials and associated installation methods that satisfy the four basic requirements of JPrCP listed in Table 1-1. For preparing shop drawings, the SDE should draw information from the standard system detail sheets the system designer previously developed for the system approval process (this is discussed in more detail in Chapter 10). Details that should be extracted from standard system detail sheets include – but may not be limited to – details for encased dowels and tie bars, matching slots or oversized holes, lifting inserts, leveling inserts for grade control, and grout retention devices for bedding and dowel grouts (if used).

Information Gathered From Precasters

The SDEs should consult with the precaster personnel who are responsible for fabricating and shipping the new panels to learn about any specific limitations or other factors that will impact the development of panel details for the project. For example, the precast manufacturer's forming equipment may limit maximum panel sizes and may also limit how dowels may be positioned in variable-width panels. Precasters should also be consulted to provide legal shipping width information, which varies between states and may also vary among different municipalities in the same state. Most states require escort cars for loads greater than 12 feet wide, so precasters try to avoid that cost by keeping panel width at less than 12 feet as placed on the truck. Similarly, precasters try to minimize freight costs by sizing the panels so each truck load, often consisting of two or more panels, weighs as close to the maximum legal load as possible (without exceeding the legal load).

To illustrate this concept, consider that a panel 12 inches thick by 13.33 feet long by 12 feet wide weighs 24,000 pounds, just half of 48,000 pounds, a payload weight that is legal in most states (without requiring an overload permit). That length of 13.33 feet, therefore, is the most freight-efficient length for panels of that thickness and width since two panels can be shipped on a single truck. Longer panels (up to about 16 feet) may be more efficient to place in the field (i.e., resulting in higher lengths of pavement replacement per shift for any given number of panels placed per shift), but obviously will be much costlier to ship since only one such panel can be shipped on a standard truck.

Pre-Construction Meeting

Once the SDE has gathered the information discussed above, it is advisable (and often required) to convene a pre-construction meeting with all project stakeholders (i.e., the project owner, engineer, contractor, subcontractors, etc.) to ensure everyone agrees upon the proposed panel details and the panel layout scheme as they relate to conformance to the specifications, installation productivity and the quality of the finished installation. Developing a consensus at this point will facilitate shop drawing preparation, enhance accuracy and hasten subsequent review and approval of the completed drawings. A pre-construction meeting will also aid the contractor in planning to fabricate and install the panels as well as help the owner in preparing to supervise and inspect the project, as is discussed in more detail in Chapter 10.

Shop Drawing Content

The following section addresses what should be included in the shop drawing submittal package to ensure all aspects of the fabrication process are addressed. Shop drawing content varies with project type. For example, more panel geometry information needs to be included for a project where non- planar panels are used than for one using only single-plane (flat) panels.

Production Note Sheet

The production note sheet, typically the first sheet of the shop drawing package, is meant to provide general production requirements and guidance (to precaster personnel) to ensure compliance with the project specifications. It also typically includes general information concerning the materials to be used in panel fabrication and describes the manufacturing processes, including curing, storage and shipping. The following information should be included in the production note sheet:

1. General notes related to conformance to specifications
2. Concrete data (stripping and 28-day compressive strengths, mix design, testing, etc.)
3. Sources of cement, aggregates, reinforcing and other hardware used in manufacturing the panels
4. Concrete mix design
5. Concrete delivery method
6. Casting information (method of pouring, screeding, finishing, etc.)
7. QA/QC procedures
8. Curing procedures
9. Fabrication tolerances
10. Yard storage information
11. Shipping information
12. System-specific information, as necessary

Panel Detail Sheets

Panel detail sheets show all the details of the panels to be manufactured for the project. Only a single sheet may be needed if the details of all the panels are the same and only the size changes. However, many sheets may be required if there are a number of different types and configurations of panels on the project.

The following information should be shown on the detail sheets:

1. Dowel and tie bar encasement details
2. Dowel or tie bar receiving slot and/or oversize hole details

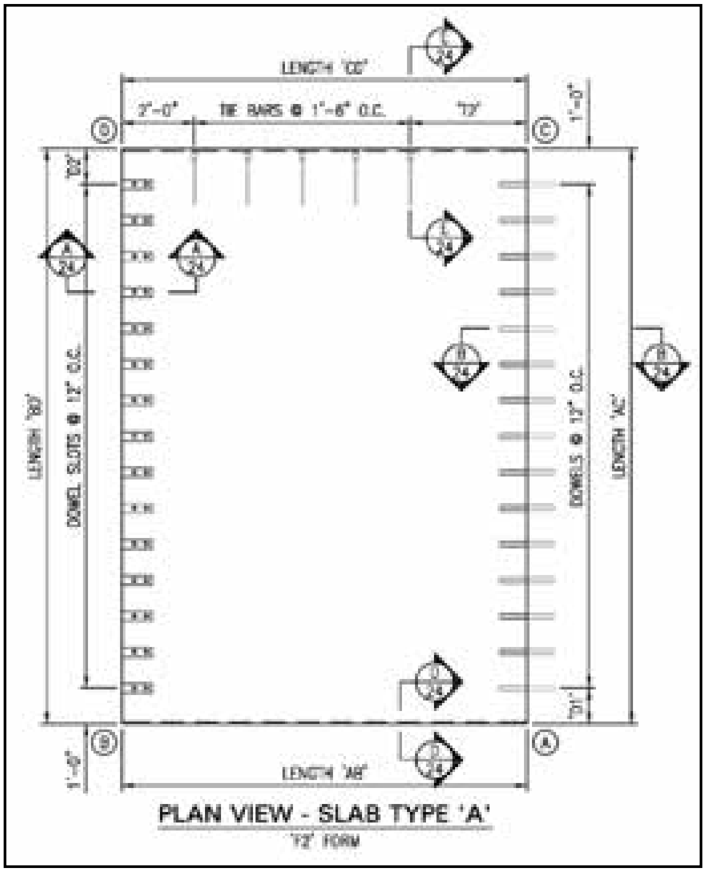


Figure 6-7. Example standard panel drawing indicating that details of all edges are shown in accompanying drawings.

3. Lifting or lift/leveling insert details
4. Dowel bar and bedding grout port details
5. Panel reinforcing details
6. Grout retention system details, if used
7. Dowel bar spacing and edge distance details
8. Other system-specific details

To aid the SDE in setting up an efficient shop drawing format, consider, for example, a panel shop drawing taken from a set of drawings that were developed for a specific project (Figure 6-7). The drawing shown in Figure 6-7 depicts a “Slab Type A.” The use of lettered side and end dimensions on this drawing allowed the SDE to use it for many different sizes of Type A panels as long as the edge details remained the same, as indicated in the drawing.

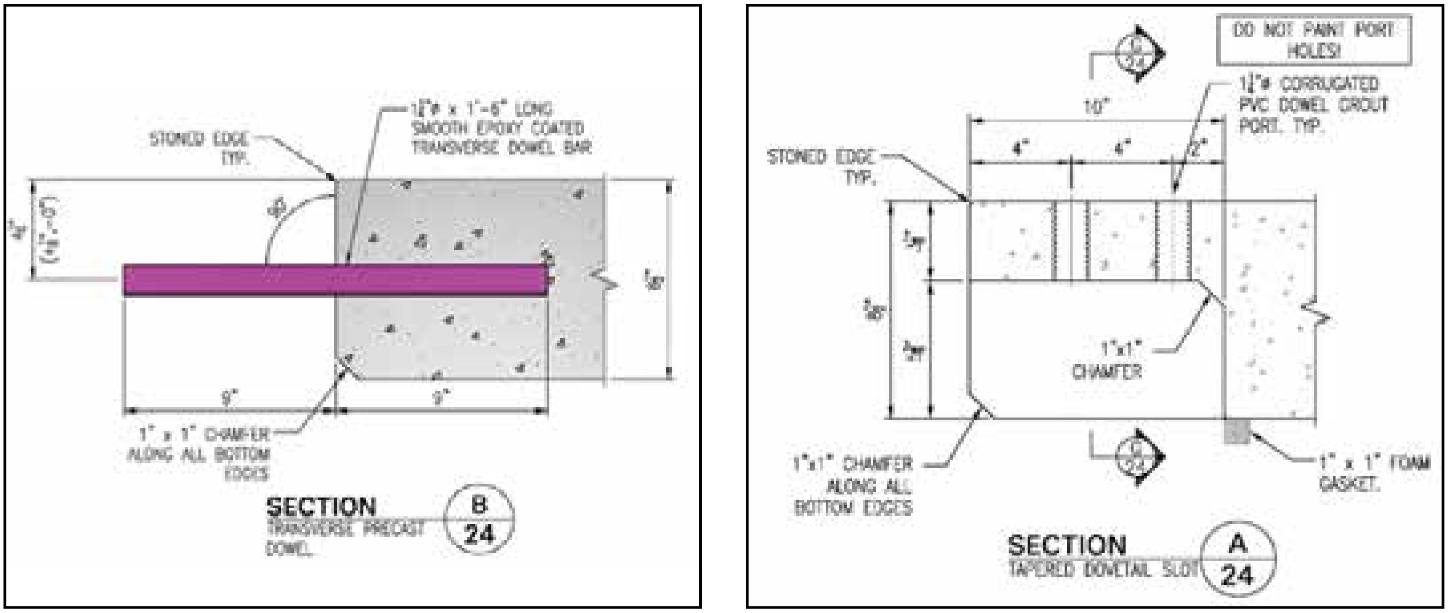


Figure 6-8. Example JPrCP transverse joint cross-sections showing an embedded dowel on one side and a matching bottom slot on the other.

Details for the two transverse edges of the standard Type A panel (shown in Figure 6- 7) are stand-alone drawings as shown in Figure 6-8. Details of the other two (longitudinal) edges were included elsewhere on the same sheet of the shop drawings for that project but are not included here for simplicity. Note that the edge details shown in Figure 6-8 applied to all Type A panels, even though edge dimensions, also not shown here for simplicity, changed as necessary. The technique of showing stand-alone edge details allowed the SDE to refer to them for other types of panels (Type B panels, for example) as well, saving drawing time and shop drawing sheets. This demonstrates the efficiency of establishing a sheet of edge details that may be referenced from several plan view drawings for several panel types.

This method of detailing was adequate for fabrication and efficient for drawing purposes, but additional distinguishing "mark numbers" (not shown in Figure 6-7) were necessary to identify each differently sized panel for storage, shipping and placement.

Features other than differing panel edges may trigger the need for additional plan view shop drawings. For example, unique shop drawings are needed for each panel when it is necessary to provide blockouts for manholes, catch basins, water valves or other utility structures. Precast pavement projects of even modest complexity may require a number of shop drawings for fabrication and installation purposes.

Establishing Dimensions for Intermittent Repair Panels

Because intermittent repair panels are often randomly located throughout a project, they are usually sized to fit each location. In most cases, longitudinal joints are retained, so the SDE will need to determine the width of each panel from information provided by project surveyors, as discussed earlier in this chapter.

The lengths of intermittent repair panels are usually established by the contractor within maximum and minimum limits indicated in the project specifications. Contractors typically establish a "menu" of standard panel lengths (e.g., 6 feet, 8 feet and 10 feet) to best address the variety of required project repair lengths. Consideration is also given to minimizing fabrication and freight costs and maximizing placement efficiency (using equipment the contractors owns) when establishing the project panel menu.

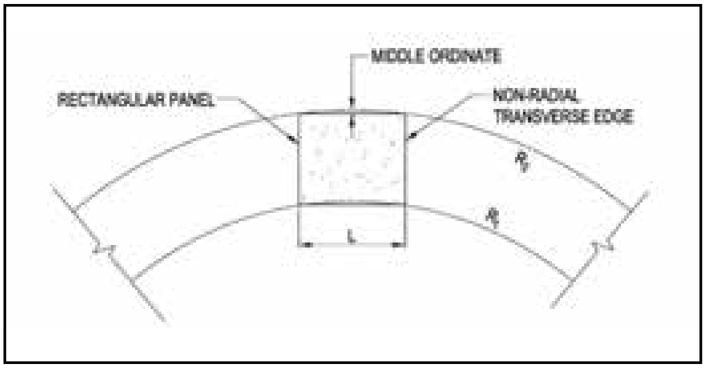


Figure 6-9. Plan view (not to scale) of a single rectangular panel in a horizontally curved roadway.

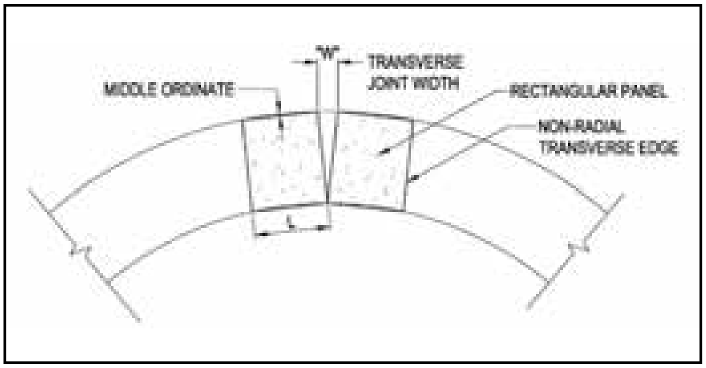


Figure 6-10. Plan view (not to scale) of a series of rectangular panels placed in a horizontally curved roadway.

Establishing Dimensions for Lane Replacement Panels

On lane-replacement projects, panels are typically placed continuously over longer distances. It is typically considered a "best practice" to cut at least one new longitudinal joint approximately 2 inches into the adjacent lane so the new panels are all the same width (typically slightly wider than 12 feet) within any given replacement segment. This practice also eliminates deteriorated concrete that may exist along the existing longitudinal joint.

The precaster and the contractor typically work together to establish the lengths of new panels on lane-replacement projects. Their goal is to minimize freight cost and to establish panel weights that the contractor can favorably manage at the site.

If the widths and lengths are constant, the SDE may need to develop only a minimum number of shop drawings for the project. If, on the other hand, the lengths are constant and the widths vary (as in the case where the existing longitudinal joints are retained), the SDE will likely find it necessary to develop more shop drawings (and/or tables) with properly developed mark numbers assigned to each panel.

Using Rectangular Panels in Horizontal Curves

A single rectangular panel design can be used on roadways of any curvature (see Figure 6-9) if the distance between the adjacent curved roadway lane and the center of the edge of the new panel (i.e., the middle ordinate) does not exceed the maximum allowable longitudinal joint width. When rectangular panels are used in such locations, it is imperative the transverse saw cuts in the existing pavement match the rectangular shape depicted in the shop drawing. More detail on this is offered in Chapter 8. The SDE will likely be responsible for checking middle ordinates based on curve data provided by the contractor's surveyor. However, the contractor's surveyor will be responsible for laying out the transverse saw cuts properly, as discussed in Chapter 8.

A series of rectangular precast panels can also be used on slightly curved roadways (see Figure 6-10) as long as the middle ordinate of each panel does not exceed the maximum allowable longitudinal joint width, the transverse joint width at the outside of the curve ("W" in Figure 6-10) does not exceed the maximum allowable transverse joint width, and the cuts in the existing pavement at the ends of the series of panels are made to match the rectangular panels (see Chapter 8 for more details). The SDE will be responsible for ensuring the first two criteria are met while the contractor's surveyor will be responsible for the third. Notice that the end transverse cuts are not likely to be radial to the curve if rectangular panels are used in a horizontal curve.

The SDE may determine middle ordinate and "W" dimensions using basic circular curve geometry. To do this, the lengths and widths of the rectangular panels must be known and the radius of the curve must be provided by the contractor's surveyor, as discussed earlier in this chapter.

Table 6-1. Joint Widths and Middle Ordinate Values for Selected Precast Panel Lengths and Roadway Radii.

RADIUS (FT.)	6 FT. LONG PANEL		10 FT. LONG PANEL		14 FT. LONG PANEL	
	W*	MO**	W	MO	W	MO
3,000	.024	.001	0.040	0.004	0.056	0.008
2,000	0.036	0.002	0.06	0.006	0.084	0.012
1,000	0.072	0.005	0.120	0.125	0.168	0.025

* MAXIMUM TRANSVERSE JOINT WIDTH, FEET

** MIDDLE ORDINATE, FEET

Transverse joint widths and middle ordinate values ("W" and "MO," respectively) for a selection of typical 12-foot-wide rectangular panels placed in roadways of various radii are shown in TABLE 6-1 The table shows that "W" exceeds allowable transverse joint widths (typically 1/2 inch or .04 feet) at relatively large radius curves – roadways that appear to be "relatively straight." To avoid exceeding specified joint widths, it is generally best practice to use trapezoidal panels that are designed to fit each curve exactly.

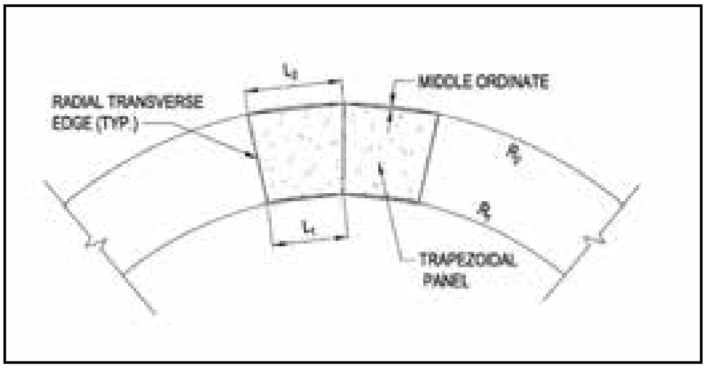


Figure 6-11. Plan view (not to scale) of a series of trapezoidal-shaped panels placed in a horizontally curved roadway.

Designing Trapezoidal Panels for Horizontal Curves

Trapezoidal panels may be designed and dimensioned to fit any horizontal curve if the radius of the curve, the width of the lane and the length of the panels are known (Figure 6-11). While this information may be shown on the contract drawings, it should be checked and provided by the contractor's surveyor to ensure panels are designed accurately. To ensure a proper fit, the SDE should design transverse edges of all trapezoidal panels along radials of the curve. Longitudinal edges may be designed as straight chords if the resulting middle ordinates do not exceed the maximum allowable longitudinal joint width. When straight chords do exceed that limit, which is typically 3/4 inch or .06 feet, it will be necessary to design panels with curved longitudinal edges.

The middle ordinate of a 14-foot-long panel with straight longitudinal edges (chords) placed in a 400-foot radius curve is approximately 3/4 inch or .06 feet, the typical maximum allowed longitudinal joint width. Therefore, it is usually necessary to design 14-foot-long panels with curved longitudinal edges for radii less than 400 feet to avoid exceeding the joint width limit. Alternatively, shorter panels with straight chords may be used on smaller radius curves. The SDE must check middle ordinates for each proposed panel length carefully when designing panels for curves with radii less than approximately 400 feet.

Dowel Placement in Non-radial Transverse Joints

Dowels in precast panels used in horizontal curves are typically detailed to be placed perpendicular to radial transverse joints, as they are in jointed cast-in-place concrete pavement. The sketches shown in Figures 6-9 and 6-10 indicate, in an exaggerated fashion, that transverse joints of rectangular panels in horizontal curves are not radial. In practice, they do not deviate greatly from a radial line (in most highway curves) as long as the panels are not longer than about 10 to 12 feet. Because of this, dowels are typically detailed to be placed perpendicular to the non-radial

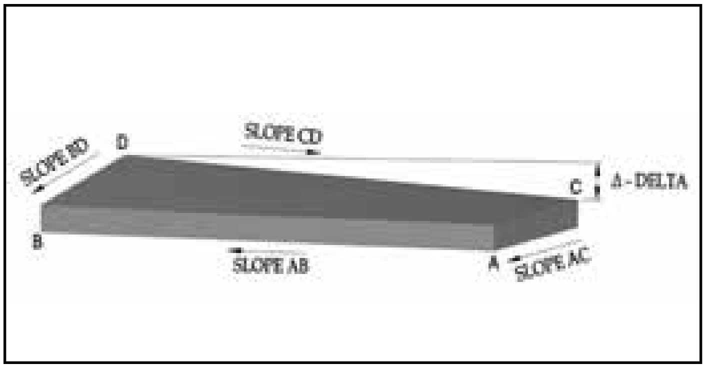


Figure 6-12. Sketch of a non-planar pavement panel showing one corner, "D," residing above the plane established by the other three corners.

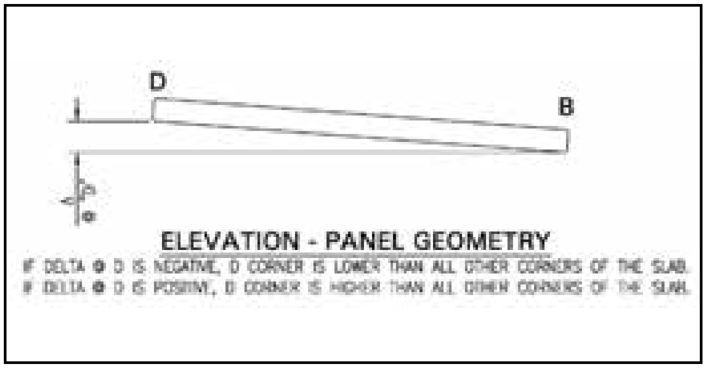


Figure 6.13. Illustration of the "delta" associated with non-planar panel geometry.

transverse joints. This has not proven problematic on such projects completed to date.

Designing Non-planar (Warped) Panels

Panel dimension discussions thus far have focused on flat (single-plane) panels. The SDE should be aware that non-planar panels are often needed to accommodate or meet existing non-planar or contoured roadway surfaces. Non-planar surfaces are commonly found at the beginnings and endings of horizontal curves (superelevation transitions), at highway intersections, where new precast panels in one lane abut uneven existing pavement in an adjacent lane or at any location where the cross-slope of the roadway varies from one end of the panel to the next (Smith, 2013).

A non-planar (warped) panel, shown schematically in Figure 6-12, may be defined as one whose surface does not reside in a single plane. For illustration purposes, all points on the surface of the warped panel shown in Figure 6-12 reside above the single plane defined by corners "A," "B" and "C." The vertical location of corner "D," relative to the plane formed by corners A, B and C, can be defined as the "delta" (Δ) distance shown in Figure 6-13.

The rectangular warped panel shown in Figure 6-12 is further defined as one in which all the sides of the panel are vertically straight and cross-sections taken perpendicular to any side vary linearly from one end (or side) of the panel to the other. This configuration of a non-planar panel is proprietary to The Fort Miller Co., Inc.

While the geometry of the warped panel shown in Figure 6-12 may appear to be complex, it's relatively easy to determine, define and include in the shop drawings. The delta distance is the only information needed to adjust corner "D" (of the bed) to the correct elevation as long as corners "A," "B" and "C" are placed level on the casting bed. Ultimately, non-planar panels cast in this manner are placed in the field to the correct "x-y-z" field coordinates for all four corners.

Shop drawings for warped panels are best developed by first creating a digital surface model of the area to be replaced. Surface models may be developed from theoretical pavement grades and cross-slopes shown in the contract drawings. In rare cases, contract drawings may include a panel layout drawing that shows "design elevations" of each corner of each panel, essentially eliminating the need to develop a digital surface model. In some cases, a design surface model of the replacement area can be obtained from the DOT.

In general, however, the SDE should ultimately use topographical survey information gathered by the contractor's surveyor, as discussed earlier in this chapter, to check any surface model provided by others or as the primary source of elevation data if that information is not available from any other source.

The "x," "y" and "z" coordinate values of each corner of each panel surface can be digitally extracted from the design surface model by superimposing a panel layout drawing on the surface model using commonly available software. The

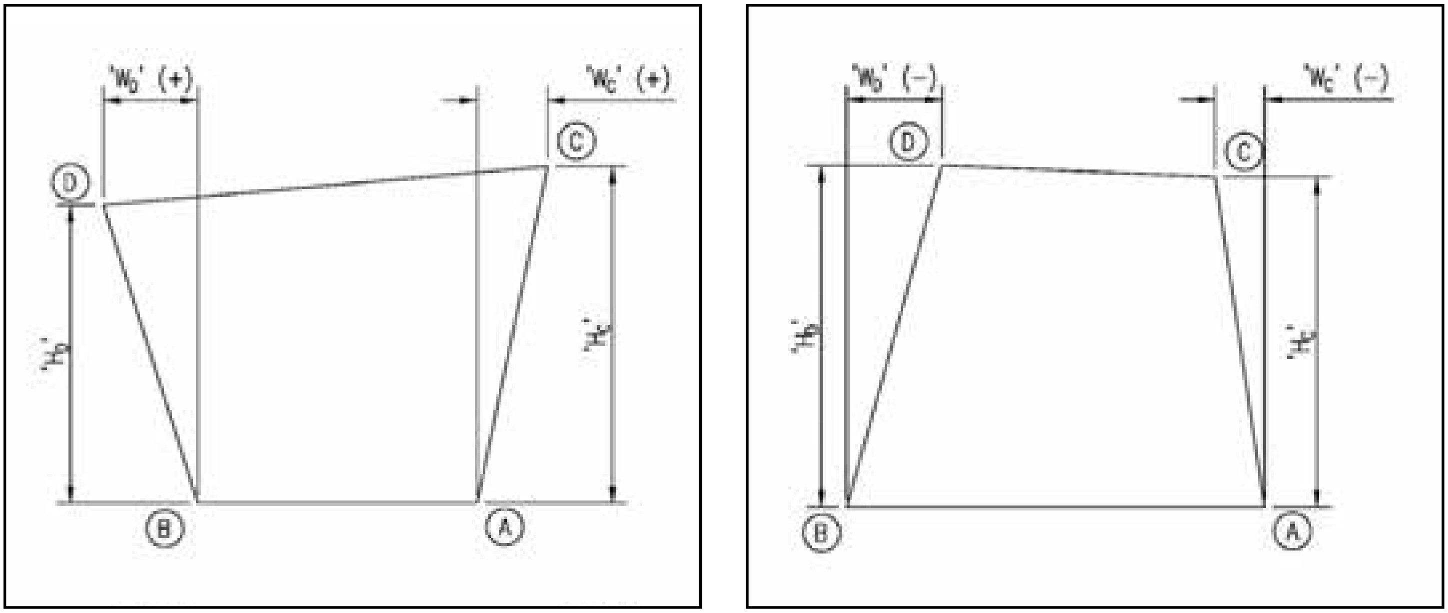


Figure 6-14. Example of master drawings showing general panel geometry.

delta values described above can be determined once the “x,” “y” and “z” coordinate values of each corner are known. Delta values for all panels should appear on the shop drawing general information table and on any shop ticket that is used for fabrication.

Note that warped panels described above are rectangular (plan view) in tangent (straight) portions of the roadway and trapezoidal the curved portions.

Establishing Dimensions for Panels of Any Shape

Panels with shapes not described above may be required in some locations, such as intersections, ramp termini and bridge approach slabs, where roadway alignments are not square or straight. Panel dimensions for such locations are best established by developing a digital surface model of the overall area as described above. Once a panel layout for the area is developed, exact panel dimensions can be determined (extracted) by combining the panel layout drawing with the digital surface model, also as described above.

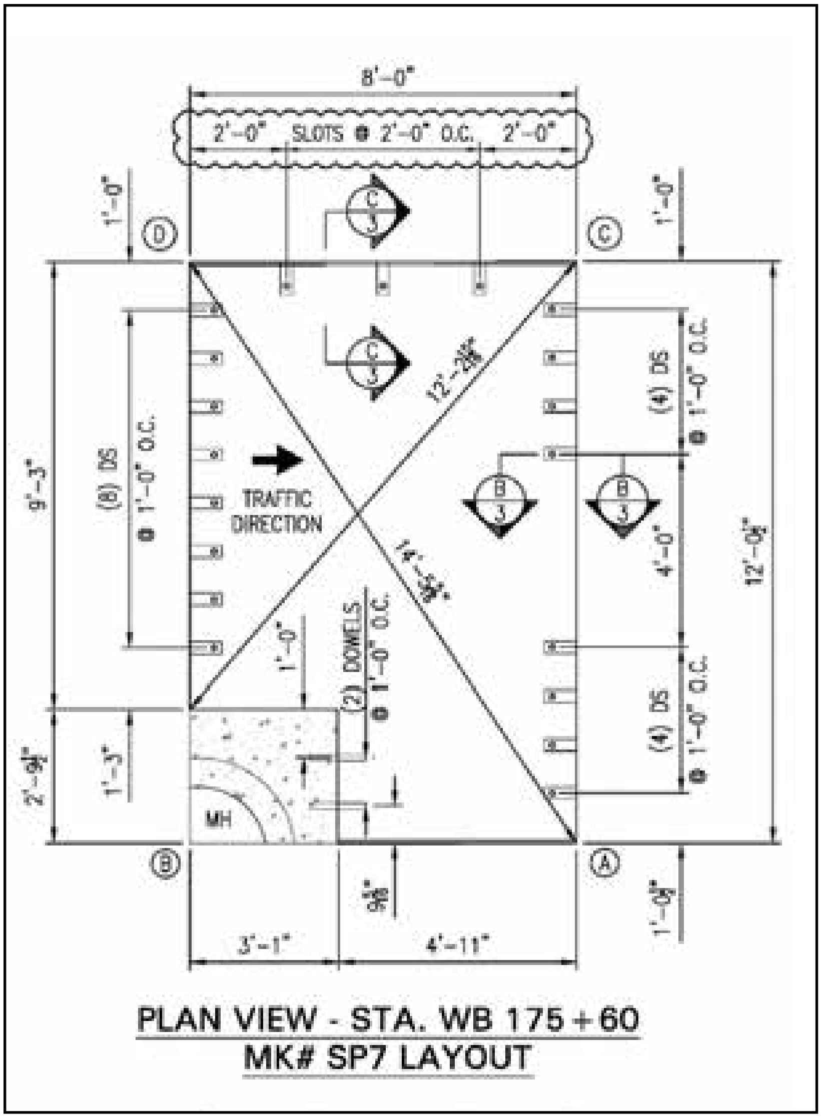
The SDE will find it useful to work with “master drawings,” such as those shown in Figure 6-14, to show dimensions of each panel as well as other auxiliary dimensions that will be useful specifically for form setup. Auxiliary dimensions, such as “WD” and “HD” in Figure 6-14, are typically included in shop ticket drawings (discussed later in this chapter) to aid precasters in setting up forms without extra support from the SDE or other surveying personnel.

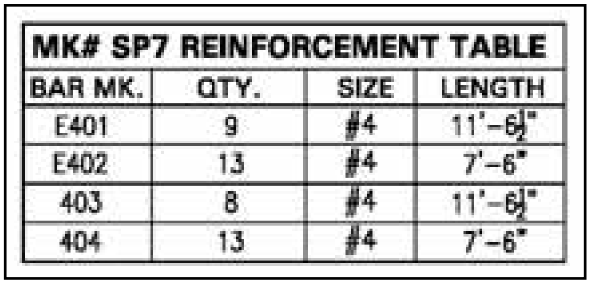
Detailed Drawings for Special Panels

It is highly likely that special panels will be required to accommodate utility structures on urban arterial and city street projects. Since such panels are not easily described in general sketches of the type shown in Figure 6-14, it is typically necessary to develop separate detailed drawings for these features, such as the one shown in Figure 6-15. These drawings may also need to include (or reference) special cross-section (edge) views that are panel-specific. Diagonal dimensions, as shown in Figure 6-15, also aid precasters in setting up their forms.

Organizing Panel Dimensions

It is typically necessary to calculate and track many dimensions on large projects (especially for projects involving horizontal curves) for fabrication, shipping and installation purposes. To manage this information efficiently and accurately, the SDE should develop a “master table” of panel dimensions and other critical information, as seen in





MK# SP7 REINFORCEMENT TABLE

BAR MK.	QTY.	SIZE	LENGTH
E401	9	#4	11'-6½"
E402	13	#4	7'-6"
403	8	#4	11'-6½"
404	13	#4	7'-6"

Figure 6-15. Example detailed shop drawing (and accompanying reinforcement table) for a special panel containing a manhole blockout.

Figure 6-16. The tabulated information should include at least the following:

1. Mark number (label or designator) of the panel
2. Quantity of each mark number
3. Panel type
4. Form type (if required by the precaster)
5. Panel area
6. Panel volume (cubic yards)
7. Panel weight
8. Panel delta (for warped panels)
9. Lengths of line segments shown in Figure 6-14
10. Panel diagonals (for shop use) shown in Figure 6-15
11. Reinforcing bar list
12. List of embedded hardware (dowels, tie bars, lifting inserts, etc.)
13. "x," "y" and "z" values of each corner of every panel

Notice that the "x," "y" "z" values (No. 13 in the list above) are not included in the table shown in Figure 6-16. For the sake of clarity, it's often better for the SDE to develop a separate table of these values that is prepared specifically for the project surveyors responsible for panel layout at the site, as discussed in Chapter 8.

MARK #	QTY	SLAB TYPE	FORM TYPE	AREA (SY)	VOLUME (CYD)	WEIGHT (TON)	DELTA * @ D	SLAB WARP TYPE	GEOMETRIC VARIABLES							
									LENGTH OF LINE SEGMENT				ADDITIONAL VARIABLES			
									AB	CD	AC	BD	Hc	Wc	Hd	Wd
3-P1	1	A	F2	10.714	3.12	6.33	(+) 0 1/16"	PLANAR	7' 6"	7' 6"	12' 10 15/16"	12' 9 9/16"	12' 10 15/16"	0' 0"	12' 9 9/16"	-0' 0"
3-P1a	1	A	F1	10.761	3.14	6.36	(+) 0 1/16"	PLANAR	7' 6"	7' 6"	12' 10 15/16"	12' 10 15/16"	12' 10 15/16"	0' 0"	12' 10 15/16"	-0' 0"
3-P2	1	A	F2	16.380	4.78	9.67	(+) 0 3/16"	WARPED	11' 5"	11' 5"	12' 10 15/16"	12' 10 15/16"	12' 10 15/16"	0' 0"	12' 10 15/16"	-0' 0"
3-P3	1	A	F1	16.379	4.78	9.67	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 10 15/16"	12' 10 15/16"	12' 10 15/16"	-0' 0"	12' 10 15/16"	0' 0"
3-P4	1	A	F2	16.379	4.78	9.67	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 10 15/16"	12' 10 15/16"	12' 10 15/16"	-0' 0"	12' 10 15/16"	-0' 0"
3-P5	1	A	F1	16.104	4.70	9.51	(+) 0 5/16"	WARPED	11' 0 1/2"	11' 4 15/16"	12' 10 15/16"	12' 10 15/16"	12' 10 7/8"	0' 3 13/16"	12' 10 15/16"	0' 0 5/8"
3-P6	1	A	F2	16.377	4.78	9.67	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 10 15/16"	12' 10 15/16"	12' 10 15/16"	0' 0 1/8"	12' 10 15/16"	-0' 0 1/8"
3-P7	1	A	F1	16.376	4.78	9.67	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 10 7/8"	12' 10 15/16"	12' 10 7/8"	0' 0 1/8"	12' 10 15/16"	-0' 0 1/8"
3-P8	1	A	F2	16.376	4.78	9.67	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 10 7/8"	12' 10 7/8"	12' 10 7/8"	0' 0 1/8"	12' 10 7/8"	-0' 0 1/8"
3-P9	1	A	F1	16.375	4.78	9.67	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 10 7/8"	12' 10 7/8"	12' 10 7/8"	0' 0 1/2"	12' 10 7/8"	-0' 0 1/2"
3-P10	1	A	F2	16.375	4.78	9.67	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 10 7/8"	12' 10 7/8"	12' 10 7/8"	0' 0 5/8"	12' 10 7/8"	-0' 0 5/8"
3-P11	1	A	F1	16.374	4.78	9.67	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 10 7/8"	12' 10 7/8"	12' 10 7/8"	0' 0 5/8"	12' 10 7/8"	-0' 0 5/8"
3-P12	1	A	F2	16.374	4.78	9.67	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 10 7/8"	12' 10 7/8"	12' 10 7/8"	0' 0 5/8"	12' 10 7/8"	-0' 0 5/8"
3-P13	1	A	F1	16.385	4.78	9.68	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 11 1/16"	12' 10 7/8"	12' 11 1/16"	0' 0 7/16"	12' 10 7/8"	-0' 0 7/16"
3-P14	1	A	F2	16.427	4.79	9.70	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 11 11/16"	12' 11 1/16"	12' 11 11/16"	0' 0"	12' 11 1/16"	0' 0"
3-P15	1	A	F1	16.490	4.81	9.74	(+) 0 5/16"	WARPED	11' 5"	11' 5"	13' 0 1/4"	12' 11 11/16"	13' 0 1/4"	-0' 0"	12' 11 11/16"	-0' 0"
3-P16	1	A	F2	16.553	4.83	9.78	(+) 0 5/16"	WARPED	11' 5"	11' 5"	13' 0 7/8"	13' 0 5/16"	13' 0 7/8"	0' 0"	13' 0 5/16"	-0' 0"
3-P17	1	A	F1	16.563	4.83	9.78	(+) 0 5/16"	WARPED	11' 5"	11' 4 1/8"	13' 1 1/2"	13' 0 7/8"	13' 1 1/2"	-0' 0 7/8"	13' 0 7/8"	-0' 0"
3-P18	1	B	F2	16.560	4.83	9.78	(+) 0 5/16"	WARPED	11' 5"	11' 5 1/16"	12' 11 3/8"	13' 1 15/16"	12' 11 3/8"	-0' 0 3/4"	13' 1 15/16"	0' 0 3/4"
3-P19	1	B	F1	16.425	4.79	9.70	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 11 3/8"	12' 11 3/8"	12' 11 3/8"	0' 0"	12' 11 3/8"	-0' 0"
3-P20	1	B	F2	16.425	4.79	9.70	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 11 3/8"	12' 11 3/8"	12' 11 3/8"	0' 0"	12' 11 3/8"	-0' 0"
3-P21	1	B	F1	16.425	4.79	9.70	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 11 3/8"	12' 11 3/8"	12' 11 3/8"	0' 0"	12' 11 3/8"	-0' 0"
3-P22	1	B	F2	16.425	4.79	9.70	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 11 3/8"	12' 11 3/8"	12' 11 3/8"	0' 0"	12' 11 3/8"	-0' 0"
3-P23	1	B	F1	16.426	4.79	9.70	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 11 3/8"	12' 11 3/8"	12' 11 3/8"	0' 0"	12' 11 3/8"	-0' 0"
3-P24	1	B	F2	16.426	4.79	9.70	(+) 0 5/16"	WARPED	11' 5"	11' 5"	12' 11 3/8"	12' 11 3/8"	12' 11 3/8"	0' 0"	12' 11 3/8"	-0' 0"
3-P25	1	SP	SP	14.081	4.11	8.32	(+) 0 5/16"	WARPED	11' 5"	SPECIAL	9' 10 1/8"	12' 11 3/8"	9' 10 1/8"	0' 0"	12' 11 3/8"	-0' 0"

Match Line

										SLAB REINFORCEMENT							
DIAGONALS (3D)		'AB' COMPONENTS		'CD' COMPONENTS		'AC' COMPONENTS		'BD' COMPONENTS		BAR MARK E501				BAR MARK E502			
AD	BC	No. COMP	'T1'	No. COMP	'T2'	No. COMP	'D1'	No. COMP	'D2'	TOP QTY.	TOP 'L'	BOT QTY.	BOT 'L'	TOP QTY.	TOP 'L'	BOT QTY.	BOT 'L'
14' 10 1/16"	14' 11 3/16"	2	3' 6"	- - -	- - -	11	1' 10 15/16"	11	1' 9 9/16"	9	12'-5"	8	12'-5"	14	7'-0"	14	7'-0"
14' 11 1/4"	14' 11 3/16"	2	3' 6"	- - -	- - -	11	1' 10 15/16"	11	1' 10 15/16"	9	12'-5"	8	12'-5"	14	7'-0"	14	7'-0"
17' 2 7/8"	17' 2 13/16"	4	3' 5"	- - -	- - -	11	1' 10 15/16"	11	1' 10 15/16"	12	12'-5"	12	12'-5"	14	10'-11"	14	10'-11"
17' 2 7/8"	17' 2 13/16"	4	3' 5"	- - -	- - -	11	1' 10 15/16"	11	1' 10 15/16"	12	12'-5"	12	12'-5"	14	10'-11"	14	10'-11"
17' 2 7/8"	17' 2 13/16"	4	3' 5"	- - -	- - -	11	1' 10 15/16"	11	1' 10 15/16"	12	12'-5"	12	12'-5"	14	10'-11"	14	10'-11"
17' 0 5/16"	17' 2 5/16"	4	3' 0 1/2"	- - -	- - -	11	1' 10 15/16"	11	1' 10 15/16"	12	12'-5"	12	12'-5"	14	10'-11"	14	10'-11"
17' 2 3/4"	17' 2 7/8"	4	3' 5"	- - -	- - -	11	1' 10 15/16"	11	1' 10 15/16"	12	12'-5"	12	12'-5"	14	10'-11"	14	10'-11"
17' 2 3/4"	17' 2 7/8"	4	3' 5"	- - -	- - -	11	1' 10 7/8"	11	1' 10 15/16"	12	12'-5"	12	12'-5"	14	10'-11"	14	10'-11"
17' 2 3/4"	17' 2 7/8"	4	3' 5"	- - -	- - -	11	1' 10 7/8"	11	1' 10 7/8"	12	12'-5"	12	12'-5"	14	10'-11"	14	10'-11"
17' 2 1/2"	17' 3 1/8"	4	3' 5"	- - -	- - -	11	1' 10 7/8"	11	1' 10 7/8"	12	12'-5"	12	12'-5"	14	10'-11"	14	10'-11"
17' 2 3/8"	17' 3 3/16"	4	3' 5"	- - -	- - -	11	1' 10 7/8"	11	1' 10 7/8"	12	12'-5"	12	12'-5"	14	10'-11"	14	10'-11"
17' 2 3/8"	17' 3 3/16"	4	3' 5"	- - -	- - -	11	1' 10 7/8"	11	1' 10 7/8"	12	12'-5"	12	12'-5"	14	10'-11"	14	10'-11"
17' 2 3/8"	17' 3 3/16"	4	3' 5"	- - -	- - -	11	1' 10 7/8"	11	1' 10 7/8"	12	12'-5"	12	12'-5"	14	10'-11"	14	10'-11"
17' 2 1/2"	17' 3 3/16"	4	3' 5"	- - -	- - -	11	1' 11 1/16"	11	1' 10 7/8"	12	12'-5"	12	12'-5"	14	10'-11"	14	10'-11"
17' 2 15/16"	17' 3 3/8"	4	3' 5"	- - -	- - -	11	1' 11 11/16"	11	1' 11 1/16"	12	12'-5 3/4"	12	12'-5 3/4"	14	10'-11"	14	10'-11"
17' 3 3/8"	17' 3 13/16"	4	3' 5"	- - -	- - -	12	1' 0 1/4"	11	1' 11 11/16"	12	12'-6 1/4"	12	12'-6 1/4"	14	10'-11"	14	10'-11"
17' 3 13/16"	17' 4 5/16"	4	3' 5"	- - -	- - -	12	1' 0 7/8"	12	1' 0 5/16"	12	12'-7"	12	12'-7"	14	10'-11"	14	10'-11"
17' 4 5/16"	17' 4 1/8"	4	3' 5"	- - -	- - -	12	1' 1 1/2"	12	1' 0 7/8"	12	12'-7 1/2"	12	12'-7 1/2"	14	10'-11"	14	10'-11"
17' 5 9/16"	17' 2 11/16"	4	3' 5"	- - -	- - -	11	1' 11 3/8"	12	1' 1 15/16"	12	12'-8"	12	12'-8"	14	10'-11"	14	10'-11"
17' 3 1/8"	17' 3 1/8"	4	3' 5"	- - -	- - -	11	1' 11 3/8"	11	1' 11 3/8"	12	12'-5 1/2"	12	12'-5 1/2"	14	10'-11"	14	10'-11"
17' 3 1/8"	17' 3 1/8"	4	3' 5"	- - -	- - -	11	1' 11 3/8"	11	1' 11 3/8"	12	12'-5 1/2"	12	12'-5 1/2"	14	10'-11"	14	10'-11"
17' 3 1/8"	17' 3 1/8"	4	3' 5"	- - -	- - -	11	1' 11 3/8"	11	1' 11 3/8"	12	12'-5 1/2"	12	12'-5 1/2"	14	10'-11"	14	10'-11"
17' 3 1/8"	17' 3 1/8"	4	3' 5"	- - -	- - -	11	1' 11 3/8"	11	1' 11 3/8"	12	12'-5 1/2"	12	12'-5 1/2"	14	10'-11"	14	10'-11"
17' 3 1/8"	17' 3 1/8"	4	3' 5"	- - -	- - -	11	1' 11 3/8"	11	1' 11 3/8"	12	12'-5 1/2"	12	12'-5 1/2"	14	10'-11"	14	10'-11"
17' 3 1/8"	17' 3 1/8"	4	3' 5"	- - -	- - -	11	1' 11 3/8"	11	1' 11 3/8"	12	12'-5 1/2"	12	12'-5 1/2"	14	10'-11"	14	10'-11"
17' 3 3/16"	15' 0 7/8"	S	P	E	C	I	A	L		12	12'-5 1/2"	12	12'-5 1/2"	14	10'-11"	14	10'-11"

Match Line

Figure 6-16. Example of a detailed "master table" of information that is useful for fabrication, shipping and installation.

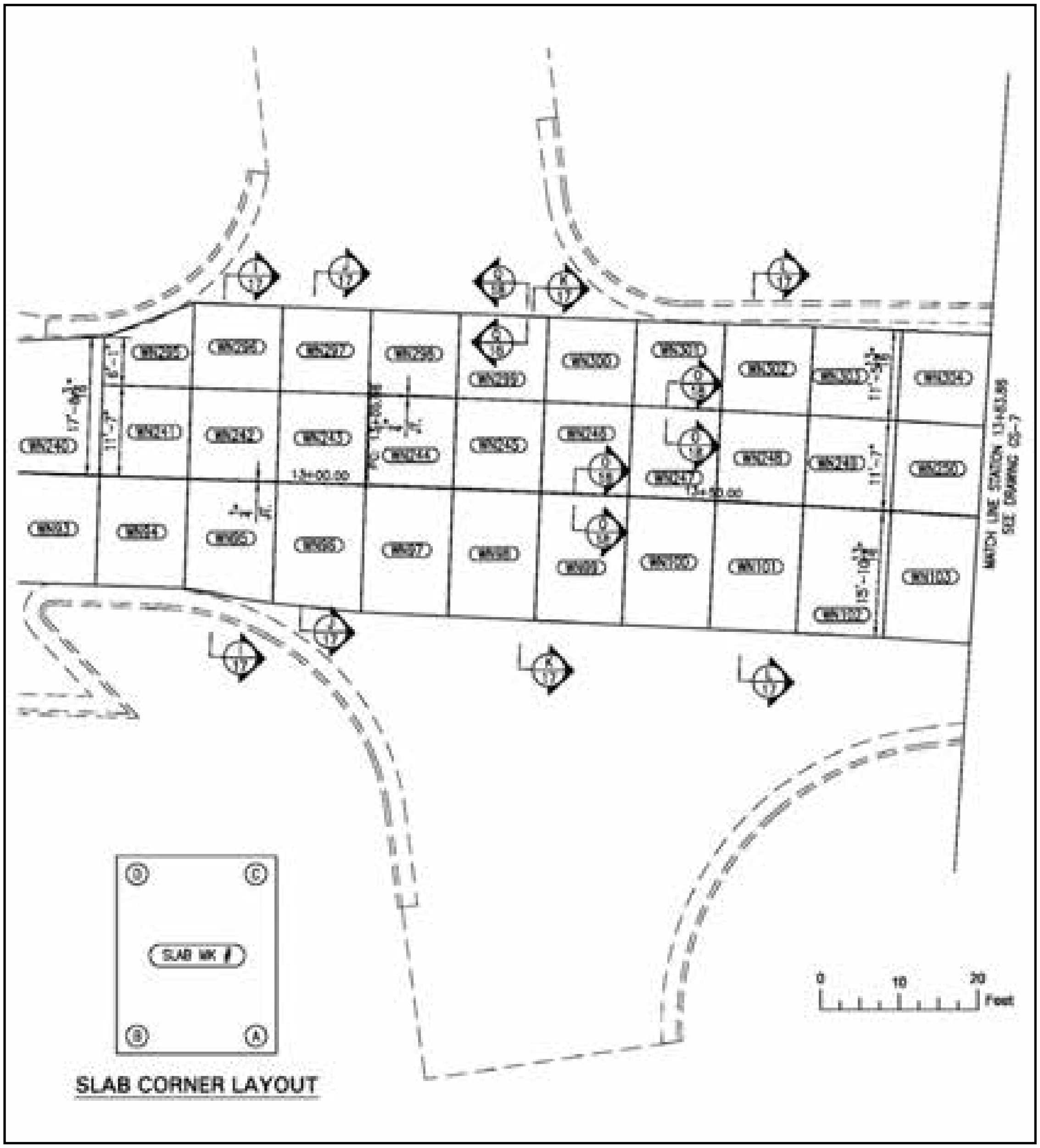


Figure 6-17. Example panel layout drawing showing the location of each panel. Panel orientation is conveyed by the sketch legend shown in the lower left corner of the drawing. The precaster marks or labels corners "A," "B," "C" and "D" on each panel.

Site Drawing Indicating Panel Layout

Panel layout drawings show where each panel is located (by mark number or label) on the project site. Such drawings may not be necessary for intermittent repair projects, but they are essential for continuous and large-area projects. They are used by surveyors for layout purposes and by placement personnel that need to know the intended location of each panel.

An example of a panel layout drawing is shown in Figure 6-17. Every panel is labeled with a mark number on the drawing that corresponds to a mark number painted or stenciled on the appropriate panel. Stations and additional dimensions may also be shown to further clarify the panel layout. Section arrows shown in Figure 6-17 refer to detailed cross-section drawings shown on other sheets of the shop drawings for this project.

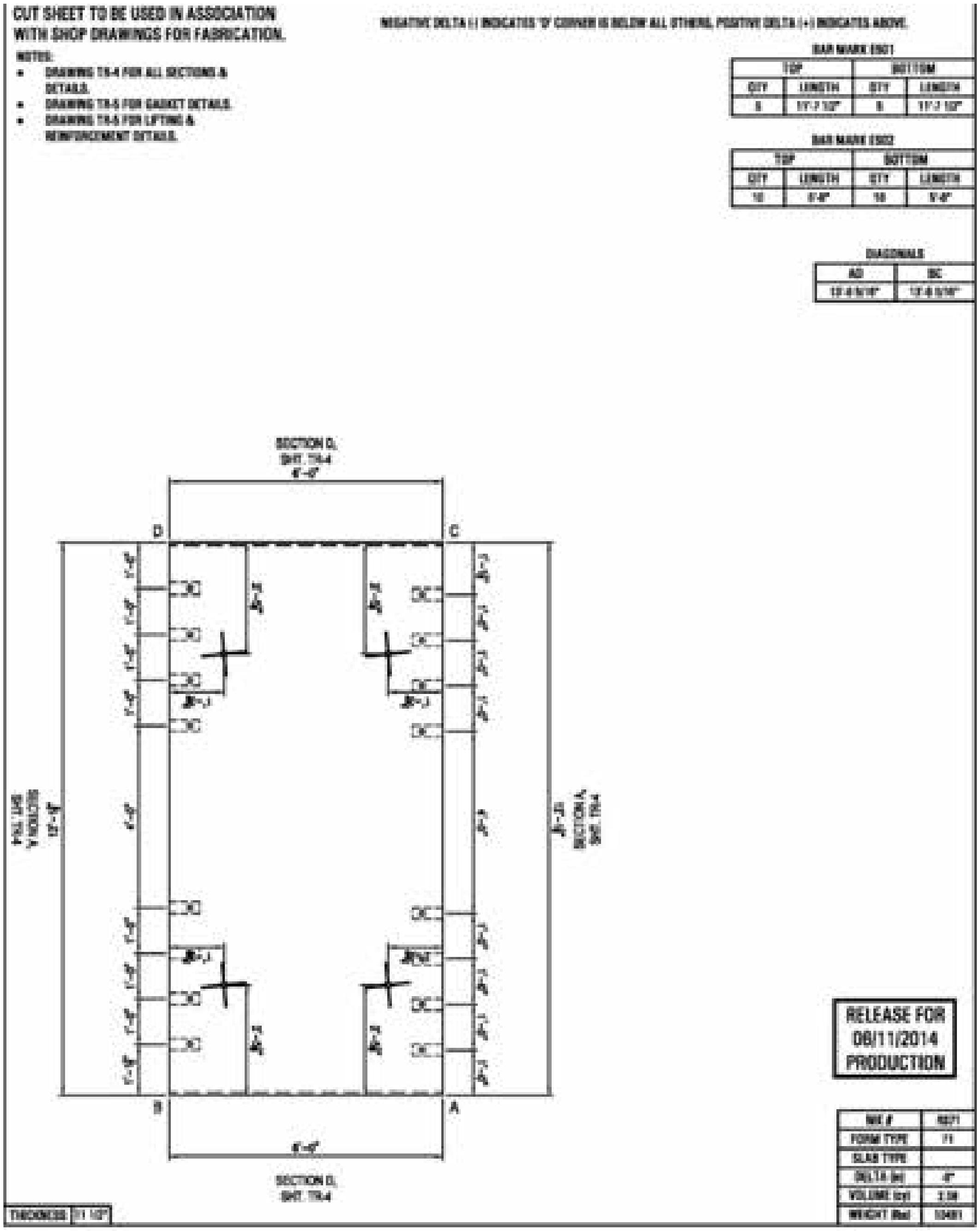


Figure 6-18. Example shop ticket showing information that is needed to produce accurate precast panels and other information needed for ordering concrete and lift panels.

Shop Tickets

Shop tickets (sometimes called shop cards or cut sheets) are drawn exclusively for precaster personnel responsible for fabricating the panels and are not typically included in the shop drawing submittal package. They typically include only information that is essential for setting up the forms, rebar, slot formers and embedments (i.e., dowels, tie bars and lifting inserts) for each panel. They also include information used by supervisors and QC personnel responsible for inspecting the panels, as discussed in Chapter 7. It is important to show all shop ticket information in a simple, easy-to-read format so fabrication and inspection errors can be avoided.

An example shop ticket is shown in Figure 6-18. Notice that, in addition to basic panel dimensions and rebar information taken from the previously referenced “master table,” the shop ticket also indicates the form type, slab type, delta value, panel volume and panel weight. This information is useful to precasters and personnel responsible for storing and loading the panels for shipment.

Summary

A complete set of shop drawings is a vital part of the precast panel production and installation processes because it contains detailed information that is needed for the fabrication and placement of every project panel. Shop drawings are developed by shop drawings engineers (SDEs) using information shown in the contract plans and specifications and additional information obtained from contractors, system designers and precasters.

Before developing any shop drawings, the SDE must first ensure the information gathered from the various sources is in agreement and contains no conflicting information. Any conflicts must be resolved with the information providers. Some differences can be resolved with a phone call, but it is a good practice to hold a formal pre-construction meeting where plans, specifications, and panel and installation details can be reviewed thoroughly so the SDE has a clear mandate from all project participants before any effort is expended on shop drawing preparation.

While it is always desirable to minimize the number of different types of panels (and, therefore, the number of shop drawings), it is typically necessary to develop multiple drawings to adequately cover the many different panel dimensions and edge details that are needed to complete even a moderately sized project. This may also be true on lane replacement projects and even on some extended intermittent repair projects involving horizontal curves, superelevation transitions and intersecting roadways.

This chapter provides guidance for shop drawing engineers regarding what should be included in the shop drawing package, efficient shop drawing formats and how dimensions for the many different types of panels are determined and shown. Emphasis is placed on the importance of developing shop drawings that are complete, accurate and easy to read to facilitate the review, fabrication and installation processes, and to ensure the fabrication of precast panels of the highest quality.

Chapter 7:
FABRICATION OF PRECAST PAVEMENT PANELS
A GUIDE FOR PRECASTERS AND AGENCY/OWNER QC INSPECTORS

Owners and pavement engineers value the concept of using precast concrete pavement (PCP) panels to replace or rehabilitate concrete roadways for two primary reasons. The first is that panels can be installed and used almost immediately, enabling overnight pavement replacement on heavily traveled highways where it is difficult – if not impossible – to provide adequate cure time (before opening to traffic) for durable, cast-in-place pavement. Techniques for rapidly installing precast panels are described in Chapters 8 and 9.

Second, PCP panels can be produced with uniformly high quality because they are fabricated in plants or facilities where casting and curing conditions can be more carefully controlled. This limits or negates the effects of sun, wind, extreme temperatures, and long hauling distances from the concrete mixing plant that can adversely impact concrete's strength and/or durability.

The benefits of plant fabrication can only be realized if the entire manufacturing process is executed in a properly equipped and calibrated plant that is managed by well-qualified individuals. This chapter addresses the physical and human resource aspects of precast plants that are necessary to produce high-quality PCP panels.

Other manufacturing aspects discussed in this chapter include: the materials used in concrete mixes, forms and form setup, proper casting techniques, curing, form stripping, detailing, yard storage and shipping. The primary areas of focus in addressing these topics are related to material handling, quality control techniques, and manufacturing processes that are unique and important to the manufacture of quality PCP panels.

Precast Plant Facilities and Resources

Physical Facilities

The exact physical makeup of precast plants can vary widely because of differences in geographical location and the products that are manufactured at each specific plant. However, there are general characteristics of all precast plants that offer the potential to enhance the quality of PCP panel fabrication above and beyond what may be possible using conventional cast-in-place paving techniques. These characteristics include:

1. Concrete batching and mixing capabilities that are located "minutes" away from the forms in which panels are cast.
2. Facilities designed to store and handle a large variety of aggregates, cements, admixtures and pozzolans.
3. Casting beds and forms that are typically made of heavy-duty, long-lasting and dimensionally accurate steel or aluminum materials.
4. Buildings or other features designed to control casting temperatures and curing conditions. Temperature-controlled buildings (Figure 7-1) are typically used in northern climates, while water chillers and covers (to provide proper curing conditions) may be provided in hotter climates (Figure 7-2).
5. A complete concrete testing lab outfitted with appropriate testing equipment.
6. Casting beds typically situated for easy and thorough inspection of each PCP panel.

Figure 7-1. An insulated, temperature-controlled building allows casting in all types of weather.

Figure 7-2. Long-line bed covered with insulated curing blankets to facilitate steam curing.

Human Resources

Precast plants typically maintain a staff of trained, year-round workers to fabricate precast products (compared to the “seasonal” workers that often staff construction projects). Year-round retention of trained workers is usually possible because precast products other than pavement panels are commonly manufactured throughout the year at the same plant. The concept of a stable, year-round workforce makes training in all aspects of plant manufacturing, including safety, manufacturing skills and efficiency, imperative. It also fosters development of a quality-conscious culture in which quality inspection, manufacturing processes and record-keeping can coexist and proceed as the normal accepted course of plant operations.

Plant Certification Programs

The many physical components and associated trained workforce of any precast plant must be properly mobilized before the routine manufacture of high-quality PCP panels can be realized. To achieve this, state and owner-agencies typically require precast plant certification through formal training and evaluation programs that lead to certification by state-developed quality assurance/quality control programs and/or by the National Precast Concrete Association (NPCA) or the Precast/Prestressed Concrete Institute (PCI). In general, certification must be obtained from one or more of these entities before precasters can manufacture precast products for use on state projects. More than 80% of U.S. states require NPCA certification for certain precast products and several other states are considering that requirement (NPCA, 2017).

Plant certification is beneficial because it serves to ensure fabrication and delivery of high-quality precast products – including PCP panels – through the establishment of a plant- specific, quality-inducing culture, rather than via a costly inspection program conducted by state or consultant inspectors. Plant certification programs are also beneficial to the precast industry in general because they establish a uniform level of quality to which all competing companies must adhere.

Elements of a Plant Certification Program

Certification programs involve a list of standards each plant must meet to demonstrate that plant’s ability to manufacture high-quality precast products. This list typically includes at least the following:

1. Requirements for record-keeping of batch weights for all concrete mixture components (e.g., aggregates, water, cements, supplementary cementitious materials (SCMs) and admixtures).

2. Standards for storing all concrete batching materials listed above.
3. Standards for controlling the concrete proportioning and mixing processes.
4. Standards for delivering concrete to the forms and for the placement, finishing, curing, stripping, repairing, marking and storage of completed precast units.
5. Standards for general plant layout and cleanliness.
6. Protocols for training and certifying concrete technicians and quality control inspectors.
7. Standards that indicate what tests must be taken and how test results must be recorded and filed.
8. An organization chart of plant personnel, including upper and middle management, supervisors, team leaders, workers, concrete technicians and inspectors. This is augmented by identifying a reporting structure that ensures quality considerations supersede production considerations in decision-making.

A more complete list of the elements of the quality control plan required by NPCA may be found in the NPCA Quality Control Manual for Precast Concrete Plants (NPCA, 2017). PCI also offers similar information specific to prestressed concrete products in their Manual for Quality Control for Plants and Production of Precast and Prestressed Concrete Products (PCI, 1999).

Certification programs typically include an initial inspection and evaluation of the subject plant by the state agency or NPCA/PCI personnel (as appropriate) to determine whether the facility is in compliance with the certification entity's published standards. These programs also indicate how many times per year plant reinspection is required and whether those inspections will be scheduled/announced or unannounced.

Plant- and Product-Specific Quality Control Plans

To qualify for plant certification, each plant must develop a detailed, plant-specific QC plan that addresses every aspect of the production process. Most of the plan must cover issues common to the manufacture of all precast concrete products in that plant, but specific references must also be made to any aspects that are unique to each product. To produce high-quality PCP panels, for example, a QC plan must be developed to address aspects of manufacturing processes that are unique to PCP panels, even if that plant has been previously certified by the state, NPCA or PCI to produce other precast products.

Unique PCP aspects to include in the QC plan. PCP panels must be manufactured to meet tolerances that may be more exacting than those required for other products. This is to keep joint widths in the field less than a specified maximum of 3/8 inch to 1/2 inch (depending on the state) and the finished riding surface smooth, as indicated in the specifications. Additionally, the top surfaces of panels must be textured to provide adequate skid resistance if panels will not be diamond-ground prior to being placed in service. The concrete must also be durable, because panels are typically subjected to extreme environmental conditions – including severe freeze/thaw cycles and multiple applications of de-icing salts in northern climates and high temperatures in southern climates – over decades of use by heavy traffic.

Quality Control Personnel

To ensure the features described above are built into the precast panels, it is especially important that key production and inspection personnel understand them and are committed to building them into the product. Personnel key to this endeavor are described below.

Senior Management

QC plans, as described above, are only as effective as senior management allows them to be. For maximum effectiveness, the precast plant owner or designated plant manager must be fully committed to meeting all standards of quality listed in the formal QC plan. Most QC programs require that commitment to be outlined in an organizational chart that clearly establishes a dedicated QC plan administrator as the senior management person responsible for all QC matters. The QC plan administrator must therefore be responsible for providing direction and support to the entire QC staff, either personally or indirectly through a designated QC manager. This individual must be the ultimate plant authority in the acceptance or rejection of precast products – in this case, PCP panels – within the requirements of the specifications.

Quality Control Manager

The QC manager and the QC plan administrator (when appropriate) must develop an effective QC plan, as required by the plant certification program. Once that plan is approved by the program administrator, the QC manager must actively manage all day-to-day activities detailed in it. The QC manager typically schedules and manages the day-to-day activities of all QC personnel (inspectors and testing personnel) and serves as the primary intermediary between the precast company and the representatives of the project owners. One of the QC manager's important roles is to develop a system for recording and storing piece checks and test results for subsequent retrieval, as may be required by the owner's representatives.

If the QC plan is properly prepared and executed, the QC manager should be able to accept or, in some cases, reject precast panels routinely. In cases where some precast units may not be in compliance with specifications, the QC manager may need to engage the QC program administrator for ultimate resolution.

Quality Control Inspectors

QC inspectors must be specifically trained to make appropriate pre-pour and post-pour checks to ensure dimensional tolerances are met and slots and matching dowel bars are located correctly in the panels. To accomplish this, they must know how to make accurate measurements and to read and interpret shop drawings and/or shop tickets correctly. NPCA and PCI provide many training programs that are useful in this endeavor, but additional training from the system designer or the shop drawing engineer is beneficial and will most likely be required.

Production Personnel

Exacting tolerances can only be achieved by workers that can properly assemble and use forms that are accurate enough to meet them. Casting personnel must be trained in proper casting, finishing and stripping techniques, as described in the QC plan. It may be advisable for system designers to participate in the training of production personnel to ensure they are capable of correctly carrying out all the system-specific aspects of the production process.

Special Requirements for Materials Used In Precast Panels

Aggregates

The required size and quality of aggregates frequently become topics of confusion – if not contention – during the mix design process. Agency specification writers tend to call for the use of larger maximum aggregate sizes (e.g., 1 to 1.5 inches), since that is what is typically used for cast-in-place concrete pavement construction, while precasters usually stock only smaller (< 1-inch top size) aggregates. Many PCP specifications allow precasters to use smaller aggregate if a viable mix design is submitted for approval; however, precasters should be aware that agency approval of the use of smaller aggregate is not always assured.

Precasters should also pay attention to the specified quality of the aggregate. Departments of transportation typically require the use of concrete aggregates that are not highly reactive to cement-based alkalis, are durable in a wet freeze/thaw environment, and that possess adequate friction characteristics and resistance to polishing. Aggregates meeting these requirements may be unfamiliar to precasters and may be more difficult and costly to source than the aggregates they commonly use for other precast products.

Cement

Most PCP specifications refer to cast-in-place specifications, which often specify the use of Type I or Type I/II cement. Some precasters prefer the use of Type III cement because it gains strength more rapidly, easily allowing 18-hour form stripping with modest cement content. Some DOTs are reluctant to allow the use of Type III cement because of their high generation of heat during the early stages of hydration and early curing, which can lead to the development of micro-cracks in the panels. The precaster should be prepared to provide evidence that such cracks do not occur in any proposed mix design that includes Type III cement.

Supplementary Cementitious Materials (SCMs)

SCMs (e.g., fly ash, slag cement and microsilica) are often specified for use as additions to or partial replacements of cement in concrete mixtures because they have the potential to enhance concrete durability and reduce overall costs. These materials work well in the fabrication of PCP panels when they are integrated in the mix design with proper consideration given to all properties of the final mixture. For example, fly ash can enhance concrete workability but may slow down strength gain when used as a cement replacement, so precasters may need to compensate by using water-reducing admixtures and/or more cement to achieve the desired 18-hour stripping strength. While SCMs can improve concrete durability and some may reduce mixture costs, others may add cost to the mix, either directly (e.g., microsilica or silica fume) or through the associated need for chemical admixtures to modify the mixture behavior. The precaster should account for possible mix cost differences in preparing project bids. The proper and effective use of SCMs in precast panel mixtures requires that the precast plant be equipped with adequate silo space for their use throughout the production process.

Chemical Admixtures

Most precasters routinely use high-range water reducers (HRWRs) to achieve more workability with low-water content mixtures that are designed for higher early strength and that might otherwise be difficult to place and finish. Unfortunately, some agency pavement material engineers experienced only in installing cast-in-place concrete pavement may not be familiar with their use. Therefore, it is important for the precaster to submit proposed mix designs – including batch quantities for HRWRs and trial batch results – early enough in the submittal process to allow time to resolve any reservations pavement materials engineers may have with the use of HRWRs.

Some precasters have also used self-consolidating concrete (SCC) admixtures in precast pavement mix designs to achieve maximum workability. Generally, this has offered favorable results. SCC admixtures are relatively new products that may also be unfamiliar to many agency pavement materials engineers, so precasters should be prepared to prove that they can be used safely without causing segregation or compromising the concrete's long-term durability.

Air entrainment is vital to the long-term durability of precast concrete pavement, especially in areas where the pavement will be subjected to thousands of freeze/thaw cycles and tons of de-icing salts over its service life. Most agencies located in such climates specify an entrained air content of 5% to 8%, though the upper limit is sometimes even higher in some states. It is important to use effective air-entraining agents that are compatible with the cement, SCMs, and other admixtures used in the mix.

Concrete Mix Designs for Precast Panels

Precasters are bound by contract to design concrete mixes that meet the 28-day design strengths indicated in the specifications, but they are also typically interested in designing mixes that reach stripping strength in approximately 18 hours so they can cast at least one panel per day in each form. For conventionally reinforced panels, the required strength at the time of form stripping is typically around 3,000 psi or as specifically required by the lifting insert manufacturer for safe lifting. For prestressed (pre-tensioned strand) panels, the required strength at the time of form stripping is typically around 4,000 psi and will depend on the strength required for releasing (cutting) the

Figure 7-3. Individual, adjustable-width forms.

Figure 7-4. Long-line prestressing beds with adjustable end rails.

strands. Mix designs capable of achieving these 18-hour strengths will usually meet specified 28-day design strengths without issue.

Forms for Precast Pavement Panels

Form Types

PCP panels are typically cast “top surface up” in individual forms, as seen in Figure 7-3, or in forms placed in long lines, as seen in Figure 7-4. Individual forms are typically used when panel sizes vary and mild steel reinforcement is used. Long-line beds are used primarily when panel widths remain constant and the plane of the panels is always flat. Long-line beds are used almost exclusively when panels are prestressed. Panels of different lengths may be easily made in long-line beds simply by positioning end rails, as required. Panels of different widths (and lengths) may also be made in long-line beds that are equipped with side rails that may be adjusted to vary panel widths, but without the efficiency enjoyed with the use of long-line, constant-width side rails.

Beds for Flat (Single-plane) Panels

Most PCP panels are cast as flat, single-plane panels, even when they are to be placed in non-planar locations, as is discussed in Chapter 11. Form beds are typically built from standard structural steel sections and steel sheets commonly sourced at local steel supply houses. The form builder should be aware that standard, mill-run steel stock may vary in cross-section and straightness and may not be straight enough to meet the tight surface and panel dimensional tolerances specified for PCP panels. Care must be taken to check all steel (or aluminum) stock for straightness and to make corrections as necessary during the form building process so specified tolerances can be met.

Bed-supporting members (typically steel channels) should be designed to maintain the specified tolerances under the heaviest load (i.e., the largest and/or thickest panel) that will be placed on them. Precast panel thicknesses may be up to 12 inches for highway pavements, 16 to 18 inches for bridge approach slabs, and thicker for airport apron, taxi and runway panels. As a rule of thumb, the bed-supporting members should be designed to deflect no more than 1/2 the allowable tolerance for panel flatness. For example, if the dimensional tolerance for panel flatness is 1/8 inch (± 1/16 inch), the allowable deflection of the supporting member should be half that, or 1/16 inch.

While wood beds and side rails can and have been used in a few special cases (see Figure 7-5), they are not recommended for general use because of the difficulty in maintaining specified panel tolerances. Wood is also not as durable as steel, and requires more frequent replacement. Steel is a usually a better choice for PCP forms because steel forms can typically be reused many times, greatly reducing the per- panel forming cost. Most states specifically prohibit the use of wood forms in certified precast plants for these reasons.

Beds for Non-planar Panels

Steel beds have been made and are used routinely for fabricating non-planar panels for many projects. Figure 7-6 shows a steel bed, proprietary to The Fort Miller Co., Inc., that can be adjusted to cast non-planar panels. This bed can be adjusted such that the cross-slope of the bed, measured perpendicular to the long sides, varies linearly along the length of the bed, meeting the definition of non-planar panels provided in Chapter 6. Each side of a rectangular panel cast on this bed resides in a straight line, enabling the use of standard straight side rails.

Prior to casting a panel, the beds are adjusted such that three of the corners ("A," "B" and "C" corners in Figure 6-12) are level – that is, they reside on a single flat plane. The "D" corner of the bed is then adjusted by the "delta" distance (which is defined in Chapter 6 and illustrated in Figure 6-13) either above or below the plane established by the other three corners, making it possible to cast a warped panel (as illustrated in Figure 6-12 and shown in a real panel in Figure 7-7). While the bed seen in Figure 7-6 is designed to accommodate a delta of up to 5 inches (in a 12-foot-by-16-foot panel), deltas for most warped panels vary from 3/16 inch to 2 1/2 inches (panels requiring a delta of 1/8 inch or less are considered single-plane panels since that falls within accepted panel fabrication tolerances).

Figure 7-5. Plywood forms used at a contractor's on-site "precast yard" under an overpass.

Figure 7-6. This photo shows one corner of the bed, "D," lowered by the specified "Delta" distance below the plane defined by the other three corners, which are supported in a level position.

Figure 7-7. Warped-plane panel with a 4-inch delta (warp) on a truck.

Figure 7-8. Turn buckles and push bolts are used to keep the tops of side rails straight.

Figure 7-9. Aluminum extrusions (faced with special plywood) anchored with magnets in a long-line bed.

While non-planar panels are cast with three corners of the bed residing on a level plane in the shop, each panel is placed in the field such that all four corners end up at the correct “x,” “y,” “z” elevations required for that particular panel, because the supporting surface is graded to the same design surface model (as discussed in Chapter 9) that is used to set up the form bed before casting. This method of casting non-planar panels and grading the subgrade surface reduces the amount of bedding grout required under the panels and minimizes (or may eliminate) profile grinding, as is discussed in more detail in Chapter 11.

Standard Side Rails

Side rails must be designed to maintain panel edge straightness and height tolerances and to firmly support embedded dowels and slot formers. They must also be designed such that they can be easily positioned to required panel lengths and widths during form setup and quickly and easily removed (stripped) at the proper time.

Panel straightness requires that side rails be fully supported at both the tops and bottoms of the rails. Heavy-duty steel channel side rails may be bolted to the bed and to each other, but top support braces may still be needed to maintain top-of-rail straightness. If standard steel channels or other standard steel sections are used for side rails, they should always be checked for straightness and corrected, as necessary. One disadvantage of using steel channels for side rails is that penetrations for dowel bars and other embedded features are costly to make and change.

Figure 7-10. Magnetically anchored side rails being used on all four sides of a single-panel form.

Some manufacturers have developed innovative side rail systems that meet all requirements efficiently. For example, Finland-based Elematic has developed a particularly versatile side rail system consisting of an aluminum extruded section that is designed to be magnetically attached to a steel bed (Figures 7-9 and 7-10). The use of anchoring magnets

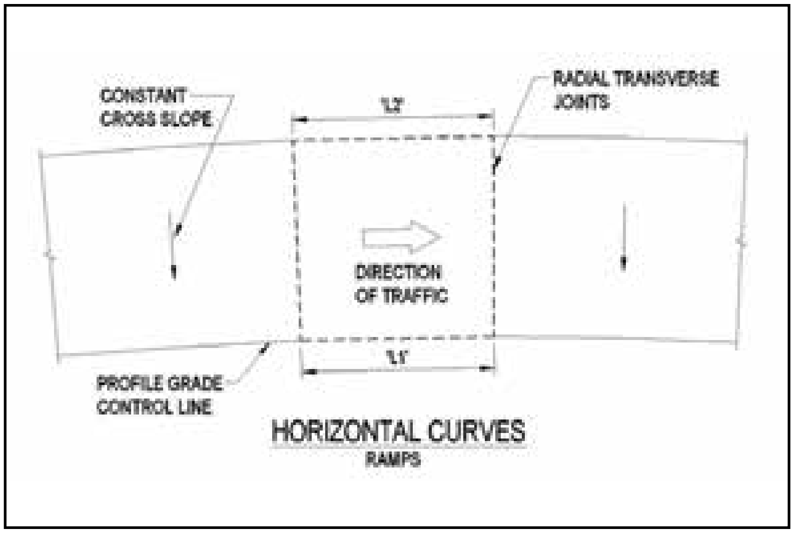


Figure 7-11. Trapezoidal (variable-length) panel for a horizontally curved ramp.

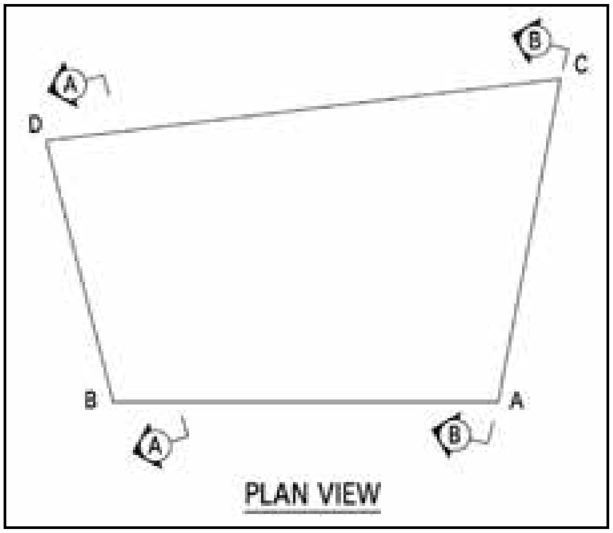


Figure 7-12. Exaggerated "general panel" for use at any location on the highway.

allows quick and easy side rail adjustment and stripping. However, for magnets to hold side rails firmly in place, both the bed and the side rails must be kept clean and the steel bed itself should be at least 3/8 inch thick for most magnets currently used in these applications. Special form plywood, cut to the exact height of the panel, is typically attached to the aluminum extrusions to complete the side rail assembly (see Figure 7-9). The plywood allows easy penetration for embedded dowels and tie bars and convenient attachment of slot formers. While the plywood side rail component is not as tough as steel, it may last for 50 to 70 uses and can be easily and economically replaced.

Figure 7-13. Adjustable side rails for producing general panels of any size or shape.

Side Rails for Variable-Width and -Length Panels

While constant-width (or constant-length) form design will accommodate the fabrication of most precast panels, there are cases where side dimensions vary from panel to panel, as discussed in Chapter 6. Consider the trapezoidal panel shown in Figure 7-11. This panel may be cast in the constant-width form shown in Figure 7-9 because chords L1 and L2 are parallel. If, however, the curved roadway shown in Figure 7-11 is also of varying width, as is the case with parts of many interstate access ramps, varying shapes of unique panels can be represented "generally" by the exaggerated drawing shown in Figure 7-12.

Building side rails for a single, unique panel of the type shown in Figure 7-12 is a common practice, but it is a challenge to build one set of side rails that can be used to fabricate many such "unique" panels – each with different side dimensions – as may be required for a variable-width ramp residing in a horizontal curve.

A form that is designed to cast a panel of any shape, such as the general panel shown in Figure 7-12, is shown in Figure 7-13. Notice that one end of each side rail abuts the side rail for the adjacent side, while the other end runs past the end of the side rail of the other adjacent side. This results in a "windmill" appearance when viewed from above. When a series of "unique" panels is made in this type of form,

Figure 7-14. Checking form diagonals during form setup.

Figure 7-15. QC check of panel lengths just prior to concrete placement.

care must be taken to ensure that slots in each panel are located to match the protruding dowels that are being cast in adjacent panels, as shown on the shop tickets.

Preparation for Concrete Placement

Form Setup

Orienting and placing side rails. Correct orientation and placement of side rails is important in fabricating panels that will fit properly in the field. It is vital to check side dimensions (lengths and widths) and diagonals, as shown in Figures 7-14 and 7-15, to ensure they are correct. Note that there should be no reinforcing or embedments in the form at this stage (as shown in Figure 7-14) so that the location of each side form can be easily adjusted until the correct side lengths and diagonals are achieved. Although not visible in Figure 7-14, form magnets are in their unlocked positions to permit easy adjustment of the side rails. The magnets are locked to prevent further movement after the side rails have been adjusted to their correct and final positions.

Dowel and slot former placement. Embedded dowels and slot formers must be positioned in strict conformance to the shop drawings (shop tickets) to ensure that dowels and slots in adjacent panels are properly matched in the field. Since placement of both dowels and slot formers requires side rail penetration, dowel and slot former locations should be laid out with consideration given to as many panels as possible to minimize the number of different penetrations, thus maximizing the life of the side rails.

Dowel bar holders should be designed to hold the dowels perpendicular to the side rails to meet dowel bar placement tolerances and to facilitate form stripping without damaging the epoxy coating – or other corrosion protection coatings – on the dowels. Bushings or “O-ring” spacers, used in conjunction with a slightly oversized steel pipe holder, will aid in the stripping process while holding the dowels firmly in position.

Placement of grout port formers and lifting inserts. Grout port formers may be made from tapered steel posts (smaller at the top) that are welded to the bed of the form so panels may be simply lifted from the bed, leaving all formers in place. However, they must be accurately placed, especially as the number of grout ports increases, because just one out-of-plumb port former will make form stripping difficult, if not impossible. Other types of formers using loose-fitting plastic ducts or sleeves over non-tapered steel posts that are rigidly welded to the bed may make stripping easier.

Grout port formers should be designed to be approximately 1/16 inch shorter than the exact thickness of the panel to allow unobstructed screed operation. They should be installed prior to placement of the reinforcing steel. The

Figure 7-16. Typical placement of lifting inserts and rebar chairs.

Figure 7-17. An example of prestressing strand used in two directions.

reinforcement steel can be adjusted slightly, as needed, to avoid conflicts with the grout ports (Figure 7-13).

Lifting inserts are typically placed directly on the form bed and are positioned as shown on the shop tickets (typically at fifth-points). They are held in position by attaching them directly to the rebar mat or, if necessary, to extra short bars that are attached to the rebar mat (Figure 7-16). Lifting inserts should be sized to provide 2 inches of concrete cover (or to a measurement indicated in the drawings and specifications) to allow for proper concrete cover and profile grinding, if required.

Placement of Reinforcement

Jointed precast concrete pavement (JPrCP) panels may be reinforced with either conventional “mild” steel rebar or prestressing strands. In some cases, both types of reinforcement may be used. While this is not unlike other precast products, certain aspects of JPrCP panel reinforcement are worth noting.

Placing mild steel reinforcing. Mild steel reinforcing can be cut to fit any panel size and shape – planar or non-planar – and bars can be easily positioned to accommodate slot formers, lifting inserts and grout port formers. Care must be taken to include all the bars indicated in the shop drawings, even if they are not evenly spaced. Rebar mats are typically supported from the bed with appropriately sized plastic chairs, such as those seen in Figure 7-16, on both single- and warped-plane beds. Concrete spacers called “dobies” are used in lieu of chairs in some states. If two layers of steel are used, as is often the case where additional structural capacity is desired for panels that are to be opened to traffic before they are fully grouted, it is necessary to comply with minimum cover requirements for both the top and bottom mats of rebar. In any case, care should be taken to use enough properly dimensioned supports to keep rebar mats in their proper positions.

Reinforcing bars are typically installed in the bed after the side rails, dowel bars, slot formers and grout port formers are in place so that these features may be avoided. Alternatively, rebar mats may be pre-assembled on jigs and stored until they are needed to save time during form setup. To be effective, jigs should account for dowel bars, slot formers and bedding grout port formers as much as possible to ensure the rebar mats can be quickly lowered into the forms without interference.

Steel mats need to be tied together with wire that matches the bar type to avoid galvanic activity between dissimilar metals. For example, epoxy-coated steel mats should be tied


Figure 7-18. Standard ASTM slump test (left) and air content testing by the pressure method (right).

together with epoxy-coated tie wire, galvanized steel should be tied using galvanized tie wire, etc. Some agencies may also require a coating of epoxy or galvanizing material over the ends of any sheared epoxy or galvanized bars.

Using prestressing strands for panel reinforcement. JPrCP panels may also be reinforced with prestressing strand in one direction and mild steel in the other. At least one California-based precaster uses prestressing strand in both directions (Figure 7-17). As indicated in Chapter 4, prestressing increases the structural capacity of the panels so that thinner panels may be used to carry the same traffic. Prestressing also reduces the risk of panel cracking during handling, thereby enabling the fabrication of panels longer than 15 feet, which is a commonly accepted maximum for panels reinforced with standard, mild reinforcing steel. Finally, the use of pre-tensioned strand may also reduce panel cost by reducing labor associated with the use of mild reinforcing.

Required levels of prestressing and mild steel reinforcing are discussed in Chapter 4.

Using fibers in precast panels. Synthetic polypropylene, nylon and steel fibers are routinely used in cast-in-place concrete floor (slab-on-grade) construction to control cracks resulting from shrinkage and curing stresses. While synthetic


Figure 7-19. Use of a conventional concrete bucket to place panel concrete in a “high” form.


Figure 7-20. Concrete placement directly from a ready-mix truck (form is low enough to permit direct placement from the truck).

Figure 7-21. A hydraulically powered roller screed saves labor and time, producing a more accurate panel surface.

Figure 7-22. Worker touching up the screeded surface near the side rails.

fibers have proven to be effective in increasing fracture toughness and in controlling cracks, they are not generally considered to be a replacement for conventional reinforcing. However, some types of synthetic macro-fibers and steel fibers are regarded by some as equivalent to conventional reinforcing in some cases. Fibers have not been widely used in PCP panels, though they continue to be considered because of the protection they provide against cracking. More information concerning the use of fibers in precast pavement panels, including typical dosage rates, is provided in Chapter 4.

Pre-pour Checking

A pre-pour check, an important part of the QC plan, is a final check of the form and all its contents that is made prior to placing the concrete. This check should be performed independently by QC personnel that were not involved in the form setup. A pre-pour checklist should verify at least the following:

1. Panel length, width and diagonals
2. Side rail depth (height or thickness of panel)
3. Dowel and tie bar size, placement and spacing
4. Slot spacing and size
5. Reinforcing bar and/or strand size and spacing
6. Top and bottom cover over reinforcing
7. Lifting insert model numbers and locations
8. Grout port former locations, including a check to ensure that the top of former is slightly recessed from the top of panel
9. Side rail straightness (sweep)
10. Side rail bottom anchoring (magnet) and top of rail lateral support
11. Bed planarity for both flat and non-planar panels

Figure 7-23. Commercially available rake being used to impart macrotexture on top of a previously applied burlap drag (“microtexture”) finish.

Figure 7-24. Use of a narrow, custom-width rake to texture a narrow strip at the edge of a panel.

Figure 7-25. A newly casted panel covered with plastic and insulating blankets for initial curing.

Concrete Placement, Finishing and Initial Curing

Concrete Testing

Plastic concrete should be thoroughly tested by qualified (i.e., American Concrete Institute-certified) technicians in strict accordance with the approved QC plan prior to placement in the form. As a minimum, temperature, slump, unit weight and plastic air should be measured and recorded for each batch of concrete placed in the form (Figure 7-18). The batch size should be indicated in the QC plan, but it is generally accepted to be either the amount of concrete batched in the mixer or the amount delivered and mixed in a properly calibrated ready-mix truck.

Concrete Placement

Concrete may be placed with a conventional bucket (Figure 7-19) or discharged directly from a ready-mix truck (Figure 7-20). No matter what delivery method is used, concrete should not be allowed to “drop” more than approximately 2 feet to minimize the risk of segregation. Workers should be trained to use vibrators properly to ensure the concrete is fully consolidated around the many slot formers and other items embedded in the form (Figure 7-16). Vibrators should be kept away from side rails during the vibration process to prevent imposing excessive lateral pressure on them.

Screeding

Achieving accurate and true top surfaces by using effective screeding techniques is especially important in PCP panel fabrication. Screeding should immediately follow concrete placement to ensure that the right amount of concrete is placed in the form. This prevents the labor of cleaning up or removing extra concrete and ensures a more accurate surface because the concrete is screeded when it is in its most plastic state. The use of a roller screed – seen in Figure 7-21 – is highly recommended over “traditional” hand-held vibratory screeds, which can be labor-intensive, slow and tend to leave an uneven surface. Hydraulically powered roller screeds reduce labor and ensure the most accurate panel surface. It is also important to complete the screeding process by hand finishing around the entire perimeter of the panel. This corrects any high or low spots along the side rails that may result from the finishing process (Figure 7-22).

Finishing and Texturing

The final finish or texture of the panels must be made as indicated in the specifications. Finishes that are commonly specified are light broom, medium broom, turf-drag and burlap drag followed by tining. Because acceptance of panel finish and texture can be somewhat subjective, the precaster

Figure 7-26. Panel placed on waist-high stands to facilitate stripping of slot formers, post-pour checking and panel detailing.

Figure 7-27. Applying foam gaskets to bottom of Super-Slab panels that have been placed on high stands.

may be well-served to submit a "sample panel" with representative finish and texture to the engineer for approval before beginning production. The approved sample panel can then become the measure or standard by which the finishes on all other panels are evaluated.

Finishers should be trained to apply the specified finish to the screeded concrete at the proper time in the concrete setting and hardening process. This time will vary with the type of texture, the mixture components, proportioning and temperature, as well as the ambient conditions at the placement site. The raked (tined) finish shown in Figure 7-23 is being applied when the paste is still plastic but firm enough to prevent lifting of any coarse aggregate during the texturing process. Since it is typically not acceptable to "lap" rake passes, it is advisable to provide a rake of a proper width that will avoid the need for using small hand rakes in narrow strips at the edge of the panel (Figure 7-24).

Initial Curing

Initial curing is of utmost importance to prevent loss of moisture and related shrinkage cracks. Panel curing should begin immediately after completion of the finishing process by covering the panel with plastic and insulating blankets (Figure 7-25) or with plastic and wet burlap, as required by the specifications.

THE FORT MILLER CO., INC.
Contract #:TANE 14-1 D214256
Job#: Item:
15986 8580
AP206 Super Slab 2.234cy
502.15011025

Figure 7-28. Example panel label showing all the information needed for identification purposes.

Alternatively, a membrane-forming curing compound may be applied to the freshly finished surface for initial curing. For maximum effectiveness, the curing compound must be applied uniformly over the entire surface of the panel at a coverage rate that complies with the manufacturer's requirements. It should be noted that some curing compounds are much more effective than others. Poly-alpha-methyl-styrene (PAMS) resin-based curing compounds are currently preferred for the construction of long-life, cast-in-place concrete pavement in many states.

Figure 7-29. Application of sprayed curing compound to all panel surfaces.

Post-placement Activities

Stripping Forms

Stripping the side rails from the panel and lifting the panel from the bed should be done with caution to prevent damage to the "fresh" (typically 18 to 20 hours old) concrete. After the magnets and side-rail-supported devices – such as slot formers and threaded tie bars – are released, the side rails may be moved away from the panel. Dowel-supporting side rails should be removed evenly and carefully to prevent damage to or displacement of the dowel bars.

Once the side rails are fully removed and as soon as the concrete has reached a minimum compressive strength (as required by the lifting insert manufacturer) or release strength (if the panels are prestressed), the panel may be lifted from the bed. When the panel is completely free from the bed, all slot and dowel bar receiving hole formers should be removed from the panel in preparation for post-pour checking and final panel detailing.

Post-pour Checking

Post-pour checking is most efficiently accomplished after the panel has been removed from the bed and placed on supports that allow convenient access for measuring and visual inspection (Figure 7-26). Post-pour checks should be made by qualified QC inspectors as indicated in the QC plan. The following list of items is the minimum that should be inspected during the post-pour check:

1. Panel ID tag or label
2. Defects such as spalls, honeycombing, etc.
3. Planarity (delta), when appropriate
4. Panel dimensions
5. Dowel and tie bar locations
6. Dowel and tie bar slot locations
7. Grout port holes to ensure they are open and clean
8. Edge squareness
9. Surface accuracy
10. Lifting devices
11. Panel planarity

Panel Detailing

Panel detailing involves removing any paste and mortar fins that remain from the casting process, rounding any sharp panel edges with a masonry stone, checking slots to ensure they are clean and sandblasted, and ensuring all grout ports are clean and open for use. It should be performed routinely but also in response to any defects that are found during the post-pour inspection. All detailing, including repair of any defects, should be done in strict accordance with the QC plan.

Simple post-pour inspection stands may be made from highway barrier forms, as shown in Figure 7-26. Attachment of bottom gaskets, as required for bottom-slot systems, is best accomplished when panels are placed on high stands (Figure 7-27). Such stands should be designed by professional engineers since they need to provide safe access to workers underneath.

Panel Labeling

Once detailing is complete and panels are ready for storage, they must be marked or labeled for identification purposes (Figure 7-28) to ensure each panel is delivered at the proper time and so that panels can be installed in their proper location. While requirements may change from job to job, the

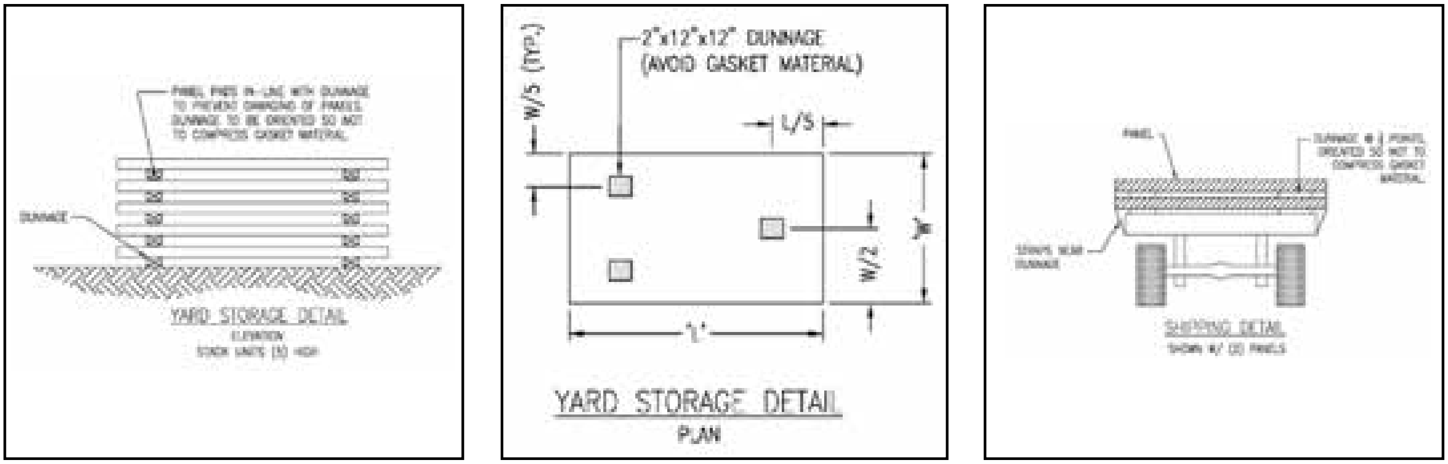


Figure 7-30. Illustrations of proper dunnage placement for panels in storage and for panels ready to be shipped.

label should generally include the following:

1. Name of the precaster
2. Mark (panel designation) number
3. Panel weight or volume
4. Casting date
5. Project number
6. Precaster item number
7. DOT item number
8. Date of approval
9. QA stamp or mark of approval

The information on the label should enable anyone, including the job site inspector, to access QC information stored at the precaster's lab (in accordance with the approved QC plan) regarding any particular panel.

In addition to the information shown on the label, it is helpful (and, in some cases, necessary) to label the corner of each panel with an "A," "B," "C" and "D" as shown on the shop drawings and in Figure 7-12. This information enables installers to orient the panel correctly as it is being placed in the field. Each precaster may choose to add other pertinent information to the label or to any other surface of the panel, as they deem necessary or as they may be directed.

Figure 7-31. Moving, stacking and storage of precast concrete panels.

Figure 7-32. Example of vehicle signage for over-width loads (requirements vary by state).

At least one state requires the top surface of the panel be embossed with a mark number or other information. In these cases, a final check of the embossed label should also be made at this time.

Final Curing

The final curing agent is applied after panel detailing is complete. Spray-on curing compound is typically preferred by precasters for PCP panel final curing and is applied to the top, bottom and all sides of the panel, as well as to the slots (Figure 7-29), unless provisions are made to cure the slots with some other material. The use of spray-on curing compound is an efficient way to cure precast panels since they can be moved to the storage area immediately after detailing is complete and the curing compound is applied. If the specifications require a wet burlap cure for a certain number of days, the panels are then stored temporarily under burlap that is kept wet, as specified.

When final curing is complete, panels may be moved to and stacked in the precast yard to await shipment.

Yard Storage and Handling

Yard storage should be carefully planned to make the best use of yard space and to provide efficient access to panels at the time of shipment. Panels should be stored so that mark number labels are readily visible and, if possible, so that panels needed first for shipment are stored in the most accessible locations.

Panels may be stored in stacks – as shown in Figure 7-30 – if the foundation soil or slab-on-grade provide adequate bearing capacity to support the entire stack as they are placed on dunnage blocks. The allowable height of the stack is a function of the bearing capacity of the foundation soil under the bottom blocks and the weight of the panels that are stored in any given stack. Ideally, identical panels with the same mark number are stored in the same stack. When many different size panels with different mark numbers need to be stored, they should be stacked in the reverse order in which they will be shipped. For example, the first panel to ship should be stacked on the top of the stack. Unfortunately, even with the best planning, it is sometimes necessary to move one or more panels to reach the panel that needs to be shipped.

Panels should always be placed on three-point – rather than four-point – dunnage in the storage yard and on the bed of the truck used to ship the panels, as shown in Figure 7-30. This is because three points define a plane and additional points of support may result in unwanted bending stress and panel deformation that may cause panel cracking. When panels are stacked, dunnage for any given panel should always be placed directly over the dunnage supporting the panel or panels under it. If this is not done properly, the panel below the misplaced dunnage may be at high risk for cracking due to stresses not considered in panel design.

Compact storage is best accomplished with a travel lift, but conventional hydraulic or drum cranes and even large fork trucks equipped with specially designed picking yokes may be used effectively for moving precast panels to storage (Figure 7-31). While each of the lifting machines shown has unique advantages, they are both equipped with frames or yokes to keep the angle of the picking cables within limits specified by the lifting insert manufacturer. The flatter the picking cable angle, the greater the horizontal load placed on the lifting inserts and the axial load induced in the picking cables. Capacities of both should be checked to keep the picking operation safe.

Shipping

Shipping PCP panels, typically the responsibility of the precaster, is generally different from shipping most other precast products in that panels are usually installed at night. The precaster and contractor must decide whether to ship directly to the contractor's "hook," or to ship and drop trailers to a staging yard near the job site during the days before installation. If the latter method is chosen, the contractor is then responsible for shuttling dropped trailers to the job site during the night as needed. There are costs, risks and placement factors associated with each method; they should be considered carefully before the shipping method is finally selected.

While every effort is made to minimize freight cost by designing panels to qualify as legal-width loads (usually 8 feet or 8.5 feet in some states), most projects will have some over-width panels that will require special permits for shipping. Most states allow over-width loads of 12 feet or less to be shipped with only a permit. Loads wider than 12 feet usually must be accompanied by a qualified over-width escort vehicle. Permitted over-width, non-escorted loads need to be clearly marked as required by the state or city in which they are transported (Figure 7-32).

Precasters must be aware of and plan for all shipping regulations that apply along the route that will be taken by their delivery trucks. Shipping regulations in most large cities are typically more stringent than state regulations. All over-width loads (over 8.5 feet wide) in New York City, for example, must be permitted and delivered only at night. Additionally, New York City requires all loads more than 10.5 feet wide to be escorted, whereas New York state does not require escorts unless the loads are more than 12 feet wide. New York City permit applications must be made at least 48 hours before the shipment date. A route survey is additionally required for all loads more than 11 feet wide. In addition to these regulations, over-width loads may not be delivered during specified holidays and certain civic event hours.

Shipping regulations in New York City are complex and extremely limiting. Other cities throughout the U.S. exercise similarly restrictive freight regulations. The precaster should work closely with the contractor during the design and shipping processes so appropriate permits can be secured and precast panels can be properly loaded. This will ensure on-time delivery of the panels.

Summary

The high quality associated with PCP panels can be realized only if the panels are fabricated in plants qualified to meet high-quality fabrication standards and by workers and inspectors who are duly trained and certified to fabricate panels that meet specified quality standards. State DOTs, NPCA and PCI regularly use long-established plant certification programs that require certification of the physical plant and a thoroughly detailed QC plan to ensure production of quality products at precast concrete plants.

The QC plan required in these programs is a formal written plan of operation that describes, in detail, the work that is to be done, the processes required to do the work, the workforce that performs the work, and the QC procedures and reports to be completed to ensure the finished panels meet specified quality standards. This chapter focuses on important fabrication processes that are unique to PCP panels, such as forming, placing and consolidating concrete, screeding, finishing panel surfaces, panel detailing, curing, labeling, storage of panels in the precast yard and shipping panels to the job site. By closely adhering to procedures set forth in the QC plans, PCP panels can be manufactured and shipped to the job site, where they will provide many decades of useful service life.

Chapter 8:
PRE-INSTALLATION PROCEDURES COMMON TO ALL SYSTEMS
A GUIDE FOR CONTRACTORS AND AGENCY/OWNER INSPECTORS

While there are significant differences in installation techniques associated with the various types of systems and system components described in Chapter 4, there are some installation techniques that are common to all systems. At first glance, many of these procedures may appear to be routine construction practices that any experienced general highway contractor should be able to execute easily. However, some are unique to jointed precast concrete pavement (JPrCP) and are sufficiently challenging, deserving of special attention here.

Procedures deserving special attention include:

- Maintenance and protection of traffic (MPT) and protection of job-site personnel
- Establishment of safe and efficient work areas
- Surveying (saw cut and panel layout)
- Saw cutting
- Removal of existing pavement
- Subbase repair
- Subbase preparation

The importance of MPT cannot be overemphasized because it affects the safety of workers and the traveling public in scarcely lit work areas that are "lightly protected," at best, with temporary traffic delineation devices. Attention should also be given to other "in-traffic-at-night" operations – such as surveying, sawing, pavement removal, and subbase repair – to ensure some of the problems encountered on JPrCP projects completed to date do not reoccur. Some of these problems, including wide joints, cracked and spalled panels, spalled existing pavement and improper surface match between panels, may be traced back to failures to properly execute these "ordinary tasks." This chapter highlights good practices related to these operations that may be followed to avoid such issues.

Figure 8-1. Men working approximately 8 feet away from live traffic, separated only by widely placed traffic cones.

Maintenance and Protection of Traffic (MPT) and Providing Worker Safety

While MPT is not directly related to PCP installation, it is important because it is intended to provide working areas in which workers feel safe to engage in best installation practices. Precast paving work is dangerous because workers are often required to operate near live traffic every night, as seen in Figure 8-1. Portable traffic control devices, such as signs, arrow boards, bumper trucks and traffic cones, are typically installed at the beginning of each work shift – in lieu of the more protective continuous concrete barriers – to delineate traffic and protect job site workers. Although there is often pressure to install these devices quickly to allow workers as much time as possible to complete their work, care should be taken to ensure they are installed

Figure 8-2. The work area on this five-lane California interstate project was three lanes wide, providing a safe, 12-foot-wide buffer zone.

Figure 8-3. The narrow buffer zone in this two-lane working area required workers to exercise extreme caution.

in strict accordance with the requirements shown in the contract plans and the approved traffic control plan. This is true even if it means taking a few extra minutes out of an already abbreviated work window. MPTs must be evaluated and monitored during each shift to ensure a safe working environment is maintained throughout the project.

Work Areas

Multi-lane Work Areas

A “buffered work area,” comprising at least two full lanes and one partial lane, is preferred for safe and efficient PCP panel installation: one lane for excavation and placement equipment, one lane for removal and delivery trucks, and at least one partial “buffer” lane for delineation devices and additional worker safety. Some states, such as California, require a full lane as a safety buffer zone (Figure 8-2). Unfortunately, the partial buffer lane on many projects is less than 6 feet wide – as seen in Figure 8-3 – triggering the need for additional precautions such as safety spotters and traffic control officers. The sole responsibility of these parties is to monitor workers and equipment (as well as the traffic), ensuring they remain within safe working zones.

Multi-lane work areas on most PCP projects are typically made available progressively each night, starting from the beginning of the shift, as traffic in adjacent lanes decreases throughout the night. For example, a common scenario is that one lane is made available at 10 p.m. and the second lane and buffer zone at 11 p.m. or midnight, as determined by traffic demands. The contractor should become familiar with the schedule of available lane closures – typically included in the special provisions – and arrange installation operations accordingly. The contractor should also be made aware that allowable closure times may vary from what is shown in the special provisions to accommodate traffic needs during holidays and other special events.

One-lane Work Areas

While multiple-lane work areas are preferred, they are not always possible, especially on two-lane interstate highways and even on interstates and arterials with more lanes, where the intensity of traffic will not allow closure of two full lanes. An example of the latter is seen in Figure 8-4, where the work area was limited to only one lane, a partial buffer lane and a shoulder. The single lane area was adequate for pavement removal and subgrade preparation, but delivery of new panels required periodic momentary closures of the adjacent lane on the left. While the concrete safety barrier on this project provided increased worker safety, it also took one lane out of service for the duration of the project, a feature not possible on many pavement replacement projects.

Figure 8-4. The work area allowed on this three-lane interstate was restricted to one lane, a small portion of the adjacent lane and the shoulder on the right.

Figure 8-5. Traffic being diverted to the left shoulder, leaving a partial lane, a full lane and the shoulder on the right as a safe working area.

Single-lane closures are restrictive for installation operations and, at best, marginally safe, especially when concrete barrier is not used. Contractors installing panels in such small work areas must plan installation operations carefully to provide adequate worker safety while enabling efficient installation.

Using Shoulders to Widen Work Areas

To maintain traffic and provide a suitable work area on two-lane interstate projects where one lane is being replaced, traffic typically needs to use at least part of the adjacent lane and part of an adjacent shoulder. Shoulders used to carry mainline traffic should be at least 6 feet wide so that as much adjacent lane width as possible can be used as a safety buffer, as seen in Figure 8-5. Additionally, the existing shoulder pavement cross-section should be evaluated prior to mainline traffic use to ensure it is structurally adequate. Use of shoulders for mainline traffic should be monitored closely to ensure pavement failures do not develop during use. Excavation operations and placement of panels in such heavily restricted work areas are discussed in more detail later in this chapter and in Chapter 9.

Pre-installation Field Surveying (Layout)

Chapter 6 discusses field surveys that must be conducted to gather information necessary for shop drawing development. A second surveying operation (for laying out saw cuts and panel locations) is typically required much later in the project, just prior to sawing the existing pavement for removal. This survey typically focuses on layout of the transverse saw cuts at the beginning and end of each repair area, although it may also include layout marks for the panels, as discussed later in this chapter. In large, multiple-panel repair (lane replacement) areas, it may also be necessary to lay out intermediate transverse saw cuts that coincide with the number of panels the contractor plans to place in any given night. The exact location of intermediate and end cuts will depend on how fast the contractor places the panels, as discussed in the following sections.

No matter how the contractor plans to install the panels, the surveyor should be aware that actual panel lengths (and widths) vary from nominal dimensions shown on the shop drawings, as allowed by specified fabrication tolerances (typically ± 1/4 inch). These variations must be considered when laying out end and intermediate transverse saw cuts.

Determining Saw Cut Layout for Single-panel Repairs

Transverse saw cuts for a single panel must be laid out far enough apart (distance “L” in Figure 8-6) such that the largest allowable panel for any given nominal panel length (nominal length plus 1/4 inch) will fit in the hole and the shortest allowable panel (nominal panel length minus 1/4 inch) will not leave a transverse joint width in excess of the maximum allowable transverse joint width (typically 1/2 inch).

The distance between end transverse saw cuts for a single panel (assuming the panel is fabricated within specified fabrication tolerances) can be determined ahead of layout time from information shown on the shop drawings using the following equation:

“L” (Distance Between Transverse Saw Cuts for a Single Panel) =
Nominal Panel Length – Fabrication Tolerance + 2 x Allowable Joint Width *(Equation 8.1)*

To illustrate Equation 8.1, the distance between transverse saw cuts for the single, 10-foot-long nominal panel fabricated to a tolerance of ± 1/4 inch and installed on a project where transverse joint widths are limited to 1/2 inch may be determined as follows (see Figure 8-6):

“L” = 10 feet – ¼ inch + 2 x ½ inch = 10 feet, 0-¾ inch

If the largest allowable panel (10 feet, 0-1/4 inch) is installed in a hole of that length, the transverse joint width (WT in Figure 8-6) will be 1/4 inch, assuming the panel is centered in the cutout area. Similarly, if the shortest possible panel (9 feet, 11-3/4 inch) is installed, the transverse joint width will be 1/2 inch. Single panels should always be centered in the cutout area during placement. Incompressible plastic shims should be placed in each transverse joint after placement to ensure panels do not move out of position during live traffic conditions (before they are fully grouted), as discussed in Chapter 9. For the example shown in Figure 8-6, it is assumed the widths of the longitudinal joints between the new panel and adjacent concrete will be within the specified tolerance as a result of the measuring and design processes discussed in Chapter 6. It is also assumed that the panel will be centered transversely in the cutout area during placement, such that longitudinal joint widths on each side of the panel will be equal.

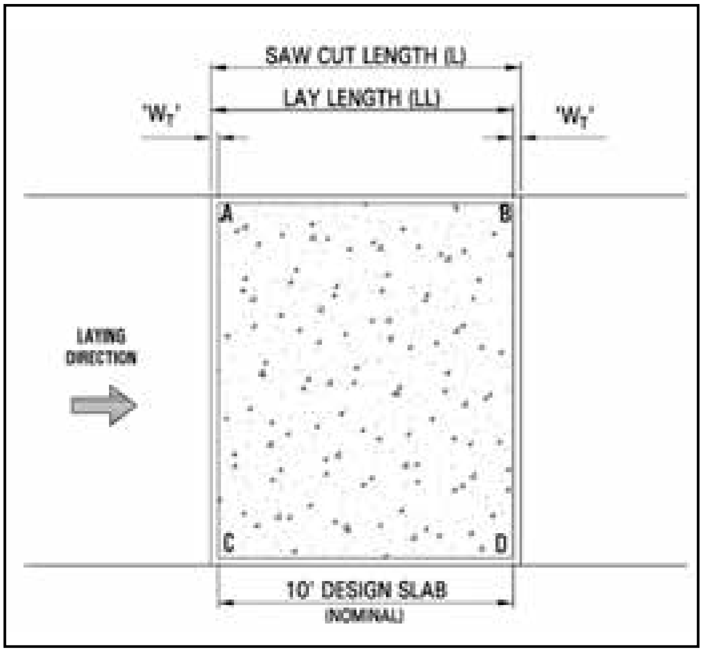


Figure 8-6. Sketch showing how to determine the length between transverse saw cuts (“L”) for a single-panel repair such that the maximum allowable joint width is not exceeded.

Considering Methods of Placing Panels in Multiple-panel Areas as They Affect Determination of Transverse Saw Cut Locations

The method used to place panels in a multiple-panel repair area affects how end cut locations will be determined. There are two basic methods of panel placement. The first method, referred to as the “lay length method,” is used primarily with the Super-Slab System outside of California. Prior to placement, theoretical lay lengths are marked on the adjacent pavement on each side of the repair area (Figure 8-7). During panel placement, the leading end of each panel (the end of the panel farthest from the beginning of the placement) is placed on a string line stretched between the two theoretical lay length marks that define the length allocated for each panel within the run.

A primary advantage of this method is that the location of the end cut – relative to the cut at the beginning – can be determined exactly prior to saw cut layout, as discussed in the following section. A second advantage is that all transverse saw cuts can be made at the same time. There is no need to have a saw on hand to make the final saw cut. A third advantage is that, if a second lane of precast panels is placed next to one placed in this manner, transverse joints in adjacent lanes will line up, a feature that may greatly speed up subsequent joint sawing and sealing operations. While the additional step of laying out panel placement points in this manner does require a small amount of additional surveying time, the advantages typically far outweigh the costs.

The second method of placing panels in a multiple-panel area can be referred to as the "end-to-end method." This method, used primarily in California, involves placing panels end-to-end, typically with foam expansion material placed between ends of adjacent panels. Each panel is translated longitudinally (along the direction of travel) during placement until it contacts the previously placed panel. This does not mean there will be no space between panels. While each panel is placed directly against the previously placed one, there is likely to be a variable-width space between panels because they are often not perfect rectangles. While this method does not require leading end layout for each panel, it does require accurate layout of the first or beginning transverse joint and requires that a saw be on hand during the placement operation to saw transverse joints at the end of each night's installation and at the last transverse joint in the run. The exact location of those cuts cannot be determined until the last two or three panels in a night's installation have been placed because the cumulative length of a series of panels varies due to allowable variances in individual panel lengths.

The perceived advantage of this second method is that exacting panel layout prior to installation is not required. A primary disadvantage of this method is that a saw (and related removal personnel and equipment) must be on hand to place the last panel in the run. Another important consequence of this method is that transverse joints in adjacent lanes of precast panels rarely line up exactly because actual panel lengths in each lane can vary.

Determining Transverse Saw Cut Locations When the Lay Length Method of Placement is Used

To determine the length "L" between end saw cuts when the lay length method of placement is used, the lay length of each panel – or the length allocated to each panel – must first be determined. The lay length can be quantitatively defined according to Equation 8.2 below and as shown for the two panels presented in Figure 8-7 (see lay lengths "LL1" and "LL2").

"Theoretical Lay Length" = Nominal Panel Length + Fabrication Tolerance *(Equation 8.2)*

For example, the theoretical lay length of the 10-foot panel project described above is the nominal panel length (10 feet) plus the maximum allowable fabrication tolerance (1/4 inch), or 10 feet, 0-1/4 inch. A panel fabricated to the longest allowable length (10 feet, 0-1/4 inch for this example), will occupy the entire theoretical lay length. A panel fabricated to the shortest allowable length (9 feet, 11- 3/4 inch for this example) will occupy only that much of the theoretical lay length, leaving behind a space or joint of 1/2 inch between the trailing end of this panel and the leading end of the previous panel, provided that the leading end of the panel is correctly placed to the theoretical lay length mark.

The total distance "L" between the beginning and ending transverse saw cuts in a multiple-panel repair area (see Figure 8-7) may be determined and laid out using the following equation:

"L" (Distance Between Saw Cuts for a Multiple-Panel Installation) = ∑ [Lay Lengths for All the Panels] + Maximum Allowable Joint Width *(Equation 8.3)*

The addition of the maximum allowable joint width in Equation 8.3 represents the maximum allowable width of the transverse joint at the end of the multi-panel repair area (W_{T3} in Figure 8-7), assuming all the panels are placed within their allocated theoretical lay lengths (LL1 + LL2 in Figure 8-7).

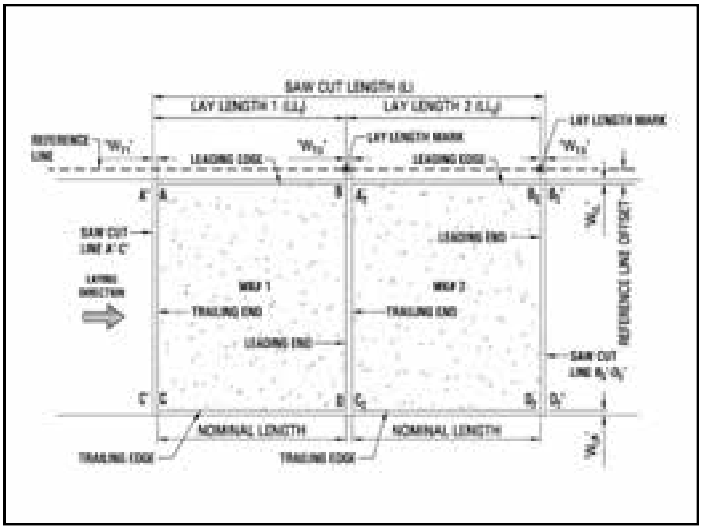


Figure 8-7. Sketch showing how to establish a “Theoretical Lay Length” that compensates for panel length variability within allowable fabrication tolerances.

Figure 8-8. An example of a contractor-designed steel template being used to lay out and score saw cut lines for a single panel.

A “zero-width” transverse joint resulting from placing the longest panel indicated above (10 feet, 0-1/4 inch) in any given allocated length is likely not realistic. This is because slight variations of the saw cut A’-C’ (see Figure 8-7) and in the fabricated edge of the new panel A-C, for example, will most likely result in a small joint at that point, causing Panel #1 to extend slightly beyond the theoretical lay length marks (leading end line) for that panel. If this does occur, it is highly likely that subsequent panels will be short enough to allow subsequently placed panels to be placed at their theoretical lay length marks, compensating for any gain in setting length (sometimes referred to as “creep”) that may result from placing maximum-length panels in any given run. The panel placement crew should always strive to place the leading end of each panel to the marked-out lay length (leading end) marks to ensure the last panel in the run will fit.

Laying Out Transverse End Cuts Using Templates (Single- panel Repair Areas)

Templates made from steel or aluminum angles, such as the one seen in Figure 8-8, may be fabricated to facilitate layout of single-panel areas. Many contractors design templates that are adjustable in length, often in increments of 2 feet, to correspond to various panel lengths that may be used on the project.

Single-panel templates should be fabricated in accordance with the length determined using Equation 8.1. To mark out a single panel, the template is placed on the roadway as squarely as possible with respect to the longitudinal joints. Workers then spray paint on the pavement adjacent to the transverse edges of the template to mark out transverse saw cut lines. In lieu of painting, a small concrete saw may be used to score the concrete along the edge of the template to create a longer-lasting line (Figure 8-8). These templates are not to be used for marking out longitudinal saw cuts because the longitudinal edges of the hole prepared for a panel are typically the existing longitudinal joints, as discussed later in this chapter.

Laying Out End Saw Cuts in Multiple-panel Tangent (Straight-run) Areas

Transverse saw cut lines (perpendicular to the longitudinal joint) may be laid out at each end of a multiple-panel repair area by turning a right angle from the existing or new longitudinal joint using a surveyor’s transit or by using the 3-4-5 right triangle method. They may be laid out more efficiently using a right-angle laser device (Figure 8-9) placed at one corner of the repair area such that one beam is aligned with the longitudinal joint while workers mark out the perpendicular transverse cut along the other projected laser beam (Figure 8-10). Workers should measure diagonals of the laid-out patch as an additional accuracy check whenever possible, recognizing the 1/2-inch maximum joint width is an exacting tolerance to meet.

Laying Out End Cuts in Horizontal Curves

The rectangular template described above can be used to mark out transverse joints for single rectangular repair panels on horizontally curved roadways or ramps if it is placed such that the transverse center line of the template is placed directly on a line that is a radial of the horizontal curve.

However, templates are not appropriate for laying out multiple-panel repair areas in horizontal curves, since the beginning and end transverse saw cut lines should be laid out and cut along radials of the curve at each location. By definition, these radial cuts are not parallel, negating the use of rectangular templates for layout purposes. A qualified surveyor should always be used to lay out radial end cuts to avoid fitting problems, such as the one seen in Figure 8-11. Additionally, precast panels placed in curved, multiple-panel areas should – theoretically – be manufactured as trapezoidal panels such that transverse ends of each panel can be placed on radials of the curve, as discussed in Chapter 6.


Figure 8-9. An example right-angle laser device for laying out perpendicular transverse saw cut lines.


Figure 8-10. Workers using a right-angle laser tool to accurately mark a perpendicular transverse saw cut for a straight roadway.


Figure 8-11. Example of a “saw-tooth” longitudinal joint created because the end cut, seen in the foreground, was not laid out and cut radially to the horizontal curve.

Laying Out Leading End and Panel Corner Marks Within Single-lane, Multiple-panel Areas

Leading end marks within multiple-panel areas may be laid out by simply using a tape. Holding zero at the first end cut, theoretical lay lengths (leading end) marks are made along the tape at lay lengths determined using Equation 8.2. Leading end marks are typically laid out on both sides of the repair area such that a string line can be stretched between them to represent the theoretical leading end during placement of the new panels, as discussed in Chapter 9.

Figure 8-12. Example leading end mark for a panel designated number 217 (see black line perpendicular to pavement edge in yellow circle).

A leading end mark for an actual project is shown in Figure 8-12. In this case, the leading end mark is represented by a black cross mark in the painted yellow circle. The cross line perpendicular to the pavement edge represents the location for placing the leading end of panel 217. The cross line parallel to the pavement edge represents the location for placing the edge of the panel at the leading end. The “F5” mark seen above the number 218 conveys the elevation to which the new panel (either planar or non-planar) must be placed (0.05 feet above the existing panel in this case) for conformance with the designed digital surface model.

Retaining (or Not Retaining) Existing Longitudinal Joints

Existing longitudinal joints are typically retained (for repairs involving one or more new panels) when they are reasonably straight or uniform in alignment and when the concrete along the longitudinal joint in the retained lane is sound. This practice minimizes sawing time if the existing longitudinal joint is wide and only longitudinal ties need to be cut. It may also facilitate adding new precast panels in the adjacent lane, if and when it needs to be replaced, because the new panels can be designed and fabricated to a standard lane width.

Figure 8-13. Example of an inaccurately sawed longitudinal joint.

When the concrete in the pavement to be retained is deteriorated along the longitudinal joint, however, it is better practice to cut a new longitudinal joint in sound concrete in the adjacent lane being retained, offset 2 - 6 inches away from the existing joint, especially when the repair area includes consecutive panels, as is the case with lane replacement areas. This practice may reduce the width of the new longitudinal joint, will provide sound concrete to host new longitudinal joint sealant and may allow the contractor to fabricate new panels of uniform width. If new longitudinal saw cuts are made to establish new longitudinal joints, saw operators should be careful not to overcut into existing pavement at the beginning and ending of the new longitudinal saw cut (and must repair any overcuts that occur).

Accurately Laying Out Longitudinal Joints Prior to Sawing

If the existing longitudinal joint is to be retained (as it is in most cases when the existing concrete in the adjacent lane is reasonably sound), it is necessary to saw along and through the existing joint to sever existing tie bars and make way for removal of the existing pavement. In some cases, the true location of these joints is readily visible. In other cases, however, the center of the visible joint seal in existing longitudinal joints may not coincide with the actual center of the longitudinal joint (see Figure 6-5). In these cases, the centers of the existing joints may be located using the “ice pick” technique (described in Chapter 6) prior to marking out the longitudinal joint. Alternatively, the joint seal can be removed entirely to expose the actual longitudinal joint. No matter the approach, the longitudinal saw cut should be clearly visible or marked so that the saw operator can easily follow the line of the actual joint. Guesswork often results in inaccurate longitudinal saw cuts, as shown in Figure 8-13.

Longitudinal cuts should also be marked out along asphalt shoulders to ensure the shoulder is sawed approximately 3/4 inch from the existing concrete pavement edge so that the asphalt is not damaged during removal. Removing pavement without first sawing the asphalt shoulder is likely to result in shoulder damage during liftout of the existing pavement, as seen in Figure 8-14.

Laying Out Longitudinal Alignment Lines for Placements in Single-lane Replacement Areas

Proper panel placement in single-lane, multiple-panel repair areas may also require layout for aligning longitudinal edges of panels as well as for transverse ends. If the longitudinal edges of the adjacent existing lanes are straight and parallel, properly designed and fabricated panels may simply be centered between them during placement such that the maximum longitudinal joint width (typically 3/4 inch) is not exceeded. When existing edges are not straight and parallel (and they frequently are not), it is advisable to lay out a straight reference line on the existing adjacent pavement for use in aligning the new panels.

The edge of the panel that is aligned to the straight longitudinal reference line is defined as the leading or measured edge of the panel, as illustrated in Figure 8-7. In practice, a leading edge line is only marked at the point where it intersects with the leading end line, as seen in Figure 8-12. The black line parallel to the edge of the pavement in the painted yellow circle is the straight reference line to which the leading edge of panel 217 is to be set.

Figure 8-14. Failure to cut the asphalt shoulder prior to pavement removal resulted in serious shoulder damage on this project.

Placing panels in a continuous run to both leading end and leading edge marks ensures panels are properly aligned and that maximum allowable longitudinal and transverse joint widths are not exceeded.

Layout for Longitudinal Alignment in Multiple Lane Replacement Areas

Leading edge marks are particularly important when placing a new precast lane next to a previously placed one. If the leading edges of panels placed in the first lane are placed to an accurate longitudinal reference line, as described above, the trailing edges (see Figure 8-7) of that lane may vary in longitudinal alignment because precast panels vary slightly in width (within specified tolerances), just as they do in length. It is advisable, therefore, to use the same straight longitudinal reference line for setting the leading edges of panels in the second lane to keep them properly aligned and to keep longitudinal and transverse joint widths within specified tolerances. If the original reference line is not available for use during placement of the second precast lane (e.g., because it is occupied by traffic), a new longitudinal reference line should be laid out for that lane.

If the panels in the first lane are placed to theoretical leading end marks, it is not necessary to lay out leading ends for the second lane since previously placed panels in the first lane serve as leading end marks. It is advisable, however, to lay out the new leading end marks on a new longitudinal reference line if more than two or three lanes are being replaced.

Figure 8-15. Panel points, identified with red paint, being used on a PCP project.

Figure 8-16. Survey crew using a robotically controlled total station to lay out panel points on a total replacement project.

It should be noted that if precast panels are placed using the techniques described in the preceding paragraphs, both longitudinal and transverse joints will line up, a factor that is important when sawing joint sealant reservoirs, as discussed previously and in Chapter 11.

Laying Out Panel Point Marks for Area Placements

A different layout approach is required when laying out leading edge and leading end marks for panels that will occupy areas where no adjacent pavement (for marking) exists, such as those seen in Figures 8-15 and 8-16. For these projects, it is necessary to mark out actual corners of the new panels (panel points) directly on the prepared subgrade surface. Placing leading corners of each panel to theoretical panel point marks ensures allowable joint widths are not exceeded and panels are placed in the locations shown on the panel layout drawing, such as the one shown in Figure 6-16. This technique is particularly important when laying out panels for intersections and toll plazas with multiple lanes extending up to one hundred feet or more. In these areas, panels must be placed to fit within the theoretical grid shown on the panel layout drawing. Failure to keep panels within theoretical layout lines will likely result in costly alterations or even replacement of panels already fabricated for the project.

Total station surveying equipment, such as that seen in Figure 8-16, is frequently used in such applications. During this process, surveyors use “x” and “y” information for each panel point developed by the shop drawing engineer during development of the digital surface model, as discussed in Chapter 6.

Laying Out Panel Point Elevation Marks in Area Placements

Discussions thus far have covered the layout of panel point elevations only in single-lane replacement areas where there is existing pavement on each side of the new lane on which such marks can be made, as seen in Figure 8-12. When new area subgrade surfaces are precisely graded, as they are with the Super-Slab system (as seen in Figures 8-15 and 8-16) and other grade-supported systems, an actual layout of panel elevations is not needed because the subgrade is precisely graded (typically using laser-controlled equipment) to follow the digital design surface model referred to earlier. In such cases, only horizontal “x” and “y” points need to be laid out, as shown in Figures 8-15 and 8-16.

Subgrade surfaces for grout-supported systems may be graded using similar equipment or by conventional, less precise stake-out methods since the final grade or elevation of the panels is established using leveling bolts. In this case, the contractor may use total station equipment to lay out or control panel corner elevations during panel adjustment or may develop some other practical method of marking out panel elevations, which are extracted from the design surface model for either method.

Figure 8-17. This sawing crew is equipped with adequately sized saws, proper lighting, a water supply and a slurry suction truck.

Figure 8-18. An undulating vertical saw cut made with a blade that was likely too flexible for the pavement.

Sawing Operations

Accurate sawing is necessary, no matter what system is used on a PCP project. Saw operators should be trained on the importance of following layout lines because precast panels require precise saw cuts to ensure maximum specified joint widths are not exceeded, unlike sawing for fast-track cast-in-place pavement, where plastic concrete is placed and will conform to any saw cut, even if it is not straight. Additionally, workers must understand that saw cuts that result in panel openings that are too narrow for the new panels result in costly delays and additional costs for making new saw cuts, while saw cuts that result in panel opening that are too large will result in excessive joint widths, which may be cause for panel rejection.

Figure 8-19. Filling a transverse overcut with dowel bar epoxy anchoring material.

Sawing Equipment

Good lighting is crucial to accurately cutting panel openings, especially at night. Adequate lighting may be provided by conventional light trailers positioned at appropriate intervals for a single night's operation or by lights mounted on pickups that can move with the sawing operation, as necessary (Figure 8-17). Notice that the saw operator in the foreground is controlling the saw by keeping the front guide directly over the saw cut line. The slurry removal/water truck in the background supplies water to both saws while also providing a vacuum line for slurry removal.

Saw blades should be selected and sized specifically for every project, taking into consideration the type of concrete being cut, the aggregate type and reinforcing steel (if present), the thickness of the pavement and the specified saw cut accuracy. Using a blade that is too flexible may result in an undulating cut face (Figure 8-18), where the cut may be correct at the top of the pavement but deviates from vertical towards the pavement bottom, sometimes resulting in a hole that is too narrow for the new panel. This may require costly and time-consuming grinding or re-sawing of the pavement to make the panel fit.

Figure 8-20. A concrete chainsaw equipped with diamond teeth is used to finish a full-depth saw cut without overcutting into the adjacent panel.

Figure 8-21. Saw blades bound up by slab expansion in hot weather.

It is also important to use proper saw operating techniques, including controlling the depth of cut, line of cut and forward speed, when sawing concrete pavement for installation of precast panels. Some operators prefer to make more than one pass to cut through the pavement, rather than trying to saw all the way through in one pass. An example of this is seen in Figure 8-17, where the saw operator has set the saw to make only a partial-depth cut, even though the saw is powerful enough to cut all the way through in one pass. Forcing the saw to make a single, full-depth cut with too much forward speed may result in inaccurate and sometimes undulating saw cuts.

Overcutting into Adjacent Lanes

Transverse saw cuts made with circular saws need to extend or overcut into the adjacent lane to fully cut the bottom of the pavement that is to be removed. Many states allow this practice, requiring only that the overcuts be filled with an epoxy repair material. This is typically the same epoxy-based material used to anchor dowels on the project, as seen in Figure 8-19.

Other states prohibit overcutting because of concerns about compromising the integrity of the adjacent pavement that is to be left in place, requiring the contractor to finish the transverse cut with a different saw, such as a ring saw or a concrete chainsaw (Figure 8-20). While this practice eliminates overcutting, it also adds cost to the operation. In addition, concrete chainsaws can be dangerous when they hit steel rebar, so they should only be used by trained workers that are equipped with full protective gear.

Sawing in Hot Weather

Making transverse saw cuts during the summer months can be problematic because pavement expands during periods of rising temperatures. Expansive forces can be so great that saw blades bind up during the sawing operation (Figure 8-21). This may be avoided by making full-depth cuts at night, when temperatures and expansion forces are lower.

Removal of Existing Pavement

The removal operation is key to maximizing installation rates because it is the first operation to occur each night. The removal excavator or removal crane and removal trucks should be ready to begin as soon as the MPT plan allows. While removal rates are important, removal operations must be conducted with care to ensure existing pavement that is to remain in place is not damaged.

Removal Methods

Existing pavement is typically removed by using either the lift-out or excavator methods. The lift-out method consists of drilling holes in slabs designated for removal

Figure 8-22. Slabs being removed using the lift-out method. Notice the spalls on the edge of the remaining pavement on the left caused by the lifting operation.

Figure 8-23. Removal of existing pavement using the excavator method with a slab-crab.

Figure 8-24. The shattered pavement seen here had to be removed with an excavator even though the lift-out method was specified.

Figure 8-25. Excavator removal using a slab-crab bucket, showing little disturbance of the underlying subbase.

to accommodate lifting inserts that are mechanically or chemically anchored in place. At the time of removal, lifting cables are attached to the inserts so a crane or excavator can remove the pavement and place it in a haul truck (Figure 8-22). Cables are then unhooked and lifting devices are removed so they can be reused.

The excavator method typically involves removal of the existing pavement using an excavator outfitted with what is commonly called a “slab-crab” bucket. The bucket is built with a notch into which pieces of the existing pavement can be wedged for lifting and removal, as seen in Figure 8-23. The bottoms of slab-crab buckets are relatively thin so that they can be forced under pieces of existing pavement with minimal disturbance to the underlying subbase. The bottoms of the buckets are typically around 4 feet long, so pieces of pavement up to about 8 feet long can be removed without the need for lifting inserts.

While the lift-out method is meant to prevent damage to the existing subbase surface and adjacent pavement, it is slower and costlier than the excavator method because it requires additional labor and equipment to drill holes for lifting inserts and to unhook the panels from the lifting cables once they are placed in the removal truck. Although the lift-out method typically does not damage the subbase (unless the subbase remains attached to the removed slab), it sometimes causes spalls along the adjacent pavement if the pieces bind against or contact the adjacent panels as they are lifted (Figure 8-22). The lift-out method is also impractical and

Figure 8-26. The versatile rubber-tire excavator can be used for removal, rough grading and placement of new panels up to 10 feet by 12 feet.

Figure 8-27. An example of undercutting 1 foot prior to replacement with geo-fabric, new subbase material and JPrCP panels.

sometimes impossible if the existing pavement is too "broken up" or shattered, as seen in Figure 8-24.

The excavator removal method has emerged to be more efficient and cost-effective than the lift-out method, primarily because anchoring and removal of lifting devices is not required. If used with care, slab removal buckets cause very little (if any) damage to the existing subbase. Minor disturbance to the subbase caused by these buckets can usually be repaired and re-compacted with little effort.

Preventing Damage to Remaining Pavement at the Beginnings of Removal Areas

A technique for avoiding damage to adjacent pavement at the beginning of removal areas is to saw a relief cut or a short gap slab that is to be removed first before attempting production removal of large pieces. This is most successfully accomplished by making two transverse saw cuts – one approximately 2 inches away from the end cut and the second 4 to 6 inches away. These extra cuts provide enough relief so the short gap or relief slab or wedge can be lifted out, as shown in Figure 8-25. Any spalling that may result from this operation occurs on the narrow (2-inch-wide) strip that will be removed by hand, leaving the permanent edge free of damage. Once the narrow relief wedge has been removed, the slab-crab bucket can be used to remove remaining larger pieces without damaging existing pavement at the beginning of the area. Care must also be taken throughout the removal process to avoid damage to longitudinal edges, such as that shown in Figure 8-22, and to the transverse edge of the existing pavement at the end of the repair area.

Removal Equipment

Since pavement removal is the first operation that must be completed before foundation preparation can begin, the contractor should select removal equipment with careful consideration given to mobility, lifting capacity and versatility, keeping in mind that, on some projects, the same equipment may be used to place the new panels. Rubber-tire excavators (Figure 8-26) are popular with many intermittent repair contractors because they meet all the criteria needed for efficient removal and placement, as discussed in more detail in Chapter 9. Track-mounted excavators are also occasionally used, but they are not as mobile and their tracks tend to mark and damage the concrete pavement surface unless appropriate track padding material is used.

Figure 8-28. Density testing of newly placed subbase material to evaluate compaction.

Figure 8-29. Spot repair during subbase preparation.

Subbase Repair

Planned Subbase Repair

Anticipated subbase repair or undercutting should be clearly indicated in the contract plans so the contractor can plan appropriately. Additional trucks will likely be needed to remove unsuitable material, and arrangements will need to be made for timely delivery of backfill materials – all prior to "normal" precast paving operations.

While undercutting takes additional time and reduces the number of panels that can be placed in any given shift, it can be easily included in a precast operation. For example, the planned undercutting operation on the intersection project seen in Figure 8-27 involved the removal of 1 foot of unsuitable subbase material so new, dense-graded base could be placed prior to normal placement and grading of bedding material and new panel placement. Despite the additional work, the contractor was able to place 10 to 12 panels during the 11-hour night work windows under live traffic conditions.

More time should also be allowed for placing and fully compacting undercut backfill materials. Newly placed backfill material should always be checked to ensure specified compaction requirements are met, as seen in Figure 8-28.

Figure 8-30. Extensive subbase repair prior to JPrCP installation (visible in the background).

Unplanned Subbase Repair

The necessity of replacing unsuitable subbase material is sometimes not obvious until after the existing pavement has been removed, as was the case on the projects shown in Figures 8-29 and 8-30. Repair areas may vary from small, isolated areas (e.g., the 8-foot-diameter area shown in Figure 8-29) to more extensive areas and serious conditions where new subbase material and underdrains are required to make a proper repair (Figure 8-29). The contractor should be ready to make such unexpected repairs by having stockpiles of base material, underdrain and other subbase repair materials on hand.

Working with Existing Cement-Treated Base

JPrCP panels are typically placed on aggregate base material in most states except for California, where they are placed on existing cement-treated base (CTB) material for isolated, individual panel replacements, and new lean concrete base rapid-setting (LCBRS) for lane replacement projects. Placement of JPrCP on existing CTB has proven to be problematic in some cases when the top of base elevation could not be determined prior to design and installation of the new panels. In theory, the top of the CTB can be determined by taking cores through the existing pavement, but this practice is often not reliable because the CTB profile and the thickness of the existing pavement may vary significantly due to variability in initial construction and diamond-grinding operations over the life of the existing pavement.

If the existing CTB is retained, the contractor needs to be aware that some of it may need to be removed to allow the new PCP panels to match the surface profile of the adjacent pavement. If only isolated high spots of existing CTB are encountered in intermittent repair areas, they may be removed by scraping with the excavator bucket, as shown in Figure 8-31. However, this is a slow and potentially costly process. When larger areas need to be removed, it is more practical to use a skid-steer-mounted milling head, like the one seen in Figure 8-32. Trimming the CTB using either of these methods is a time-consuming and costly process that should be considered carefully during the design phase of the project.

High CTB in larger-lane replacement areas may be lowered more efficiently using conventional, large-scale milling equipment (Figure 8-33). While this type of machine can remove CTB efficiently, doing so typically involves more equipment, such as trucks and mechanized brooms, which may add to project costs and time. In addition, removal of a significant amount of CTB may compromise its structural integrity – a factor that should also be considered during the design phase of the project.


Figure 8-31. Trimming isolated high spots in CTB (red marks) with an excavator bucket.


Figure 8-32. A skid-steer-mounted milling head trimming a large area of CTB.


Figure 8-33. CTB removal with a large-scale milling machine, followed by a conventional “street sweeper” broom truck to ensure all milled material is removed.

Replacement of Existing CTB with New, Rapid-Setting Lean Concrete Base

At least one state has adopted the practice of removing existing CTB in its entirety and replacing it with a new layer of rapid-setting lean concrete base when entire lanes are being replaced. This practice avoids the uncertainties and costs associated with high CTBs and allows the designer to specify new panel and base thicknesses, as necessary to ensure long-term performance and proper surface profile match with adjacent pavement. The process of placing new, rapid-setting lean concrete base prior to panel installation is described in detail in Chapter 9.

Drainable Concrete and Asphalt Bases

Placement of new, grade-supported JPrCP panels on existing or new drainable base material is generally not recommended because unbound, fine-grained bedding material placed between the base and the new panels may wash into voids in the drainable base over time unless measures are taken to prevent it. One such measure is to use cement-treated bedding material (CTBM) in lieu of unbound concrete sand or stone dust on top of the drainable base. The benefit of using this material is that it turns into a lean concrete layer (as the cement hydrates) that will not wash through the drainable base. CTBM also prevents fluid bedding grout from filling voids in the drainable base below.

The placement of grout-supported JPrCP on drainable base material is not recommended because bedding grout placed beneath the panels will penetrate and may fill up voids in the base.

Summary

While there are significant differences in installation techniques associated with the various systems described in Chapter 4, there are some that are common and important to all systems. For example, establishing a work area that is safe for workers and the traveling public is crucial to productive and quality-inducing installation operations.

Accurate field layout and surveying are also particularly important to ensure that the precast panels fit properly in prepared holes such that allowable joint widths are not exceeded and panel surfaces match adjacent pavement profiles properly. This chapter describes layout procedures required for intermittent, continuous and area replacements. Accurate layout must be followed by saw cutting that is equally accurate, performed by saw operators that exercise a high level of control to ensure panels fit within specified tolerances. While pre-installation layout focuses primarily on horizontal “x-y” alignment, it is necessary on some projects, such as intersections, ramps and toll plazas, to lay out marks for panel elevations (“z”) as well.

Removal of the existing pavement may appear to be a simple operation, but it must be done with care to avoid damaging pavement that is to remain in place and in service. Repair and preparation of existing subbases (discussed in more detail in Chapter 9) can be challenging because work windows on precast pavement projects are typically short. This chapter provides information on techniques associated with the seemingly simple yet uniquely important steps that facilitate the subsequent placement of precast panels, as required by each system to ensure a high-quality JPrCP installation.

CHAPTER 9:
SYSTEM-SPECIFIC INSTALLATION PROCEDURES

With every system described in previous chapters there are specific, and, in some cases, unique installation methods used (after the preliminary work discussed in Chapter 8 has been completed) to achieve the four basic requirements for jointed precast concrete pavement (JPrCP) listed in Table 1-1:

1. Panels are placed or adjusted to the correct grade
2. Panels are uniformly and completely supported
3. Effective load transfer between panels is established
4. The top surface of the panels conforms to and meets the surface of the surrounding pavement

While they are presented in this chapter as "stand-alone" methods, they are ultimately combined as a set of procedures or system that accomplishes the four basic requirements listed above.

It is important to note the differences in equipment and manpower requirements associated with each method, as well as possible differences in production rates, installation costs and in how soon newly installed panels can be opened to traffic. Other important system-specific aspects of precast paving – such as panel placement and opening panels to traffic – are also discussed. The chapter concludes with a discussion of how to select a system or a set of procedures that best fits the contractor's operation and meets the project's needs.

Placing or Adjusting Panels to the Correct Grades

Determining Correct Grades

The first requirement in Table 1-1 is that systems must provide methods of placing panels to correct grades. Before that can be done, one must first establish what grades are correct for single- and multiple-panel placements.

Grades for Drop-in and Lane-replacement Panels

For panels that are placed next to existing pavement – whether for one panel or a series of panels – the correct "grade" for each panel is the plane defined by the surfaces at the edges of the abutting or adjacent pavement. Whether those edges are vertically uneven (as they often are) or not, the correct grade for each new panel is the one that best matches those edges.

If single-plane (planar) panels are used in a multi-panel patch, the grades or planes of each placed panel surface may vary with the grades defined by the edges of the adjacent pavement panels. When best-fit placement of planar panels results in a difference in surface elevation between the new panels and the adjacent pavement that exceeds the specified allowable difference, it will be necessary to design and use warped (non-planar) panels, as discussed in Chapter 6, or to diamond grind the surfaces of the precast and adjacent existing pavement. This may be the case even on tangent (straight) sections of interstate highways in situations where the existing pavement slabs have shifted out of their original positions over time.

Grades for Area Placements

Grades for area placements (e.g., toll plazas, intersections ramps and some multiple-lane mainline areas) will likely need to be determined during the shop drawing process, as discussed in Chapter 6 and Chapter 8, because adjacent existing pavement may not be available to use as a grade reference. In these cases, new grades determined during the preparation of shop drawings will need to be laid out by project surveyors for subgrade preparation and, in some systems, for adjustment of new panels. Exact grade

Figure 9-1. Screeding device using adjacent existing pavement as the frame of grade reference.

Figure 9-2. Workers use rails set to specific elevations to provide an accurate grade reference irrespective of the undulating existing pavement underneath.

requirements will vary, depending upon the system selected for use, as discussed in the following sections.

Grade Control for Grade-supported Systems

The most common method used to bring new panels to grade is to place them on an accurately prepared subgrade surface that positions them to the correct grade without further adjustment. A thin (1/4 inch minimum to 3/4 inch maximum) layer of fine aggregate bedding material – sometimes blended with cement – is typically placed over the existing subgrade material. The material is then fully compacted and graded to an accuracy of ± 1/8 inch.

This method of grade control provides two benefits. First, if done correctly, it eliminates a separate adjustment operation. Second, panels may be opened to traffic immediately upon placement because the surface provides nearly uniform support. This is particularly advantageous since the first "vehicle" that typically uses the panel is the placement crane, as discussed later.

The key to providing an accurately graded surface is to use a grading device that is controlled from an accurate frame of grade reference. One device, seen in Figure 9-1, uses the adjacent existing pavement as a grade reference, a practice that will produce acceptable results if the edges of the existing pavement are accurate – i.e., if they reside in the same plane. If they do not, which is often the case, the graded surface provided using this method will reflect any vertical variations that may exist in the adjacent pavement.

To avoid transferring variations in adjacent pavement profile to the graded surface, screed rails may be placed on top of the existing pavement. The Super-Slab system screed rails seen in Figure 9-2 are placed and adjusted to a best-fit plane, as discussed earlier, before any grading begins.

The screed rail system seen in Figure 9-2 may also be used on longer lane replacement areas, as seen in Figure 9-3. For smaller areas, screed rails are set to cut or fill marks developed from information provided by the shop drawing engineer, as discussed in Chapter 6, and placed by the project surveyor. Cut and fill marks (see Figure 8-12) represent vertical distances below or above the existing pavement, respectively, in cases where the existing pavement varies above and below a straight-line grade. Cut and fill marks are developed to produce a best-fit subbase surface, as described above.

Accurate subbase surfaces may also be produced using laser-controlled grade boxes mounted on standard, track-mounted skid-steers (Figure 9-4). This commercially available equipment uses a digital surface model produced by the shop drawing engineer – rather than rails – for an accurate frame of grade reference. Pre-positioned, robotically controlled


Figure 9-3. A larger, hand-operated grader controlled by pre-set grade rails set to specific elevations.


Figure 9-4. A laser-equipped skid-steer and grading box using a digital surface model for grade control.

total stations continuously transmit “x” and “y” values (collected from the laser prism located on the grading box) to a computer mounted on the machine so it can then vertically adjust the grading bucket to match the surface model at those points. While this equipment is costlier than the type of equipment seen in Figure 9-3, for example, it does require less labor and can far outproduce the hand-operated equipment in any given amount of time.

TABLE 9-1
Typical Gradation for Aggregate Bedding Material

SIEVE SIZE DESIGNATION	PERCENT PASSING BY WEIGHT
1/2 INCH	100
NO. 4	80-100
NO. 10	55-75
NO. 40	10-40
NO. 200	5-15

Aggregate Bedding Material

As described above, precision grading requires bedding material that is easy to grade and compact. The material most commonly used for this purpose is an aggregate material with a gradation like that shown in TABLE 9-1. This material includes no particles larger than 1/2 inch to facilitate the grading process and finer particles to fill voids within the material. The fines in this material also serve to facilitate compaction.

Cement-treated Bedding Material

Although the material specified above has seldom been problematic, some engineers are reluctant to use unbound fine-grained bedding material because of concerns that it may be susceptible to erosion and loss of panel support if used in areas where excessive water could cause pumping. That concern can be addressed by using a bedding material consisting of cement and concrete sand in a ratio of approximately 1-to-6 (cement-to-sand) by weight. Concrete sand typically includes no particles greater than 1/2 inch and the cement provides the fines needed for proper compaction. Cement-treated bedding material (CTBM) used for this purpose is typically mixed and delivered dry to the site in a standard concrete truck, as shown in Figure 9-5. After the material is graded and compacted (the addition of some water may be necessary to facilitate this process), it is dampened with water prior to panel placement. Care must be taken to use a fine spray of water to avoid disturbing the finished grade of the CTBM. The water added during and after compaction will hydrate the cement over time, rendering the entire mixture non-erodible. While the material cost for CTBM is a bit higher than for aggregate bedding material, the installation labor involved is about the same for both materials.

Figure 9-5. Cement-treated bedding material being discharged from a standard concrete truck.

Compaction of Bedding Material

All bedding material must be fully compacted, as required by specifications, even if it is placed in a relatively thin layer. Proper compaction requires appropriate conventional vibratory rollers (and plate compactors for corners) and the addition of water, if necessary, all as required for subbase compaction for conventional concrete pavement. Because of the importance of providing a fully compacted subbase for the PCP panels, it is highly recommended that compaction levels be monitored and measured using a lightweight deflectometer (LWD), as described in the SHRP R05 Report, Chapter 6 (Tayabji et al., 2013).

Grade Control for Grout-supported Systems

PCP panels may be adjusted to a “best fit” to the grades of the surrounding pavement by using leveling bolt systems embedded in the precast panels, as shown in Figure 9-6. Because of this adjustment capability and the subsequent use of a thicker layer of grout to fill the gap between slab and subbase, the surface of the subbase theoretically need not be as accurate for grout- supported systems as is required for grade- supported systems that use fine aggregate bedding material.

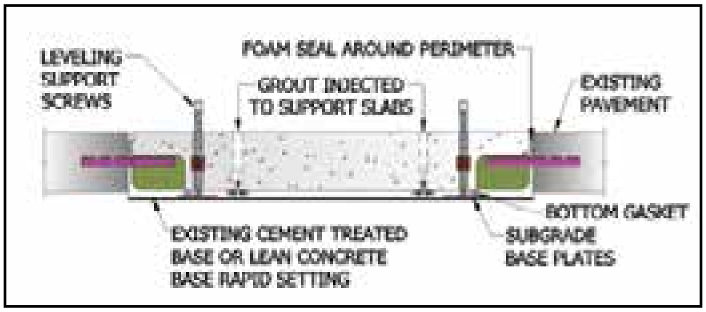


Figure 9-6. Illustration showing how embedded leveling support bolts are used to adjust panels to the grade of the surrounding pavement.

However, the bolt-leveled panels cannot be opened to traffic until the space below the raised panel has been filled with bedding grout.

This type of system may save some of the labor costs associated with precision grading of bedding material, but it also requires a significant amount of costly bedding grout to fill the space below the raised panels (typically up to 1/2 inch) as well as costly labor for the grouting operation.

To minimize bedding grout costs with leveling bolt systems, some contractors using these systems have developed techniques to finish lean concrete subbase materials to an accuracy of +0 / -0.25 inch (plus zero and minus 1/4 inch) – similar to that used for grade-supported systems. For example, the crew shown in Figure 9-7 is running a “homemade,” wheel-mounted concrete screed on a rail that is set to a “smoothed-out” grade on the shoulder side of the panel and directly on the existing pavement on the other side. A concrete roller screed, such as the one shown in Figure 9-8, may be used to increase production and efficiency, but hand-finishing is still required along the edges.

Grade Control Using Expansive Polyurethane Foam

Expansive polyurethane foam may also be used to raise precast panels to grade, as it has been used for many years to

Figure 9-7. A wheel-mounted concrete screed using a pre-set rail on one side of the hole and the existing pavement on the other as a grade reference.

Figure 9-8. A “homemade” mechanized roller screed is used to screed new lean concrete base while masons hand-finish the new lean base on each side of the placement.

raise depressed cast-in-place pavement slabs. This method involves placement of PCP panels that are cast with 5/8-inch-diameter portholes, spaced on approximately 3-foot centers around the panel, through which expansive polyurethane foam is injected. Provisions are made for approximately 1 inch of expanded foam below the panel by over-excavating the existing base by as much as 1 inch (Figure 9-9), or by making the new panels 1 inch thinner than the surrounding pavement so they can be raised to the correct grade, as shown in Figure 9-10.

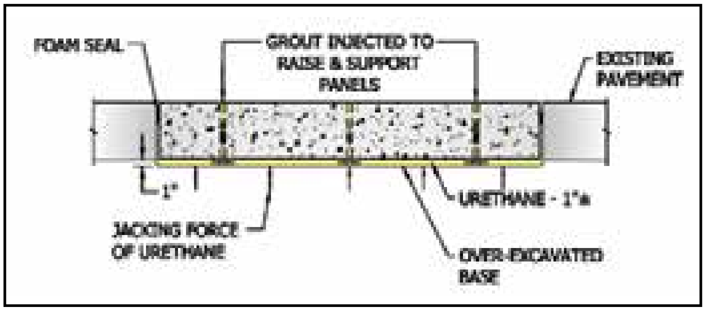


Figure 9-9. PCP panel with the same thickness as the surrounding pavement and subbase over-excavated approximately 1 inch.

The contractor should be aware that the quality of the foam is important when using this method and that only those foams meeting specification requirements for density, tensile strength, elongation, compressive strength and volume change should be used. For example, the Roman Road system uses foam manufactured by the Uretek Corporation that meets a density of 6 pounds per cubic foot and other criteria indicated above and as specified by the New York State Department of Transportation.

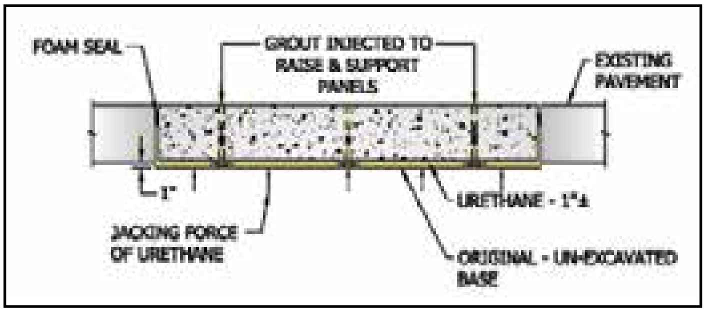


Figure 9-10. PCP panel fabricated approximately 1 inch thinner than the surrounding pavement to allow injection of the foam without over-excavating.

To create expansive urethane, workers pump resin and hardener in separate hoses to the injector tip, where the materials are mixed before being forced into grout ports (Figure 9-11). Each new batch of resin and hardener is tested prior to installation to ensure the specified criteria are met. At least two trained workers are required to inject the foam efficiently in the various grout ports.

Figure 9-11. Two workers, each equipped with a urethane injector tip, installing foam to the underside of the panels through foam ports.

Figure 9-12. A worker drills a new foam port in a part of the panel that needs extra force to provide vertical uplift.

Foam is injected beneath each panel in an iterative fashion by moving the injectors from port to port to ensure the panel is raised evenly and in small increments (to avoid panel cracking) to the target grade lines relative to the surrounding panels. It is essential to lift the panel in small increments at each location in a series of injection cycles. Over-lifting at any one location (e.g., by more than 1/4 inch) can result in high slab stresses and cracking. Slab movement gauges are typically placed at each panel corner where injection personnel can see them to monitor slab movements as the urethane is injected into the various holes.

Occasionally, it is necessary to clean out the ports or to drill a new port hole where extra upward force is needed (Figure 9-12). Only trained workers should perform this process to ensure panels are fully bedded without damaging the precast panels. Workers should also be trained to monitor the injection process to ensure it can be stopped at the right moment to prevent the panel from being raised too much above the elevation of the surrounding pavement.

Expanding foam reaches design density and hardens in approximately 5 to 15 minutes after mixing and injection, depending on the combination of chemicals used and the ambient surrounding temperature. Uretek foam, for example, may be placed in temperatures as low as 32 F but is ideally placed at about 70 F. Since urethane foam is non-reactive to water, it may be injected in holes and into voids that are not completely dry. As with other bedding materials, polyurethane foam should be installed in strict accordance with the foam manufacturer's directions.

Providing Complete and Uniform Panel Support

The second requirement listed in Table 1-1 is that PCP panels must be completely and uniformly supported (bedded) once they have been positioned to the correct elevation (grade), as has been described in preceding paragraphs. Different supporting materials are employed for each of the systems currently in use.

Grade-supported Systems

Full and complete bedding in grade-supported systems is accomplished in a two-step process. The first step is to provide a precisely graded and fully compacted aggregate bed that serves to support the panels at the correct grade and to provide permanent support for the new panels, as described previously. Since the bedding surface is not perfect, as indicated by the typical allowable tolerance of ± 1/8 inch, the panels come to rest on the "high parts" of the graded surface, leaving small voids that must be filled, typically with bedding grout, to provide complete and uniform support.

Figure 9-13. A flow chamber equipped with a Plexiglass bottom to allow observation of simulated grout flow under a panel as it fills a void that varies from 0 to 1/4 inch deep.

Figure 9-14. A worker performs a flow test in accordance with ASTM C939 to ensure proper consistency of the bedding grout.

Bedding Grout

Small voids remaining between “high points” under grade-supported panels are typically filled with a free-flowing bedding grout that can flow into – and completely fill – very small voids. Bedding grouts used for this purpose are commonly comprised of water, cement and chemical admixtures that enhance flowability and other stiffening, expansion and water- retention properties (Kosmatka, 1990). No sand or other aggregate particles are present in this grout.

Bedding grout’s effectiveness in filling small voids is a function of the flowability of the bedding grout and the pressure at which that grout is installed. Bedding grout is typically installed under low pressure because high-pressure injection increases the risk of lifting the panel out of position and/or possibly cracking it. Therefore, it is important to verify every bedding grout is sufficiently fluid (i.e., low viscosity) to fill small voids before use is allowed.

The system designers for each grade-supported system should verify and approve bedding grouts used under their respective systems. The Fort Miller Co., Inc., for example, has developed a flow chamber (Figure 9-13) to verify that any proposed bedding grout is capable of filling the small voids described above. The flow rate of a proposed bedding grout is first measured with a standard ASTM C939 flow cone test (Figure 9-14). It is then poured into the flow chamber, where the grout flow can be viewed as it fills a cavity that ranges in size from 0 to 1/4 inch deep. If the proposed grout successfully fills the void and if it also meets specified compressive strength requirements, that flow rate is adopted as the required flow rate of all bedding grout installed on the project.

No matter what grade- supported system is used, an ASTM C939 flow cone test (Figure 9-14) should be performed each time bedding grout is installed on the project. This will help ensure all voids under the panels are properly filled.

Mixing, Installing and Curing Bedding Grout

Bedding grout is mixed at the site and pumped or injected directly beneath the panel through the grout ports described previously. Many mixers and pumps that are commercially available can be used to mix and pump bedding grout. Two of the most common are batch-type pumps, such as those made by ChemGrout (Figure 9-15), and volumetric mixer pumps, such as those manufactured by Machine Technologies (Figure 9-16). Batch-type mixers (e.g., Figure 9-15) mix one batch at a time in the mixing hopper while the pump below the hopper pumps previously mixed grout into discharge hoses. Volumetric pumps (e.g., Figure 9-16) mix

Figure 9-15. A grouting crew using a trailer-mounted batch-type mixer/pump.

Figure 9-16. Workers dumping grout powder into the top of a volumetric mixer/pump.

pre-bagged dry grout powder (consisting of portland cement and admixtures), dumped into a hopper on top of the pump, and metered water in a mixing chamber at the bottom. The mixing auger in the mixing chamber also serves to pump the grout produced into the discharge hose for distribution into the various grout ports, as seen in Figure 9-18.

The contractor should be aware of the advantages and disadvantages of each type of mixer/pump and what supporting equipment is required for each (e.g., air compressor, generator, etc.) before making a selection for use on any project. Grout pump operators must be fully trained in the use, cleanup and repair of any pump before full-scale grouting is attempted on any project.

Bedding grout for grade-supported systems does not need to be cured before the panels are opened to traffic because the accurately graded surface supports loaded panels while the bedding grout cures. Super-Slab panels, for example, are often opened to traffic before bedding grout takes initial set. Bedding grout then cures to a typically-specified compressive strength of 650 psi in about 12 hours.

Rapid-setting bedding grout is specified by some states for the grade-supported systems on projects where there is concern of early-age bedding material erosion and as added assurance that the bedding grout reaches the specified strength during colder weather. Because rapid-setting grout is more difficult to use – as discussed in detail in the following section – it is important to choose the right equipment to ensure the specified grout is mixed and installed properly and expeditiously.

Bedding Grout Distribution

Grade-supported systems must include details and procedures that ensure bedding grout is distributed to fill all the randomly located voids under the panels. In addition, grade-supported systems should also include gaskets or other devices/methods for keeping bedding grout within the boundaries of the panel bases. Retention gaskets or other devices used for this purpose should be continuous, positive and nearly waterproof since the bedding grout described above is only slightly more viscous than water.

The Super-Slab system includes a grout distribution system that consists of an array of grout distribution channels (connected to surface ports at the end of each channel) and foam gaskets attached to the bottom of the panels (Figure 9-17). Bedding grout is installed by pumping grout into a port at one end of each distribution channel until it exits the port at the other end of the same channel (Figure 9-18) under a head pressure equal to the thickness of the panel multiplied by the density of the bedding grout

Figure 9-17. The bottom of a Super-Slab panel with built-in bedding grout distribution channels and black grout retention gaskets.

Figure 9-18. A worker pumping bedding grout into one end of a distribution channel until it comes out the other, a technique that verifies bedding grout has flowed under pressure for the entire length of the channel, indicating full distribution of grout under the panel.

(approximately 118 pounds per cubic foot). For example, the fluid pressure developed in a bedding grout port 10 inches high (for 10-inch thick pavement) is approximately 118 lb/ft^3 X 10/12 ft = 98.33 lb/ft^2 = 0.68 psi, a pressure value that is too low to lift a 10-inch thick panel if it were equally applied to the entire bottom of the panel without leakage.

Bedding grout is distributed in other systems using a series of closely spaced grout ports that are cast into the slab at about 3-foot centers. Bedding grout is retained by placing a foam backer rod on the grade prior to panel placement or by installing expanding foam around the perimeter of the panel, prior to or after panel placement. Alternatively, some systems flood the bottom of the panels with grout until the grout partially fills joints between panels. No matter what retention system or grout installation method is used, the contractor should monitor all grout ports within the panel during bedding grout installation to ensure they are full. This serves as an indication that the bedding grout has been fully distributed under the entire panel.

Grout-supported (Leveling-Lift) Systems

With leveling-lift systems, precast paving panels are intentionally raised off the subbase to their final position before grout installation. Some state agencies specify a minimum of 1/2 inch of bedding grout under leveling-lift system panels. Therefore, the bedding grout used for these systems is typically more viscous (to fill thicker voids) than for grade-supported systems. These bedding grouts often include fine sand, which increases the viscosity of the material and extends the volume of the material by acting as a low-cost filler.

Grouts used under grout-supported systems are typically designed to be rapid-setting because the panels cannot be opened to traffic until the bedding grout is installed and cured to a minimum specified compressive strength –typically around 650 psi but as high as 2,500 psi in some states. Rapid-setting bedding grouts now in use for grout-supported systems typically reach a compressive strength of 1,000 psi or more in about one hour. Contractors should be aware that it is difficult to mix and place these grouts because of their tendency to set and harden rapidly, sometimes in the equipment or discharge hoses. Workers must therefore be thoroughly trained in their use before attempting to install them in field conditions.

The contractor should also be aware that a significant amount of grout must be mixed and placed under leveling-lift supported systems. A 1/2-inch void under a 12-foot-by-12-foot slab, for example, requires approximately 6 cubic feet of bedding grout. If 20 of those panels are placed on any given night – a typical production rate on a modestly sized project

Figure 9-19. A dual-drum, high-capacity mixer/pump mounted on a service trailer with an adequate supply of grout and water and a safe working space.

– approximately 120 cubic feet or 4.5 cubic yards of rapid-setting grout needs to be mixed and pumped through many grout ports to ensure the panels are fully bedded in a timely manner.

Contractors accustomed to pumping large volumes of bedding grout under levelling lift-supported panels typically use a high-volume pump setup, such as the one shown in Figure 9-19, which consists of two 70-gallon mixing tanks and a 15-gallon holding hopper over the pump. This arrangement allows the contractor to mix and pump continuously, an absolute necessity when handling rapid-setting grouts. To avoid having the grout set up in the discharge hose, the pump should be pumping either grout or clean-out water continuously.

Urethane-supported Systems

One of the major benefits of urethane-supported systems is that full and complete support is achieved during the panel lifting process described earlier in this chapter. Since the urethane is very fluid in the mixed liquid state, it will penetrate very small voids under modest pressure. This material not only lifts the panel to the proper grade as it expands, but also provides uniform and complete support in the process.

Figure 9-20. A fully equipped urethane injection support truck is seen in the background.

While the low viscosity of the urethane is advantageous in that it very effectively penetrates to fill very small voids, it can be difficult to keep it confined along the edges of panels that are being lifted. This is relatively easy to accomplish for single drop-in panels because the pavement around the new panel confines and prevents unwanted flow. When multiple urethane-supported panels are installed, urethane is free to flow under adjacent new panels in the same lane, so retention strategies must be devised to keep the urethane under the panel that needs to be raised. This should only be attempted by skilled injection personnel using proper mixing and support equipment (Figure 9-20).

Installing Load Transfer Devices at Transverse Joints

Establishing effective load transfer at transverse joints is the third key component to achieving proper PCP panel installation, as noted in Table 1-1. Several methods and systems have been developed for installing dowel bars in JPrCP transverse joints, including:

Figure 9-21. Two newly installed panels marked out for field saw cutting at precast-to-precast and precast-to-existing joints.

Figure 9-22. A dowel positioned in shop-cast top slots in two new adjacent PCP panels.

1. Conventional “Wide-Mouth” Top-Slot Method (Dowel Bar Retrofit)
2. Bottom-Slot Method – The Fort Miller Super-Slab System
3. Illinois Tollway Narrow Top-Slot Sliding Dowel System
4. California Cast-Slide (Tear-Drop) Narrow Top-Slot System
5. Barra Glide Load Transfer System

Top-Slot Methods

Conventional “Wide-Mouth” Top-Slot Method (Dowel Bar Retrofit)

The top-slot method of establishing load transfer across transverse joints for JPrCP panels is a derivative of the dowel bar retrofit method of stabilizing un-doweled joints and cracks in conventional concrete pavement. It consists of using parallel, gang-mounted diamond saw blades to create top slots that are typically 3 inches wide and with a length at the bottom of the slot sufficient to accommodate the dowel (typically 18 inches long); the slot length will be greater at the pavement surface due to the radius of the saw blade. Once the sides of the slots are cut, the concrete between them is chipped out, the slots are cleaned and new dowels are placed in them (Figure 9-22) on specially designed chairs that help to maintain dowel alignment in the slot while allowing the dowels to be fully encased with high-strength, rapid-setting backfill material. More information regarding the top-slot method may be found in the Second Edition of the Concrete Pavement Preservation Guide (Smith and Harrington, 2014).

Top slots in existing pavement must always be cut in the field. Top slots in new PCP panels may be cut in the field or may be cast in the panels during the fabrication process. Contractors using this method typically choose field cutting on intermittent repair projects that involve drop-in panels, as seen in Figure 9-21, while cast-in slots, as seen in Figure 9-22, are typically preferred on multiple-panel lane replacement projects to minimize field cutting.

The success of the top-slot method is highly dependent on the cleanliness and texture of the vertical (bonding) surfaces of the slots and the composition and quality of the backfill material around the dowels. To ensure good bond between the backfill material and slot sides, the slots must be thoroughly cleaned by sandblasting or other means before installing the grout. Additionally, the grout must be mixed and installed properly, in strict accordance with the manufacturer’s directions.

Figure 9-23. A Super-Slab panel being lowered over the dowels of a previously placed panel.

Figure 9-24. This gang drill is capable of drilling four holes at once in approximately 20 to 30 seconds.

Contractors must also be aware of other aspects of the top-slot method that will affect the timing of the overall operation. For example, once top slots have been created in PCP panels, they must be filled before the panels can be opened to traffic because 3-inch-wide, unfilled slots present hazards to traffic, including possible trapping of narrow motorcycle tires and fragmentation and ejection of concrete from between the slots. In addition, backfill material must reach a minimum compressive strength of 2,500 psi (as specified in most states) to ensure dowels can effectively transfer load across the joint before panels can be opened to traffic. This means that installation of panels with cast-in wide slots cannot be installed less than two hours before the panels are to be opened to traffic (assuming the use of rapid-setting backfill material), essentially reducing the number of panels that can be installed during that work window.

Bottom-Slot Method (The Fort Miller Super-Slab System)

The bottom-slot (Super-Slab) method features dovetail-shaped slots that are cast on the bottom of the panels (Figure 9-23). The slots are located to line up with dowels cast or drilled and anchored in adjacent panels and are oriented such that the slots are wider on top than on the bottom. This provides mechanical resistance to dowel grout pop out. While the top of each panel is free of open top slots, panels are cast with a series of grout ports – two for each dowel slot – as seen in Figure 9-23. This arrangement eliminates any concern with opening un-grouted panels to traffic because the ports are only about 1.25 inches in diameter.

To connect Super-Slab panels to existing pavement, dowels are drilled, as seen in Figure 9-24, and anchored into the existing pavement (using epoxy or another anchor material) prior to installation of the new panels. Holes to accommodate new dowels must be drilled expeditiously because new panels cannot be placed and opened to traffic before new dowels are installed and properly anchored. The use of an accurate mark-out template, such as the one shown in Figure 9-25, is very helpful in ensuring that dowel holes are drilled at the right locations. Drill operators should be trained to position drill bits directly on the marks to ensure holes for the dowels are drilled at locations and spacings that match bottom slots cast in adjoining panels.

After the holes are drilled, they are cleaned out with a high-pressure air source to ensure a good bonding surface prior to injection of dowel-anchoring material (typically epoxy) in the back of each hole. Epoxy is typically injected with an air-powered epoxy caulking gun, as seen in Figure 9-26. Dowels are then inserted into the holes with a twisting motion to ensure air bubbles are forced out and the epoxy material completely fills the annular spaces around the dowels. Plastic epoxy-retainer disks are then pushed against the end of the panel around the dowels to keep epoxy in place until it sets. This topic is discussed further later in this chapter.

Figure 9-25. The template seen here consists of pre-drilled plywood supported by an attached 2-inch-by-4-inch horizontal member.

Figure 9-26. An air-powered, epoxy injection (caulking) gun is used to install anchoring epoxy. White epoxy retainer discs are visible around the dowels.

Installing Bond Breaker Material

After dowel installation is complete, the face of the existing pavement, as shown Figure 9-26, (or the face of a previously placed panel, as the case may be) is typically sprayed with an oil-based bond breaker material to allow dowel grout, installed later, to bond to only one face of the adjacent panels.

Mixing and Pumping Dowel Grout for the Super-Slab System

Grouts approved for use in the bottom-slot Super-Slab system are typically pre-portioned, bagged sanded, non-shrink cementitious structural grouts that are designed to reach the required minimum compressive strength of 2,500 psi in about two hours. These grouts are formulated so they can be mixed and pumped in the same batch-type or volumetric pumps (Figures 9-15 and 9-16) as those used for mixing and pumping bedding grout. Because field testing of the fluidity of these grouts is not practical – dowel grout is too thick to run through a flow cone – it is important to use the exact amount of water per bag specified by the grout manufacturer.

Figure 9-27. Injection of structural grout in dowel grout ports. Momentary pressure – to ensure the bottom slot is completely filled – is developed when an installer places a foot over the front port while dowel grout is pumped into the back port.

Bottom slots are filled with grout by injecting it through the grout ports, as shown in Figure 9-27, typically during the night after the panels have been placed. Once dowel grout has been installed, the panels must be closed to all traffic, including construction traffic, until the grout has reached a compressive strength of at least 2,500 psi.

Rapid-setting dowel grouts have a short pot life (working time) of only about 10 to 15 minutes. They must, therefore, be discharged from the pump in a rapid, continuous fashion to ensure grout does not set up in the discharge hose. Pumping should continue until all the grout in the hopper has been discharged. Both the mixer and the pump should be cleaned out with water immediately after the grout has been discharged to prevent grout buildup in any part of the

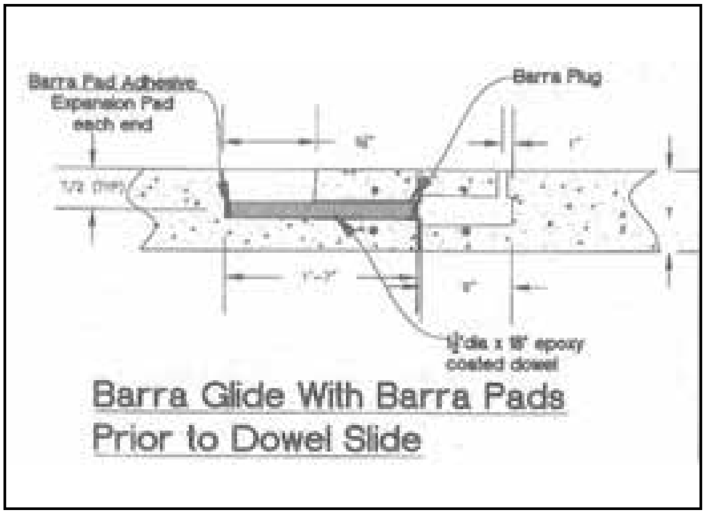


Figure 9-28. This sketch shows the dowel residing completely within the holding panel prior to dowel slide.

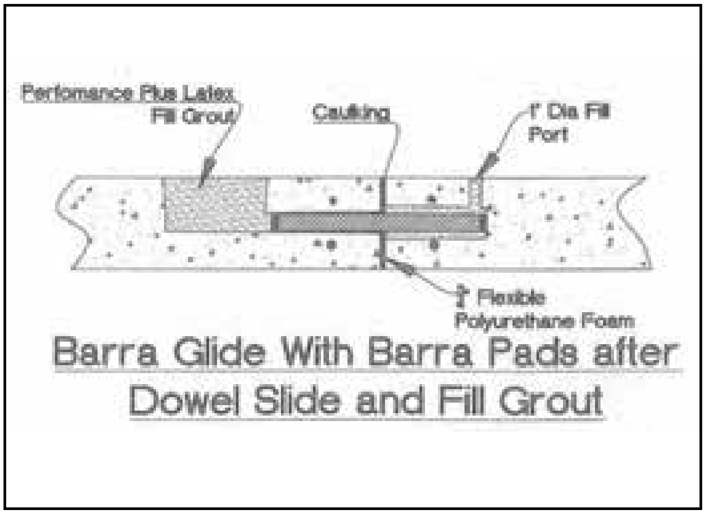


Figure 9-29. Sketch showing a dowel in its final position and fully encased with backfill material.

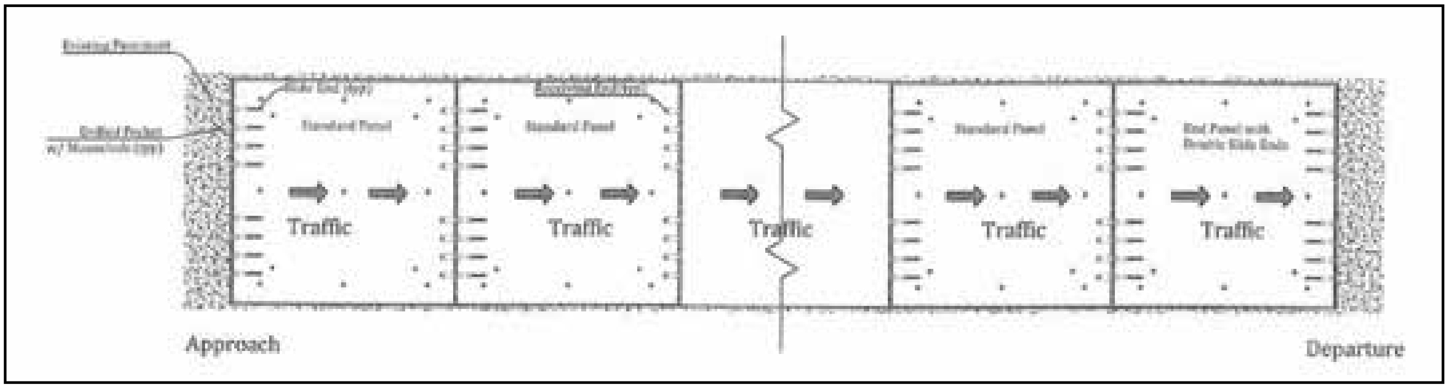


Figure 9-30. Sketch showing a typical multiple-panel repair area. The approach and departure joints require field-drilled receiving holes and vertically drilled grout ports.

system. Also, because dowel grout sets rapidly, excess grout that puddles on top of the panels should be removed as soon as possible before it bonds.

Sliding Dowel Methods

Barra Glide Load Transfer System

The Barra Glide system consists of holes cast in the center of two abutting panels (Figure 9-28). The hole in the holding panel is as long as the dowel (typically 18 inches) and only slightly larger in diameter, while the hole in the receiving panel is only half as long as the dowel, but larger in diameter to accommodate variations in fabrication and panel placement. The hole in the holding panel is accessed by a narrow (1-inch-wide), 9.25-inch-long slot that extends to the top of the panel (Figure 9-28). The narrow top slot allows panels to be opened to traffic before they are grouted because slots that narrow do not present a hazard to traffic. The oversized hole in the receiving panel is accessed by a single, 1-inch- diameter grout port (Figure 9-29).

The dowels are inserted in the holding panel, either at the precast plant or at the job site, just prior to panel installation. The dowels remain there until the panels have been placed in their final position (Figure 9-28), allowing vertical placement and adjustment of the panels. A rod or flat bar is then inserted from the surface into the slot in the holding panel to push the dowel into the oversized hole in the receiving panel (Figure 9-29).

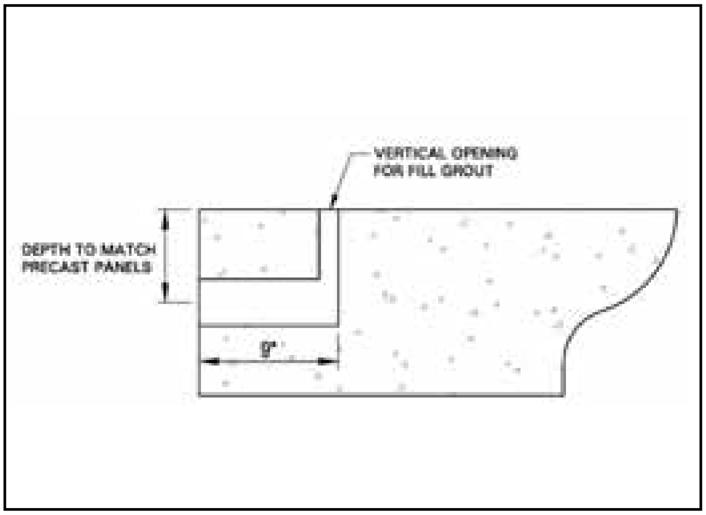


Figure 9-31. Sketch showing dowel bar receiving hole and grout port drilled into existing pavement for the Barra Glide system.

Figure 9-32. Latex grout being poured into the narrow top slot of the Barra Glide system.

The Barra Glide load transfer described so far is appropriate for joining two new, adjacent PCP panels together. In a typical multiple-panel repair area, like the one shown in Figure 9-30, the contractor must create oversized receiving holes in the existing pavement at the departure end of the area. This allows dowels to be slid into position in the existing pavement. Vertical grout ports that are approximately 1 inch in diameter must also be drilled through the surface into each slot location to allow installation of dowel grout (Figure 9-31) to encase the dowels.

The Barra Glide connection is completed by installing a latex-cement fill grout in the slot and grout port described above. Latex-cement grout is a mixture of cementitious grout powder, water and a co-polymer latex compound added to increase adhesion and improve overall performance. This grout is typically mixed for about two minutes in 5-gallon buckets using a drill-powered paddle mixer. It is then poured out of the pail directly into the grout ports and top slots (Figure 9-32). If necessary, the grout is consolidated around the dowels with the aid of a small-diameter ("pencil") vibrator. Contractors are advised to contact Barra Glide representatives for more information about set times and more specific installation instructions.

Figure 9-33. Slot openings in the Illinois Tollway system are dovetail in shape (narrower at the top than at the bottom).

Illinois Tollway Narrow Top-Slot Sliding Dowel System

The Illinois Tollway load transfer system features dowel-holding slots that are long enough to hold an entire dowel. The entire slot extends to the top of the panel and is approximately 2.5 inches wide at the bottom and 1 inch wide at the top of the panel (dovetail-shaped, see Figure 9-33). Like the Barra Glide System, the narrow top slots present little (if any) hazard to traffic, which allows panels to be opened to traffic before the slots are grouted. Access pockets or "hand holes" are cast at the joint end of the slot to allow

Figure 9-34. The hole drilled for the dowel in this photo was not closely aligned with the cast-in slot, making dowel installation difficult.

workers to manually slide dowels into holes that are cast or drilled into adjacent JPrCP panels or existing pavement, respectively. The receiving hole in the adjacent panel or existing pavement is typically cast or drilled at least 1/8 inch larger in diameter than the dowel to facilitate flow of epoxy or other anchoring material around the dowel while it is moved horizontally into position, as described below.

During the installation process, dowels are placed in the dowel holding slots just prior to panel placement. They reside there until they are inserted and anchored into the cast-in or drilled holes. An appropriate dowel anchoring material (typically epoxy-based) is injected in the back of the receiver hole. Then, workers reach into the 3-inch-square access pocket so they can push and twist dowels into position, removing all air pockets and totally encasing the dowels with anchor material.

A variety of tools have been developed to aid in proper dowel installation with this system because it is a difficult procedure to complete by hand. Off-center holes, such as the one accommodating the dowel seen in Figure 9-34, make dowel installation much more difficult, so it is important that receiving holes be laid out accurately for drilling or casting, and that panels be properly aligned when placed.

Slots and pockets for this system may be filled with cementitious backfill grout – similar to what is used for the conventional wide-mouth top-slot system – once the dowels have been properly anchored. Note that dowel grout used in these systems may be thicker than that used for the bottom-slot system because it can be poured in place using a bucket rather than being pumped (as it is with the Super-Slab system). Dowel grout, once installed, must reach a compressive strength of at least 2,500 psi before traffic of any kind is allowed on the panels.

California Cast-Slide (Tear-Drop) Narrow Top-Slot System

This recently developed Caltrans system consists of panels that are cast with embedded dowels in one end and teardrop-shaped slots – open to the tops of the panels – in the other. The tops of the slots are narrow (approximately 1 inch wide), so panels may be opened to traffic before encasement grout is installed.

In a typical, multiple-panel lane replacement installation, panels are placed with the embedded dowels positioned forward (at the leading end) of the panels being placed and the oversized receiving holes positioned at the trailing end, as seen in Figure 9-35. The panel being placed is tilted slightly and then moved toward the previously placed panel until the oversized holes completely encase the dowels protruding from the new panel.

Figure 9-35 does not show that the existing pavement or previously placed panel is sloped transversely (cross-slope), typically at a 2% nominal slope (approximately 3 inches for a 12-foot-wide panel on a straight roadway; cross-slopes in horizontally curved roadways are often greater due to super-elevation requirements). Therefore, the panel being placed should be hung from the crane at approximately the same cross-slope as the previously placed panel to avoid damaging the protruding dowels or the holes in the panel being placed. This can be accomplished by using picking cables that can be adjusted in length until the cross-slope of the panel being placed approximately matches the cross-slope of the previously placed panel.

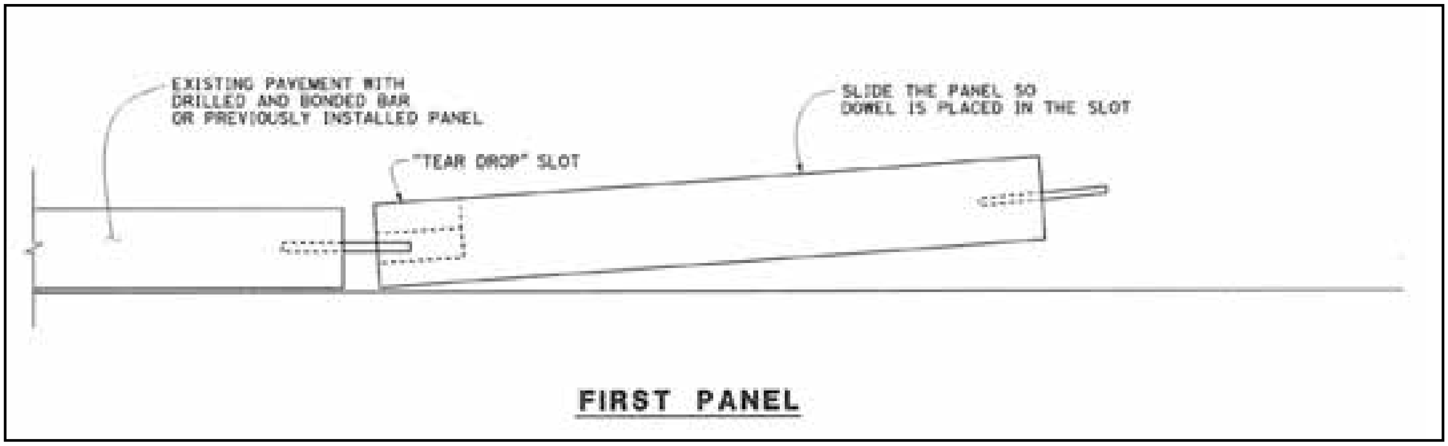


Figure 9-35. This sketch depicts the orientation of Cast-Slide panels during installation.

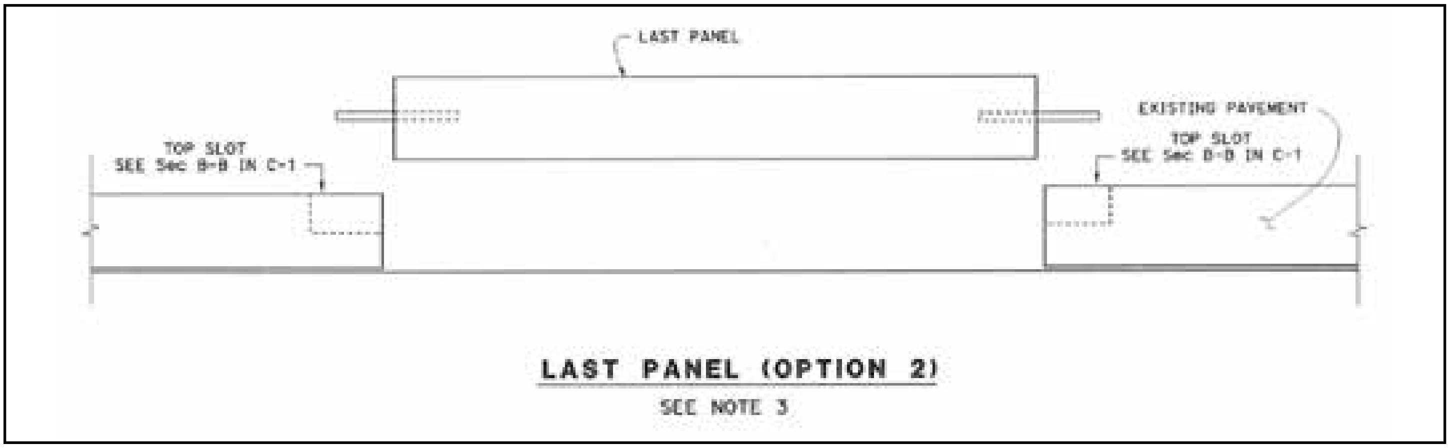


Figure 9-36. This sketch shows the orientation of the last panel in a Cast-Slide run during installation.

It is important to note that each picking cable needs to be adjusted to a different length. Once adjusted for a particular cross-slope, the picking cables do not need to be adjusted differently for every panel provided the cross-slope of the roadway remains the same. However, when the cross-slope changes, as in the case for a super-elevation transition, the cable lengths will need to be changed accordingly.

Panel translation during the placement process is accomplished by swinging the crane, lowering the crane boom or both. If this maneuver is not executed carefully, the translating force may cause the panel being placed to strike the previously placed panel in a manner that may spall the top edge of the new panel, the top edge of the existing pavement or both. The translating movement may be continued until the desired joint width between the new panels is reached or, to avoid spalling, the panels may be stopped short of their final positions so that a set of come-a-longs can be used to draw the panels together safely.

The last panel in a Cast-Slide run cannot be cast or translated into position as described above. Dowels can be installed at this joint using the top slot system or by casting the last panel with dowels embedded in both ends so it can be lowered vertically into previously created slots, as seen in Figure 9-36.

Filling Cast-Slide Tear-Drop Slots

Tear-drop slots of the Cast-Slide system are backfilled with polyester grout that is typically a combination of resin, catalyst and accelerator (the polymer component), all mixed with fine sand aggregate at a ratio of 12% polymer to 88% sand. The grout is typically mixed in 5-gallon pails using

Figure 9-37. Holes for new dowels in this photo are evenly spaced at a uniform distance from the top of the existing pavement, ready for insertion and anchoring of dowels.

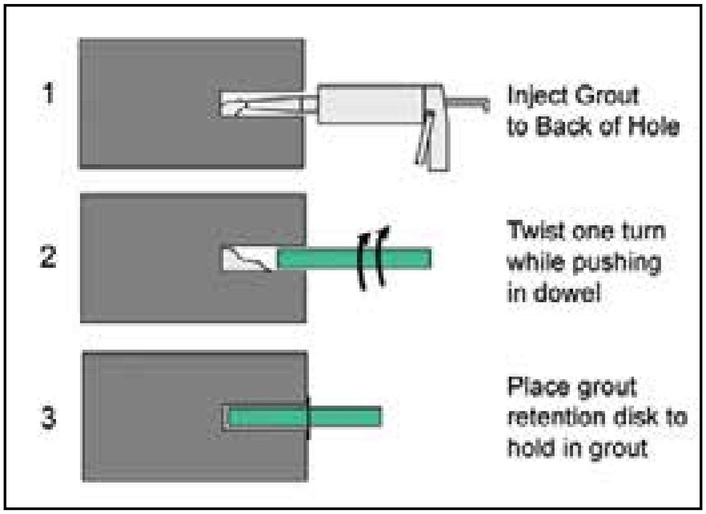


Figure 9-38. Schematic of three-step technique for properly anchoring dowels in drilled holes.

a drill-powered paddle mixer. The manufacturer's mixing and installation directions should be strictly followed, particularly as they relate to setting time, strength gain and temperatures.

Although polyester grout may appear to be viscous, it will flow as it consolidates around the dowels. Care should be taken to seal the slots to ensure the grout does not leak into the transverse joints, thereby compromising full encasement around the dowels at the point where it matters most.

Epoxy-Anchoring Dowels in Existing Pavement – All Methods

Proper anchoring of dowels in existing pavement is vital to establishing effective load transfer between existing pavement and new PCP panels, no matter what system is used. In addition to locating the holes properly, holes of the proper diameter (typically 1/8 inch greater than the diameter of the dowel or as recommended by the anchor material manufacturer) must be drilled to sufficient depth to accommodate half the length of the dowels. More information on epoxy-anchoring dowels may be found in the Second Edition of the Concrete Pavement Preservation Guide (Smith and Harrington, 2014).

Gang drills, such as the E-Z Drill shown in Figure 9-24, can be used to drill dowel holes for bottom- and center-slot systems. Care must be taken with all systems to ensure holes are laid out and drilled properly to fit matching holes or slots in adjacent panels, as shown in Figure 9-37.

After the holes are drilled, they are cleaned out with a high-pressure air source to provide a clean surface for bonding prior to injection of the dowel anchoring material in the back of each hole. Anchor material (usually an epoxy resin) is typically injected through a long nozzle using an air-powered or hand-held caulking gun. Other suitable dowel anchor materials and anchoring systems are also available. Dowels are then inserted into the partially filled holes with a twisting motion, as shown in Figure 9-38, to allow air bubbles to escape and to ensure that the anchor material completely encapsulates the dowel and fills the annular space around the dowel. A plastic anchor material retainer disk (usually pre-installed on the dowel prior to dowel insertion) is then pushed against the end of the panel face to keep the anchor material in the hole until it has set.

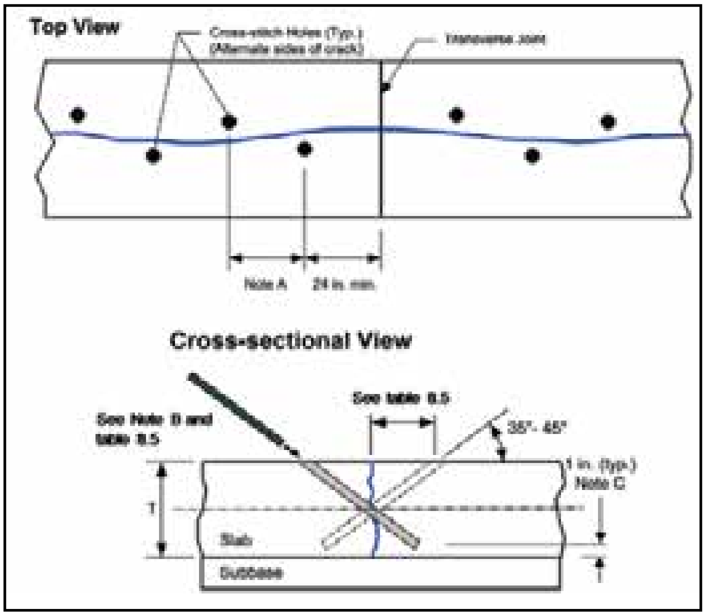


Figure 9-39. Schematic showing the typical hole-drilling pattern and angle for cross-stitching concrete pavement cracks and longitudinal joints.

Figure 9-40. A worker uses a pneumatic drill to create cross-stitch holes across a longitudinal slab crack.

Tie Bars Across Longitudinal Joints

The inclusion of tie bars across longitudinal joints is a design feature that should be shown in the contract plans or addressed in the project specifications when required. When tie bars must be installed between new panels and existing pavement, the contractor lays out tie bar locations as shown on the approved shop drawings, considering the design width of transverse joints between new precast panels in the process.

It is important to note that tie bars across longitudinal joints in PCP are often not evenly spaced due to the need to avoid conflicts with dowels, joints in adjacent panels, etc. For this reason, single-bit drills are typically used to drill tie holes (Figure 9-41). If a precast panel abuts a transverse joint in an adjacent lane, the precast panel should be tied to the panel that shares the longer boundary and the other panel should be isolated from the new precast panel using foam board or other typical isolation joint materials. Failure to follow this requirement may result in “sympathy cracking” of the new precast panel as the adjacent transverse joint opens and closes with temperature and moisture changes.

Typical tie bar installation methods are listed below.

Generic Tie Bar Installation Procedures

Tying precast lanes together can be accomplished by using generic cross-stitching techniques, as seen in Figures 9-39 and 9-40 and described in detail in the Second Edition of the Concrete Pavement Preservation Guide (Smith and Harrington, 2014). Cross-stitching is a pavement preservation technique that involves drilling and epoxy-anchoring deformed bars at angles of 35 to 45 degrees across longitudinal joints. Figures 9-39 and 9-40 show cross-stitching across a longitudinal crack, but the same technique also works across longitudinal joints. The cross-stitching method keeps lanes tied together and provides additional vertical load transfer across the joint (Smith and Harrington, 2014).

Another generic option for retrofitting tie bars across longitudinal joints and cracks is slot stitching. This is similar to installing dowels in conventional wide-mouth top slots except that the slots are cut transversely across the longitudinal joint and are longer to accommodate typical tie bar lengths. Details concerning slot stitching techniques are provided in Smith and Harrington (2014).

Figure 9-41. A single-bit air drill used for drilling tie bar holes at correct locations.

Figure 9-42. Installation of a bottom-slot precast panel over tie bars drilled in vertical faces of adjacent existing pavement.

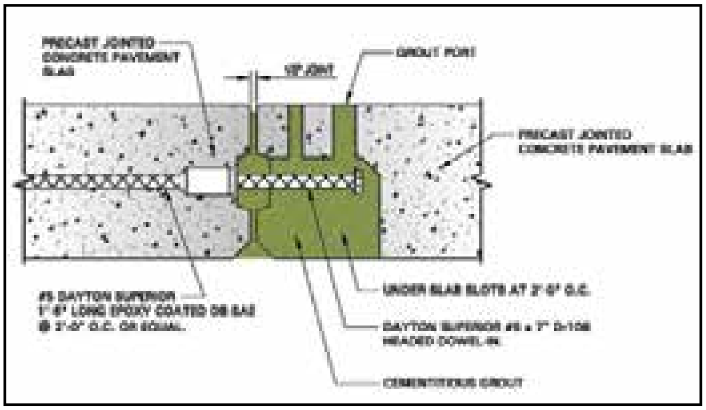


Figure 9-43. Two-piece headed tie bars embedded in a new panel on the left and grouted in a new bottom slot panel on the right.

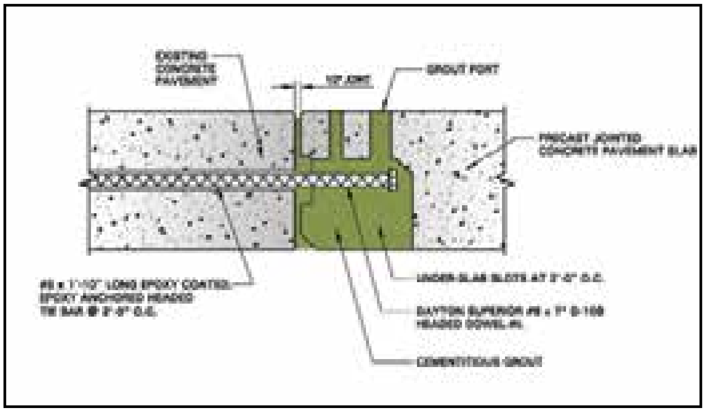


Figure 9-44. Single-piece headed tie bar epoxy-anchored into existing pavement and engaged in a bottom slot on the right.

Tie Bar Installations for Bottom-Slot Designs (The Fort Miller Super-Slab System)

For bottom-slot designs, tie bars are installed in the adjacent pavement panels (existing or precast concrete) prior to the placement of the bottom-slotted precast panel over the tops of the tie bars (Figure 9-42). The slots and longitudinal joints are filled with structural grout through ports in the panel surface in the same manner used for filling dowel bottom slots.

Tie bar holes in existing pavement are typically drilled with a single-bit pneumatic drill (Figure 9-41). Tie bars are anchored in these holes using techniques and materials like those described for anchoring dowels in existing pavement, except that anchor material retention rings are not typically used for tie bar installations.

Headed tie bars, such as those shown in Figures 9-43 and 9-44, have recently been used to reduce the required length of bottom slots in the precast panels (which reduces the volume of structural grout required and allows more effective reinforcing of the precast panel). The headed bars may be single-piece bars when installed in field-drilled holes (Figure 9-44), but are often threaded, two-piece bars (Figure 9-43) when installed in precast panels. When two-piece bars are used, the “female” piece is embedded flush with the panel face to allow maximum panel sizes for shipping and

Figure 9-45. A rubber-tired excavator placing a 12-foot-wide-by-10-foot-long panel that was “picked” from the truck positioned alongside.

Figure 9-46. A 65-ton capacity hydraulic crane picking panels from a truck positioned in front of, rather than alongside, the crane.

for placement next to sawed existing pavement that will be subsequently removed to make room for new precast panels in the next stage of construction. The “male” end is threaded into the embedded piece in the field to provide the necessary extension into the bottom slot of the next panel (Figure 9-43). The connection is completed when the structural grout is pumped into the slot through the surface port.

Panel Placement

Panel placement topics discussed in the following sections generally apply to all systems.

Preparing the Subgrade Surface

Subbase preparation for grade-supported, grout-supported and urethane-supported systems is discussed earlier in this chapter. Recall that a surface accuracy of ± 1/8 inch is required for grade-supported systems, while such an accuracy is not “technically” required for the other systems. However, in practice, the vast majority of all installations require an aggregate or lean concrete subbase surface of that accuracy because newly placed panels are typically occupied by a placement crane and/or highway traffic before bedding grout or urethane has been fully installed. Failure to provide uniform support of newly placed panels through an accurately graded subbase surface in their un-grouted positions places these panels at high risk for cracking under crane or traffic loading.

Equipment for Placing Panels

The equipment the contractor chooses for any given project will depend on the size of the panels and amount of working room that is allowed on the project. On most projects, working room is limited to about two lanes or, in some cases, one lane and a shoulder. Placement cranes or excavators need to be selected accordingly, so that the heaviest panel on the project can be placed at the largest anticipated picking radius.

When the working area is wide enough, delivery trucks can be positioned directly alongside the placement crane or excavator. This technique keeps the picking radius to a minimum and frequently enables the use of smaller picking equipment, such as the rubber-tired excavator seen in Figure 9-45. In contrast, the working area seen in Figure 9-46 was limited to one 12-foot lane and a 10-foot shoulder, preventing the delivery truck from backing alongside the picking crane. This increased the picking radius and required the use of a higher-capacity hydraulic crane to reach the panels on the front of the delivery truck. Notice that both the excavator and the crane seen in Figures 9-45 and 9-46 are occupying newly placed, un-grouted panels, as described previously.

Figure 9-47. The outrigger of this rubber-tired excavator is located outside of the PCP panel area.

Figure 9-48. Both sets of outriggers on this hydraulic crane are positioned on existing pavement.

Outrigger Placement

The contractor should exercise care in positioning outriggers of placement equipment to avoid critically located point loads on PCP panels that have not yet been fully bedded. If possible, the outriggers should be placed on existing pavement outside of the lane that is being placed, as seen in Figures 9-47 and 9-48. When it is necessary to place an outrigger on a new, un-grouted panel, it should be placed as near to the middle of the newly placed panel as possible to avoid highly stressing panel edges or corners.

Rigging

Rigging is a general term used to describe the combination of cables, chains, shackles and (sometimes) picking frames used to connect panels to picking equipment. Every component of the rigging should be designed by a qualified engineer to ensure no component of the rigging apparatus, including the lifting inserts embedded in the panel, is overstressed. For safety purposes, engineers checking component stresses should recognize that it is industry practice to assume the total weight of the panel is carried by only two of the four cables typically used for picking.

It is also important to consider the length of the cables, as length determines the picking angle. The greater the picking angle away from vertical, the larger the cable needs to be to support the weight of the panel. For example, the picking cables seen in Figure 9-46 must be sized to carry a larger tensile load than the more vertical cables seen in Figure 9-49 due to the larger (flatter) angle of the cables in Figure 9-46 (assuming equal panel sizes in both cases).

Figure 9-49 Because equal-length picking cables were used over a sloped surface, PCP panels on this project had to be placed numerous times to bring joint widths within specified tolerances.

Contractors should also be aware that panels lifted by equal-length picking cables will be gravity-level. This can be problematic when placing panels on a sloped surface, as seen in Figure 9-49, where the uphill corner of the level panel will hit the ground first. As the panel is further lowered into position, it will rotate about the uphill corner (which will contact the ground first) so the final position of the

Figure 9-50. A track-mounted excavator placing a PCP panel under an overpass on Interstate 94 in Kalamazoo, Mich.

Figure 9-51. A large loader carrying and placing a PCP panel under an interstate overpass.

panel, relative to the adjacent previously placed panels, is not known until all four corners hit the ground. Placement is greatly facilitated when cable lengths are adjusted so the panel hangs from the crane approximately parallel to the ground. This technique is especially beneficial when translating tear-drop panels into position, as discussed previously.

Panel Placement Under Overpasses

Placing panels under interstate overpasses is particularly challenging because clearances are typically little more than 14 feet, which is too low to allow the use of many conventional hydraulic cranes or rubber-tired excavators. In these cases, contractors have resorted to using specialized hydraulic cranes, specially rigged track-mounted excavators (Figure 9-50), or large fork trucks or loaders (Figure 9-51) to carry the panels into position after being off-loaded from the delivery truck away from the overpass. In these cases, it is advisable to limit panel length to 10 feet or less so panel weight, equipment size and front axle loads can be kept to a minimum.

Positioning Panels Horizontally

Horizontal positioning of a single panel in a hole cut specifically for it is typically a matter of centering the panel in the hole. When a series of panels is placed in a row, as in a lane replacement repair area, panels may be positioned (horizontally) using two different techniques.

In the first technique, panels may be placed end-to-end so that each panel is placed or positioned tightly against the previously placed one. Using this approach, the exact position of the last panel in the run is not known until the last panel in the run is placed because each panel length varies slightly, as allowed by fabrication tolerances (discussed in Chapter 8). As a result, the final transverse cut in the existing pavement cannot be made, the last portion of the existing pavement cannot be removed and the last portion of the subbase cannot be prepared until just before the last of the new panels is placed. Using this technique, transverse joints between new PCP panels placed in an adjacent lane will not line up with those in the lane placed first because actual lay lengths of panels – as fabricated – vary, as also discussed in Chapter 8.

The second technique requires layout of the leading end of each panel in the run using the theoretical lay length method, as discussed in Chapter 8. This technique requires project surveyors to lay out the leading end of the last panel in the run ahead of time so that the last transverse saw cut can be made, the existing pavement can be completely removed and the subbase can be prepared before the last panel is placed. If each panel is placed to leading end marks, as shown in Figure 9-52, the allowable transverse joint width is never exceeded

Figure 9-52. A PCP panel being placed to a leading end line stretched between two leading end marks.

Figure 9-53. All the panels in the lane replacement repair area shown here were placed to leading end marks so the last panel being set precisely fits the space left by the previously placed transverse saw cut.

and the last panel in the run will fit the hole exactly, as seen in Figure 9-53.

When multiple panels are placed in adjacent lanes, it is imperative that each panel be set to leading end marks or to a leading end line to ensure transverse joints in adjacent lanes line up (Figure 9-52). This is particularly important when transverse joints are sawed to create a sealant reservoir and sealed with an appropriate joint seal material, as is discussed in more detail in Chapter 11.

Opening Panels to Traffic

For most projects, it is necessary to open newly placed PCP panels to traffic immediately following installation. However, exactly how soon they can be opened is an important factor to consider when selecting a particular PCP system, especially in situations where allowable work windows are as short as five hours.

Grade-supported Panels

Grade-supported systems, which use a precisely graded bedding material for grade control or other systems that feature use of precisely finished lean concrete base, may be opened to traffic "immediately" upon installation – before any dowel or bedding grout is installed. It is common to open new panels supported by such subbases to traffic within 10 or fewer minutes (as needed to clear the highway of placement equipment and traffic delineation devices) after placing the last panel of the night.

If PCP panels are opened to traffic before they are fully grouted, installers should insert "incompressible" shims in transverse joints between newly placed panels to prevent them from hitting each other under live traffic conditions, which could result in joint spalling. In addition, if dowels are protruding from the last panel that has been placed in an uncompleted run, care should be taken to protect them from dynamic traffic loads. This is easily accomplished by using a short, temporary, reusable panel with bottom slots that covers and protects the dowels while providing a smooth pavement surface over the doweled area.

It is always preferable to install both dowel and bedding grout before panels are open to traffic. However, since this is often impractical and sometimes impossible – especially on five-hour work window projects – grout should be installed the next night or as soon thereafter as possible. In no case should un-grouted panels be allowed to carry traffic for more than three nights (one weekend).

Grout-supported Panels

Grout-supported panels placed on inaccurately graded bases or subgrades should not be opened to traffic of any kind, including placement cranes, until they have been adjusted to grade and the bedding grout has been installed and adequately cured. Bedding grout installation and curing usually take one to two hours after the last panel has been placed.

Installers and engineers should be aware that the tops of grout-supported panels placed temporarily on a surface that has been intentionally graded or finished 1/2 inch low to allow installation of 1/2 inch of bedding grout (as is specified in some states) will leave a 1/2-inch drop off at the beginning and end of each run. This typically does not present a hazard to traffic or cause damage to the new panels if shims are placed in transverse joints, as described above.

Urethane-supported Panels

Urethane is typically installed under urethane-supported panels immediately after placement of the panels. Installation of the urethane under a single panel usually takes about 24 minutes for an 8-foot-by-12-foot panel (96 square feet). The urethane reaches density adequate for supporting traffic within 5 to 15 minutes after urethane installation has been completed.

Because of the time required to install and cure urethane, as discussed above, it is a common practice to use temporary (reusable) panels in the last five holes in any given work shift to allow the saw cutting and excavation team to stay ahead of the urethane grouting crew. At the beginning of the next work shift, the temporary panels are removed to allow immediate placement of permanent panels on the already-graded subgrade surface and subsequent installation of urethane. This practice allows crews to work and place panels right up to the end of the work window.

Permanent urethane-supported panels placed on inaccurately graded or finished bases should not be opened to traffic of any kind – including placement cranes – until urethane has been installed.

Achieving Smooth Pavement Surfaces

The fourth requirement of precast paving listed in Table 1-1 and at the beginning of this chapter is to achieve a smooth pavement surface. While it is generally possible to place precast pavement using any system to within a commonly specified tolerance of + 1/8 inch, it is typically necessary to diamond grind JPrCP to meet more stringent smoothness requirements that may be specified for high-speed traffic. Since this requirement is generally not system-specific and because smoothing or diamond grinding is typically performed after the panels have been installed and opened to traffic, this work is considered a finishing operation and, as such, is covered in detail in Chapter 11.

Selecting Methods That Work Together as a System

At some point before work begins on project shop drawings, someone (typically the contractor) must decide what system or “set of specific panel details, materials and associated installation methods,” as indicated in Chapter 1, work best for the contractor on that particular project. System selection and identification is important for the following reasons:

1. It gives owner agencies (typically state DOTs) a description of how the panels will be installed and details the finished product.
2. It provides installation monitoring guidelines to construction inspectors.
3. It informs shop drawing engineers of the details to be included in the shop drawings.
4. It provides information to surveyors responsible for laying out saw cuts and panel locations.
5. It identifies what materials need to be purchased, an aspect important to contractor purchasing agents.
6. It provides important information to the contractor responsible for providing proper equipment and manpower for the project.

Once the system has been defined and delineated, it should be evaluated to ensure it meets the requirements listed at the beginning of this chapter and that it can be installed in

Table 9-2 – Field Tests for System Evaluation

FEATURE	TEST	EXAMPLE REQUIREMENT
Grade and panel elevation	Measure pavement surface elevations by field survey	Within ± 1/8 inch of design elevation
Vertical match between panels	Measure vertical difference at joints by using straight edges or shims	Within 1/8 inch
Panel surface straightness	Measure any space below a 10-foot straightedge	1/4 inch maximum
Full and complete bedding	Examination of observation ports cast in test panels to detect presence and level of bedding grout after it has been installed under the panel	Not more than 1/4-cubic-foot void around any observation port as measured by pouring bedding grout in port until it is even with bottom of panel
Load transfer devices	Falling weight deflectometer (FWD) tests	Relative deflection less than 5 mils
Completeness of grout encasement around dowels	Examination of random cores taken through dowel slots (after they have been grouted)	No void around dowel or in dowel grout more than 1/2 inch in any direction
Dowel grout	Compression test on sample dowel grout cubes	2,500 psi to open to traffic; 6,000 psi at 28 days
Bedding grout	Compression tests on bedding grout cubes	650 psi before opening to traffic after it has been installed; 1,500 psi at 7 days

short overnight work windows, as necessary for the project. Common field tests that may be used to aid in the evaluation process are listed in TABLE 9-2.

The tests listed in TABLE 9-2 are typically performed most efficiently in conjunction with a “formal” trial installation – described in detail in Chapter 10 – involving fabrication and installation of a minimum number of panels at a location and time not subjected to live traffic conditions.

While the tests indicated in TABLE 9-2 are excellent measures for initial system evaluation, they are also useful in evaluating the contractor’s capability of installing the system correctly, both at the beginning of the installation (contractor trial installation) and as necessary throughout the project to ensure installation quality is maintained. The specifications should indicate how often these tests should be performed. For example, it is reasonable to check the vertical match between all panels as they are being installed, but other tests, such as compression tests for dowel and bedding grout, can be performed periodically, perhaps on a weekly basis or as dictated by changes in weather.

Benefits of Choosing an Established System

One of the major benefits of choosing an established PCP system is that time may be saved during system evaluation. For example, system fabrication and installation instructions already prepared and proven to work for previous trial installations (and projects) may not need to be developed again unless changes in the system are being proposed.

Another benefit of using an established system is that the system designer is typically available to provide support during the trial installation and subsequent submittal, fabrication, installation and inspection processes. This greatly facilitates the approval process at the beginning of the project (when pressure to start installation may be the greatest) and subsequent training of installation and inspection personnel at the project site.

Considerations for Developing a New System

A contractor may wish to use only one or some of the already established methods for grade control, load transfer and bedding presented in this chapter, choosing different methods that may be perceived to be faster, more cost-effective or more compatible with their workforce and equipment. While this is typically allowed and even sometimes encouraged, it should be attempted with careful thought given to all parameters and criteria required of PCP systems.

New systems or features of systems should not be proposed for evaluation unless they have previously been proven to meet the criteria listed in Table 1-1 and tests listed in TABLE 9-2. Sketches and unproven installation instructions developed without prior testing and experience increase the risk of failing a costly and time-consuming trial installation evaluation process.

Summary

There are several different installation methods that may be used to install JPrCP panels such that they meet the requirements listed in Table 1-1. This chapter presents them as stand-alone methods that are ultimately combined to form sets of methods that comprise a complete system.

Placement and adjustment of panels to the correct grade first requires an understanding of what grades are correct and how they are identified. Panels may be set to grade by placing them on precisely graded subgrade material such that no further adjustment is required. Panels may also be placed on a surface that is intentionally graded low so that they can subsequently be adjusted to more precise grades using leveling devices that are cast in the panels. A third method of adjusting panels to grade is to inject expansive polyurethane under the panels in an iterative fashion until the panels are raised to the correct grade.

Once panels are in their final position, bedding grout (or urethane foam) needs to be injected under them to provide complete and uniform support. This step should be considered carefully because the type and amount of bedding grout used may significantly affect the overall cost of the installation and may also affect how soon panels can be opened to traffic – a vital consideration on most overnight projects.

There are several different methods of establishing load transfer between precast panels and between precast panels and existing pavement. While all can be designed to be effective, consideration should be given to what grout materials are to be used to encase dowels and tie bars, the impact of shape and orientation of dowel slots on opening panels to traffic, and whether or not payment of a royalty will be required for the use of any particular method (i.e., proprietary methods).

Equipment required for placement of JPrCP panels varies greatly with the type of project. Intermittent repair panels may be placed with smaller excavators, while larger cranes may be more efficient for lane replacement projects where panels tend to be larger and heavier.

The final requirement listed in Table 1-1 is that the finished surface of the panels meets specified smoothness requirements. Since this is typically dealt with after all the panels are installed, it is discussed in detail in Chapter 11.

This chapter concludes with an important discussion about selecting methods that are compatible and work well together so they may be considered a precast pavement system. This choice may affect overall project costs and installation time. While contractors are free to develop any system of their choosing, there are benefits to selecting proven systems that have been used successfully on previous projects.

Chapter 10:
ORGANIZING AND MANAGING A PROJECT FOR A QUALITY INSTALLATION

The previous chapters in this manual have provided detailed information on the various methods of precast paving and specific tasks associated with each one. This chapter focuses on the human aspects of precast paving and the requirements for organizing, training and motivating installation crews to install panels efficiently and correctly, as required by the project plans, specifications and the system designer's guidelines.

Organizing a precast paving project is somewhat different from organizing a conventional concrete paving project in that the tasks, materials and equipment needed for installation are typically new to most contractors and DOT engineers. Adding one more level of complexity to the effort is the fact that there are many different systems for installing precast panels, so each project needs to be somewhat "custom-organized" to accommodate the system selected for the project.

It is the contractor's right and responsibility to organize a project to maximize profit. This is often best achieved by adopting procedures that lead to a high-quality installation while enhancing productivity and minimizing costly corrective actions.

Organizing and managing a precast paving project to achieve a high-quality installation requires a thorough understanding of the processes required to install the selected system. That understanding must reside first with the contractor's project managers, who are then responsible for transferring their knowledge of the system – including any unique fabrication and field installation details – to the owner/agency staff and to the contractor's fabrication and installation crews.

This chapter is intended to aid agency project management and design personnel, contractors and precasters. It provides an overview of factors that need to be considered when organizing a precast paving project and the roles played by system trial installations, contractor trial installations, project meetings and quality control plans in achieving a high-quality installation. Specific attention is focused on the composition of contractor crews and contractor QC inspectors and how they can contribute to the quality of the overall installation.

Beginning a Precast Paving Project – System Validation

One of the first and, perhaps, most important decisions the contractor must make is to determine what system will be used on the project, as discussed in Chapter 9. In addition to considering the viability of a particular system in terms of how it passes the tests listed in Table 9-2, consideration should also be given as to adequacy of installation instructions for workers to follow and inspectors to monitor.

Validating Systems Before the Bid

Selecting a Pre-Approved System

It is always faster and easier to start a precast paving project by selecting a system that has been pre-approved by the owner. Pre-bid system approval processes have been established in a few states as a prerequisite to being included on a published list of approved precast concrete pavement systems, as discussed in Chapter 5. Selecting a system from such a list allows the contractor to proceed with project organization immediately upon award of the contract, without concern of whether the system will be approved. Specifications in these states still typically require shop drawings and other submittals, but valuable time is saved because the selected system does not need to be reevaluated.

Figure 10-1. State DOT engineers witness the installation of a precast panel at a system trial installation.

Validating Systems After the Bid

Systems Approved by Other Agencies

In states that have not yet embraced the "approved list" type of specification, validation of the selected system must be done after the contractor has been awarded the project. In these cases, the contractor may save valuable project time by choosing a system that has been previously validated in other states. It is usually preferable to proceed with installation processes that have been proven to work in other locations, since the contractor has only to replicate previously completed system trial installations.

Validating New Systems

When a contractor chooses to use a new system that has not been validated in any other state, system validation must occur after the contractor has been awarded the project and before the contractor can proceed with shop drawings and other submittals. This is typically accomplished by performing a specified trial installation or demonstration of the proposed system off-site where DOT approval and inspection personnel have sufficient room and time to view and evaluate the system safely (Figure 10-1). The contractor should allow for some additional time in case modifications to the system must be made.

System Trial Installation Meeting

A system trial installation meeting should be held as soon as possible after the project is awarded to ensure the trial can be conducted in a timely manner. The meeting should be attended by the system designer, key contractor staff and any owner/agency personnel associated with the trial installation. This meeting is an opportunity for DOT personnel to examine and preliminarily evaluate the proposed system before the trial begins to ensure that all appropriate features and tests are included. Either prior to or during this meeting, the contractor should submit trial panel fabrication drawings, proposed fabrication instructions, trial installation plans, a description of tests that will be performed to prove that the selected system meets the specified criteria (see Table 9-2) and proposed trial installation procedures.

System Trial Installation

The system trial installation typically involves installing trial panels in a manner that demonstrates:

- The mechanism or method to be used for bringing the panels to the proper grade and cross-slope.
- The materials and equipment to be used to fully support (or "bed") the panels.
- The techniques for dowel insertion, anchoring and encasement to establish load transfer across joints.
- The finishing and placement techniques that will be used to ensure smoothness and surface requirements will be met.

Tests should be included during or after the trial to prove that the selected system meets the four basic requirements for PCP systems listed in Table 1-1 and discussed in further detail in Chapter 5:

1. Panels can be placed (or adjusted, as required) to the correct grade.
2. Panels are uniformly and completely supported.
3. Effective load transfer is established between panels.
4. The top surface of the precast panels conforms to and matches the top surfaces of the surrounding panels.

Figure 10-2. Falling weight deflectometer equipment measuring load transfer efficiency at a trial installation in Chicago, Ill.

The panels used for the trial installation should be fabricated in accordance with the proposed fabrication instructions submitted at the trial installation meeting. Similarly, the panels should be installed exactly as indicated in the proposed installation instructions submitted at the same meeting, at a location acceptable to all parties involved. Grout tests should be performed at appropriate times after trial panel installation. Other tests listed in Table 9-2, such as falling weight deflectometer tests (Figure 10-2), should be performed as soon as possible – typically within one or two days of installation, after the dowel grout has reached design strength – to expedite the system approval process. If any of the test results are unacceptable, it may be necessary to repeat the trial installation entirely. Alternatively, it may be possible to modify the installation instructions or to specify different grout or other materials at the discretion of the engineer in charge of approving the system.

Once the trial installation is approved, the fabrication and installation instructions and system details can be adopted so that work on the project can begin. It is generally not advisable to proceed with the development of shop drawings or any other work until after the proposed system has been proven and approved by the owner/agency.

An important co-product of a system trial installation is a set of fabrication and installation instructions that can be approved by the DOT and used to guide and train workers for subsequent fabrication and installation operations and to inform inspection personnel of aspects of each that need to be monitored and checked. The approved installation instructions will ultimately become the basis for fabrication and installation QC plans.

Pre-construction Meeting

Pre-construction meetings are held before any of the permanent work on the project begins – and after the proposed system has been approved – to ensure all project parties fully understand the approved system and all the processes associated with its installation. This meeting should be held before any surveying is performed and shop drawings and other submittals are made.

The topics that are covered at the pre-construction meeting should include:

- Details of the proposed system
- Project surveying requirements
- Shop drawing preparation
- Precast panel fabrication
- Job site processes (e.g., saw cutting, subgrade preparation, and placing and grouting panels)
- Pavement smoothness requirements

The material, manpower and equipment needs for each operation associated with panel installation should also be determined and reviewed at this meeting, with an emphasis placed on the amount of time required for each operation. For example, shop drawing preparation may require days or even weeks, and it's probable that survey information will be needed before shop drawing preparation can begin. On some larger projects, it may be possible to begin fabrication work before all of the shop drawings are completed, which will allow for some schedule compression. All of this information should be assembled, considered and provided in an overall project schedule so all parties can plan accordingly.

It is customary for the pre-construction meeting to be conducted by the owner/agency's project EIC, accompanied by appropriate inspection personnel. The designer of

Figure 10-3. Entrained air meter and compression testing equipment in a precast plant testing lab.

Figure 10-4. An American Concrete Institute-certified concrete technician measures air content.

the approved precast system (system designer) and all contractor personnel associated with project supervision, engineering, shop drawings, fabrication (precasting) and installation should also attend the meeting. The system designer should be prepared to answer any questions that arise regarding materials and proper installation procedures.

Fabrication Quality Control (QC) Plans and Quality Assurance (QA) Programs

Fabrication Quality Control (QC) Plans

Quality control plans for plant fabrication are formal documents, typically written by the precaster, that provide detailed descriptions of how the PCP panels will be manufactured, who will perform the work, how the panels will be produced, what measures will be taken to ensure that panels are of high quality (Figures 10-3 and 10-4) and who will perform QC functions. QC plans are typically required of precasters in most states as part of the state plant certification process to ensure that the panels are fabricated to the quality standards listed in the project specifications, as described in detail in Chapter 7.

The rationale behind requiring precaster-generated QC plans is that precasters can best develop QC plans that fit their specific operations (provided they ensure that the quality of the products they produce meet specified levels of quality set by owner/agency quality assurance staff). Some states may instead allow – or require – plant certification by the National Precast Concrete Association and/or by the Precast/Prestressed Concrete Institute in addition to state requirements already in place, recognizing that both organizations require extensive QC plans as part of their respective plant certification processes.

Fabrication Quality Assurance (QA) Activities

In the context of fabrication of precast paving panels, QA activities are distinguished from the QC activities described above in that they are primarily performed by owner/agency inspectors to monitor, spot-check and audit precaster QC activities. The QA plan and program requirements are typically not referenced in specifications, but often exist within owner/agency internal organizational directives. By necessity, state QA programs for fabrication are generally flexible so that they can be adapted to mirror and monitor the precaster's QC plan.

Effectiveness of Fabrication QC Plans and QA Programs

Fabricator-developed QC plans, coupled with owner/agency-sponsored QA programs, have generally proven to be effective in ensuring the fabrication of high-quality PCP

Figure 10-5. Panels arriving on trucks are easy to inspect for defects and flaws because all six surfaces of each panel are visible.

panels. In almost all cases, only panels meeting specified quality requirements reach the job site. Defective panels are typically identified at the precast plant and replaced or repaired accordingly. Contributing to the success of these programs are QC plan audits, which are commonly performed on an annual or biannual basis to ensure that QC plans are kept current and technologically up-to-date.

Installation QC Plans and QA Programs

The Need for Installation (Contractor) QC and QA Programs

Evaluations of some recently installed PCP projects have revealed that defects in some installations have resulted from improper installation procedures, not from defective panels. The quality of panels arriving at the job site is assured because the panels are thoroughly inspected upon arrival (Figure 10-5). This has led to an awareness that improper installation procedures can be a primary cause of defective panel installations and has pointed to a need for more effective QC and QA procedures at the job site.

The Evolution of Installation QC Plans

Most PCP specifications issued to date have been written around the traditional premise that the contractor's responsibility is to "follow the specifications," while the responsibility for QC generally falls to owner/agency inspectors. This may be a justifiable approach if every detail of precast panel installation is prescribed in the specification in a manner that leaves no confusion or room for interpretation by contractors and inspectors as they execute their respective tasks. A few well-written, product-specific specifications do contain such a level of detail, but many "more generic" specifications do not – a factor that has contributed to many of the previously referenced installation issues.

A more effective approach now being included in some PCP specifications is to allow the contractor the freedom to select the PCP system that best fits their operation and, at the same time, require them to accept responsibility for developing an accompanying QC plan that considers the details and features of the selected precast system and their specific operational parameters. The resulting QC plan is designed to control installation quality and to ensure that owner/agency-specified quality parameters are met. As with fabrication QC plans required of precasters, this approach makes contractors – not inspectors – responsible for QC of the installation, leaving the responsibility for QA up to inspectors.

Effective Contractor-generated Installation QC Plans

Installation QC plans need to specifically state or describe what PCP system is going to be used, step-by-step instructions for panel installation, who will be responsible for performing each operation, how each installed panel will be checked to ensure proper installation, who is responsible for checking and controlling quality, and what information will be recorded for state inspector evaluation and future reference. A complete installation QC plan must also include an organization chart that indicates the hierarchy of the contractor's supervisors, work crews and QC inspectors so that owner/agency QA inspectors can properly identify and interact with them.

Figure 10-6. A contractor's crew checks saw cut layout lines prior to sawing.

Figure 10-7. A grading crew checks and adjusts screed rails to ensure an accurate grading frame of reference.

As with QC plans for fabrication, QC plans for installation should be developed to fit the contractor's operation and the specific PCP system being used. QC plans vary by system and project type. For example, a QC plan for an intermittent (patching) project will probably be very different from a QC plan for a lane replacement or intersection project because different crews, equipment and types of panels may be required for each. Similarly, a QC plan for a grade-supported system will likely be quite different from a QC plan written for a grout-supported system because the equipment, operating personnel and installation processes are very different.

QC Plan Details – What to Check and Control

The QC plan should indicate the specific checks to be made during every step of the installation process as well as the checks to be made on the completed installation. Process checks are especially important because they greatly affect the quality of the finished installation.

For example, the importance of saw cutting is sometimes overlooked because it is often performed ahead, out of sight of removal and installation operations. However, the saw cut layout and the saw cutting process should be carefully checked because saw cut locations and orientation greatly affect the joint widths of the final installation (Figure 10-6). Saw cut lines must be laid out with care and checked prior to sawing to ensure they are dimensionally accurate. Those responsible for saw cutting should also be regularly monitored during the cutting process to ensure they follow the layout lines properly and make cuts that are straight and vertically square. Similarly, the results of the subbase surface preparation process are also not seen after the panels are installed, but the accuracy of the subbase surface grade and elevation affect the vertical positioning of the panels, especially with grade-supported systems.

Process items that should be routinely checked during installation as a part of the QC plan include – at minimum – the following:

- Saw cut layout lines (location and orientation)
- Pavement removal to ensure that the existing pavement left behind is not damaged
- Grade control and panel layout survey marks
- Accurate placement and elevation/slope of grade control rails or other devices used to control aggregate or concrete subbase material screeding (Figure 10-7)
- Operations related to compaction of the subgrade layers
- Anchoring (by grout or epoxy) of dowels in holes drilled in existing pavement

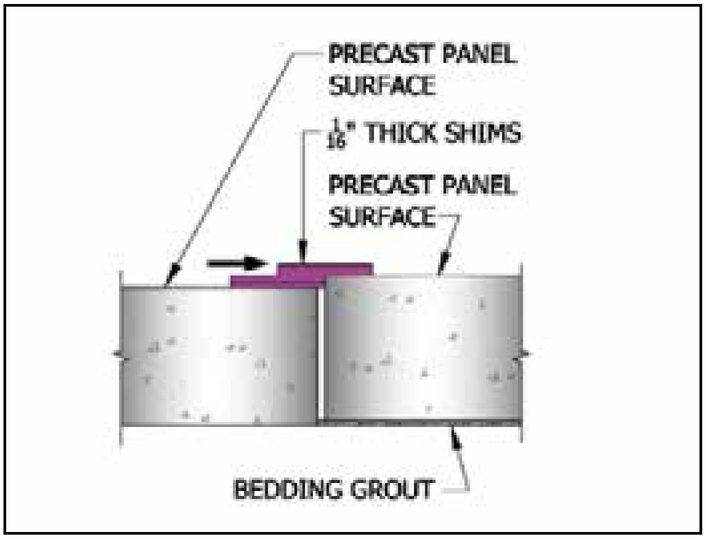


Figure 10-8. Sliding a stack of 1/16-inch-thick plastic spacers (typically used for shims under panels) across the joint aids in measuring vertical differences in elevation between adjacent panels.

- Joint widths around the panels during the placement process
- Installation of structural grout to ensure full encasement of dowels
- Completeness of bedding grout distribution

The QC plan should also indicate what parameters of the completed installation should be checked to ensure it meets specified quality standards. Completed installation items that should be routinely checked as a part of the QC plan include – at minimum – the following:

- Vertical deviation between new precast panels and adjacent precast or existing pavement (Figures 10-8 and 10-9)
- Transverse and longitudinal joint widths
- Dowel and bedding grout compressive strengths
- Accuracy (straightness) of pavement surfaces across joints, as can be measured using a 10-foot straight edge
- Planarity of panel surfaces to ensure proper surface fit
- Profile of riding surface, as may be measured using a profilograph or similar instrument
- Deviation from a specified theoretical surface (applicable in certain continuous applications)

Figure 10-9. Two shims left behind indicate an actual vertical differential of 1/8 inch between the two panels.

Owner’s Installation QA Program

The owner’s inspection staff provides QA on behalf of the owner of the project. An effective QA program should be designed to monitor and audit QC activities performed by the contractor’s personnel operating in accordance with the approved contractor’s QC plan and the project specifications. Project specifications should always be followed if there are any omissions in the contractor’s QC plan. Any differences or ambiguities between the QC plan and the specifications should be identified and resolved at the time the contractor’s QC plan is submitted for approval.

The makeup of the owner’s inspection staff is typically comprised of the project EIC, a resident engineer (if a third-party is retained to manage inspection on the project) and all inspectors deemed necessary to “cover” the contractor’s crews. The exact duties of the inspection staff should reflect the contractor’s QC plan and/or the contract specifications. If the specification is written in a prescriptive format that does not require a contractor-generated QC plan, the owner’s inspectors are responsible for ensuring the quality of every step prescribed in the specification. But if the specifications are systems-based, requiring a contractor-generated QC plan, inspectors are responsible for ensuring that panels are installed properly by auditing reports generated by the contractor’s QC staff and by performing appropriate spot-checks of the installation (Figure 10-10).

Figure 10-10. A DOT inspector checks the finished elevation and grading of the subbase.

Project EICs and REs serve as the owner's representatives and represent the ultimate authority on the project. They must be intimately familiar with PCP construction, in general, as well as with the specific system being installed on the project so that they can offer proper direction to inspection personnel. They must also be prepared to interpret the specifications, resolve any ambiguities and provide timely resolutions of installation problems associated with unexpected field conditions.

Installation Plan

The installation plan should provide an overview of the entire installation process so that agency engineers can be assured the contractor intends to install the panels in accordance with the contract plans, specifications, system designer requirements and the approved installation instructions before actual installation begins. Items that should be included in the installation plans include – at minimum – the following:

- Plans for the maintenance and protection of traffic, including provision of signs, equipment (e.g., bumper trucks) and personnel (e.g., flaggers and/or police officers)
- Lighting equipment for night work
- Number of traffic lanes required for installation
- A list of required sawing and slurry cleanup equipment
- Methods and means (equipment and procedures) for pavement removal and disposal
- Methods and means of grading and/or screeding
- Type and size of installation cranes, excavators and other equipment
- Methods and means of delivering new panels to the site
- Standard installation procedures
- Methods and means of drilling and anchoring dowels in existing pavement
- Trucks and trailers for transporting grout materials and equipment
- Equipment used for mixing and installing grout
- Provisions for cleaning up after grouting operations
- Methods and means for grinding pavement to meet smoothness requirements

Contractor Installation Crews

The composition of construction crews required for PCP installation will vary from job to job, depending on the type of installation, the PCP system being used, the size and location of the project, and the length of the work window allowed. This section focuses on the composition and responsibilities of specific installation crews and the specific contributions to quality for which they are responsible. The role of contractor QC inspectors is also discussed.

Project Manager

As the contractor's designated manager for the entire project, the project manager is responsible for the activities of all crews and subcontractors. Since the PM's understanding of proper installation techniques for the selected system is vital for a high-quality installation, the PM:

- Should be certified to install the precast system used on the project
- Must be responsible for ensuring that all crew members are properly trained prior to the beginning of the project
- Must ensure that additional training takes place, as necessary, throughout the duration of the project

The PM is responsible for organizing the project to achieve maximum productivity and profitability. The PM must also ensure that all quality criteria set forth in the specifications are met. To achieve maximum productivity and profitability, the PM should actively monitor installation quality and make modifications to the installation process in a timely manner. It is typically much more expensive to repair a defective installation than it is to spend a little extra time and effort installing the panels correctly.

Surveying Crews

Some form of surveying or measuring is required for all PCP projects, as discussed in detail in Chapter 6. The survey crew for a simple intermittent (patching) project may consist of only two or three workers whose sole task is to measure the distance between longitudinal joints to accurately determine required repair widths. As simple as this sounds, this crew should be trained – preferably by the system designer – to make these measurements properly because this process greatly affects the constructed widths of the longitudinal joints in the final installation.

Crews for more sophisticated "x-y-z" or 3-D surveys need to be trained in using the equipment necessary for this type of surveying (Figure 10-11). The supervisor of this crew also needs to work closely with the shop drawing engineer to ensure that all of the information necessary for preparing the shop drawings is being collected during the initial field surveying process, and to ensure that the right information from the drawings is transferred to the field in the form of leading end/edge and cut/fill marks prior to the placement of the panels. The accuracy achieved in performing both of these tasks will affect how well the panels fit in the field, especially with regard to joint widths and surface elevation matches between adjacent panels.

Shop Drawing Engineers

The shop drawing engineer (SDE) is a key participant in the fabrication and installation of every PCP project, even though the SDE typically works for the precaster and not directly for the contractor. The SDE must become intimately familiar with the system that is chosen for the project and must be capable of accurately communicating field data requirements to the project surveyors. The SDE must also acquire appropriate data from project plans and specifications and other sources – as indicated in Chapter 6 – to produce shop drawings that that can be easily followed by fabricators and contractor personnel. An accurate set of shop drawings is absolutely vital to a high-quality installation.

Figure 10-11. A surveyor uses a total station to establish panel points and grades for continuous PCP.

Sawing Crew

Although it typically takes place well ahead of the main work crew, pavement sawing should be treated as a key operation. Saw operators must be skilled in accurately following layout lines so that over-width joints may be avoided. Operators may also need to be adept at using specialized concrete ring or chain saws to finish repair area cuts without cutting into adjacent pavement.

The sawing crew usually consists of one or more saw operators and helpers to manage water hoses and water trucks and to clean up slurry left behind by the sawing operation (Figure 10-12). The PM or general foreman should provide timely and consistent guidance on where saw cuts are to be made and arrange for adequate lighting so saw operators can follow layout lines properly. The accuracy of the sawing crew should be checked on a daily (or nightly)

Figure 10-12. A sawing crew consisting of two saw operators and one slurry cleanup man.

Figure 10-13. A four-man crew grading fine aggregate bedding material.

basis by a QC inspector to ensure that accurate saw cuts, which are vital to a quality installation, are being made.

Removal Crew

The removal crew typically consists of an excavator operator, one or two laborers, and two or more haul truck drivers. The expertise of the excavator operator is key to overall productivity because pavement removal and subgrade cleanup precede subgrade preparation and panel installation and ultimately control how many panels can be installed in any given work shift. For these reasons, removal equipment operators should be chosen with care.

Since the removal crew does not install panels, it does not need to be trained and certified by the system designer. However, the contractor should train the crew to remove existing pavement without damaging adjacent pavement, as described in Chapter 8. The excavator operator bears most of the responsibility for this operation because he or she is in command of powerful, fast equipment that can easily chip and spall adjacent pavement. Laborers working in the removal crew should be trained to help guide the excavator operator so that such damage can be avoided. Chips and spalls are costly to repair and detract from the quality of the finished installation.

Subbase Preparation Crew

The subbase preparation crew typically consists of four-to- six laborers. At least two members of this crew should be skilled in screeding granular subbase and bedding material or lean concrete subbase, depending on project requirements and what type of system is being installed (Figures 10-13 and 10-14). At least two crew members (preferably more) should be skilled and trained in setting screed rails that are used to control screeding operations. When lean concrete subbase is installed, additional concrete finishers may be required behind the screed to finish the freshly screeded concrete surface (Figure 10-14).

The foreman and at least one other member of the subbase preparation crew should be trained and certified by the system designer to grade or finish subbase surfaces to an accuracy of ± 1/8 inch, as described in Chapter 9 and referred to above. This is generally required for all systems – even those that are not designed to be grade-supported – because panels placed on the finished subbase surface are often trafficked immediately by cranes or other panel transport and placement equipment. Inaccurate and uneven subbase surfaces that do not support the panels uniformly during this process place them at increased risk for cracking.

The subbase preparation crew also plays an important role in achieving final pavement surface smoothness in grade-supported systems that depend upon subbase layer


Figure 10-14. Two concrete finishers working behind four workers screeding newly placed lean concrete subbase.


Figure 10-15. A grading crew using string lines (foreground) to check the rough grade of bedding material.

surface accuracy for panel grade control. This demands the presence of trained crew members at all times during panel installation.

Checking the accuracy of the finished subbase surface is not a casual task and should not be attempted without proper training and proper equipment. The subbase preparation crew and the contractor's QC inspector should be trained to check surface accuracy using a properly adjusted screed and an accurate frame of reference provided by screed rails that have been set to grade. The use of string lines – as shown in Figure 10-15 – is not a reliable technique for checking the accuracy of final subbase surfaces because of their tendency to sag, especially over longer distances and/or with inadequate tension.

Panel Placement Crew

The placement crew typically consists of a foreman who is trained and certified in the techniques of safe and proper panel placement, at least one worker for each panel corner and at least one worker on the delivery truck to attach lifting bails to the panels (Figure 10-16). Workers should be trained to place the panels without bumping them into the adjacent pavement, which often results in spalls at the contact points. In addition, workers must be trained to set panels to leading edge marks in multiple-panel installations – as shown in Figures 8-6 and 8-13 – or as required by the system designer.


Figure 10-16. An ideally sized panel placement crew of five, with one man in each corner and one man on the truck.

The placement crew plays a vital role in meeting specified in-place tolerances. Final joint widths are established during the placement process, so this crew is responsibile for "optimizing" joint width while the panel is being placed. Crew members and the contractor's QC inspector should also check vertical elevation differences between panels or between panels and existing pavement during this operation.

If the vertical elevation difference between grade-supported panels exceeds the specified tolerance, the crew should pick up the panel, re-grade (for grade-supported systems) and replace it, as necessary, until the vertical elevation difference is within the specified tolerance. The placement crew should be made aware that, if the panel being placed is raised for repositioning after it has been placed, it will easily spall if the panel being lifted touches or rubs against an adjacent one during the lifting process. Similarly, the placement crew should vertically adjust grout-supported panels as many times as necessary to bring vertical elevation differences within specified tolerances.

The placement crew plays a significant role in final joint widths and panel match, both of which greatly affect the quality of the completed installation. As with the subbase preparation crew, the placement crew should be staffed with trained and certified personnel during every placement operation.

Grouting Crew

The grouting crew is responsible for mixing and installing bedding and dowel grouts to ensure that panels are fully bedded and that proper load transfer is established across joints, as described in detail in Chapter 9. To accomplish this properly, crew members should be trained and certified by the system designer in mixing and in pumping grout using the equipment the contractor has chosen for the project.

In addition to being trained by the system designer, the grouting crew should also be trained by the manufacturer of the mixer pump used on the project so that workers can completely dismantle and clean out the pump periodically, as necessary, to ensure that grout does not build up in the mixing and pumping chambers and in discharge hoses. Failure to do this may result in grout setting up in the pump and/or the discharge hose, triggering a delay in the work.

The grout crew is required to perform the following quality checks:

1. Determine the amount of water used in each batch (for batch-type mixer pumps).
2. Perform a flow cone test for bedding grouts to ensure proper grout consistency and adequate bedding grout support.
3 Prepare grout cube specimens for compressive strength tests, as required.
4. Observe and inspect adjacent grout port holes and joints to ensure dowel slots and under-panel voids are completely filled with grout. This process is system-specific, so the system designer should provide techniques for performing these checks.

A grout crew on a typical 400-panel, grade-supported project should consist of at least two workers mixing and pumping grout, two workers managing the grout nozzle and at least one person responsible for cleaning the top surface of the panels. A grout-supported panel project usually requires two to three additional workers because much more bedding grout is needed.

The foreman or team leader of the grouting crew must be adept at keeping track of which panels have been grouted and when they were grouted to ensure compliance with special provision requirements related to loading freshly grouted panels. This may be challenging on larger projects, where a large number of panels are installed in any given work shift.

The grouting crew plays a significant role in the long-term performance and quality of a PCP installation, which is affected by the performance of the bedding and dowel grouts. If either grout fails prematurely, so too will the pavement.

Contractor QC Crew

Contractor QC requires at least one person on smaller jobs and a small crew consisting of two or more on larger jobs. The QC crew must:

- Perform QC checks on the installation process, as indicated in the QC plan
- Effect any process changes necessary to meet specified levels of quality
- Record findings, as required by the QC plan
- Interface with the owner’s QA personnel

Operating in this capacity, the QC crew greatly affects the quality of the completed installation.

Pre-Installation Table of Contents

- Surveying and Layout
- Saw Cutting
- Drilling (and Anchoring) dowels
- Super-Grading techniques
- Placing slabs to points
- Checking for line and grade
- Grouting
- Grinding

Figure 10-17. Table of Contents (agenda) slide for a Super-Slab pre-installation meeting presentation.

Figure 10-18. On-the-job training of a grout crew.

It may be possible for a QC inspector to work in a crew and still perform QC functions on smaller projects, but a dedicated QC member will almost certainly be required on larger project operations. In all cases, the size and duties of the QC crew should be clearly shown on the contractor QC plan.

Pre-installation Meeting

A pre-installation meeting is typically held about a week before installation begins. Note that the pre-installation meeting is different from the pre-construction meeting described earlier in this chapter and is typically held at a different time. The primary purpose of a pre-installation meeting is to review – in detail – the installation process that was presented briefly at the pre-construction meeting. This ensures that all personnel involved in the installation are fully informed and prepared for installation. Every step of the installation is presented, as shown in the "Table of Contents" or agenda in Figure 10-17. Each topic is discussed to ensure that there is no confusion or misunderstanding of what is expected of each crew and crew member during the installation. This meeting also offers the contractor and project EIC an opportunity to make last-minute adjustments to their crews, schedules, materials and equipment.

Training, as described in the following section, is best conducted during or immediately following the pre-installation meeting because all parties requiring training should already be present. Keep in mind that training is not complete until trainees undergo hands-on training during the first night (or two) of installation (Figure 10-18). It is also important to discuss the contractor trial installation (test strip) – discussed in the following section – during the pre-installation meeting. All installation personnel, including inspectors, should be fully informed of their respective roles before a contractor trial installation is attempted.

Training

Formal training of installers and inspectors should be required on all PCP projects because precast paving involves relatively new and unique installation techniques. Requirements for training contractor personnel should be provided in the project specifications, while training requirements for DOT inspectors should be delineated in internal agency directives. In all cases, contractor installers and inspectors and agency inspectors should be trained by experts intimately familiar with the system being used on the project (i.e., the system designers). These individuals should all undergo training at the same time so that they receive consistent instruction and are made equally aware of critical system features.

An effective training program should consist of formal classroom training followed by a written examination and hands-on training provided before and during the first few nights of installation. The grout crew, for example, can be trained to mix and pump grout off site (before actual panel installation), but complete training under job-site conditions can only be completed on site during actual installation. All job-site training should be concluded with appropriate performance evaluations and the issuance of formal certification by the designated trainer.

Trainer Selection

In the context of precast paving, training may be described as the act of transferring expertise related to installation of the system used on the project from an individual who is an expert in that system to others who are not. It should not be confused with training (referred to in at least one state as "Just-In-Time-Training," or JITT) that covers all aspects of precast paving, including design, an overview of precast paving systems, what systems are used in other states, the benefits and disadvantages of each system, maintenance, repair, etc. At this stage of the project, the system to be used on the project has been selected, it has been proven to work in the system trial installation process, shop drawings have been approved and panels have been fabricated. Installation trainers should be selected to focus primarily on techniques related to installation of the system chosen for the project.

The person most qualified to train installation and inspection personnel is the individual or entity that designed and tested the system in the first place – previously defined as the system designer – or an individual that has been trained and certified by that individual. If a contractor proposes to develop and test a new system, that contractor is the expert most qualified to train and transfer detailed installation skills related to particular grouts, grout mixer pumps, grading or screeding devices, finishing equipment, load transfer mechanisms and any other processes related to installing that system.

Some agency engineers have expressed concern that the use of trainers not specifically approved by the agency may lead to a conflict of interest in that they may favor the interests of contractors over the agency's interests, as set forth in the plans and specifications. This should not be of concern because designers of approved systems must still meet the requirements of the agency plans and specifications. Furthermore, owner-designated QA inspectors still exercise final authority in evaluating and judging the quality of the final installation. Of utmost importance is that PCP installers be trained in every physical aspect of the installation of the system used on the project, particularly the manual processes.

Classroom Training Topics

Until PCP systems evolve further and installation techniques converge into a commonly accepted and proven practice, there is not a "universal training agenda" that applies to all systems. However, the following general topics should be addressed in classroom training:

- **Surveying:** Surveying is largely the same for all systems. An exception is when 3-D surveying, consisting of the measurement of "x," "y," and "z" coordinates, needs to be performed to fabricate and install warped (non-planar) panels. Systems that rely on grinding flat panels to achieve non-planar surfaces generally do not require 3-D survey data.
- **Sawing:** Sawing requirements are similar for all systems.
- **Removal:** Techniques for the removal of existing pavement should be the same for all systems.
- **Grading and Screeding of the Subbase:** This process is system-specific in that different materials (e.g., aggregate or lean concrete) may be used for different systems, and these materials will impact the interval of time between panel placement and when panels can be opened to traffic.
- **Panel Placement and Grade Control:** Both of these operations are system-specific and training should be conducted accordingly.
- **Dowel Grout:** This is system-specific involving different grout installation techniques and materials. Some grouts are cementitious and may be machine-mixed and pumped, while other grout materials, such as polyester grout, need to be hand-mixed.
- **Bedding Grout:** The types of bedding grout and their respective methods of installation are system-specific.

Bedding grout mixing and installation training should be conducted accordingly. The mixer-pumps required for grout-supported systems need to be of higher capacity than those required for grade-supported systems because of the need for more bedding grout in grout-supported systems.

- **Smoothing Panel Surfaces:** Training for this process is system-specific.

Training Examination and Certification

A formal examination should follow the classroom training session to ensure that attendees retain sufficient information concerning the topics discussed. Questions should adequately represent the most important aspects of the range of topics covered in the training process. It is advisable that each trainee be trained in all aspects of precast panel installation since there is a high probability that workers will be switched within the initial crew or among crews throughout the course of the project.

A training certificate should be issued to all trainees that successfully complete the course. At minimum, this certificate should include the name of the trainee, the date of training completion, the name or description of the precast system covered by the training and the name of the qualified trainer.

Contractor Trial Installation (Test Strip)

The contractor trial installation is different from, and is held at a different time than, the system trial installation discussed earlier in this chapter. The purpose of a contractor job site trial installation is to verify the contractor's ability to install the selected system correctly in accordance with the project specifications and the installation instructions established during the trial installation process. This trial typically involves the closely monitored installation of a specific number of panels during the first night or shift of production installation.

The contractor trial installation is usually evaluated the same way a system trial installation is evaluated – using the tests listed in Table 9-2 to ensure that the four basic system requirements shown in Table 1-1 are met. The contractor should be aware that complete trial installation testing and evaluation may take a few days or more, as indicated in the specifications. This interval of time should be built into the installation schedule. The logistics and time required for the contractor trial installation and subsequent testing should be thoroughly discussed at the pre-installation meeting to ensure that it does not delay production installation.

Modifying Installation Procedures After the Contractor Trial Installation

Contractors almost always determine more efficient crew sizes and identify more efficient equipment and procedures once production installation begins. Minor changes to the installation procedure typically do not require changes to the previously submitted and approved installation plan. However, major changes that represent processes that are significantly different from those tested and approved during the trial installation process generally need to be evaluated and approved before full-scale installation operations resume.

Emergency Provisions

Most specifications require that the contractor be prepared to provide temporary pavement in case new panels cannot be placed in the excavated area(s) in time to open the roadway to traffic. Contractors should consider this possibility carefully when selecting the system to be used on any given project because emergency situations are possible on most projects.

A number of short, reusable precast panels should be on hand at the job site to carry traffic temporarily in emergency situations, even if they don't fit perfectly. This approach is generally more reliable than counting on getting an asphalt plant to open in the middle of the night to provide emergency pavement repair or paving materials. In addition, using asphalt to fill open holes in any precast paving operation is a costly proposition that involves significant expenses for both placement and eventual removal prior to the resumption of precast panel placement.

If temporary panels are not available for emergency situations, permanent panels may be used temporarily and removed at a later time when they can be properly reinstalled. If the permanent panels are damaged during emergency use, they can always be removed and replaced with new permanent panels at some later date. In no case should sub-standard panels, placed because of emergency situations, be left in place permanently.

Working Together

Precast paving is somewhat unique in that it almost always occurs at night when, in many cases, PMs, EICs and REs are not present on the job site. Therefore, it is important that the contractor's workforce and the owner's inspection staff be organized to work together without the presence of senior management personnel. This is greatly facilitated if organizational charts include worker names and phone numbers, descriptions of duties and the authority of each individual listed.

Effective communication between the two groups is also facilitated when regular daily or weekly project meetings are held to discuss work progress, quality issues and changing job-site conditions (e.g., traffic patterns, special civic events, weather, etc.).

Cost Of QC/QA Plans and Programs

Costs associated with the contractor QC plans and QA programs described in this chapter are typically small compared to the potential costs of remediation or replacement of panels that are installed incorrectly. There is a significant future cost associated with the shortened service life of panels that are not installed in accordance with specified quality standards. These costs are certain to be far greater than the costs associated with a contractor QC plan and an owner QA program.

Summary

PCP projects can be challenging to organize and manage because the materials, equipment and crews necessary to perform the work are typically unique and different from those encountered on conventional concrete paving projects. The key to good management of a precast paving project is for project managers to fully understand – from the start – the processes required to install the system chosen for the project so that a high-quality installation can be achieved. The project managers must then transfer that information to workers, QC inspectors and agency QA personnel.

The best way to transfer installation information is to conduct a system trial installation, during which installation processes can be demonstrated for all to see and consider. The trial installation is also used to compile a set of fabrication and installation instructions that can subsequently be used for successful full-scale production installation.

The system trial installation should be followed immediately by a pre-construction meeting of all project participants to ensure that they have a complete understanding of the precast paving process before any work – including shop drawing preparation – begins on the project. Shop drawings are then prepared and submitted for approval, along with other submittals such as the fabricator's QC plan, the contractor's QC plan, the training program and the installation plan.

The contractor's installation crews play a significant role in achieving a high-quality installation. This chapter provides a brief description of each of those crews and how they affect the quality of the finished installation. It's important to implement an effective training program that is conducted by experts in the system being installed on the project.

It is not enough to prove the suitability of the system being used on the project. A contractor trial installation should also be conducted during the first night or shift of installation to ensure the contractor is using correct and proper installation techniques. Adjustments to the installation process can always be made using findings from the contractor trial installation, as long as they are vetted to confirm that they meet system designer and specification requirements.

While there are costs associated with the quality-assuring activities described in this chapter, these costs are far less than those of the corrective measures that may need to be taken to rectify defective installations.

Chapter 11:

AFTER PANEL INSTALLATION – THE FINISHING TOUCHES

After precast concrete pavement (PCP) panels have been placed and grouted, some finishing touches must be made before installation is complete. Because PCP consists of panels cast individually and placed intermittently or continuously, each one should be checked to ensure defects did not develop during or after placement and that the assembled panels and adjacent pavement meet smoothness and other requirements indicated in the specifications.

Minor defects such as spalls, panel cracks and hairline cracks around dowels and tie bars are typically repaired in the field without removing the panels. However, in some rare cases it may be necessary to remove and replace panels that exhibit major damage. While this is an extreme repair measure, removal and replacement can be performed without disturbing adjacent precast pavement or existing pavement. This chapter describes that process, including a description of how originally placed load transfer dowels may be retained.

Surfaces of all concrete pavements are typically evaluated for smoothness and frictional properties at the end of paving operations. PCP is no exception. PCP specifications typically require that adjacent panels match (vertically) within 1/4 inch, as has been discussed in previous chapters. That amount of deviation may be smooth enough, especially for slower traffic. If not, diamond grinding may be required to meet smoothness (and, in some cases, friction) requirements, as discussed later in this chapter.

The final step in the installation of PCP is joint sealing. While this process is essentially the same as sealing joints in cast-in-place (CIP) concrete pavement, it is usually more challenging in PCP because joints in PCP are typically wider and more variable in width, as discussed in more detail later in this chapter.

The finishing touches discussed in this chapter are presented in the order in which they should generally be completed in the field.

Figure 11-1. The relatively thin spall in the existing pavement seen along the longitudinal joint in the lower-right corner was caused by improper removal techniques.

Figure 11-2. Transverse joint spalls in both the existing pavement and the new precast panel in this photo resulted from the red shim pad – placed to keep adjacent panels from hitting each other – being placed too close to the surface.

Figure 11-3. Two layers of foam (with black tape adhered to the near panel) were used along this transverse joint to retain the joint reservoir for the joint sealing material while repair material was installed.

Figure 11-4. Photo showing failure of backfill material in top slots around the dowels and failure of the concrete between the slots.

Spall Repair

Identifying Minor Defects in Need of Repair

Minor defects, such as edge spalls, chips, and damaged edges and corners that are commonly found along precast panel edges and the abutting edges of adjacent existing pavement, are typically the result of improper removal and placement techniques. Edges of all joints – especially transverse joints – should be examined carefully after all the panels have been placed, prior to grouting. Any damage requiring repair should be noted and clearly marked because it could be inadvertently hidden by excess grout during the dowel grouting process, especially if cementitious dowel grout is used to fill dowel slots and transverse joints.

Spalls and chips resulting from the installation process are typically limited to 3 inches in depth, 6 inches in width (measured perpendicular to the joint) and up to 12 inches in length along the edge of the panel (Figures 11-1 and 11-2), though larger spalls may occasionally be found. While such spalls are small compared to the size of the panel and seldom involve exposure of reinforcing steel or dowel bars, they still must be addressed using best practices for partial-depth repair to ensure that joint sealants can be installed in a manner that ensures their function.

Spall Repair Procedures and Materials

Most spall repair specifications require the removal of all unsound concrete prior to making any repair. Most spalls or chips encountered in PCP construction are found in new precast panels that are obviously sound, or in adjacent concrete pavement that has been deemed sound enough to leave in place, so removal of unsound concrete is seldom required. Spall repair preparation is therefore typically limited to "squaring up" and cleaning the repair area in accordance with good repair practices.

A commonly specified and appropriate partial-depth repair technique for shallow spalls in sound concrete begins by defining the repair area limits using a vertical saw cut extending to a depth of approximately 1 inch. The next step is to remove the concrete within the repair limits using a small chipping hammer to an appropriate depth (1 inch minimum) prior to cleaning the area and filling it with a suitable repair material (Figure 11-3). It is important to thoroughly clean and dry all surfaces of the repair area to ensure proper and complete bond of the repair material. It is also essential that a snug-fitting compressible joint material be inserted in the joint before installing repair material to avoid intrusion of the repair material in the joint. Detailed guidance on constructing partial-depth repairs is presented in Smith et al. (2014).

Figure 11-5. The original dowels in the top slots seen in the foreground were sawed out and replaced with new, full-length dowels and the slot was backfilled with polyester concrete.

Another spall repair technique that is preferred by some contractors but not typically preferred by departments of transportation is to “fill in” the spalled area during the dowel grouting process without the outline-sawing and removal process described above. This technique can be successful if proper attention is paid to cleaning the surface to which the repair material is to be bonded and provided that the repair material is prevented from intruding into the joint. Success is further assured by selecting a repair material that exhibits good bond characteristics. Commercially available bonding agents may enhance the bond between the repair material and the surface to be repaired. This is especially useful along feathered edges, where repair material may be thin.

No matter how the repair area is prepared, partial-depth repair material for precast paving must exhibit excellent bond characteristics, be durable, and set up and cure rapidly, since work windows are typically limited to 5 to 8 hours. The latter requirement often precludes the use of conventional concrete mixtures, so proprietary cement-based, polymer-based and resinous concretes are commonly used (Smith et al., 2014). Most state DOTs maintain a list of approved materials that are suitable for partial- depth repairs, but care must be taken to select only those materials that cure in two hours or less so that panels may be opened to traffic on time.

Repair of Defective Dowel Installations

Dowel installations – particularly backfill material around dowels – should be closely examined during final inspection to ensure dowels are fully encased and the dowel encasement material is fully bonded to the precast panel. Conventional top-slot installations are especially vulnerable to failure (see Figure 11-4) when the vertical faces of the slots are not properly sandblasted and cleaned prior to installing dowel encasement material, as discussed in Chapter 9.

Defective dowel bar installations can be remediated by making saw cuts in the panel on both sides of the failed dowel so that the dowel and original encasement material can be removed and a new slot can be created. This technique applies to all load transfer systems – top slots, center holes and bottom slots. Care must be taken to prepare the new slots and install new backfill material in accordance with project specifications. If the repair is made after the diamond-grinding operation is complete, as was the case for the slots seen in Figure 11-5, the new backfill material may need to be diamond-ground to match the texture of the adjacent pavement surface.

Cracks in Precast Pavement Panels

Cracks in newly placed precast panels are not common but may occasionally develop, usually as a result of improper installation procedures, during placement or after panels have been open to traffic for a period of time. When they do occur, most cracks are hairline in width and are usually difficult to find. However, some may be wider and more obvious. In all cases, it is good practice to examine the pavement carefully at the completion of the project, especially after diamond grinding has been completed, since that process often makes cracks easier to find.

Finding Cracks

Cracks in precast panels are often difficult to find because surface inspection is typically conducted at night during normal installation hours; cracks can be more easily located when adequate lighting is present. Crack location is often

Figure 11-6. A transverse crack in the foreground lane lines up approximately with a joint at a cast-in-place concrete patch in the adjacent lane.

Figure 11-7. This diagonal crack – visible because it is wet – emanated from a bottom slot directly under the core drill. The crack was likely caused by inadequate corner support resulting from improper grading and/or installation of bedding grout.

made more difficult because most cracks are hairline in width and because high-friction surface textures – such as tined or AstroTurf drag finishes – further disguise them. Some inspection teams find that flooding the pavement with water just prior to inspection aids in locating cracks because water that soaks into the cracks evaporates less rapidly than water on the surface of the panel, providing a temporary color contrast between cracks and the pavement surface.

Structural cracks are generally isolated (i.e., not part of a broad pattern of surface cracks in a single panel) and may be oriented in any direction – transversely, diagonally across a panel corner or parallel to the direction of traffic (Figures 11-6 and 11-7). This is because cracks are often caused by random, non-uniform support of an inaccurately graded or finished surface below the panels. They may also be caused by boundary conditions (e.g., how the panels are tied to adjacent lanes). An example of this is shown in Figure 11-6, where a precast panel in one lane was tied (across the longitudinal joint) to two panels in the adjacent lane, resulting in a “sympathy crack” in the precast panel propagating from the point where the adjacent transverse joint intersected the longitudinal joint.

Shrinkage cracks generally appear as a pattern of hairline, shallow and often interconnected surface cracks due to drying of the cementitious material before the concrete has gained enough strength to resist cracking. It generally stabilizes soon after the concrete cures and, if not severe, does not reduce pavement performance potential. It can be prevented with mix design modifications (e.g., improve aggregate gradation while reducing water and cementitious material content) and improved concrete curing (to reduce early moisture loss and control concrete temperature). No treatment is typically required for shallow, hairline shrinkage cracks, although they can be treated with high-molecular-weight methacrylate (HMWM), as described in Chapter 12.

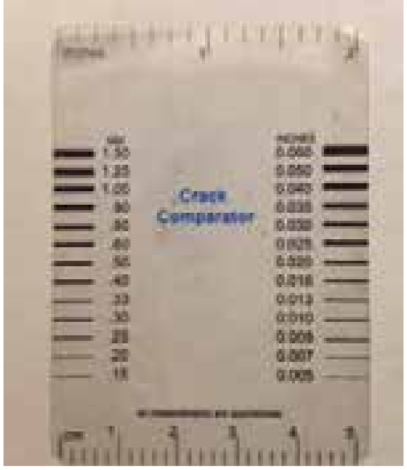


Figure 11-8. A simple crack comparator used to estimate crack widths in inches or millimeters.

Measuring Crack Widths

Crack widths at the panel’s surface can be quantified using a commercially available crack comparator (Figure 11-8). More information on crack width and depth can be gathered by taking a core through the crack so that the width of the crack

Figure 11-9. The shallow crack in this core, measuring approximately .02 inches wide at the top of the panel, stopped at the top layer of reinforcing.

Figure 11-10. The crack in this core measured .06 inches wide at the top of the core and stopped at the bottom layer of reinforcing.

– visible in Figure 11-9 – may be measured at any point from top to bottom.

From the limited number of cores taken through cracks in PCP to date, a correlation between the width of the crack at the surface and the depth of the crack in the panel has been observed. Cracks that measure around .02 inches wide at the surface of the panel generally extend down to the top layer of steel when two layers of reinforcing steel are used in the panel (Figure 11-9). Larger cracks (e.g., those that measure approximately .04 to .06 inches wide at the top surface of the panel) usually stop at the bottom layer of steel (Figure 11-10). Cores should always be used for the most accurate determinations of crack depth.

Crack Evaluation

In most states, cracks in unreinforced CIP concrete pavement are typically cause for rejection of a pavement panel because, without reinforcement, cracks in these pavements are likely to widen over time to the point where aggregate interlock between cracked sections is eventually lost, resulting in poor load transfer, faulting and possibly joint spalling and further distress. Cracks in jointed precast concrete pavement (JPrCP), on the other hand, should be viewed differently because the relatively heavy amount of reinforcing (conventional and/or prestressing) in PCP panels is expected to keep cracks tightly closed. This expectation is well-founded because hairline cracks found in some precast pavement installed as early as 2001 have not grown or deteriorated, as detailed in Tayabji et al., 2013.

Cracks in precast panels are somewhat like cracks in continuously reinforced concrete pavement (CRCP) in that both pavements are built with relatively high amounts of reinforcing steel. CRCP is longitudinally reinforced with a steel percentage of 0.65% to 0.80% (by cross-sectional area of concrete), with lower percentages in mild climates and higher percentages in harsher ones (Plei & Tayabji, 2012). Transverse cracks in CRC are typically .02 inches wide, full-depth and occur on 2- to 8-foot centers. They are expected, considered benign and are not sealed.

By comparison, most JPrCP is reinforced with one or two layers of reinforcing steel (usually epoxy-coated) that typically provide a total steel content of up to 0.40% by cross-sectional area of concrete. Thus, the mild reinforcement steel content used in non-prestressed panels approaches the lower limit of that used in CRC in milder climates. Alternatively, JPrCP may be prestressed (as described in Chapter 4), a reinforcing mechanism that actively keeps most cracks tightly closed. While the mechanisms that cause cracks in precast pavement are typically different from those causing cracks in CRCP, the cracks may be similarly benign since they are comparable in width to those found in CRCP and are also reinforced.

Figure 11-11. The over-width transverse joint in this photo resulted from incorrect saw cut layout in the existing pavement on the left. The error was not discovered until the precast panel on the right was placed.

It should be noted that the design cracking threshold is typically much higher for JPrCP (20-30% – see Table 4-1) than for conventional jointed CIP concrete pavement (5-15%). This is because of the heavy reinforcing in JPrCP and because precast pavement occasionally experiences some cracking due to transportation and construction issues (e.g., non-uniform foundation support). These cracks are typically stable and do not deteriorate rapidly.

Remediating Typical Cracks

The currently accepted practice for remediating hairline cracks less than about .07 inches wide in precast pavement panels is to seal them with high-molecular-weight methyl methacrylate (HMWM). Prior to applying the sealer, the pavement surface around the crack is cleaned in accordance with the manufacturer's recommendations to remove any contaminants. The HMWM is then mixed in accordance with the manufacturer's directions and poured, brushed or squeegeed into the crack. After the sealer has been allowed to penetrate the crack and begins to set (typically about 20 minutes), it may be covered with a fine sand to soak up any excess sealant and render the surface tack-free prior to opening the panels to traffic.

Remediating Wide Cracks

Cracks wider than .07 inches may remediated by epoxy injection, as described in ACI 224R, "Control of Cracking in Concrete Structures," if the panel is not otherwise structurally damaged and if the supporting subgrade is stable. Panels with irreparable structural damage should be removed and replaced, as described later in this chapter. Any subgrade problems should also be rectified at that time.

Figure 11-12. The transverse joint seen here varies in width from about 1/2 inch on the far end to approximately 2 inches on the near end because of incorrect saw cutting of the existing pavement.

Remediation of Excessive Joint Widths

Joints in PCP are full-depth spaces between panels that result when panels are placed next to each other or next to adjacent existing pavement. They are generally wider and more variable in width than the close, uniform-width joints in CIP pavement, which are typically formed by casting concrete directly against a previously placed slab or sawing a partial-depth cut to initiate a controlled crack below the cut. The width and variation in width of PCP joints depends on the dimensional accuracy of the fabricated panels, how accurately the existing pavement is cut to make way for the precast panels, and how accurately the panels are placed within the holes that are cut for them.

Transverse joint widths in precast pavement are typically limited by specification to 3/8 inch or 1/2 inch, which is the widest joint theoretically possible when panel length fabrication tolerance is +/- 1/4 inch and placement tolerance is +/- 1/4 inch. Wider transverse joints may cause tire slap noise and may also affect ride quality. While these limits can be (and usually are) met, errors in sawing, panel fabrication or panel placement sometimes results in over-width joints,

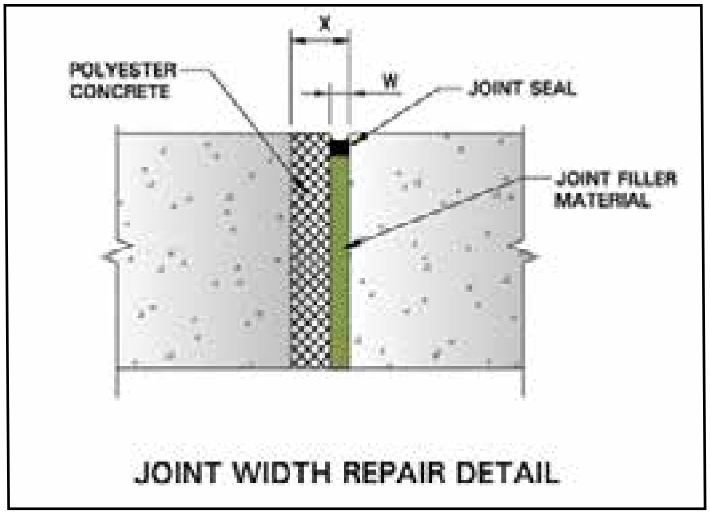


Figure 11-13. Sketch showing a full-depth joint treatment that may be used to close over-width longitudinal joints using polyester concrete.

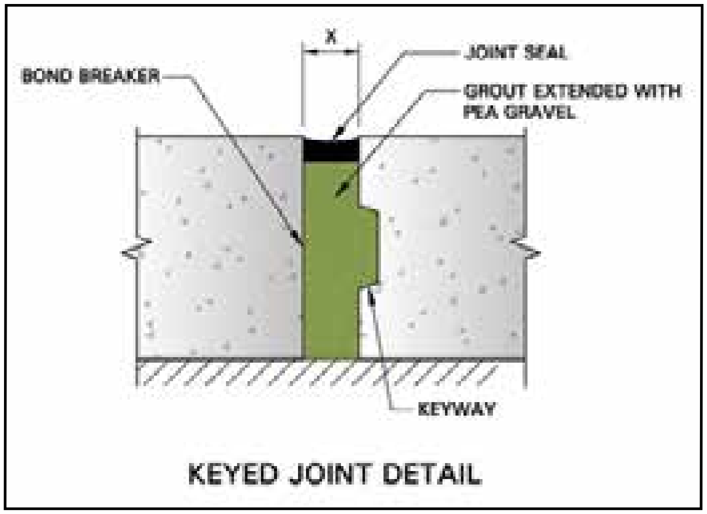


Figure 11-14. The longitudinal joint keyway helps to keeps joint repair/filler material in place without relying on bond.

such as those seen in Figures 11-11 and 11-12. A recent project specification recognized this with the following language: “3/4-inch transverse joints are allowed to provide for panel edge plumbness, panel end bowing and installation tolerances” (Hawaii DOT H-1 Project Phase I - Specification Section 416.04(E)).

PCP longitudinal joint widths of up to 3/4 inch may (and should) be allowed (by specification) to facilitate panel installation because the edges of adjacent existing CIP pavement are frequently not plumb and because tire slap is not an issue for longitudinal joints.

Remediating Transverse Joints

After panel placement, little can be done to close over-width transverse joints, such as the ones shown in Figures 11-11 and 11-12, because of the presence of dowels in the joint. This underscores the importance of accurately laying out and sawing repair holes and of placing panels correctly in the repair area, as discussed in detail in Chapters 8 and 9.

Over-width transverse joints up to approximately 2 inches wide are usually left in place and filled with dowel grout even though they may produce more tire-pavement noise (e.g., wheel slap) and may render dowel bars slightly less effective in transferring load from one panel to another. While these consequences are not desirable, they are generally not considered to be harmful enough to warrant panel removal and replacement. Sealing or not sealing such joints is discussed later in this chapter.

Transverse joints wider than approximately 2 inches, such as the joint shown in Figure 11-11, may compromise the performance of the dowel bars beyond acceptable limits. Such joints may be remediated by extending the repair area further into the existing pavement to accommodate an additional precast panel with transverse joints of acceptable width. Alternatively, the newly placed precast panel in Figure 11-11 could be removed and replaced with a new (longer) panel specially fabricated to fit the hole that was cut in error. Each of these solutions may require a significant amount of time (to locate or fabricate a new panel), so the unacceptably wide joint may need to be temporarily backfilled with a suitable material (e.g., base material) or a dummy panel, if available.

Remediating Longitudinal Joints

Although they do not cause tire slap, over-width longitudinal joints can be objectionable and difficult to seal if they are too wide. One state requires joints greater than 3/4 inch wide to be remediated by bonding an appropriate repair material – such as polyester concrete – to one side of the joint, as shown in Figure 11-13. Success of this repair is highly dependent on choosing a durable repair material that bonds well to

Figure 11-15. This photo shows a cast-slide panel that shattered around the dowels before the slots were grouted.

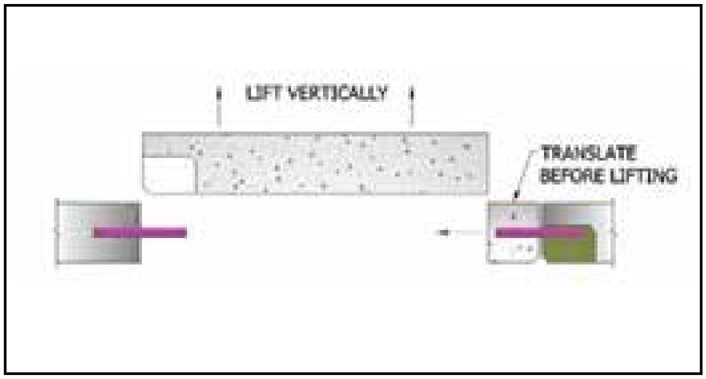


Figure 11-16. The precast panel is cut full-depth inside the embedded dowels to allow the main portion of the panel to be lifted out. The portion of the panel with embedded dowels seen here can then be translated to the left and removed without damaging dowel slots in the panel on the right.

the vertical concrete surface and on properly preparing the surface to which it is bonded. Surface preparation may include sandblasting, thorough cleaning and drying the surface of the pavement to which the material is bonded. This is a challenging task to accomplish in joints that are only 1 to 2 inches wide, for example.

Rather than closing (remediating) over-width longitudinal joints, it's typically more practical to fill them entirely with a durable filler or repair material that will perform over an extended period, as shown in Figure 11-14. Some pre- bagged cementitious grouts used to fill bottom dowel bar slots are formulated to be durable when mixed and installed exactly as specified by the manufacturer. Some manufacturers require such grout to be extended with pea gravel (to reduce volumetric shrinkage and provide added strength and stability) if it is placed in an area or a joint that is greater than approximately 3/4 inch wide. This method of filling longitudinal joints should not be attempted, however, unless measures are taken to keep the grout material in place, such as providing panels with keyed longitudinal edges (Figure 11-14). Notice, in Figure 11-14, that a bond breaker material should be applied to the vertical surface of the existing pavement to ensure the grout material bonds to only one side of the joint.

Removing and Replacing Unacceptable Panels

Newly placed precast panels that have been structurally damaged, spalled or cracked too severely for repair by any of the methods mentioned above – such as the panel seen in Figure 11-15 – should be removed and replaced. Although removing a panel out of a completed installation may seem to be an extreme measure, it is a straightforward procedure that can be accomplished relatively quickly.

Removing Ungrouted Bottom-Slot Panels

Removal is easier if the damage is discovered before the dowels are grouted. If the panels use top slots for load transfer, the panel is simply removed and replaced before the dowels are installed. A single damaged panel can be removed and a new one installed vertically without touching adjacent panels.

Removal of a damaged bottom-slot (Super-Slab) panel or a narrow-mouth top slot (Cast-Slide) panel before it has been grouted is somewhat more problematic in that the panel cannot be removed vertically because of the dowels protruding from the adjacent panel. In this case, the damaged precast panel may be cut transversely inside of the embedded dowels, as seen in Figure 11-16, so the main portion of the panel can be removed vertically. The remainder of the panel, shown in Figure 11-16 (which includes the embedded dowels), can then be translated and removed vertically. The repair is completed by installing a new, double-bottom-slotted panel over chaired dowels, as seen in Figure 11-17.

Damaged California Cast-Slide (Tear-Drop) panels may be

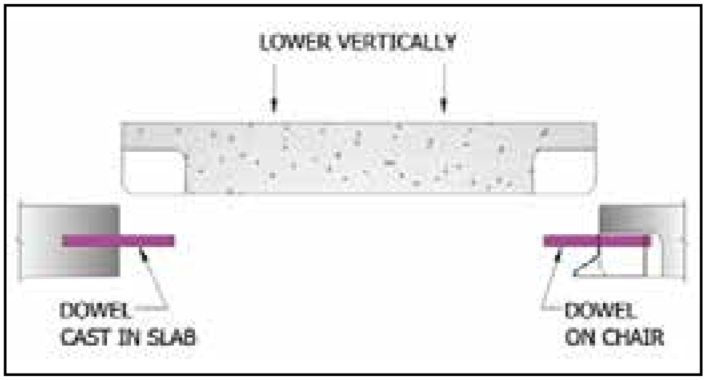


Figure 11-17. This sketch shows a new, double-bottom-slotted panel being lowered over dowels protruding from the panel on the left and dowels supported on chairs on the right.

removed in a similar fashion. However, before installing a double-slotted panel – as shown in Figure 11-17 – new dowels must be chaired or otherwise supported in the oversized holes in the adjacent panels.

Removing Grouted Panels

A damaged panel from any system that has been fully grouted can be removed by removing the dowels connecting that panel to adjacent ones. This can be done by sawing the panel (from the top of the panel) on both sides of each dowel so the dowels and concrete or grout around them may be removed along with the dowels. This process is similar to the procedure described earlier in this chapter for creating new top slots. After dowels are removed, full-depth saw cuts are made in the longitudinal and transverse joints around the damaged panel (to remove any grout or other material) so the damaged panel can be lifted out using the original lifting inserts (after the grout that was used to fill them has been drilled out). After a new panel is installed, load transfer dowels may be installed in newly cut top slots across transverse joints, as described in Chapter 9 and earlier in this chapter.

An alternative and sometimes preferred method for removing previously grouted panels is to cut along the ends of the embedded and encapsulated dowels at both ends of the damaged panel, as shown in Figure 11-18, so the then “un-doweled” center portion of that panel may be lifted out (Figure 11-19). The rest of the concrete around the embedded

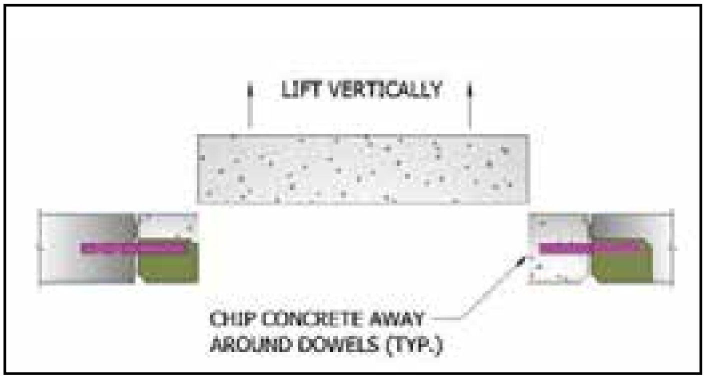


Figure 11-18. A transverse cut is first made adjacent to the dowels in the damaged panel to allow vertical removal of the damaged panel.

Figure 11-19. The damaged panel, less the concrete around the dowels, is removed.

Figure 11-20. A small hoe ram removing concrete around dowels that are to remain in place.

Figure 11-21. Closely spaced saw blades can be seen in this photo of a diamond profile grinding head.

Figure 11-22. Typical diamond grinding profiler with grinding head near the center of the photo. The bogie wheels on the left control the cross-slope of the head while the dual in-line center wheels on the right establish the longitudinal profile of the grinding machine.

dowels at both ends of the damaged panel is then removed by using a small hoe ram and chipping hammers, if necessary, as shown in Figure 11-20. This makes way for installation of a new panel with bottom slots on both ends to be placed over the remaining protruding embedded dowels. Care must be taken to avoid damaging the dowels and dowel coatings when removing the surrounding concrete.

To ensure the new panel will fit the hole, it is highly recommended to accurately measure the damaged slab dimensions – including joint grout and location of the existing embedded dowels – before the new panel is fabricated. The new panel should be finished and ready to install before the damaged panel is removed. If the new panel is ready, the damaged panel can be removed and the new panel installed in 3-to-4 hours using this method.

Diamond Grinding

Grinding to Improve Pavement Smoothness

Evaluating Pavement Smoothness

Precast pavement smoothness should be evaluated after all panels have been completely installed (including bedding and dowel grout installation) and rendered structurally sound through any necessary spall and crack repairs.

Smoothness of both intermittently and continuously installed panels is primarily a function of how well the installed panel surface profile matches that of the surrounding precast and existing pavement panels, although some of the panel surface variation allowed during the fabrication process may also show up at this point.

Most specifications require that the finished surface of intermittently placed panels does not deviate from a 10- or 12-foot straightedge by more than 1/4 inch anywhere in the lane when the straightedge is placed parallel to the direction of traffic flow. The same tolerance is typically required when the straightedge is placed perpendicular to the direction of traffic flow across adjacent lanes.

Smoothness of continuous lane replacement may also be checked in the same manner, panel by panel, although some specifications require more sophisticated surface evaluation methods, such as those typically specified for new CIP concrete pavement (e.g., pavement surface profile measurement equipment). If the latter is specified, the CIP specification should be reviewed in detail since smoothness evaluation techniques and requirements vary widely among different states (and sometimes even among jobs within a given state).

Figure 11-23. Non-uniform surface texture resulting from partial coverage by diamond grinding machine.

Figure 11-24. The existing pavement in the lower left corner of this photo was ground on both the approach and leave ends of a panel because the precast panel was placed too low.

Corrective Diamond Grinding

Diamond grinding of concrete pavement is the removal of a thin layer of the pavement surface using a profile grinder that is equipped with a grinding head made up of a series of closely spaced, diamond-tipped concrete saw blades (Figure 11-21). The grinder is designed so that the head can be precisely positioned to exact elevations and cross- slopes relative to a frame of reference created by front and back bogie wheels, which are typically spaced 10-to-15 feet apart (longitudinally), depending on the size of the machine. Smaller machines with shorter wheel bases are also available for use in smoothing smaller or heavily contoured surfaces.

Smoothing Continuous Installations

Precast panels placed continuously in any given lane should match within ± 1/8 inch if the techniques discussed in Chapter 9 are used. If a smoother finish is required, as is often the case on high-speed interstate highways, a profile diamond grinder of the type commonly used in the CIP concrete pavement industry will need to be used (Figure 11-22).

Precast panels can sometimes be ground to an acceptable smoothness without grinding the entire surface. While this may satisfy the smoothness specification, it may result in an unacceptable, non-uniform textured surface because the unground, plant-finished surface will not look the same as the diamond ground surface (Figure 11-23). If a uniform, diamond-ground surface texture is required, additional (or deeper) grinding passes may need to be made.

Figure 11-25. Severe cross-slope and vertical profile grade changes at the far end of new panels.

Smoothing Intermittent Installations

When an entire roadway containing intermittently placed precast panels is diamond ground, no special grinding technique is needed – the precast panels are typically ground along with the rest of the pavement. Some specifications allow spot-grinding as needed where the new panels are too high or too low. If the panels are high, only these panels need to be ground, although there may be a short transition

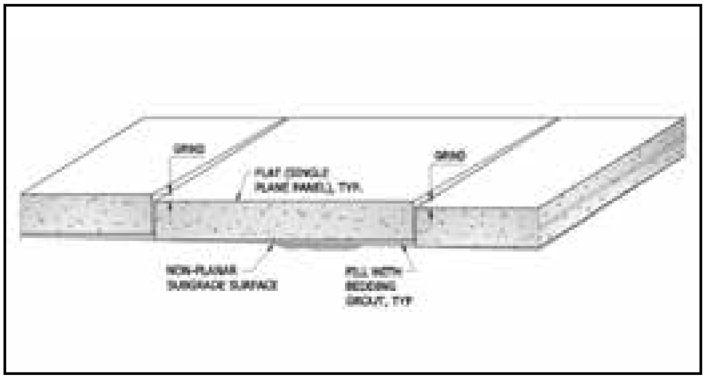


Figure 11-26. This sketch shows “steps” between flat panels placed in a super-elevation transition. Such vertical differences may require significant grinding to meet specified smoothness requirements.

Figure 11-27. These panels, finished at the precast plant with a burlap drag-and-raked finish, did not require diamond grinding. Friction requirements were met during panel fabrication and smoothness requirements were met during panel placement.

or “feathering” of the grind on either side of the target panel. If the panels are too low, the transition grind on either side of the panel may be significant, with longer transition grinds for greater depths of cut at the panel boundaries (Figure 11-24). If the new panels match the existing pavement within allowable tolerances, no action is necessary. Because contractors often absorb the cost of diamond grinding on many PCP projects, there is monetary incentive to place panels to the proper grade during installation.

Grinding to Meet Pavement Profile Requirements

Grinding Heavily Contoured Continuous Pavement

Surfaces of heavily contoured pavement surfaces such as those found in some intersections, ramp termini and some straight city streets (Figure 11-25) may be difficult to smooth out when the design profile and cross-slope of the roadway changes more rapidly than the plane represented by the 10- to 15- foot wheel base of the grinder. In some heavily contoured cases, the grinding head may remove too much material, such as when the grinder wheel base plane is below the design profile of the roadway. In the case of a sag vertical curve, the head may not even reach the pavement unless the head is adjusted constantly. In such locations, it may be better to use a smaller grinder or to not grind in those areas at all.

If non-planar surfaces exist within a project (as determined by the field survey or pavement geometry included in the contract plans), the vertical surface geometry shown on the shop drawings should be studied carefully before selecting a profile grinding machine for the project. It may be appropriate to use both a large machine and a smaller one on the same project so that all surfaces are ground uniformly and efficiently.

Grinding Flat Panels Placed on a Contoured Subgrade Surface

As discussed in Chapter 2, the surface of a series (continuous installation) of flat (single-plane) panels placed in a non-planar location, such as in a super-elevation transition area, will be stepped (Figure 11-26). Multiple passes of the profile grinder may be required to bring such panels to within the typically specified surface tolerance.

Steps or vertical differences between adjacent single-panels in some non-planar cases may be significant – up to 1 inch or more. If sufficient sacrificial panel thickness has not been provided during fabrication, removal of that amount of the thickness may affect the structural integrity of the new panels. Some contractors rely on profile grinding to meet smoothness requirements (rather than using non-planar panels) even when sacrificial thicknesses have not been provided. To prevent this practice, some specifications require cores to monitor or verify pavement thickness after the pavement has been ground, imposing penalties for – or rejection of – thin, over-ground panels.

Grinding to Meet Pavement Friction Requirements

Some states specify diamond grinding to achieve both specified friction values and smoothness requirements in new panel installations. Surfaces ground for smoothness will typically meet friction requirements if saw blades are selected and spaced as required in the diamond grinding specifications.

The surfaces of precast panels that remain unground may also meet friction requirements if the precast panels are finished in the plant with equipment that produces a sufficiently textured surface (Figure 11-27). It is highly beneficial to adjust or place such panels to grade during initial placement to avoid grinding away surfaces that already meet friction requirements.

Not all precast panels are fabricated with a raked (tined) finish. If the project specifications require diamond grinding of the entire project to meet smoothness and friction requirements – as is often the case on high-speed highways – it is typically more cost-effective to require only a temporary light broom finish (for friction) on the panels. However, that practice may result in a non-uniform final texture if any part of the pavement surface is not ground, as seen in Figure 11-23.

Sealing (or Not Sealing) Precast Pavement Joints

Most highway agencies generally agree that concrete pavement joint sealing and joint sealant maintenance are beneficial and cost-effective. These agencies generally believe that well-sealed joints resist water infiltration into the base and subgrade layers and prevent intrusion of incompressible materials, such as sand and small stones, that might otherwise be trapped in the joint, causing joint spalling or other damage. Joint sealing is also considered to be beneficial in reducing infiltration of de-icing salts and other chemicals that can attack concrete and/or cause corrosion of the load transfer devices (ACPA, 2018).

A few agencies have adopted policies of not sealing concrete pavement joints because they believe it is probably not cost-effective and has not been proven to prolong pavement life. The Wisconsin Department of Transportation (WisDOT) was one of the first U.S. state highway agencies to adopt this policy, justifying the decision with a study of more than 50 years of data concerning the effects of PCC joint/crack sealing on overall pavement performance (Shober, 1986). They began using unsealed, narrow (single-cut, width <1/4 inch) transverse joints in all WisDOT concrete pavements. They recently modified this policy to require joint sealing for concrete pavements with lower posted speed limits and with curb and gutter, still leaving joints in high-speed roadways open and unsealed because they believe that high-speed traffic tends to keep joints free from incompressible materials (ACPA, 2018).

The “no seal” decision by WisDOT and other agencies is usually applied to narrow joints in cast-in-place pavement where the induced crack below the sawed joint is even narrower than the < 1/4-inch saw cut. Joints in precast pavement are generally wider than 1/4 inch and are open through the full pavement thickness. If these joints are not filled with some material, they provide a ready conduit for water and incompressible materials. When the joints are filled with dowel grout, the effective joint width is much smaller than the distance between panel faces – and is probably less than the width of cracks below sawed joints in cast-in-place concrete. Such cases may justify a no-seal policy for precast panel installations, depending upon the local traffic and environmental conditions.

ACPA (2018) provides guidance on considering traffic, climate and foundation conditions in determining whether or not to seal concrete pavement joints. The following sections describe best practices for sealing joints in precast concrete

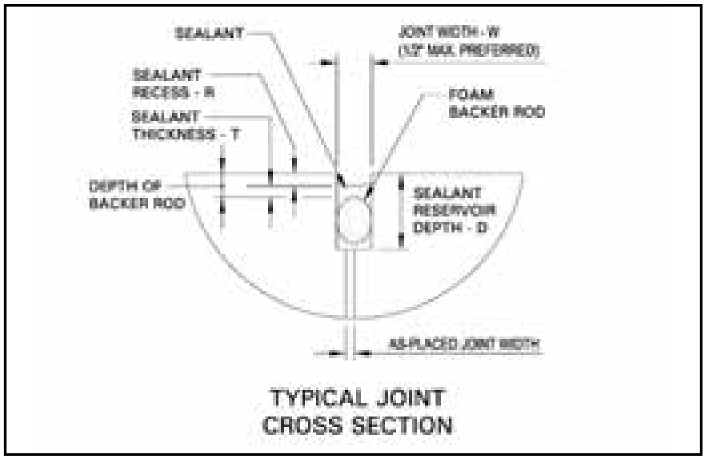


Figure 11-28. A typical joint cross-section showing the width and depth of the sealant reservoir and the shape of the sealant.

Figure 11-29. 1/2-inch-thick white isolation foam attached to the longitudinal edge of the existing pavement.

Figure 11-30. The isolation foam in this longitudinal joint does not completely fill the joint.

pavement when joint sealing is warranted.

Mechanics of Successful Joint Sealing

Sealing joints in new CIP concrete pavement is a straightforward, well-known process. Joints are sawed to a uniform width that is selected based on the expected seasonal joint movements and the properties of the selected joint sealant material. The best-established practice is to thoroughly clean joint faces prior to installation of sealant material. A foam backer rod may also need to be installed in the joint prior to installation of the sealant material to establish the proper shape factor for the selected sealant material (Smith et al., 2014).

Sawing joints of uniform width in newly placed precast pavement is not as simple, however, because joints that were established during panel placement are not necessarily uniform in width from joint to joint and even across or along any given joint, as discussed in detail earlier in this chapter. To end up with a joint sealant reservoir with uniform width, it is generally necessary to “chase” the joint with additional saw cuts to produce a sealant reservoir that is at least as wide as the maximum joint width established during panel placement. Joint sealant material and sealant reservoir design should be matched to ensure good long-term performance.

To work properly over an extended period, joint sealants must adhere to the sides of the joint and withstand both internal stresses (potential cohesion failure) and bond stresses (potential adhesion failure) imposed as the pavement expands and contracts with changes in concrete temperature and moisture. Proper adhesion is achieved by providing a certain minimum sealant depth and by thoroughly cleaning (and drying) the sides of the joint reservoir prior to installing joint sealant material. Stresses within the sealant are managed by developing a proper relationship between sealant reservoir width and sealant depth during sealant installation (Figure 11-28). In general, deeper sealants experience greater internal stress than shallower ones (Smith et al., 2014).

The ratio of the sealant width to the sealant thickness (W:T), as shown in Figure 11-28, is defined as the shape factor. Shape factors used to keep stresses in commonly used sealants within acceptable limits are indicated in Table 11-1

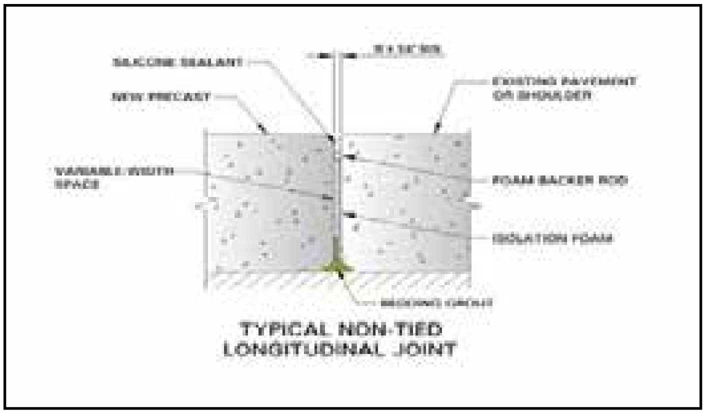


Figure 11-31. Sketch showing the details of a non-tied, foam-filled longitudinal joint commonly used in California.

Table 11-1. Typical Recommended Shape Factors (Evans et al., 1999)

Sealant Material Type	Shape Factor (W:T)
Polymerized/Rubberized Asphalt	1:1
Silicone	2:1
Polysulfide and Polyurethane	1:1

Figure 11-32. Small-diameter backer rod being braided together to fill a variable-width longitudinal joint prior to sealing.

(Evans et al., 1999)
Round foam backer rods are typically installed in the sealant reservoir to aid in developing a proper shape factor, to prevent uncured sealant from leaking beyond it and to prevent the sealant from bonding to the bottom of the reservoir – a factor to be avoided to successfully achieve the best sealant performance (Smith et al., 2014). More information on sealing joints in concrete pavement that also applies to sealing joints in precast pavement may be found in the Second Edition of the Concrete Pavement Preservation Guide (Smith et al., 2014), in the FHWA Technical Advisory on Concrete Pavement Joints (FHWA, 2018) and in the ACPA Technical Bulletin on Concrete Pavement Joint Sealing/Filling (ACPA, 2017).

Joint Filler Material

All joint spaces below the sealant should be filled with a durable joint filler material when the panels are installed. This material supports joint sealant and helps to prevent water incursion. To most closely emulate jointed CIP pavement, joints in precast pavement should be filled with rigid material such as a cementitious grout below the sealant.

At least one state specifies the use of preformed, closed- cell foam material conforming to ASTM D7174, “Standard Specification for Preformed Closed-Cell Polyolefin Expansion Joint Fillers for Concrete Paving and Structural Construction,” as seen in Figure 11-29. Because preformed cell material is manufactured to a uniform thickness (typically 1/4 inch-to-1/2 inch), it does not completely fill variable-width joints (Figure 11-30). This is a significant departure from the CIP model because it may leave an open void below the joint allowing undesirable water incursion in case of sealant material failure.

If isolation foam is placed in the longitudinal joint, at least the top 2 inches should be removed to allow for proper installation of the joint sealant (Figure 11-31). It is typically necessary to use backer rod in these joints as a bottom shape former and sealant dam since the isolation foam material does not uniformly and completely fill the longitudinal joint, as seen in Figures 11-30 and 11-31.

A variety of backer rod sizes should be kept on-hand when preparing longitudinal joints (in JPC pavement) for sealing because they tend to vary significantly in width. Alternatively, smaller foam rods may be braided together, as needed, to fill to space (Figure 11-32). All backer rod must be flexible, non-absorptive (i.e., closed-cell construction) and compatible with

Figure 11-33. A joint cutting saw equipped with a stack of blades equal to the desired joint width.

Figure 11-34. The sealant reservoir in this over-width joint was incorrectly cut with a 1/2-inch-wide blade. The remaining grout has already de-bonded from the existing pavement and is ready to fall out of the joint.

the sealant material it contacts (Smith et al., 2014).

Joint Sealant Materials

Sealants most commonly used with concrete pavement are either one-component, hot-applied thermoplastic bitumen-based products or cold-applied, one- or two-component thermosetting materials. Thermoplastic or hot-poured rubberized asphalt sealant is about half the cost of thermosetting silicone sealant but can accommodate only about half as much movement as silicone sealants (Smith et al., 2014).

Of the two types of sealant, silicone, a one-component thermosetting material, is most often used for sealing precast pavement because heating equipment and heating time is not required, rendering it more appropriate for many overnight installations that require only small amounts of sealant at a time. Selection of joint material that will be used on any given project should be based on these considerations and the maximum amount of movement expected in the panels (shorter panels will move less).

Although commonly used for sealing joints in CIP pavement (where joint widths are constant), pre-molded neoprene joint seals are not practical for use in precast pavement joints because of the variability in joint widths. Both longitudinal and transverse joints can vary beyond the limits specified for any single compression seal within the length or width of one panel. For example, a longitudinal joint may vary from 3/4 inch on one end of a panel to 1/4 inch on the other. That variation may require two different width pre-molded joint seals. In addition, the much higher cost of wide (i.e., approximately 3/4-inch) neoprene seals is hardly justifiable, especially in longitudinal joints that see little expansion and contraction movement over time.

Sealing Transverse Joints

Preparing Sealant Reservoirs for Transverse Joints

The key to achieving a proper sealant shape factor for any joint is to create a sealant reservoir (typically by sawing) deep enough to allow placement of a foam backer rod at a depth that will produce the correct shape factor (Figure 11-28) for the selected sealant material. Joints are cut with a joint-cutting saw, such as the one shown in Figure 11-33, using a thick single blade or multiple thin blades stacked together to achieve the desired reservoir width.

Following the guidelines listed in Table 11-1, the shape factor for silicone sealant is 2:1 – that is, the width of the sealant should be twice the thickness, as is shown in Figure 11-28. Assuming the maximum width of the joint is 1/2 inch, the saw should be equipped with blades that provide a 1/2-inch-

Figure 11-35. A standard caulking gun being charged with silicone sealant.

Figure 11-36. Silicone sealant being applied through a nozzle attached to a pressurized drum.

wide saw cut. The depth of the cut should be deep enough to accommodate a sealant recess of 1/8 to 1/4 inch, a sealant thickness of 1/4 inch (one half the width, as recommended in Table 11-1) and room for a foam backer rod, as seen in Figure 11-28 (Smith et al., 2014). Assuming the depth needed for the backer rod is approximately 1 inch – if 3/4-inch-diameter backer rod is used – the joint should be cut to 1.5 inches deep.

If the joint is wider than 1/2 inch at any point along the panel, the entire joint should be cut to the maximum width (as mentioned earlier) and to an appropriate depth. For an extreme example, if the maximum width along the transverse joint is 1.5 inches, the reservoir needs to be cut to a uniform depth of 3 inches to accommodate a larger backer rod (approximately 1.75 inches in this example) to produce a sealant recess of 1/4 inch and a sealant thickness of 3/4 inch. Assuming silicone sealant is used, this will result in the recommended 2:1 shape factor.

Removing Joint Filler (Grout) From Transverse Joints

If cementitious grout is used to fill transverse joints, as it is with bottom-slot systems, it needs to be totally removed across the width of the joint – to the proper depth, as discussed above – so that the sealant can bond directly to the panels on both sides of the joint.

If any grout is left along the edges of the reservoir during the saw cutting process, the sealant will bond to the grout rather than the panel and will be at risk for de-bonding from the precast panel, resulting in failure of the sealant at that point (Figure 11-34).

Installing Joint Sealant

Installation of joint sealant in precast pavement is similar to sealing joints in CIP pavement except that joints tend to be wider, there is typically less time allowed for the sealing operation and the ambient temperature is typically cooler because most precast pavement work is done at night.

Prior to installing the backer rod and sealant, the sealant reservoir must be thoroughly cleaned and dried to ensure the reservoir is free of any oils, grease and other coatings that may interfere with proper sealant adhesion to the reservoir side walls. Light sandblasting followed by high-pressure air blasting is an effective method for removing saw slurry, oils and other debris after sawing operations are complete. Compressors used for air and sandblasting should be equipped with filters and dryers to keep the air free from oils and moisture.

Sealant materials should be installed using appropriate equipment in strict accordance with the manufacturer's recommendations. Small quantities of silicone sealant may be installed using a standard caulking gun, as seen in Figure 11-35. When larger quantities of sealant are required (e.g., when sealing many longer joints), it is more appropriate to use bulk installation equipment, such as that seen in Figure 11-36.

Particular attention should be paid to the sealant temperature, pavement temperature and ambient (air) temperature at the time of sealing, as these affect sealant curing, especially when joints are sealed during cooler months. Some silicones may be installed below freezing temperatures if substrates are completely dry, frost-free and clean. For best adhesion results, some silicone manufacturers also recommend application of a primer prior to installing the sealant.

If freshly applied sealant is not allowed to cure properly before pavement is opened to traffic, the sealant may be "tracked" from the joints to the pavement surface. While this is seldom a problem when silicone sealants are used (because they are typically recessed below the pavement surface), it is an important factor when bituminous sealants are applied flush with or above the pavement surface. The time required for the sealant to "skin over" or to be "tack-free" should be indicated on the product data sheet or may be obtained by calling the manufacturer's technical representative.

Sealing Longitudinal Joints

Preparing Sealant Reservoirs for Longitudinal Joints

Longitudinal joints between precast panels vary in width for the same reasons they do for transverse joints, as discussed earlier in this chapter. Thus, longitudinal sealant reservoirs should be cut to the maximum width of the joint within the run and to a depth indicated in Table 11-1. Some deviation from Table 11-1 may be exercised in the case of longitudinal joints, however, because longitudinal joint widths typically do not increase and decrease with changes in temperature as much as transverse joints – especially if joint ties are used to keep adjacent lanes together. In all cases, the width and depth of longitudinal sealant reservoirs should be kept within the joint sealant manufacturer's recommendations.

Figure 11-37. This new asphalt – placed directly against new precast panels – was barely wide enough to allow proper and uniform compaction.

Installing Longitudinal Joint Sealant

The guidelines presented above for installing transverse joint sealant are applicable to the installation of longitudinal joint sealants as well.

Sealing Longitudinal Joints at Asphalt Shoulders

Special consideration should be given to sealing longitudinal joints at asphalt shoulders because of the effect they have on the total amount of water that infiltrates into the subgrade area. A study conducted at Mn/ROAD, the Minnesota road research test facility, showed proper sealing at these joints could reduce water infiltrating through joints in concrete pavement by as much as 85% (Olson & Roberson, 2003).

Installation of precast pavement along existing asphalt shoulders is unique in that a longitudinal saw cut is typically made in the existing asphalt shoulder pavement approximately 1 inch away from the existing concrete pavement – as discussed in Chapter 8 – to aid in pavement removal and to avoid the damage seen in Figure 8-14. It is common practice to fill that space with cementitious grout immediately after installation of the panels to maintain the shoulder edge under traffic conditions.

Cementitious grout alone will not properly seal this joint because of differential horizontal and vertical movements between the precast panel and asphalt shoulder pavement

(Smith et al., 2014). In preparation for a proper seal, any grout installed in the top 1 inch of this joint during the dowel grouting process (longitudinal joints are typically filled during the dowel grouting process) should be removed to create a proper sealant reservoir (if it was not kept low during grout installation), as discussed above. Hot-poured rubberized asphalt sealant is recommended to withstand the high sealant stresses that develop along these joints (Smith et al., 2014).

On some JCP projects, a new asphalt shoulder is installed against precast panels after they have been installed. Whether the entire shoulder or just a portion is replaced, the joint between the precast panels and the newly placed asphalt should be sealed in a similar manner. In this case, a 1-inch-deep, 1-inch-wide (or less) cut can be sawed after the asphalt has been installed and prior to installation of pourable asphalt sealant, following commonly accepted joint sealant practices.

As with any asphalt pavement, shoulder asphalt should be properly compacted against the new precast panels prior to sawing the sealant reservoir. If only portions of the shoulder need to be replaced, as seen in Figure 11-37, they should be of sufficient width to allow the use of proper compaction equipment during the asphalt placement operations so an effective seal against water infiltration can be created.

Summary

Precast pavement panels may be used as soon as they are installed and grouted, but installation is not complete until all the panels are examined to ensure defects such as spalls, chips, failed dowels, cracks and non-conforming surfaces are corrected. This chapter describes how defects may be remediated and what materials may be used in the process. Panels that are structurally damaged may be replaced with relative ease using a variety of techniques, depending on the precast pavement system used on the project. If dowels in adjacent panels are to be retained in this process, proper attention must be paid to preserving them while the surrounding pavement is removed.

While cracks in precast panels are not common, they can occur if installation procedures are not performed correctly. Cracks in precast pavement may not be identified until the top surfaces of the panels have been examined carefully because most cracks are hairline in magnitude. Hairline cracks are typically not a cause of great concern because the steel reinforcing or pre-tensioned prestressing strands in the panels tend to keep them tightly closed throughout the panels' service life. If cracks are hairline, they may be sealed (to minimize potential for corrosion of reinforcing steel) with methyl methacrylate sealers commonly used for tight cracks in bridge decks. Wider cracks may need to be examined more carefully to determine whether epoxy crack injection or panel replacement is more appropriate.

Joint sealing of precast pavement is typically more challenging than sealing joints in CIP pavement because joints may vary significantly in width. Cold-applied silicone sealants are typically used on most small precast pavement projects because they are easy to install without sophisticated heating equipment. Silicone sealants also work well in wider joints. Hot-applied asphalt sealants are typically used in lane-shoulder joints with asphalt shoulders, and are also popular in all joints on larger projects because they tend to cost less and generally work well in most precast pavement joints.

Chapter 12:
PRECAST CONCRETE PAVEMENT MAINTENANCE REQUIREMENTS

Future maintenance requirements of precast concrete pavement (PCP) are of great interest to agency engineers who have embraced its value for rapid replacement of heavily traveled concrete highways and the enhanced durability characteristics gained during the plant fabrication process. While pavement engineers are well acquainted with maintenance requirements of cast-in-place concrete pavement, little is known about PCP maintenance because experience with it has been limited. Interest in PCP maintenance is further heightened because future maintenance events of any kind are likely to have an even greater impact on traffic flow than did the PCP installation as traffic volumes increase over time.

It is important to examine what maintenance has been required on jointed precast concrete pavement (JPrCP) projects that have been in service for an extended period. One example is the Tappan Zee Bridge Toll Plaza project in Tarrytown, N.Y., which was installed in 2001 and 2002. This is one of the oldest significant JPrCP projects because of its size and its servicing of approximately 140,000 vehicles per day since installation was completed. In 2016, it was taken out of service to make way for a new plaza built specifically for a new bridge at an adjacent location, but it is important to note that the New York State Thruway Authority has reported that minimal maintenance was required to keep the PCP in service during the years it was in service.

Good performance and low maintenance of JPrCP were also reported on at least 11 other projects in the 2013 SHRP2 R05 Report after researchers field-tested and evaluated PCP installations in eight states, including the Interstate 15 project in Ontario, Calif., seen in Figure 12-1. The report also indicated that “development of distress (in precast pavement) is expected to be at a slower pace (than that experienced in cast-in-place pavement), and some of the common distresses may never develop” (Tayabji et al., 2013).


Figure 12-1. Interstate 15 in Ontario, Calif., carries approximately 200,000 vehicles per day and includes high-quality precast panels (seen in the left two lanes) that were installed in a series of eight-hour night work windows.

While this represents reason for optimism, it does not mean that concern for JPrCP maintenance is unfounded. Some JPrCP installed so far has required maintenance. This work has been primarily focused on the features or details associated with initial installation, including replacement of construction-related spall repairs, poorly installed load transfer devices, wide joints and replacement of initially installed joint sealant. While most of these repairs have been minor, they still required some degree of traffic interruption, events that engineers hoped to avoid when choosing precast panels, because excellent performance was expected.

This chapter focuses on maintenance activities that may be unique to or more prevalent in JPrCP. Maintenance required for cast-in-place pavement (such as correction of D-cracking, freeze/thaw deterioration, scaling and loss of surface texture) is covered extensively in other publications and is not discussed here. Replacement of precast panels exhibiting these and other structural issues is discussed.

Typical PCP Features and Conditions Requiring Maintenance

The first maintenance events to occur with PCP will likely be related to features that were not part of the factory-controlled fabrication process, including:

1. Field repairs made at the time of the initial installation (spall repair)
2. Dowel bar (connecting precast to precast) failure related to early degradation of dowel grout, particularly around top-slot dowels
3. Joint grout
4. Joint sealant

Other maintenance events may be related to the following:

1. Maintenance of grout in lifting insert holes
2. Crack maintenance
3. Surface texture maintenance
4. Cracking of panels because of loss of underlying soil support

Some of the conditions listed above may be repaired using the same techniques as those used to repair similar distresses in cast-in-place concrete pavement. There are many good sources that describe these techniques in detail, such as highway agency guidelines, the American Concrete Pavement Association and Federal Highway Administration technical publications. One particularly useful publication on this topic is the Concrete Pavement Preservation Guide (Smith et al., 2014). However, there are some unique issues associated with PCP repair and maintenance that require slightly different techniques than those required for conventional cast-in-place concrete pavement.

Figure 12-2. This digital survey vehicle gathers data while traveling at or near highway speeds.

Identifying and Quantifying Distresses

Traditional techniques for surveying and evaluating distresses and determining appropriate repair techniques for cast-in-place concrete pavement may be used for PCP, but traditional "walk the pavement" shoulder or windshield methods may not be appropriate because of the high volume of traffic typically associated with PCP installations. In many of these cases, it is safer and more appropriate to use vehicle-based pavement imaging and laser-based measuring equipment (digital survey vehicles) that can take high-resolution photographs and video while traveling at highway speeds. Roadway surface data can be extracted from these images and data records by office-based technicians.

A digital survey vehicle is a state-of-the-practice data collection vehicle that may be used to rapidly and simultaneously collect a variety of highway data. One such vehicle, shown in Figure 12-2, collects digital pavement and right-of-way images, longitudinal profiles, roughness and faulting measurements, cross-slope grade and GPS data – all while traveling at or near posted speed limits.

After the data are collected, they are analyzed, quantified and evaluated to determine the quantities and severities of distresses so appropriate decisions can be made regarding

Figure 12-3. Roadway distresses are labeled and quantified on this printout.

which distresses need to be repaired. An example printout of roadway distresses is shown in Figure 12-3.

No amount of automation replaces detailed analyses of historical information compiled during highway design, construction and subsequent maintenance operations. It is particularly important to review as-built information regarding thicknesses of existing pavement surrounding a planned precast repair, as well as any subsequent grinding operations that may have reduced that thickness, as both may affect the planned thickness of new precast panels. Historical thickness data should always be verified by taking cores at appropriate intervals.

Typical Maintenance and Repair Operations

Replacing Construction-related Spall Repairs

One of the earliest and most common repairs required for some PCP panels is the replacement of spall repairs that were made incorrectly during or shortly following initial installation. Spall repairs that are not made using proper partial-depth repair techniques are at risk for premature failure in both precast and cast-in-place concrete pavement. These failures tend to be common in PCP because of the tendency for contractors to "repair" edge spalls with cementitious grout or mortar of the type typically used in JPrCP dowel slots without properly preparing and cleaning the repair area to ensure good bond. Recommended materials and techniques for constructing durable partial-depth repairs are discussed in Smith et al. (2014), Frentress and Harrington (2012) and in Chapter 11.

Figure 12-4. Bond failure between the grout encasing the dowel and the vertical sides of the slot.

Repairing Failed Load Transfer Dowels

Load transfer dowel failure may occur within just a few years of the initial installation if the material – typically a cementitious grout – used to encase the dowels is not proportioned and mixed properly during installation, if the dowel is not fully encased in grout, or if the bond between the grout and slot wall fails, something which is mainly a concern for vertically sided top slots (Figure 12-4).

Failed load transfer dowels must be replaced by cutting new top slots directly over the failed dowels, as discussed in Chapter 11. In this case, the new top slots should be slightly wider than the original slot to ensure the new vertical slot walls are in sound concrete rather than previously installed grout. After the original dowels and grout have been removed, the new slots should be sandblasted and cleaned to provide a surface with good potential for bond development, as typically specified for dowel bar retrofitting.

Figure 12-5. This excessively wide transverse joint resulted from cutting the existing pavement (on the right of the joint) at the incorrect location. The dark material at the center of the joint is backfill grout that spilled onto the adjacent slabs during installation.

Repairing Excessively Wide Grout-filled Joints

Improperly repaired wide joints (Figures 12-5 and 12-6) often require "early" maintenance. In the case of the joint shown in Figure 12-5, the saw cut in the existing pavement was laid out improperly, resulting in concrete being removed over a length that was approximately 6 inches longer than the precast panel it was intended to accommodate. Instead of ordering a longer panel to fill the gap, the resulting wide transverse joint was filled with grout. While this solution may work initially, hairline cracks may develop in the grout material in a relatively short period of time – as seen on a different project in Figure 12-6 – especially if the grout is not installed correctly. In addition, dowels extending across wide transverse joint material (grout) that is not an integral part of the adjacent pavement may not perform as effectively.

One procedure for properly repairing an in-place, excessively wide transverse joint is to cut out an additional section of the existing pavement to make room for an additional precast panel of the proper length. This will allow restoration of effective load transfer across the affected joint. The process for accomplishing this is similar to the one described in Chapter 11 for removing and replacing unacceptable precast panels.

Figure 12-6. Hairline cracks in a 2-inch-wide grouted joint between two precast panels.

Figure 12-7. This 1.5-inch-wide, grout-filled longitudinal joint, located between an existing curb on the left and precast panels on the right, is performing well after being in service for more than five years.

Over-width longitudinal joints that are properly filled with dowel grout – as discussed in Chapter 11 and seen in Figure 12-7 – typically require minimal maintenance. An exception to this may occur when hairline shrinkage cracks have developed (often because of failing to properly "extend" the grout using pea gravel). The life of these grouts may be extended by sealing such cracks with low-viscosity methacrylate sealer, as discussed in Chapter 11.

Figure 12-8. Joint-filling grout between the silicone seal on the left and the panel on the right has de-bonded from the panel, creating a maintenance problem in this variable-width joint.

Figure 12-9. The bond between the silicone seal and concrete failed after approximately five years of service in this constant-width joint. Joint cleanliness problems during installation are suspected.

Maintaining Joint Sealant in Precast Pavement

Restoration of joint seals is one of the first maintenance events that typically occurs in most jointed concrete pavement. The service life of the original sealant varies considerably with the type of joint sealant material, the sealant reservoir quality, prevailing climatic conditions and the quality of the joint seal installation process. The performance of concrete joint resealing installations has been noted to range from two to eight years, or the time until 25% of the sealant installation is no longer functional (Smith et al., 2014). Longer service lives have been observed in some climates for some sealant materials.

Sealant life in PCP may be shorter than with cast-in-place pavement because of the difficulty in creating a joint sealant reservoir with the proper shape factor during the initial joint sealing operation, as discussed in detail in Chapter 11. One example of this is the early sealant failure that sometimes occurs in Super-Slab installations if all the joint-filling grout is not removed when the original sealant reservoir is cut, as seen in Figure 11-30. Early joint sealing failure may also occur – even if all the grout was properly removed – if the sides of the reservoir are not thoroughly cleaned and dried as part of the initial sealing process (Figure 12-9).

Joint seals in PCP may be restored using commonly accepted joint sealing practices – such as those described in the Concrete Pavement Preservation Guide – after the old sealant is removed (Smith et al., 2014). Faces of variable-width joints can be cleaned by thorough sandblasting or by refacing the joints (using concrete saws) to remove old sealant material and other contaminants. The latter technique can be challenging as it requires careful control of the saw.

The presence of unrepaired joint spalls can also contribute to premature sealant failure because they distort the sealant shape factor and may present poor bond potential. For example, the spall seen in the panel on the right in Figure 12-8 is approximately 4 to 6 inches away from the closest dowel, so it is not likely related to any type of dowel bar failure. However, it is a candidate for an edge repair prior to resealing the joint. Joint spalls such as this should be repaired using accepted spall repair techniques and materials as described in Chapter 11 and in the previously referenced Concrete Pavement Preservation Guide. Once the spall repair is complete and the entire joint has been properly cleaned and sandblasted, new joint sealant may be installed.

Figure 12-10. Grout in some dowel grout ports may have debonded here, potentially allowing water to penetrate to the dowel bar level.

Figure 12-11. This bedding grout port was not properly filled during initial panel installation.

Maintaining Grout in Grout Ports and Lift Insert Recesses

Grout ports are formed vertical tubes through precast panels – typically measuring about 1.25 inches in diameter – through which grout is pumped for bedding and filling bottom slots.

It is important to ensure dowel grout port holes are always filled and kept sealed against intrusion of water and de-icing salts to protect dowels from corrosion. Grout that has been approved for bottom-slot dowel applications has also been used to fill bedding grout ports and has generally shown no tendency to erode or wear due to its high strength, good bond characteristics and freeze/thaw durability. However, loss of grout has occasionally been observed at some dowel bar grout port locations (Figure 12-10), most likely because they were filled initially with bedding grout instead of dowel grout.

Grout ports that are no longer filled with grout should be repaired by drilling out the grout to a depth of about 1.5 inches to expose sound material. The port should then be re-filled with high-performance repair material such as epoxy grout or a similar material.

While bedding grout ports are not located near dowels or reinforcing steel, they do penetrate the entire depth of the panels. As a result, they may provide a path for water to reach the subgrade area if they are not kept completely sealed with grout. Occasionally, ports that were never filled correctly in the first place may be found during early distress surveys (Figure 12-11). Any ports that were not filled initially or that exhibit more than 1/2 inch of grout loss or erosion should be repaired using the technique described above.

Grout used to fill round lifting insert holes generally stays in place as well as it does in grout port holes because both holes are about the same diameter. Although lifting inserts provide no function after the panels have been placed, holes cast in the panels to access them should be kept filled, as described above. This prevents degradation of the surrounding concrete and possible intrusion of surface water into the subbase below the panels, which could result in loss of panel support.

Although their use is not recommended, rapid-attaching lifting inserts – such as those seen in Figure 12-12 – have been used on a few PCP projects. Elliptical recesses cast in the top surface of precast panels for these inserts place infill grout at great risk for popping out over time because they

Figure 12-12. SwiftLift lifting inserts are favored by some precasters because they allow quick and safe attachment of lifting cables to precast panels.

Figure 12-13. Recesses required for SwiftLift lifting inserts are elliptical in shape, providing little resistance to grout pop-out.

provide no mechanical resistance to grout pop-out. If such pop-outs are found, the recesses should be retrofitted using accepted partial-depth repair techniques (referenced earlier in this chapter) or repaired with special epoxy grouts in recesses properly prepared for that purpose.

Crack Maintenance

While hairline cracks in PCP panels are likely to be held tightly closed by the panel reinforcing steel, as discussed in Chapter 11, they should be closely monitored over time so any growth in size may be identified. Stable cracks less than .07 inches wide that have not expanded may need no treatment other than what is described in Chapter 11. Cracks that increase in width over time may indicate a more serious condition that may warrant further investigation and full-depth repair or restoration.

Full-depth Panel Replacement

Material-related distress in precast panels may require maintenance just as it does in cast-in-place pavement. For example, poor choice of aggregates may result in D-cracking or early loss of frictional resistance of the surface. Similarly, poor control of entrained air may result in early freeze/ thaw deterioration and improper curing may contribute to shrinkage cracking that may cause early scaling of panel surfaces.

Precast panels are also subject to structural failure or distress related to failing subgrade support. Panels that crack due to loss of support may perform better than unreinforced cast-in-place panels because they are typically heavily reinforced (up to 0.4% by area of concrete in each direction). However, they are still vulnerable to structural failure if subbase support is lost over time.

The most effective technique for addressing precast panel(s) that exhibit the distresses described above is often to simply replace the panel(s), depending on the specific case. Full- depth replacement of precast panels is described in detail in Chapter 11.

Surface Texture Maintenance

PCP surfaces will suffer from vehicle tire wear just like all concrete pavements, so surface textures will likely need to be restored every 12 to 16 years to maintain ride quality and restore surface friction values to agency standards (Smith et al., 2014). Over that period, aggregates may be polished (depending on the hardness of the aggregates) and wheel ruts may develop as a result of abrasion from studded tires.

While workers may grind PCP to maintain surface quality, it is advisable to check pavement thickness and original panel design drawings before doing so to ensure the structural capacity is not compromised. Panels may have already been ground initially by up to 1 inch to meet smoothness requirements, as discussed in Chapter 11. In such cases, additional grinding may also reduce cover over the top layer of reinforcement to less than desirable levels.

Maintenance of Adjacent Original Pavement

A problem commonly associated with PCP is the distress or failure of existing pavement adjoining new precast panels, particularly intermittent repair panels. While this is not a fault of PCP, it may be described as a natural progression of pavement failure that required installation of the new precast panels in the first place. The remedy for such failures is to simply replace distressed adjoining pavement with additional new precast panels. This concept is discussed in detail in Chapter 13.

Summary

Many state highway departments and other agencies have limited experience with JPrCP maintenance due to its relatively brief history as an accepted pavement rehabilitation and construction technique. Completed installations have generally exhibited good performance with little if any maintenance required. Most maintenance needed may be traced to replacement of initial joint spall repairs, joint sealing and field-installed load transfer devices.

PCP will eventually need to be repaired as it ages, just as is the case with cast-in-place concrete pavement. Joint spalls, failed load transfer devices and joint seals may be repaired using techniques similar to those used to repair cast-in-place concrete pavement.

PCP will also need to be monitored for cracks or more serious distresses related to loss of foundation support over time. While the steel used for transportation and handling generally keeps minor cracks from becoming wider, cracks still need to be evaluated and sealed or repaired accordingly. Severely failed panels may be need to be removed and replaced using intermittent repair techniques, as described in other chapters of this manual.

Chapter 13:
FUTURE APPLICATIONS FOR JOINTED PRECAST CONCRETE PAVEMENT

Chapter 3 provides specific examples of where and how "standard" jointed precast concrete pavement (JPrCP) has been used routinely in certain locations to great benefit in the rapid repair or replacement of concrete pavement. This chapter focuses on less widely used variants of precast pavement that may have great potential in future applications. Some of these have been reduced to practice and installed on a limited scale while others are still in conceptual or developmental stages.

The intent of this chapter is to highlight how current JPrCP technology can be modified to meet unique needs as they become apparent on future projects. In addition to the information presented here, designers and owners are encouraged to review the National Precast Concrete Association (NPCA) and Precast/Prestressed Concrete Institute (PCI) websites for current information on the latest technology related to new uses of precast concrete pavement (PCP).

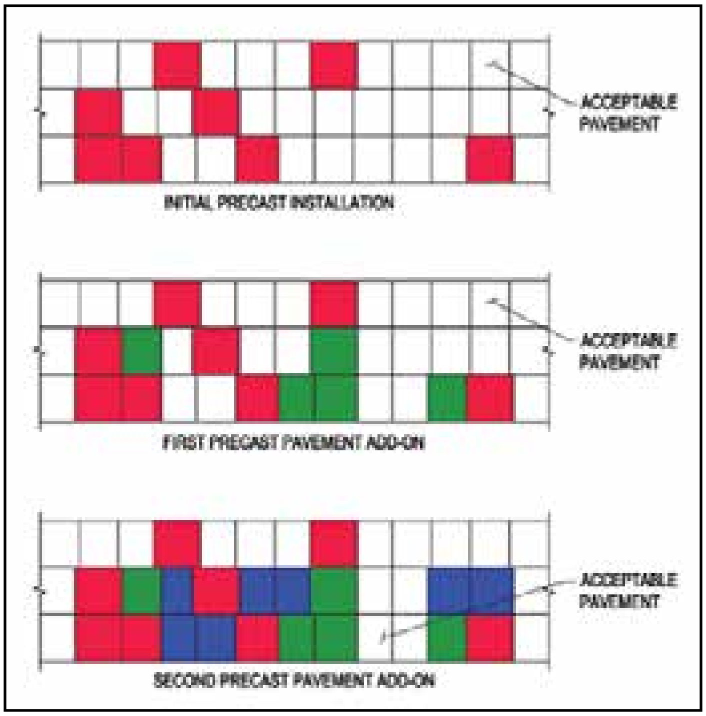


Figure 13-1. Sketch showing incremental addition of precast panels to previously placed panels.

Addable Precast Concrete Pavement

The reasons for placing precast panels intermittently on heavily traveled concrete roadways are discussed in Chapter 3. Recently, it has become clear that it is sometimes beneficial – if not necessary – to add new PCP panels to panels that were placed intermittently several years before as the existing concrete roadway around the originally placed precast panels continues to deteriorate.

The concept of incrementally adding to previously placed PCP panels is demonstrated in Figure 13-1. The first plan view shown in Figure 13-1 shows new (red) precast panels placed intermittently (as needed) in a concrete roadway that is generally in good condition. This represents the current type of intermittent PCP repair activity that has occurred in roughly half of the states in the U.S. to date. The next plan view shows (green) precast panels placed (again, as needed) about 7 years later between or adjacent to previously placed precast panels and existing pavement that is still in "good" shape. The blue panels shown in the third plan view represent yet another intermittent placement of precast panels that once again occurred about 7 years after the green panels were placed.

Chapter 9 describes how load transfer devices are typically installed between precast panels and adjacent existing pavement. What is not presented in Chapter 9 or shown in

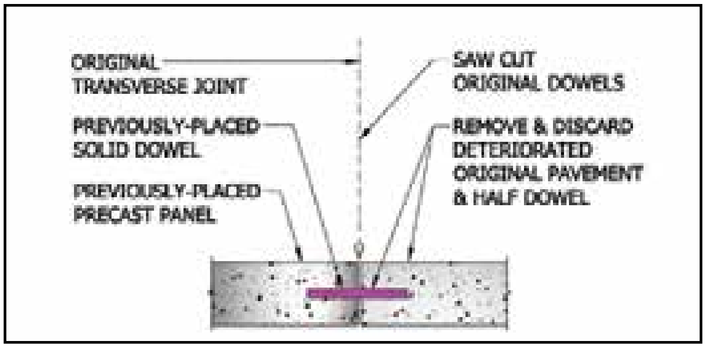


Figure 13-2. The original pavement dowels in this sketch are cut to allow removal of deteriorated pavement to the right of the joint.

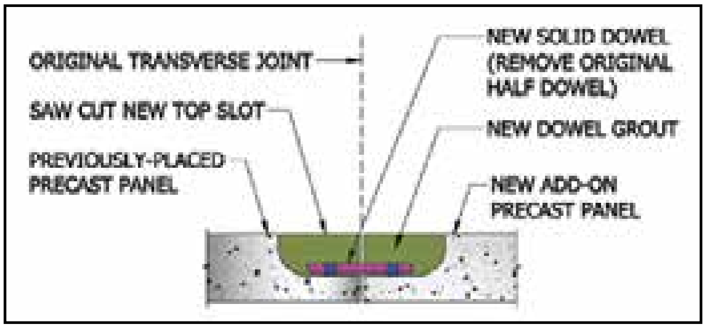


Figure 13-3. Sketch showing how a new slot may be cut to remove previously placed dowels to make room for new dowels between precast panels.

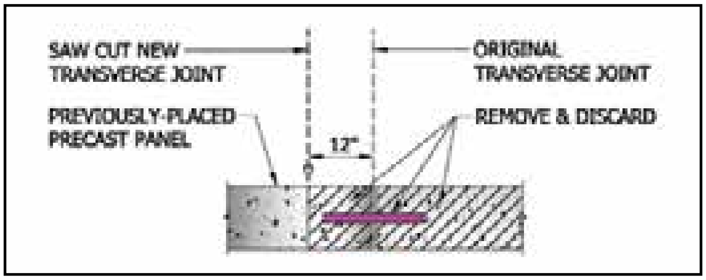


Figure 13-4. Sketch showing removal of 1 foot of previously placed panels so new dowels may be installed.

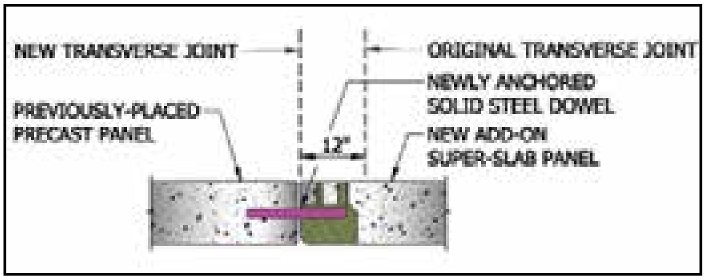


Figure 13-5. The removed 1-foot section of the previously placed precast panel is replaced with a new precast panel.

Figure 13-1 is how load transfer can be established between newly installed and previously placed precast panels.

One method is to expose the dowels embedded in previously placed panels by chipping the existing pavement away from them. This allows placement of new bottom-slot panels over them. This process isn't practical on a large scale because it is labor-intensive and requires new, likely custom-made panels with slots that exactly match existing dowels that are not visible. Three methods that are more practical are covered in the following paragraphs.

Dowel Bar Retrofit Method

A standard method of establishing load transfer between previously placed panels and newly added panels is to use the dowel bar retrofit method described in Chapter 9. In this case, workers cut through the originally placed dowels when sawing the transverse joint to allow easy removal of deteriorated existing pavement (Figure 13-2). After new replacement or add-on precast panels are placed, new top slots are cut in both adjacent panels to enable removal of the cut half-dowels remaining in previously placed panels. This process also enables installation of new dowels (Figure 13-3).

This method of establishing load transfer is generic and can be used to add onto top-slot, bottom-slot or middle-hole precast panels. However, this method may not be appropriate or desirable for use on some projects because significant time is required to prepare the slots, install the dowels and encasement grout, and allow the grout to cure, as discussed in Chapter 9.

Bottom Slot and Solid Dowel Method

Another method of establishing load transfer between add-on panels and previously placed panels was developed specifically for the Super-Slab system on a New York State Thruway Authority (NYSTA) project in 2014. Because solid steel dowels were used to connect precast panels to existing pavement about 7 years prior, NYSTA decided to saw cut previously placed panels approximately 1 foot away from the transverse joint just behind the dowels – as seen in

Figure 13-6 A flanged nut is welded inside both ends of a tubular stainless steel Super-Dowel, shown at right. An epoxy-coated tubular carbon steel dowel, capped and ready for installation, is pictured on the left.

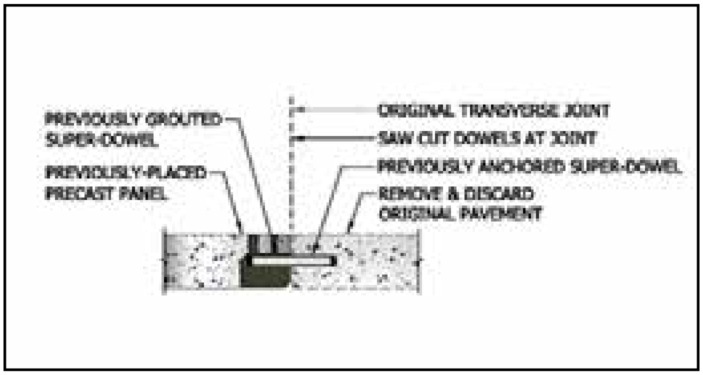


Figure 13-7. Sketch showing how a removable dowel, previously placed in the existing pavement, is cut to aid in removal of existing pavement and the half dowel remaining in the previously placed panel.

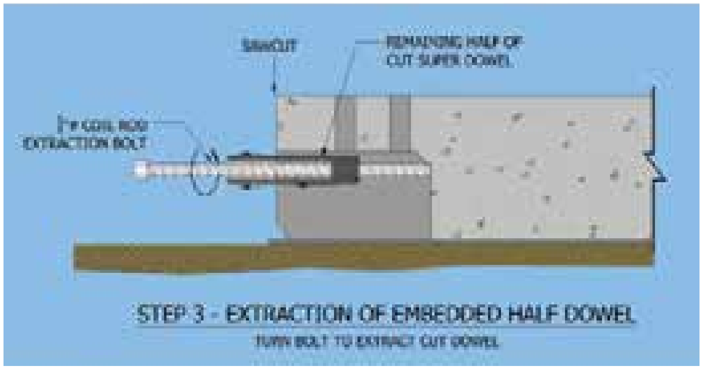


Figure 13-8. Sketch showing half of the original Super-Dowel being removed from the original encasement grout.

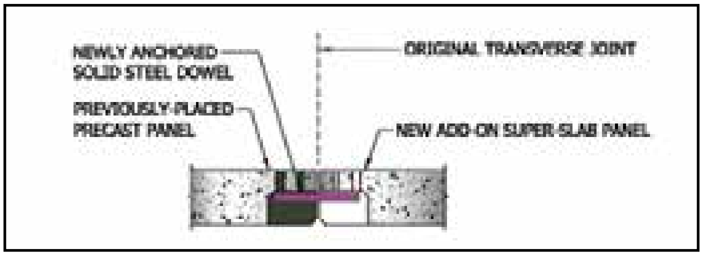


Figure 13-9. A new solid steel dowel is epoxy-anchored in the hole left by removal of the half Super-Dowel from the previously placed panel on the left. The exposed half of the new dowel is ready to be grouted in the bottom slot of the new add-on panel on the right.

Figure 13-4 – to allow efficient removal of the old pavement and installation of new dowels. Once the old pavement was removed and holes were drilled, new dowels were epoxy-anchored into previously placed panels and new bottom-slot panels were placed over them (Figure 13-5).

While this is an acceptable method, it is time-consuming and costly because approximately 1 foot of the previously placed panel is discarded and replaced with new precast just to facilitate installation of new dowels.

Bottom Slot and Removable (Hollow) Dowel Method

In response to the costly add-on method described above, The Fort Miller Co., Inc. established a more efficient method by developing a new removable dowel. The proprietary Super- Dowel, fabricated from schedule 40 steel pipe, is outfitted with flanged nuts welded in each end, as seen in Figure 13-6.

This method requires Super-Dowels to be used between new precast panels and the existing pavement in the first installation shown in red in Figure 13-1. When the time comes to add a new precast panel to the previously placed one (red to green in Figure 13-1, for example), the dowels in the original joint are cut, as shown in Figure 13-7. The half dowels left embedded in the previously placed precast panel are then extracted by threading an extraction bolt into the end nut and continuing to turn the bolt as the half-dowel is extracted (Figure 13-8). This allows workers to epoxy-anchor new conventional (solid) steel dowels or Super-Dowels in the same locations. Once the new solid dowels are anchored in the previously placed precast panel, a new bottom-slot panel can be added, as shown in Figure 13-9.

The possibility of easily adding new precast panels to previously placed ones may have a significant impact on

Figure 13-10. An example of city street pavement with many utility cuts (First Avenue, New York City).

Figure 13-10. An example of city street pavement with many utility cuts (First Avenue, New York City).

future strategies for replacing and maintaining concrete pavement on some of our most heavily traveled urban arterials because it allows for the continued use of previously placed precast panels (that will likely provide decades of additional service) and maximize use of the original surrounding concrete pavement.

Reusable Urban Pavement

Many city and metropolitan agencies have experienced difficulty maintaining pavement along city streets that have been repeatedly cut to gain access to underlying utilities for repair and replacement. The result of such activity is often a patchwork of various types of pavement repairs that are unsightly and rough, as seen in Figure 13-10. To make matters worse, some of the material used to patch such areas has not been durable, soon requiring repair and replacement ("fixing the fix," as mentioned earlier in this manual). There is a need for durable pavement systems that can be removed, to allow work on utilities below, and replaced, such that the functionality and aesthetics of the original pavement are restored.

In response to this need, the removable urban pavement (RUP) system was developed in France by a team of researchers at the Central Laboratories for Bridges and Roads and was installed in the cities of Saint- Aubin and Nantes, France, in 2005 and 2007, respectively. This system included a specially designed subbase and, in the case of the Nantes installation, a non-grouted keyed joint that provided load transfer between adjacent panels. This dry-laid concept allows pavement units to be disassembled piece by piece as necessary, thereby facilitating access to underlying utilities. It also allows subsequent reassembly and restoration of the pavement surface after repairs to utilities below are completed (De Larrard et al., 2013).

Figure 13-12. Super-Paver unit being installed over Super-Dowels in adjacent units.

A more recent RUP development is the Super-Paver system that was developed in the U.S. by The Fort Miller Co., Inc. in 2011 (Figure 13-12). This system features relatively small (e.g., 6 foot by 6 foot) square or rectangular precast panels

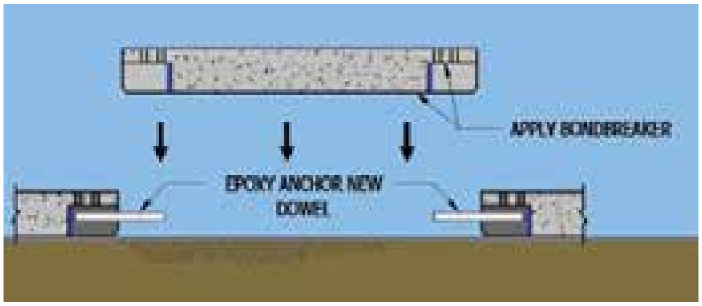


Figure 13-13. Schematic showing a restored Super-Paver unit being installed over new Super-Dowels epoxy-anchored in adjacent panels.

that are cast with a modified version of standard Super-Slab bottom slots on all four sides to allow panels to be placed vertically over Super-Dowels anchored in adjacent Super-Paver panels, as seen in Figure 13-13. Load transfer is accomplished when structural grout is pumped into grout ports in each slot. This procedure is similar to adding onto previously placed precast panels except that new Super-Dowels – rather than standard solid steel dowels – are installed between precast panels.

Individual panels can be removed from an assembly of Super-Pavers (to provide utility access, for example) by first cutting through the dowels and tie bars (if used) around the perimeter of the panels. After removal, panels are restored to their original condition by removing structural grout from the bottom slots and bedding grout from the bottom surface of the units. New dowels are installed by first removing the half dowels still residing in the undisturbed surrounding pavement, as shown in Figure 13-8, and anchoring new, full-length Super-Dowels in the same location. The removed, “cleaned-up” panel is then reinstalled in the same fashion in which it was originally installed (Figure 13-13).

The first full-scale project constructed using the Super-Paver system is located at the utility-intensive Broadway Junction subway station in Brooklyn, N.Y. All the panels installed on the project were designed to be removable and replaceable, as described above. Removable precast pavement may be used on more future projects as the value and practicality of the process becomes more widely known and understood.

Overlay and Inlay Precast Panels

Cast-in-place (CIP) concrete pavement installed as an overlay on existing concrete (and in some cases, asphalt) pavement has attracted attention in recent years as a cost-effective alternative to full-depth replacement of concrete roadways.

More recently, precast pavement has been considered for the same reason, particularly in areas where traffic cannot be detoured long enough to allow installation of “conventional” CIP concrete overlays.

Precast Overlays

CIP overlays are typically placed on top of existing pavement, lane by lane, while traffic is detoured around the paving operation. The resulting drop-off between the overlay and existing pavement is typically managed by various patterns of traffic staging techniques and delineation devices that are left in place for the number of days required for new concrete to cure.

Precast panels may also be installed as an overlay in a similar manner, but drop-off management may be more problematic because precast pavement, typically installed in relatively small areas (compared to CIP overlays), requires nightly changes in traffic delineation. Drop-off management is especially problematic when traffic needs to cross newly placed precast panels, as is often the case in intersection replacement, one of the locations where a precast overlay may be most advantageous. Because of the difficulty of drop-off management, however, precast overlays are not likely to be used in these locations on a widespread basis.

Precast Inlays

Rather than placing precast panels on top of existing pavement as an overlay, the existing pavement may be removed or milled out to allow installation of the new panels as an “inlay.” This concept simplifies traffic management since the new and old pavement surfaces are flush or nearly flush with each other, eliminating or minimizing drop-off management and making precast pavement inlay more useful as a pavement replacement option where heavy traffic is involved.

JPrCP panels have already been widely used – particularly in California – as a "type" of inlay replacement for existing concrete pavement, as discussed in Chapter 3. However, rather than milling out the existing concrete pavement to allow installation of the new panels, all the existing pavement is removed with excavators, making this process essentially a full-depth replacement of the existing pavement. The installation is like inlay installation, however, because the new precast panels are placed on existing "pavement," in this case existing cement-treated base (CTB) material or new lean concrete base (LCB) material.

The concept of placing new "inlay" JPrCP panels on newly installed LCB has proven to be largely successful on many large projects in California. While specific details concerning the accuracy of the new lean base profile and the type and amount of bedding grout placed under the new panels are still evolving, it is likely that many more future projects will specify this method.

Precast Inlays in Existing Asphalt Pavement

CIP concrete inlays in asphalt pavement have been installed successfully in many locations throughout the U.S., commonly in the form of thin (4 to 8 inches thick) or ultra-thin (less than 4 inches thick) concrete overlays. Precast is now being considered in some locations where traffic flow cannot be diverted long enough to allow conventional concrete to cure. This concept is potentially more cost-effective than the full-depth type of replacement referenced in Chapter 3 because it requires less concrete and uses existing remaining asphalt as a useful base for the new panels.

Pilot Precast Panel Inlay Project

While installation of thin precast panel inlays has not been attempted in the U.S., the Ministry of Transportation (MTO) in Ontario, Canada, is currently considering the use of ± 8-inch-thick (203-millimeters-thick) precast panels to "harden up" the surface of thick asphalt pavement on certain portions of Highway 401 around Toronto, Ontario, where heavy truck traffic creates deep wheel ruts in freshly milled and filled asphalt pavement in as little as three years after installation.

Figure 13-14. A transverse saw cut being made at the terminus of a single night's installation. An additional saw making the longitudinal cut is seen in the background.

To test the concept, the Ministry installed a pilot project on Highway 400 in Barrie, Ontario, in September 2016. One of the main objectives of the 328-foot-long (100-meter-long) project was to prove that it is possible to mill out enough asphalt – starting at about 10 p.m. – fast enough to place new, 12-foot-by-15-foot-by-8-inch-thick (3.7-meter-by- 4.6-meter-by-205-millimeter-thick) precast panels in time to reopen the highway to traffic by 6 a.m. Another main objective was to determine which of three different grade control and bedding methods used on the project was the most efficient and showed the most promise for future projects. A third major objective was to determine how accurately the milling machine could mill the asphalt surface in the hope that new precast panels could be placed directly on the milled surface.

The entire project was completed in four nights. On the first night, the contractor sawed around the perimeter of the repair area and sawed transversely at the anticipated terminus points of each night's installation (Figure 13-14). The milling machine milled the full 8 to 8.5 inches (205 to 220 millimeters) depth in a single pass at the approximate rate of 10 to 20 feet (3 to 6 meters) per minute, as seen in Figure 13-15.

Figure 13-15. A 1.2-meter-wide milling machine makes a full-depth pass.

Figure 13-16. A moisture sensor and load cell being installed.

A research team from the University of Waterloo placed a load cell and a moisture sensor under one panel in each support condition area, as shown in Figure 13-16, to monitor moisture intrusion and panel behavior over the next two years. After the instrumentation was installed, the panels were placed at a rate of about 7 to 8 panels per hour, as seen in Figure 13-17. As expected, the installation crew improved their installation rate with each successive night as crew members became familiar with the process.

If this pilot project performs successfully over the next few years, the concept may be of great value to the MTO as well as department of transportation and highway agency personnel in other states and provinces as they work to maintain surface quality on many heavily traveled asphalt highways.

Figure 13-17. A precast panel being placed in the grade-supported section of the project.

Pervious Precast Concrete Pavement Panels

Pervious CIP Concrete

Pervious concrete is a mixture of open-graded coarse aggregate, cement paste, admixtures, water and small amounts of fine aggregate (when higher compressive strengths are desired). The concrete used in pervious pavement is designed to have a void content of approximately 15% to 25%, depending on the application. If it is used to drain only the rainwater that falls on the pavement, a void content on the lower end of the range is adequate. Higher void contents are more appropriate when water from adjacent pavements or surfaces are pitched to discharge on to the pervious pavement.

Pervious concrete pavement is used for parking lots, alleys, driveways, sidewalks (Figure 13-18) and some low-volume roadways as an effective means to manage stormwater runoff by allowing it to percolate through the pavement into a storage layer or the subgrade below. This helps to avoid flooding by reducing excessive stormwater flow in gutters, catch basins and storm sewers. In addition to removing

Figure 13-18. The sidewalk in this photo consists of pervious precast panels.

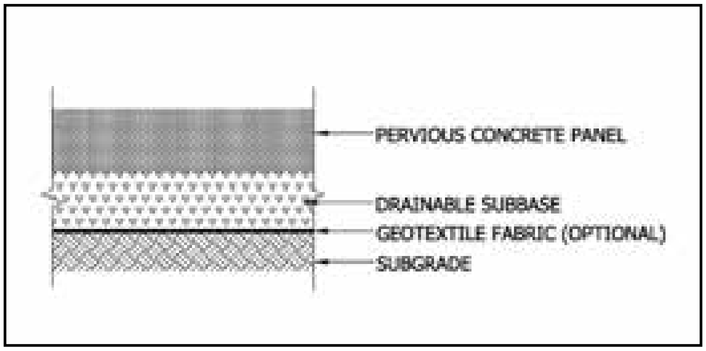


Figure 13-19. Sketch showing the components of a typical pervious pavement system.

rainwater, pervious pavement is considered environmentally friendly because it traps suspended solids and filters pollutants from runoff.

The effectiveness of pervious concrete in removing rainwater and runoff is highly dependent on the collection layers below it. Pervious concrete pavement is typically placed on a drainable, 6- to 12-inch-thick aggregate base consisting primarily of 1-inch crushed stone aggregate. The aggregate base serves to receive and store water percolating from above until it seeps through the underlying soil or is diverted to additional drainage areas through under-drains placed at the bottom of the drainable base.

In addition to developing a concrete mix of sufficient void content, a proper design includes consideration of the amount of expected rainfall, an appropriate thickness of drainable base and the drainage characteristics of the underlying soil. The combination of the pervious pavement, drainable base, geotextile fabric and auxiliary under-drain – if needed – make up a pervious pavement system (Figure 13-19).

Pervious Precast Pavement

There is an increasing interest in precasting pervious concrete because manufacturers can accurately control the size, gradation and moisture content of the aggregates as well as the water-cement ratio of the mixture and mixing, casting and curing procedures. Another reason for this interest is that pervious precast pavement can be used immediately upon installation without concern for field casting and curing.

While these are important benefits, there are challenges associated with installing pervious precast pavement in the field. Like standard precast pavement panels, pervious panels must be installed to the correct grade such that surfaces of adjacent panels match properly. Additionally, they must be fully bedded and supported, and, in the case of panels used for roads with heavy trucks, load transfer dowels must be placed between adjacent panels.

The standard methods for providing full bedding and support to standard precast panels are to install “accurately graded” fine bedding material and cementitious bedding grout between the bottom of the panels and the subgrade or to install only cementitious bedding grout directly on top of the subgrade layer after the panels have been adjusted to grade, as described in Chapter 9. However, these methods do not work well for installation of pervious precast panels. Fine bedding material will likely wash into the porous subgrade material over time unless geofabric is used between the bedding material and the porous base. Even in that case, cementitious bedding grout will create an impervious layer

Figure 13-20. Non-planar, specially shaped precast panels were manufactured to meet the adjacent granite curb and pronounced surface contours while providing continuous commercial access.

under the panels, defeating the purpose of the pervious panels. Bedding grout alone will also percolate into the porous subgrade material during installation, when it is still in a fluid state, also defeating the purpose of the pervious panel.

Pervious precast panels can be installed on existing, well-graded "sand" layers that exist naturally or are installed in a subbase layer. If sand is used as a subbase material, consideration should be given to the adequacy of the aggregates and other materials below it to store runoff water as intended.

Inclusion of load transfer dowels across transverse joints of pervious precast pavement – necessary in more heavily traveled roadways – offers another challenge. Details to prevent dowel grout placed in bottom slot panels from penetrating into the drainable base must be developed. In addition, pervious concrete mix designs must have sufficient strengths to accomodate dowel load transfer systems.

Although there are challenges associated with the manufacture and installation of pervious precast pavement, they can and likely will be overcome as users embrace and demand the benefits provided by manufacturing panels in controlled conditions, and master field placement and bedding processes.

Precast Panels for Industrial Use

Most industrial operations can be shut down long enough for floors, aprons, building approaches, driveways and other traffic-intensive throughways to be replaced by casting concrete in place. However, there are occasions when precast panels are extremely beneficial in industrial applications due to time constraints or other conditions.

Commercial Driveways

Business establishments that depend on frequent deliveries and shipments are particularly sensitive to any interruption relating to access to and from their properties. Because of this, municipalities are sometimes forced to provide adequate, uninterrupted temporary throughways when street and highway improvements are made adjacent to their facilities. One example of this application occurred in Mamaroneck, N.Y., when a roadway in front of busy commercial properties was rebuilt. Access to those properties was provided around the clock during construction by installing precast panels that could be used immediately upon installation. Many of the specially shaped precast panels were also significantly warped to meet severe contour requirements, as seen in Figure 13-20.

While precast panels for commercial driveways have not been used extensively to this point, they may be of great value on future projects where commercial traffic to and from business facilities must be maintained at all times during reconstruction of adjacent roadways and streets.

Acid- and Abrasion-resistant Industrial Floor Panels

JPrCP panels may be used to good advantage in unique industrial applications where chemicals and abrasive agents accelerate deterioration of conventional concrete. Unique concretes involving special aggregates, cements, polymers, admixtures and mixing techniques – required for some

Figure 13-21. Mixed polymer concrete being discharged from a mixer into a concrete bucket.

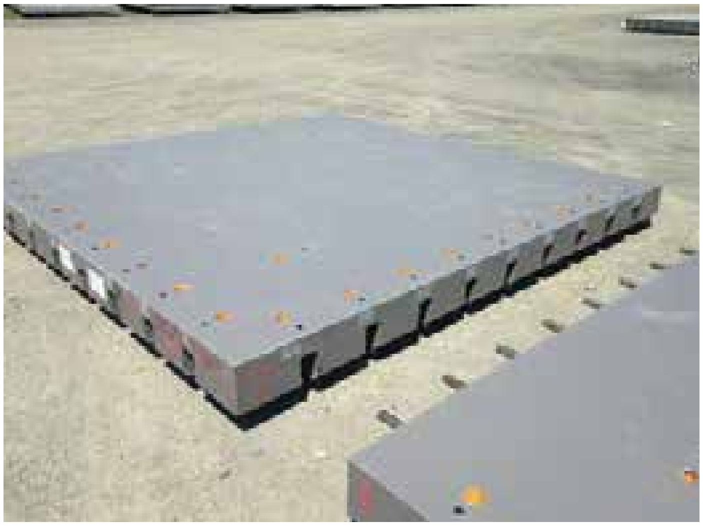


Figure 13-22. Finished panels stored at the precast yard prior to shipment to the job site.

applications – may be easier to make at precast plants that are equipped to source, store, mix and cast “exotic” concrete materials for various special applications.

One example of this application is the fabrication and installation of 10-foot-long, 10-foot-wide, 8-inch-thick precast panels made with polymer concrete for a lead battery recycling plant in New York state. The original CIP concrete floor showed signs of serious deterioration after about five years of use due to abuse from spent battery fluid (consisting of up to 20% sulfuric acid), heat generated from piles of broken batteries and heavy solid-tire loaders that handled lead battery debris. Complicating matters further, the facility worked up to 24 hours per day and, at times, seven days per week.

The solution was to manufacture JPrCP panels made from polymer concrete using chemicals and technology developed by Corrosion Engineering of Jackson, Miss. The Tufchem Epoxy Polymer Concrete used in the panels was a three-component, epoxy-based polymer concrete mix consisting of an epoxy resin, epoxy hardener and blended inert aggregate (mainly quartz) with a maximum size of 3/8 to 1/2 inch. This material was chosen for its chemical resistance to sulfuric acid, low shrinkage, low exothermic properties and high resistance to abrasion.

After the polymer concrete was mixed in a horizontal-paddle grout mixer at the precast plant, it was discharged into standard concrete buckets for delivery to the forms (Figure 13-21). All the equipment, including the mixer, concrete bucket, forms, screeding tools and finishing tools required cleaning with an acetone-based solvent after every use. Workers were required to wear masks and other protective equipment because of the noxious fumes generated by the process.

The panels were cast with standard Super-Slab details including bottom slots on two sides of each panel and cast-in dowels on the other two sides, as seen in Figure 13-22. Stainless steel reinforcing bars, lifting devices and dowels were used in lieu of standard epoxy-coated steel because of the extremely corrosive environment. At the job site, panels were placed on a bedding layer of fine granite aggregate that was precisely graded to an accuracy of ± 1/8 inch to provide grade control. The same resin and hardener components were used with appropriately sized aggregate for both the bedding and dowel grouts. The resulting floor should provide years of service under the extreme conditions present at this site.

Instrumented Pavement

Concrete pavement has been a highly effective host for a

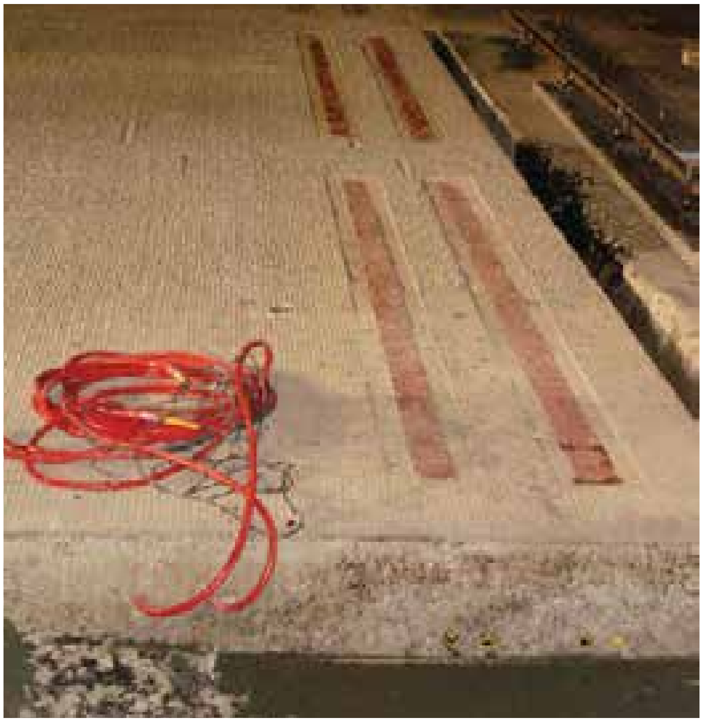


Figure 13-23. Construction photo showing night-time installation of an open-road-tolling precast panel at a New York State Thruway toll plaza in 2006.

Figure 13-24. Overhead open-road-tolling equipment integrated with treadles embedded in precast panels below at New York Thruway Spring Valley toll plaza.

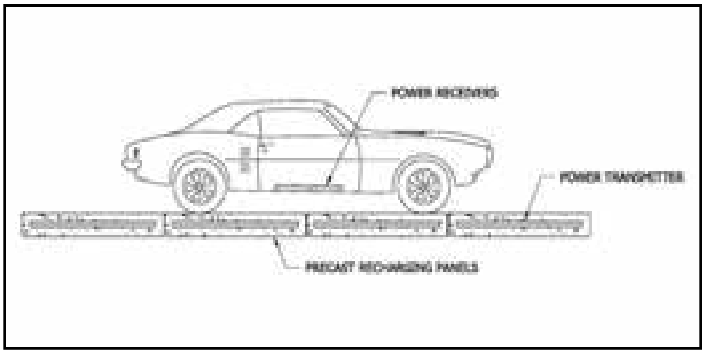


Figure 13-25. A schematic of battery-charging roadway panels constructed with PCP panels.

wide variety of embedded devices and instruments for many years. For example, mechanical treadles have been embedded in concrete pavement for to aid in collecting tolls. Precast concrete panels have recently been used (because they could be installed overnight) to house more sophisticated treadles that are designed to work with overhead sensors for open-road-tolling purposes, as shown in Figures 13-23 and 13-24. PCP panels have also been used on many projects in New York state in recent years to house weigh-in-motion (WIM) equipment, as discussed in Chapter 3. Other possible future applications for instrumented and multi-function pavement are presented in the following sections.

Battery-charging Roadway Panels

The increasing use of electric vehicles in the U.S. and other countries has resulted in a need for efficient and rapid recharging of the batteries that power them. Most recharging facilities are plug-in stations located at homes, offices or other convenient locations. A charge at a home-based, 120- volt charging location typically takes one hour per 25 miles of charge or up to 10 hours for a complete recharge. Special, high-speed charging stations may completely recharge a battery in as little as one hour, but these require a cord, power source receptacle and a timeframe during which the vehicle is unusable.

While plug-in recharging units may be adequate for commuters that travel limited distances, faster charging rates are needed for commercial electric vehicles such as taxis and battery-powered public transportation buses. Functionality of both types of battery-powered vehicles is severely impacted if they must be parked and plugged in for long periods of time. Dynamic charging (charging while the vehicle is in motion) eliminates parked charging time and may also reduce the required size of the vehicle battery if such facilities are appropriately placed along travel routes.

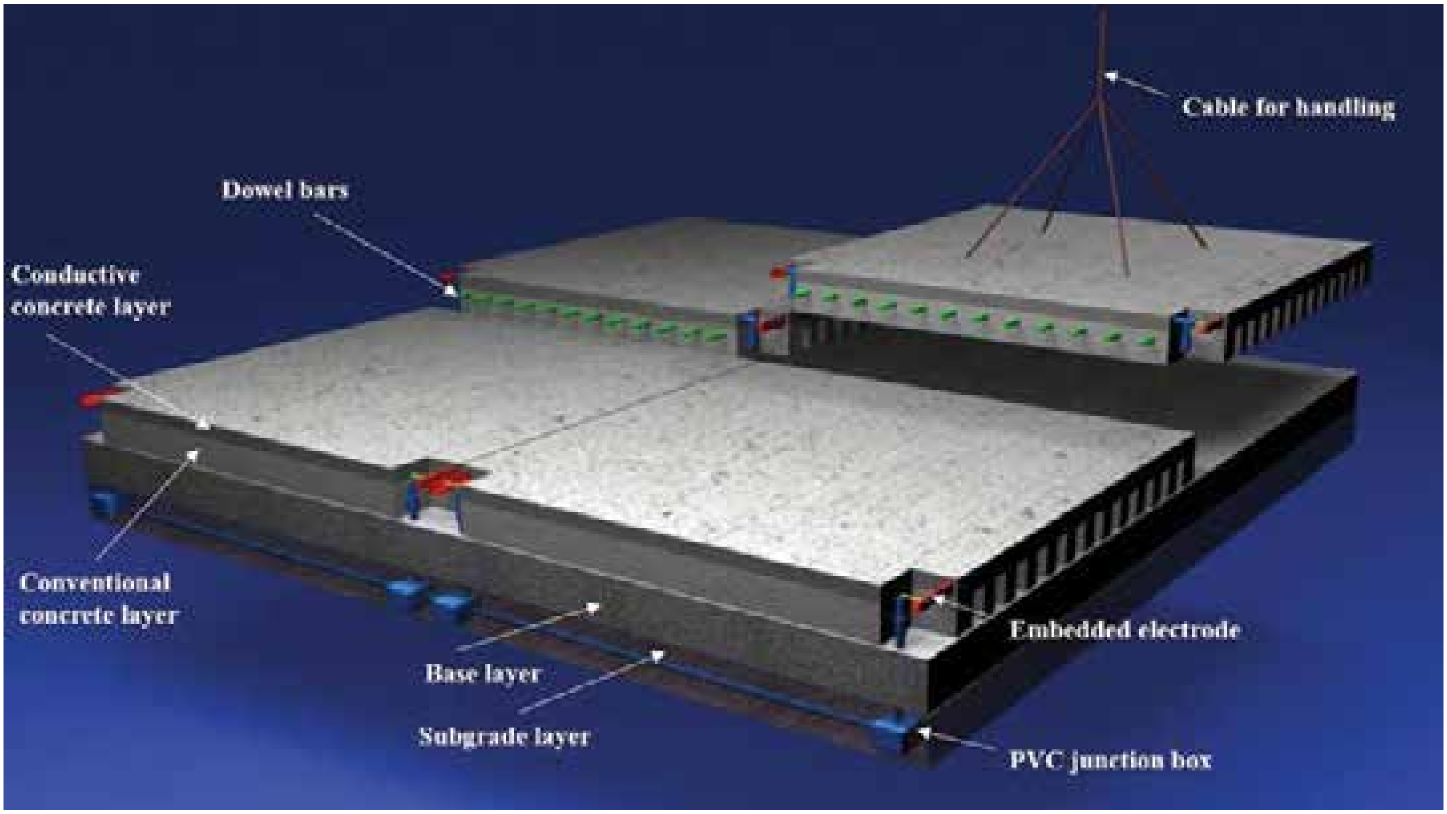


Figure 13-26. This rendering of heated slabs shows how embedded electrodes are placed along two opposing slab edges. Electricity flowing through conductive concrete from one electrode to the other heats the top concrete layer.

In recent years, researchers in Asia and Europe have independently developed methods of wireless power transfer from equipment embedded in roadways to receiving equipment attached to battery-powered buses and taxis. In late 2015, Montreal, Quebec-based Bombardier adapted their technology for commercial use for a project in Brunswick, Germany, where two buses traversing an approximately 7-mile route recharged their batteries at bus stops equipped with inductive charging equipment.

Inductive charging stations consist of charging pavement panels equipped with embedded primary coils that create magnetic fields when charged with electricity. Power from the magnetic field is inductively transferred to power- receiving equipment mounted on the underside of the vehicles when they are parked over or when they pass over the charging panel (Figure 13-25).

Precast Recharging Panels

Factory conditions and the trained technicians available in precast plants make them ideal facilities in which to manufacture battery-charging roadway panels. Precast forms fabricated to very tight tolerances and specialized installation equipment aids skilled precast workers in placing primary coils and equipment with the precision necessary to make them perform at maximum efficiency and to maintain the required cover to ensure long-term protection of the induction equipment against moisture, de- icing salts and other potential sources of attack.

Durable concrete that provides long panel life and long- term protection for the embedded charging equipment is vital for precast recharging panels. It's also important to use panel reinforcing, load transfer dowels and lifting devices that are compatible with embedded charging equipment (e.g., in some cases, glass fiber-reinforced plastic or similar reinforcement may be required). Certified precast plants are typically well-equipped to manufacture high-quality concrete and to provide and install specialized reinforcing and devices.

Precast recharging panels are not limited to the bus recharging pads developed so far. Smaller-scale panels may be developed in the future for other electric vehicles such as taxis, delivery vans and cars, opening new markets for precasters to pursue.

Heated Precast Pavement

Snow and ice on concrete sidewalks and pavements in northern climates are typically removed with de-icing chemicals such as calcium chloride and sodium chloride, both of which are labor-intensive to apply as well as messy and potentially damaging to concrete surfaces. In addition, many de-icing agents are harmful to vegetation and may be major pollutants to groundwater aquifers when used in large quantities.

A more environmentally friendly way of removing ice and snow from pavement and other surfaces is to heat them during snow and ice events. Heated pavement systems that have been installed to date include electrically resistive heat cables, pipes through which heated water is circulated and electrically conductive materials – included in the concrete mix – that generate heat when electricity is transmitted through them (Abdualla et al., 2016).

While the practicality of heating cables and hydronic systems may be questionable, recent developments in electrically conductive paving materials appear to be promising. An efficient, electrically conductive material developed at Iowa State University uses carbon fiber-infused concrete sandwiched between specially designed electrodes – as seen in Figure 13-26 – to generate enough heat to melt snow and ice when electricity passes between the two electrodes. Voltage is controlled to produce the necessary heat required to remove snow and ice as it accumulates on the pavement.

Iowa State researchers suggest the costly conductive concrete be placed as an overlay on conventional concrete pavement that serves as a structural platform for the heat- producing layer. They further speculate the structural layer may preferentially be precast rather than CIP so that the quality of the structural layers may be enhanced. Additionally, placement on real projects may be facilitated since such a two-layer precast system may be used immediately upon installation. While such systems may be too costly for ordinary roadways, they may be cost-effective for such applications as airport runways and taxiways, where safety is of utmost importance (Abdualla et al., 2016).

More research and cost analysis will need to be conducted before this concept is fully proven to be practical on a large-scale basis, but there may be significant potential for use once it is fully developed.

Solar Power-generating Pavement Panels

Solar power generation is generally perceived as a sustainable way to harvest energy from the sun. As such, generating power from photovoltaic panels mounted on roofs or specially designed supports arranged in field-sized arrays has gained popularity over the last few decades.

However, effective energy-harvesting farms may require acres of costly land that must be exclusively devoted to that purpose for as long as they are kept in service. Recent efforts to develop multipurpose energy-harvesting areas have focused on using committed areas, such as bikeways, parking lots, driveways and even roadways, as a strategy to save the cost of land devoted only to that purpose.

U.S.-based Efforts

One U.S.-based company that has been working to develop solar power-generating vehicle panels is Solar Roadways Inc. Founded in 2006 by Scott and Julie Brusaw in Sandpoint, Idaho, Solar Roadways has been working to develop roadway pavements that house photovoltaic power-generating cells under transparent textured glass surfaces. In addition to containing power-generating cells, the hexagonal-shaped structural panels also include LED lighting for highway striping and roadway lighted signs that are actuated by

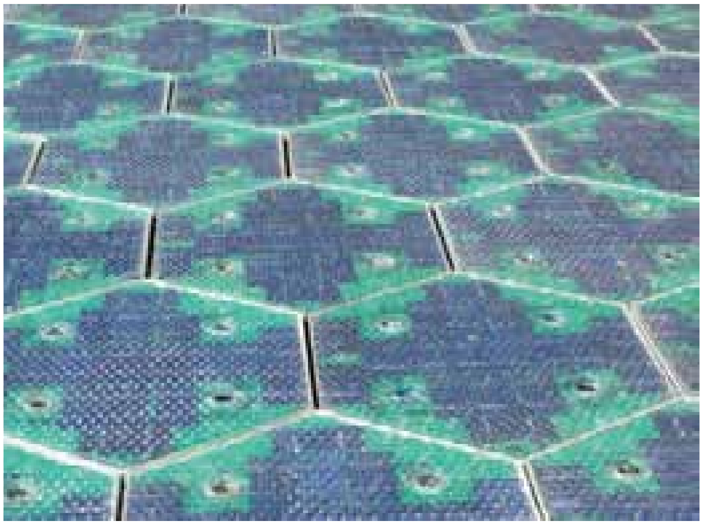


Figure 13-27. LEDs and other electronic elements can be seen through the transparent surface of the hexagonal-shaped Solar Roadway panels.

Figure 13-28. Bikers traveling on SolaRoad power-generating panels.

integrated circuit controls – all connected to an exterior grid that collects and transmits power (Figure 13-27).

Solar Roadways demonstrated the feasibility of including power-generating cells in roadways by building a 12-foot-wide-by-36-foot-long parking lot under a Small Business Innovation Research grant received from the U.S. Department of Transportation in 2011. The structural cells, fully equipped with solar cells, LED lighting, heating elements and textured glass, were supported by a CIP concrete foundation that included an adjacent stormwater-collecting trench as well as a utility corridor that housed circuit controls and power-collecting cables. The Brusaws envision the use of PCP panels on future installations as a platform to house panel attachment devices and cable connections for power-generating cells.

European Efforts

The province of North Holland, in conjunction with Netherlands-based engineering firm TNO, Ooms Civiel and Dynniq introduced their concept of solar power-generating pavement panels in 2009. Their method uses crystalline silicon solar cells nested under a 1-centimeter-thick layer of textured and transparent safety glass. After feasibility studies and laboratory testing of a working prototype were completed, a more advanced version of the concept was developed in 2011, culminating in the 2014 installation of a working test project on a bike path near the town of Krommenie (Figure 13-28).

The project, dubbed “SolaRoad,” consisted of a full-scale bike path 230 feet long by 11.5 feet wide that was installed at a standard roadway cross-slope. The precast portion of these panels served to provide a structural platform for the power-generating cells above it and to house the conduits and junction boxes necessary for interconnecting them. The precast panels included a tube-filled, double keyway load transfer system to provide load transfer from panel to panel, as seen in Figure 13-29. This short stretch of bikeway was reported to have produced enough electricity to power a single-person household for a full year.

A 62.4-foot-long extension to the 2014 project was installed in September 2016 and features new and improved solar elements as well as a top surface that is more suitable for roadway pavements. The entire 292-foot-long pilot installation will continue to gather power and data until 2018 when it will be evaluated and improved as necessary to make it suitable for larger-scale roadway applications.

Plans are already being made to increase the length to 330 feet, an area that would provide enough electricity to power three single-family homes.

Figure 13-29. Precast power-generating panels being installed on accurately graded bedding material.

The Role of Precast Panels

Two developers of solar power-generating panels working independently on two different continents both concluded that precast panels may play an important role in advancing this revolutionary technology. This is due to many reasons:

1. Precast plants provide a controlled environment where skilled workers may accurately assemble the many sensitive parts and pieces associated with power-generating panels, resulting in a high-quality product.
2. Repetitive, factory-controlled processes typically lead to a reduction in cost of panel fabrication over time.
3. Precast power-generating panels may eventually be developed as roadway elements that may be "plugged and played" as soon as they have been installed in the field.
4. Existing highway-grade precast pavement systems may be readily modified to include power-generating cells.

Much development work is yet to be done on both continents to render solar power-generating roadway panels an economic reality, precast or otherwise. But the goal of developing a sustainable source of power is one worth pursuing, especially for the precast pavement industry.

Summary

PCP panels are readily adaptable for much more than the roadway patches or lane replacements that constitute most precast pavement installations to date. Recent developments in load transfer dowels enable routine additions to previously installed precast pavement and existing pavement, making it possible to permanently replace heavily traveled existing concrete roadways on an as-needed basis without the traffic-crippling restrictions that are frequently necessary to replace the same highways using conventional CIP methods.

Precast pavement may also be designed to be removable (to provide access to underlying utilities for maintenance purposes) and replaceable (so the aesthetics and functionality of the original pavement may be restored quickly).

CIP concrete has been used in many states to "white- top" or harden up asphalt roadways in areas that benefit from the use of a more durable, rut-resistant pavement material, such as intersections and busy city streets. It is now possible to install JPrCP panels for the same purpose in shorter overnight work windows in those areas that cannot be isolated long enough to support proper curing of conventional CIP white-topping.

Although more development work needs to be completed, precast panels may also be designed to be pervious to enable efficient dissipation of stormwater without overtaxing existing drainage systems or polluting rivers, streams or aquifers.

Precast panels using polymers and other specialized concretes may be manufactured for special applications such as acid-resisting industrial floors and heated concrete runways and taxiways. Precast panels may also play a significant land-saving role in hosting solar power-generating equipment as a source of clean, sustainable energy.

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