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Tech Brief

Load Transfer Systems for Jointed Precast Concrete Pavement

INTRODUCTION

Precast concrete pavement (PCP) technology is gaining wider acceptance in the U.S. for rapid repair and rehabilitation of concrete pavements, as well as for reconstruction of heavily trafficked asphalt concrete intersections. Widespread use in the U.S. is fairly recent, with most projects in service less than about 14 years. Nonetheless, dozens of projects have been constructed, and advances continue to be made in all aspects of the technology, including panel design, fabrication, and installation. PCP technology is being used for intermittent repairs (both full-depth repairs and full panel replacement) and for continuous applications (longer-length/wider-area rehabilitation) with service life expectations of at least 20 years for repairs and at least 40 years for continuous applications, without significant future corrective treatment.

Available PCP systems include jointed PCP with reinforced or prestressed panels installed singly or in a continuous series, as well as PCP that typically incorporates thinner reinforced or prestressed panels installed and posttensioned in a continuous series, resulting in fewer joints. The use of PCP technology can significantly reduce the impacts that roadway repair and reconstruction projects have on traffic, particularly on heavily traveled routes. The technology is applicable to small segments, enabling flexibility in construction phasing, and for use in corridor-wide pavement rehabilitation/reconstruction. A review of projects constructed in the U.S. and field testing of selected projects has shown that sufficient advances have been made to reliably design and construct PCP systems to achieve five key attributes of successful pavements, as follows:

- Constructability – Techniques and equipment are available to ensure acceptable production rates for the installation of PCP systems.
- Concrete durability – Plant fabrication of precast panels results in excellent concrete strength and durability.
- Load transfer at joints – Reliable and economical techniques are available to provide effective load transfer at transverse joints in both jointed and prestressed PCP systems.
- Panel support – Techniques to provide adequate and uniform base support conditions are available and continue to be improved.
- Performance/efficiency – Panels can be thinner than standard cast-in-place concrete and last longer because of prestressing and/or reinforcing elements in the PCP systems.

U.S. Department of Transportation
Federal Highway Administration

The use of both jointed PCP and posttensioned PCP systems has advanced during the last decade due to a combination of work sponsored by the Federal Highway Administration (FHWA), projects constructed by highway agencies, and innovations by the highway agencies and the construction industry. One area of innovations relates to improvements in the load transfer features used at PCP transverse joints. The load transfer features currently used at transverse joints in PCP systems are described in this Tech Brief.

BACKGROUND

Transverse joint faulting negatively affects the ride quality of jointed concrete pavements (JCP). Significant joint faulting has a major impact on the life cycle costs of the pavement in terms of rehabilitation and vehicle operating costs. A pavement design feature that has been found to have a significant impact on joint faulting is the use of load transfer devices, typically round dowel bars, at transverse joints. The transverse joint spacing must be optimized for intermittent repair and for continuous applications by considering the constraints on panel size fabrication, shipping, and structural performance. In addition, it is necessary to ensure that adequate load transfer will be available at all active transverse joints, including posttensioned PCP expansion joints, over the long term. PCP installations with poor or no load transfer provisions at active transverse joints will not provide the desired level of service under truck traffic. For long-term service, it is necessary to maintain load transfer efficiency (LTE) of 70 percent or greater at transverse joints, irrespective of the panel support condition.

Tiebars for longitudinal joints may be required to prevent panel or lane drift, particularly for continuous panel placements greater than about 50 ft (15 m).

TRANSVERSE JOINT SPACING REQUIREMENTS

Transverse joint spacing requirements for PCP systems are similar to the requirements for cast-in-place (CIP) concrete pavement and are as follows:

- Intermittent repairs – Transverse joint spacing is not directly considered for intermittent repair projects. Rather, the panel length is considered. Panels are typically single-lane width. Panel length depends on the area that needs to be repaired and may range from a minimum of about 6 ft (1.8 m) to about 15 ft (4.6 m). Longer panels up to 20 ft (6.1 m) or more may be used. Panels in excess of 15 ft (4.6 m) are typically prestressed at the panel fabrication plant.
- Continuous jointed applications – A common joint spacing that is widely used for CIP JCP is 15 ft (4.6 m). This joint spacing has provided good performance throughout the U.S. and has significantly reduced the risk of early-age cracking for CIP JCP. The use of the 15-ft (4.6-m) joint spacing is recommended for jointed PCP applications with panel thicknesses of 8 to 13 inches (200 to 330 mm). However, a longer joint spacing up to 20 ft (6.1 m) or more may be used for individually prestressed panels that are 10 to 13 inches (250 to 330 mm) thick. In California, a panel length of 36 ft (10.8 m) has been used.
- Posttensioned PCP applications – The expansion joint spacing for posttensioned PCP is project-dependent and involves consideration of factors such as base type, prestressing system, load transfer at the expansion joints, climatic conditions, and cost. Using too short a joint spacing may not be economical, and using longer joint spacing may result in a need for a wider joint gap to accommodate larger seasonal joint end movements. Wider joint gaps can impact load transfer at the expansion joints. Use of an expansion joint spacing of 200 to 250 ft (60 to 75 m) is typically considered acceptable.

LOAD TRANSFER PROVISIONS

Load transfer provisions for jointed PCP systems are similar to the provisions for dowel bar retrofitting. Essentially, the process involves the use of a dowel bar slot on either one or both sides of a joint. The dowel bar slots may be located at the panel bottom or at the panel surface. The surface slots typically incorporate a narrow mouth at the surface and may be fully open at the surface or open along a partial length of the slot. The following techniques/features associated with dowel bar slots are commonly used in the U.S.:

- Dowel bar slots at the panel bottom – The Fort Miller Company Super-Slab® system incorporates dowel bar slots at the slab bottom, as shown in figure 1, requiring the use of a flowable grout and the need to fill the vertical gap (about 0.5 inches [13 mm]) along the four sides of the panel.

Figure 1. Photo. Super-Slab® with dowel bar slots at the bottom of the panel.

- Narrow-mouth dowel bar slots at the panel surface – This concept was developed as part of the Strategic Highway Research Program 2 (SHRP2) Project R05, Precast Concrete Pavement Technology. The slots are narrow, about 1 inch (25 mm) wide at the surface and tapering out to about 3 inches (75 mm) in width about an inch below panel mid-depth. The slots are about 16 to 18 inches (400 to 450 mm) long to accommodate a 14- to16-inch-long (350- to 400-mm) dowel bar within the slot. For repair applications, the concept is to slide dowel bars into the slot just before the slab is placed on the base/bedding. During the same or the next lane closure, the dowel bars are then slid into predrilled holes in the existing pavement after the holes are partially filled with epoxy. For continuous applications, the dowels are slid into companion dowel bar slots in the adjacent precast panel. The dowel bar slots are then patched using the dowel bar retrofitting technique.

  The narrow-mouth application options include the following:

  - Full dowel bar retrofit – Narrow dowel bar slots along both sides of the joint for continuous applications.
  - Partial dowel bar retrofit – Dowel bar slot along one side of the joint. For repair applications, narrow-mouth surface slots are located in the panel side of the joint. For continuous applications, a panel will have embedded dowel bars along one side of the panel and matching surface dowel slots (narrow mouth) along the other side of the panel.

Three versions of the narrow-mouth surface slot system were developed, as are shown in figures 2, 3, and 4.

Figure 2. Photo. SHRP2-developed surface slot system, standard version.

Figure 3. Photo. SHRP2-developed surface slot system, Illinois Tollway version 1.

Figure 4. Photo. SHRP2-developed surface slot system, Illinois Tollway version 2.

Illinois Tollway's versions incorporate a widened slot at the joint face, as shown in Figures 3 and 4. The widening was provided to allow hand access within the slot for easier pushing of the dowel bars into the drilled holes and to allow for the twisting motion of the dowel bar for better epoxy distribution around the dowel bars. The tollway has adopted Version 1 for intermittent repair applications.

- Rapid Roadway System's Barra Glide Load Transfer Feature® – In this feature, dowel bars are pre-placed in narrow-mouth slots that are partially open at the surface, as shown in figure 5. After the panel is installed, the dowel bar is pushed into a circular or oblong hole in the adjacent panel or existing slab. The dowel bar slots are then patched using the dowel bar retrofitting technique. The dowel bar holes are grouted using a fast-setting, high-strength cementitious grout.

Figure 5. Photo. The Barra Glide dowel system, showing the partially open narrow slots at the surface of the precast panel.

- Caltrans Generic Teardrop Surface Slot Feature – This feature is very similar to the SHRP2 system, except for the slot shape, as shown in figure 6. This feature requires dowel bars to be embedded in the adjacent (next placed) panel. The embedded dowel bars are slid into the teardrop slots of the previously placed panel, as shown in figure 7. The slots are then patched using the dowel bar retrofit technique.

Figure 6. Photo. Caltrans teardrop-shaped surface slot.

Figure 7. Photo. Embedded dowel bars being slid into the teardrop-shaped slots.

- The use of the full dowel bar retrofit technique with wide-mouth surface slots sawed at the site or fabricated at the precast plant may be used. However, this option requires patching of the wide-mouth slots during the same lane closure as the panel installation because the wide-mouth slots cannot remain open during traffic operation.
- New load transfer systems should be field-tested before production use.

DESIGN OF LOAD TRANSFER SYSTEM

For both repair and continuous applications, the dowel bar design is dependent on the axle load location. A 12-ft-wide (3.65-m) precast panel would require consideration of approximately a 3,000-lbf (13-kN) load transferred by the critical corner dowel bar, and a widened panel would require consideration of only about a 1,200-lbf (5.3-kN) load transferred by the critical dowel. It is important that the dowel bar spacing is considered in the critical axle loading condition. In any case, dowel bars should not be placed more than 12 inches (0.3 m) from the outside corner location for a 12-ft-wide (3.7-m) lane.

Most dowel bars used in highway pavement construction are smooth, round, solid steel bars conforming to ASTM A615 or AASHTO M31. In addition, corrosion protection is typically provided in the form of a fusion-bonded epoxy coating, about 0.008 to 0.012 inch (0.203 to 0.305 mm) thick, which acts as a barrier against moisture and chloride intrusion. Other dowel bar types that can be used to mitigate corrosion include the following:

- Stainless steel clad bars.
- MMX steel bars.
- Glass fiber reinforced polymer bars.

Several dowel bar features are critical to ensure the long-term effectiveness of load transfer systems. These features include dowel diameter, dowel length, dowel spacing, and dowel coating. The overall dowel design recommendations are as follows:

- Dowel diameter – For precast panels less than 10 inches (250 mm) thick, a dowel diameter of 1.25 inches (32 mm) is recommended. For slab thicknesses between 10 and14 inches (250 and 360 mm), a dowel diameter of 1.5 inches is recommended.

- Dowel length – Typical dowel length used in the U.S. is 18 inches (450 mm). However, since precise locations of the dowel bars are known, the use of 15-inch (380-mm) dowel bars is considered adequate, allowing for embedment of at least 7 inches (175 mm) at each side of the joint and accounting for a joint width of up to 0.5 to 1.0 inch (13 to 25 mm).
- Dowel spacing – Dowels are typically placed at a spacing of 12 inches (300 mm). However, the middle dowels do not contribute to the load transfer at a joint. Therefore, a cluster of four dowels per wheelpath, spaced at 12 inches (300 mm), is considered adequate for both intermittent and continuous applications.

Dowel Bar Alignment

In addition to the LTE at the joint, the load transfer system must allow opening and closing of transverse joints due to concrete expansion and contraction. When a dowel bar is used, at least half of its length is coated with a debonding material, and all dowels need to be aligned properly, within the tolerances established by the highway agency.

Figure 8 shows the various types of dowel bar misalignment. In general, rotational misalignments tend to restrict free joint movement, while translational misalignments (vertical, horizontal, and longitudinal misplacements) impact the effectiveness of individual dowel bars in providing load transfer. The critical level of rotational misalignment is the level at which the joint may lock or the concrete around the bar may spall. The critical level of translational misalignment is the level at which the LTE of the dowel bar is adversely affected. In general, the limit for placement error is much greater for translational misalignments than for rotational misalignments. For example, the typical specification in the U.S. for longitudinal, horizontal and vertical translation is 1 inch (25 mm), whereas the requirement on rotational misalignment is 1/2 to 5/8 inches (12 to 15 mm) along the length of an 18-inch-long (450-mm) dowel bar. The dowel placement tolerances specified by an agency for CIP JCP construction also should be specified for PCP projects.

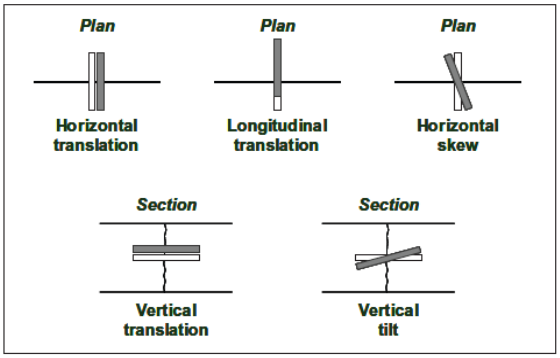

Figure 8. Diagram. Types of dowel bar misalignment.

Dowel Bar Caps

Dowel bar caps allow for expansion and contraction of the precast panels and, if applicable, the adjacent existing concrete pavement. If expansion of the concrete pavement is prevented, joint spalling or cracking adjacent to the affected joints may develop. In addition, there will be a potential for blowups during warm summer days.

In addition, many older jointed reinforced concrete pavements that are good candidates for intermittent repairs incorporate expansion joints at a spacing ranging from 60 to 80 ft (18 to 24 m). When areas with expansion joints are repaired using PCP, expansion joints must be recreated at these locations. Otherwise, there will be a potential for blowups during warm summer days. Dowels at the expansion joints must be fitted with appropriately sized dowel caps.

Dowel Bar Slot Patching Material

The dowel bar slots may be patched right after the panel installation; that is, during a single lane closure or during the next night's lane closure. In any case, the joint slot patching material needs to develop strength rapidly. Typical strength requirements are 2,000 to 3,000 psi (13.7 to 20.7 MPa) within 4 hours or by the time of opening the PCP section to traffic. All patching materials need to be durable and have a fail-safe bonding ability. The opening-to-traffic strength requirement for the patching material is critical to ensure adequate dowel bearing strength and adequate bonding strength between the patch material and the precast panel concrete or the existing slab concrete.

The dowel bar slot patching materials are typically rapid-setting proprietary materials and may be free-flowing cementitious or polymer-based, with or without aggregate beneficiation.

SUMMARY

The incorporation of a well-designed load transfer system at active transverse joints is critical to long-term performance of jointed PCP systems. The practice for providing load transfer at active transverse joints in PCP installations should be similar to the well-established practices used for CIP JCP. If a practice has not been successful for CIP JCP or has not yet been used, it should not be considered for PCP systems without additional investigation or field verification. The risk of failure of the load transfer system for PCP installations should be as low as possible. The long-term performance of PCP should not be sacrificed for construction expediency that may result from the use of marginal or unproven load transfer systems.

REFERENCES

For additional information on SHRP2 Project R05, see Tayabji, S., Ye, D., and Buch, N., “Modular Pavement Technology Final Report,” Project R05, Strategic Highway Research Program 2, Washington, DC, May 2012.

For additional information on PCP systems, applications, guidelines, and usage, refer to FHWA publication, Tech Brief FHWA-HIF-15-022 (http://www.fhwa.dot.gov/pavement/concrete/pubs/hif15022.pdf). This publication summarizes the technical resources available to engineers and planners seeking an understanding of PCP technology. The Tech Brief includes weblinks that provide easy access to recent documents covering a range of PCP topics.

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