TECH BRIEF

OPTIMIZED DESIGN DETAILS FOR CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

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INTRODUCTION

Continuously reinforced concrete pavement (CRCP) is widely used by several highway agencies in the United States, typically for heavily-trafficked roadways. CRCP has the potential to provide long-term "zero-maintenance" service life under heavy traffic loadings and challenging environmental conditions, provided that proper design and quality construction practices are utilized. CRCP differs from other concrete pavements as follows:

1. CRCP has no active transverse joints, except at ends.
2. CRCP provides continuous longitudinal reinforcement, which results in tight cracks in the concrete at about 2–6 feet (0.6–1.8 m) spacing. Sufficient reinforcement is necessary to keep the cracks tight, <0.02 inches (<0.5 mm). In the United States, the longitudinal reinforcement, typically No. 6 bars, is placed over transverse bars to ensure proper placement with respect to depth and transverse spacing.
3. CRCP can extend, joint-free, for many miles with breaks provided only at structures (e.g., bridges). Joints, designed as *expansion joints*, are provided at structures or at a terminus of the CRCP.

CRCP design focuses on managing the cracking that develops so as to reduce the structural distresses that may develop as a result of traffic and environmental loadings. These distresses include punchouts, steel rupture, and crack spalling. CRCP design involves determining the proper combination of slab thickness, concrete mixture constituents and properties, and steel reinforcement content and location; providing for sufficient slab-edge support; strengthening or treating the existing soils; and providing non-erodible bases that also provide friction, which leads to desirable transverse cracking patterns. In addition, CRCP design details must ensure that the large movement that can occur at CRCP terminal ends is managed adequately.

Over the years, many improvements in the best practices in the design of CRCP have been implemented to improve long-term performance. These improvements have resulted from experience from the field, better understanding of CRCP behavior, improved structural modeling of CRCP, improved materials, and improved construction processes. A compendium of the best practices was included in the CRCP Manual, published in 2016 (Ref. 1). In addition, the Federal Highway Administration (FHWA) has published several documents that provide additional guidance on design, construction, and maintenance of CRCP (Ref. 2–5).

This Tech Brief provides guidance on optimizing several key design features based on the information included in the previously cited references and recent refinements implemented in the field. These key design features include the following:

- Optimizing longitudinal steel content
- Simplified details for terminal ends
- Improved transverse construction joint detail
- Shoulder type
- Concrete slab/base interface

OPTIMIZING LONGITUDINAL STEEL CONTENT

The structural design of CRCP is based on determination of slab thickness that can carry the future traffic over the designated service (design) period considering the pavement support, cracking in the CRCP, and site and environmental/climatic conditions. For CRCP, it is important to ensure that the cracking that develops is not detrimental to load transfer across the cracks. The effective long-term load transfer is maintained across the cracks by optimizing the use of longitudinal steel, in terms of steel content, bar size, and bar spacing. As such, CRCP longitudinal steel design focuses on managing the cracking that develops so as to reduce the structural distresses that may develop as a result of traffic and environmental loadings. These distresses include punchouts, steel rupture, and crack spalling.

The use of longitudinal steel reinforcement, typically Grade 60 bars, results in a series of closely spaced transverse cracks. The steel reinforcement is used to control the crack spacing and the amount of opening at the cracks so as to maintain high levels of load transfer across the cracks. Modern CRCP is built with longitudinal reinforcing steel percentages in the range of 0.70–0.75 percent (lower in milder climates, higher in harsher climates). Equally important as the percentage of steel content is the bond area between the concrete and the bars, which is recommended to be a minimum of 0.030 square inch (19 square mm) of steel bar surface per 1 cubic inch (16 cubic cm) of concrete.

CRCP crack spacing is significantly impacted by concrete strength at early ages and the longitudinal steel characteristics (i.e., steel content, bar size, and bar spacing). Because the tensile strength of the concrete and the restrained tensile stress in the concrete slab vary along the length of the slab, the transverse crack spacing pattern is never uniform, but the majority of cracks that develop within a few years should be spaced from 2 to 6 ft (0.6 to 1.8 m). Design steel content provides a balance between desired crack width (<0.02 inch (<0.5 mm) at the surface over the design life), desired crack spacing (3–6 ft (0.9 to 1.8 m) over the design life), and desired crack load-transfer capability (>90 percent over the design life).

The overall structural design of CRCP involves determining the proper combination of slab thickness, concrete mixture constituents and properties, and steel reinforcement content and location; providing for sufficient slab edge support; strengthening or treating the existing soils; and providing non-erodible bases that also provide friction that leads to desirable transverse cracking patterns. Although most of these features are common to all good pavement designs, reinforcement and edge support are particularly critical to a CRC pavement. Various design procedures have been developed for CRCP, including the mechanistic-empirical procedure (Ref. 4). All of these procedures require the longitudinal steel content as a designated input.

Table 1 shows a recommended standard for bar size, bar spacing, and calculated steel percentage for a range of slab thickness.

Table 1. Recommended standard for longitudinal steel use in CRCP.

Slab Thickness in inches (mm)	Bar Size and Spacing in inches (mm)	Percentage Steel
9 (228)	No. 6 @ 7.0 (178)	0.70
10 (254)	No. 6 @ 6.0 (152)	0.73
11 (280)	No. 6 @ 5.5 (140)	0.73
12 (305)	No. 6 @ 5.0 (127)	0.70
12 (305)	No. 7 @ 7.0 (178)	0.71

In general, a higher steel percentage keeps transverse cracks tighter and thus keeps concrete aggregate interlock tight and allows for good load transfer over the long life of CRCP. A tight crack also keeps out incompressibles, minimizes crack spalling, and greatly reduces the potential for development of punchouts in the CRCP. For slab thickness of 12 inches (305 mm) or larger, the change in bar size from No. 6 to No. 7 allows the longitudinal steel bars to be spaced further apart, facilitating concrete placement and flow around the steel bars. Bars spaced too tightly in one horizontal plane may cause concrete consolidation issues, and in rare cases, may cause horizontal delamination of the concrete at the steel level. Steel supply or cost would not be affected by use of No. 7 bars. The availability of No. 6 bars and No. 7 bars is similar.

In general, increasing the steel content above 0.75 percent is not considered necessary. Years of study of CRCP performance in the United States have shown excellent performance of CRCP with nominal 0.70–0.75 percent steel. Given this, it is expected that results from the mechanistic-empirical design procedure would show very minimum increases (if any) in CRCP performance with increased steel use above this level if other design inputs are kept constant. In addition, adding more bars beyond this level could unnecessarily add to CRCP cost and would likely increase concrete consolidation concerns because of increased congestion due to additional steel bars.

In summary, use of longitudinal steel content in CRCP of about 0.70–0.75 percent is in the right direction and will reduce the risk of undesirable cracking patterns in new CRCP. It should be noted that it is important to ensure that the specified 28-day concrete flexural strength is about 650 psi (4.5 MPa) to ensure an optimum balance between concrete strength and steel content. A common misconception is that providing a higher strength than specified for CRCP construction is a good thing.

SIMPLIFIED DETAILS FOR TERMINAL ENDS

As the name implies, CRCP is a continuously reinforced concrete pavement with no active transverse joints within the length of the pavement. The continuous longitudinal reinforcement interacts with concrete to produce tight cracks at about 2 to 6 ft (0.6 to 1.8 m) spacing and then holds the cracks tight. As such, CRCP behaves as a monolithic pavement over its length. However, as with any concrete slab on grade structure, CRCP exhibits expansion and contraction as a result of daily and seasonal changes in concrete temperature. The expansion and contraction are manifested at the CRCP end points, commonly referred to as *CRCP terminals*. If the ends are free to expand and contract, then the seasonal end movement can range from 0.5 to 2 inches (13 to 25 mm). Two approaches have been used to manage the end movement as follows:

1. **Restrain the end movement**—This practice requires use of multiple anchor lugs at the CRCP ends. Lug anchors are cumbersome to construct and have not provided good performance. This practice has been discontinued by most agencies.
2. **Allow end movement**—This practice is currently the preferred practice. Studies and observations indicate that only the end 120–150 ft (35–45 m) is active in the expansion and contraction that takes place daily and seasonally, as illustrated in figure 1. The rest of the CRCP length in the interior does not undergo expansion and contraction due to slab-base restraint. The specific length at each end that undergoes expansion and contraction is greatly influenced by the slab–base interface friction. Smoother interfaces will result in greater length at the end that undergoes expansion and contraction and will result in a larger daily and seasonal end movement due to concrete temperature changes. The seasonal—over a year—movement at each end may range from about 0.5 to 2 inches (13 to 25 mm), depending on the slab–base interface friction and seasonal temperature range.

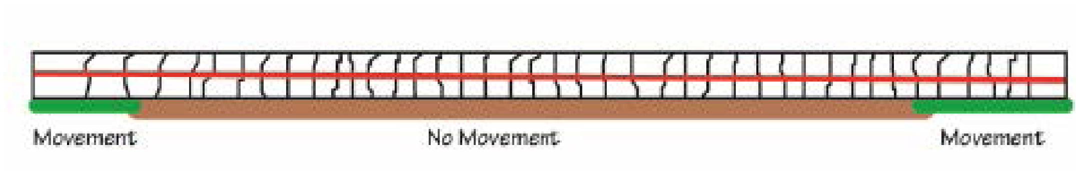

Figure 1. Schematic. Illustration of CRCP end movement.

For expansion joint designs that allow end movement, the joint needs to accommodate the seasonal length changes as well as provide for reduced deflections at the ends. The approaches that have been used or have recently been introduced are discussed in the following sections.

Wide-Flange I-Beam Expansion Joint

A wide-flange beam expansion joint design, incorporating a wide-flange I-beam and a sleeper slab, was once widely used by many agencies. However, because of poor performance of the wide-flange I-beam, this practice is not favored anymore.

Simplified Expansion Joint

Version A—Doweled and Sleeper Slab

A simplified version of a doweled expansion joint, with a sleeper slab, similar to that specified by the Oregon Department of Transportation (ODOT), is shown in figure 2. One or two jointed concrete transition slabs, about 12–15-ft (3.7–4.6-m) long, are used between the expansion joint and another pavement or a bridge approach slab. This is a simple design to construct. The joint requires regular monitoring of the low modulus joint seal to ensure that debris does not enter into the joint gap and prevent expansion of the CRCP during hot summer days. The joint also requires that the dowel bars are well aligned, otherwise the risk of slab blowups at this joint would be high.

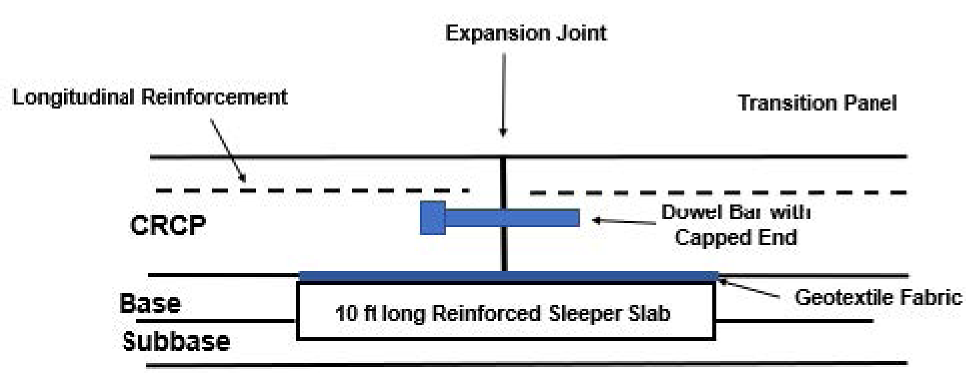

Figure 2. Diagram. CRCP terminal design adjacent to a bridge approach slab.

Version B—Doweled and No Sleeper Slab

Another simpler version of the terminal joint design incorporating dowel bars but without a sleeper slab is shown in figure 3. The dowel bars provide the necessary load transfer across the wide expansion joint. This approach eliminates the additional step of constructing a sleeper slab. There is good experience with this type of joint, as used with cast-in-place prestressed concrete pavements and with posttensioned precast concrete pavements. The joint also requires that the dowel bars are well-aligned, otherwise the risk of slab blowups at this joint would be high. The intermediate transition slab is 14 to 16 ft (4.3 to 4.9 m) long and the same thickness as the CRCP slab.

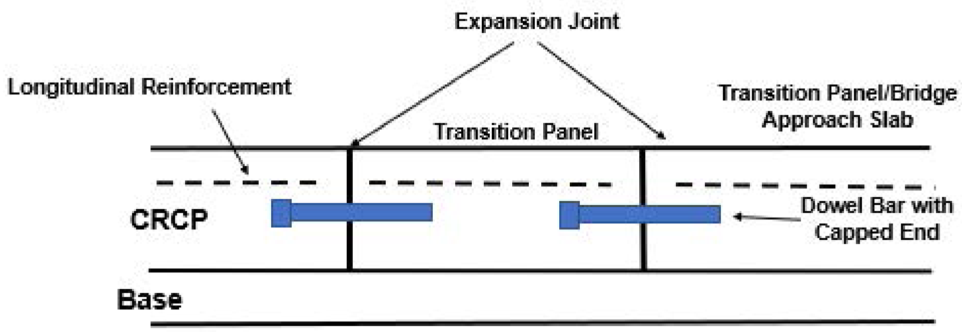

Figure 3. Diagram. Doweled expansion joint without a sleeper slab.

Version C—Sleeper Slabs and No Dowel Bars

Another simpler version of the CRCP terminal expansion joint, similar to that specified by Oklahoma DOT, uses a sleeper slab at the expansion joint but does not require use of dowel bars at the expansion joint. There is zero risk of joint spalling or slab blowup due to misaligned dowel bars. The use of a sleeper slab helps reduce deflections at the joint. The expansion joint design is shown in figure 4.

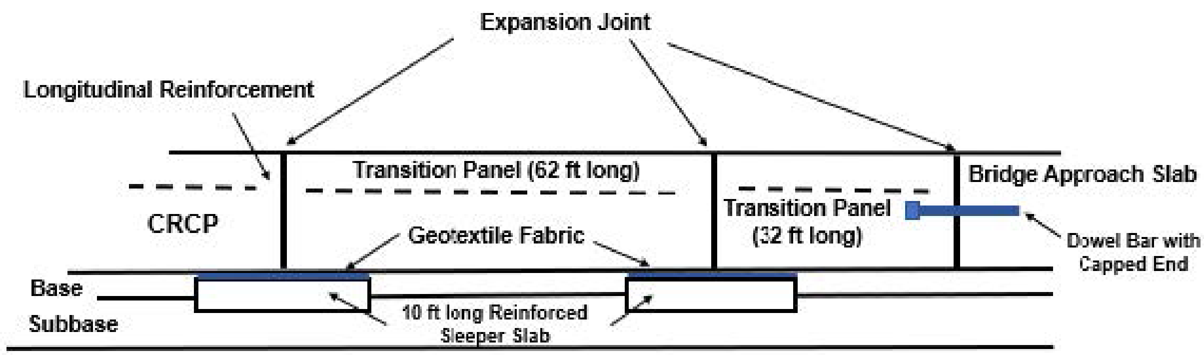

Figure 4. Diagram. Non-doweled CRCP terminal joint design.

Version D—Single Sleeper Slab and No Dowel Bars

Another simpler version, recently adopted by Caltrans, is shown in figure 5. This version is similar to the Oklahoma DOT design, except shorter, 14-ft long (4.3 m), transition slabs are used, and only a single sleeper (support) slab is used to simplify sleeper slab construction. Use of a nonwoven geotextile fabric over the sleeper slab is required. This design also has zero risk of joint spalling or slab blowup due to misaligned dowel bars.

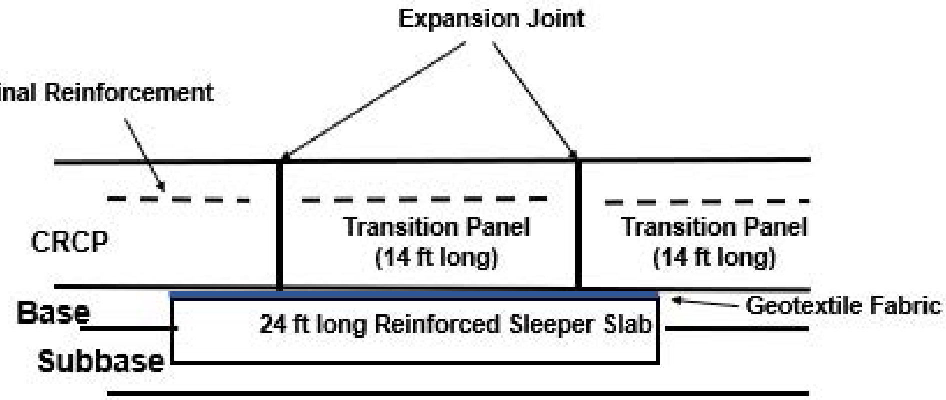

Figure 5. Diagram. Caltrans CRCP terminal joint design.

The simplified expansion joint, such as Versions C and D, at CRCP terminals is easily constructible and should be less costly to construct. These versions of the expansion joint can be maintained relatively easily, in line with the typical maintenance-free CRCP. The benefits of the simpler versions of the expansion joint are:

- The joint allows unconstrained expansion/contraction of the CRCP terminal ends.
- The use of sleeper slabs reduces deflections at the expansion joints.
- The risk of possible joint spalling or slab blowup due to misaligned dowel bars at the wide expansion joint is eliminated.

IMPROVED TRANSVERSE CONSTRUCTION JOINT DETAIL

Transverse construction joints are formed at the end of each day of paving, or whenever paving operations are halted long enough to form a cold joint (typically about 30 minutes). The transverse construction joint design requires maintaining the continuity of the longitudinal steel and provision for adequate load transfer across the joint, which will have smooth faces. Poorly designed and constructed transverse construction joints are potential locations of early-age punchouts. In the past, there was a practice to add double the number of longitudinal bars crossing the construction joint, with the thought that the additional bars would be sufficient to provide the necessary load transfer across the joint. However, this practice has not resulted in good performance under heavy truck traffic. A recommended approach is to ensure that the necessary load transfer across the smooth joint faces is provided by use of dowel bars, as shown in figure 6, designed similarly to load transfer for jointed concrete pavement. Depending on the agency practice, a minimum of four dowel bars should be used per wheel path. Dowel bars may be smooth or deformed. The longitudinal bars that cross the joint are sufficient to maintain the joint tightly closed, similar to the tight cracking maintained by the same longitudinal bars. The need for extra “steel” at the joint is to ensure that the necessary load transfer is available at this smooth-faced joint.

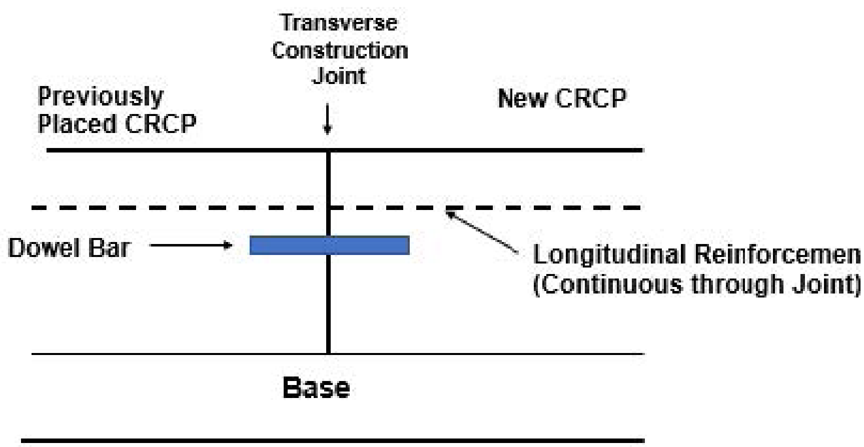

Figure 6. Diagram. Recommended CRCP transverse construction joint design.

The construction joint should be at least 12 ft (3.7 m) from the last construction joint, and the distance from the construction joint to the nearest longitudinal bar splice should be at least 42 inches (1.1 m).

SHOULDER TYPE FOR USE WITH CRCP

Proper edge support using tied concrete shoulders adjacent to mainline CRCP reduces wheel load stresses and deflections and reduces the occurrence of punchouts. Proper edge support also reduces the need for longitudinal joint and shoulder maintenance and provides support for traffic detours. It is a common practice in the United States to have shoulders constructed of the same materials as the mainline pavement to facilitate construction, improve performance, and reduce maintenance costs. Although use of asphalt concrete (AC) shoulders provides an economical first-cost advantage, AC shoulders typically do not provide good long-term performance when used with concrete pavements because of shoulder drop-off and the difficulty with the longitudinal joint maintenance.

Ideally, the shoulder type should be a tied CRCP shoulder. However, many agencies prefer to use tied jointed concrete pavement (JCP) shoulders to reduce cost. The tying of the JCP shoulder to the CRCP needs to be considered carefully. Because JCP transverse joints open and close as a result of concrete temperature variation, any restraint to the joint opening can lead to cracking in the JCP slabs. However, the same restraint can lead to secondary cracking in the CRCP lane at the joint location or wider opening of the intended crack in the CRCP if the crack has already formed near the JCP joint location. As a result, the recommendation is not to distribute tie bars uniformly along the shoulder longitudinal joint. The tie bars should be concentrated only within the middle region of each JCP panel, as illustrated in figure 7. This allows the JCP transverse joints to open and close without much restraint.

It should be noted that an economic option for providing edge support for low-volume CRCP is the use of a widened outside lane in combination with an AC shoulder. Monolithically constructed widened outside lanes, ranging in width from 13 to 14 ft (4.0 to 4.2 m), have been used successfully by many highway agencies. The widened lane will significantly reduce deflection along the free edge and the development of punchouts.

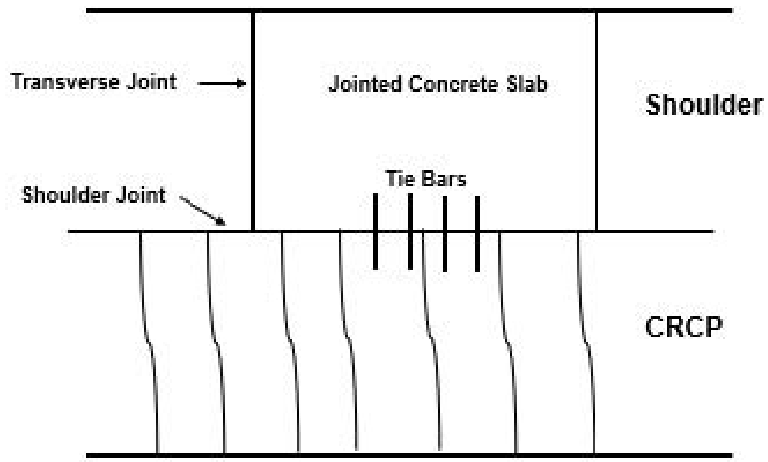

Figure 7. Diagram. Example of CRCP/JCP shoulder joint design.

SUMMARY

CRC pavements have a long history of good performance in the United States and other countries when designed and constructed well. Many U.S. highway agencies consider CRC pavements their pavement of choice for implementing long-life pavement strategies that have lower life-cycle costs and require fewer lane closures for routine maintenance and repair/rehabilitation. Since the 1950s, CRCP design and construction practices have advanced considerably, resulting in a truly low-maintenance concrete pavement.

FIGURE CREDITS

All figures were provided by Shiraz Tayabji with the Advanced Concrete Pavement Consultancy LLC and used with permission.

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