Tech Brief

MARCH 2021 FHWA-HIF-20-081

Continuously Reinforced Concrete (CRC) Roundabouts

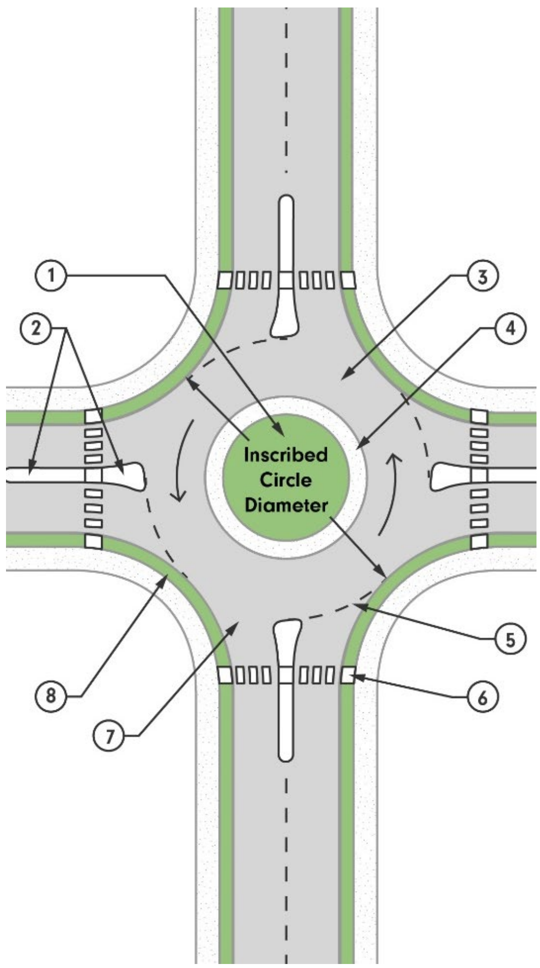
U.S. Department of Transportation
Federal Highway Administration

Image sources (from top):

Introduction

General Background on Roundabouts

A roundabout is a form of circular intersection in which traffic travels counterclockwise (in the United States and other right-hand traffic countries) around a central island and in which entering traffic yields to circulating traffic (Rodegerdts et al. 2010). Compared with signalized and stop-controlled intersections, modern roundabouts provide better overall safety performance, shorter delays and shorter queues, better management of speed, and lower management and operation costs while also adding aesthetic value (FHWA 2010). Figure 1 presents a general schematic of a roundabout, along with a brief description of some of the key design features.



1. Central Island – Raised area around which the traffic circulates.

2. Splitter Island – Raised or painted area on the approach used to separate entering and exiting traffic, control entering traffic, and accommodate pedestrians crossing the roadway.

3. Circulatory Roadway – Curved path used by vehicles to travel around the central island in a counterclockwise direction.

4. Truck Apron – Part of central island that facilitates wheel tracking of large vehicles.

5. Entrance / Yield Line – Marks the point of entry to the circulatory roadway. Also functions as a yield line in the absence of a separate yield line.

6. Accessible Pedestrian Crossings – Provided before the entrance / yield line; splitter island is cut to allow access for pedestrian, wheelchairs, strollers, and bicycles in accordance with ADA requirements.

7. Exit – Marks the point of exit from the circulating roadway.

8. Landscape Buffer – Separates vehicular and pedestrian traffic and guides pedestrians to designated crossing locations.

Figure 1. Key roundabout design features.

Roundabouts are typically classified into three basic categories: mini, single lane, and multilane (FHWA 2010). Most roundabouts constructed in the United States are single lane (roughly 70 percent) and multilane (28 percent) (Rodegerdts 2017). As shown in figure 2, a cross slope of 2 percent away from the central island is typical for the circulatory roadway on single-lane roundabouts (WSDOT 2019). This not only helps in surface drainage, but also promotes safety by raising the height of the central island and improving its visibility, encourages lower circulating speeds, and minimizes breaks in the cross slopes of the entrance and exit lanes (FHWA 2010).

Various pavement types can be used in the construction of roundabouts, including hot-mix asphalt pavement (HMAP), jointed concrete pavement (JCP), continuously reinforced concrete pavement (CRCP), and precast concrete pavement (PCP). This Tech Brief describes the application, design, and construction aspects of CRCP roundabouts.

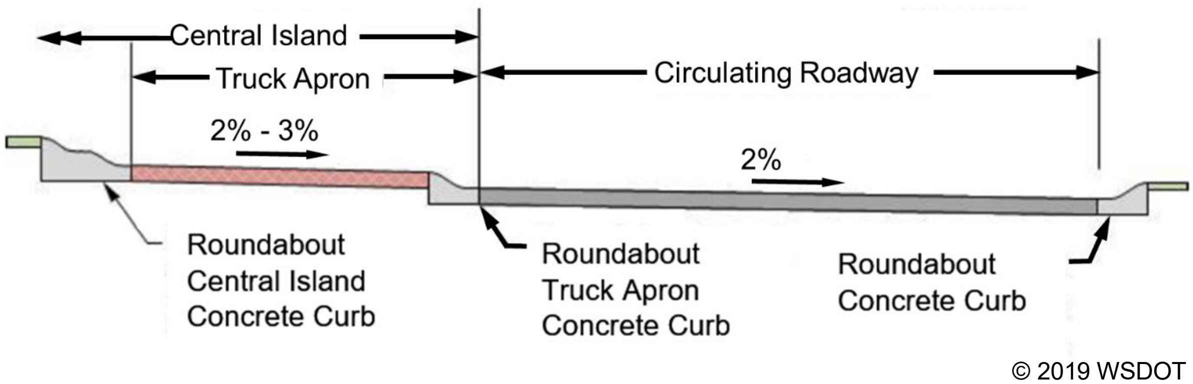


Figure 2. Typical circulatory roadway section with truck apron.

Background on CRC Roundabouts

CRCP is widely used by several U.S. State highway agencies, typically for heavily trafficked roadways. CRCP has the potential to provide a long-term, “zero-maintenance” service life under heavy traffic loadings and challenging environmental conditions, provided that effective design and quality construction practices are employed. CRCP is a unique concrete pavement in that it has no constructed transverse contraction or expansion joints except at bridges or at pavement ends. 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 and to maintain high levels of load transfer across them.

Many aspects of CRCP roundabouts are like linear CRCP designs, with some of the key distinguishing features for both applications described below:

- For linear pavements, CRCP has no active intermediate transverse contraction joints and expansion joints are typically used at ends. At roundabouts, CRCP would not have any active transverse contraction or expansion joints.
- Continuous longitudinal reinforcement results in tight cracks in the concrete at about 2- to 6-ft spacings and keeps the cracks tight. The transverse crack spacing along a roundabout CRCP should be like linear CRCP.
- For linear pavements, CRCP can extend, joint free, for many miles with breaks provided only at structures, such as bridges. On roundabouts, CRCP may have one or two non-active transverse construction joints that would include provisions for longitudinal steel continuity and load transfer across the construction joint.
- For linear CRCP, tie bars are used to prevent lane drift, especially the outside lane. For roundabout CRCP, the use of tie bars may not necessary. The roundabout CRCP lanes form a closed circle and are physically restrained from drifting apart. The CRCP lanes do not undergo volume change lengthwise and maintain the circular geometry. The CRCP lanes do undergo very small volume change in the transverse (radial) direction because of concrete drying shrinkage and temperature variations, but these volume changes are insignificant and do not affect the longitudinal joint behavior.

It should be noted that many of the design, construction, and maintenance aspects of CRCP roundabouts are like linear CRCP (Roesler and Hiller 2013: Roesler, Hiller, and Brand 2016). This Tech Brief focuses on details that are unique to CRCP roundabouts.

Current CRCP Roundabout Usage

In the last decade or so, the use of JCP roundabouts has been on the increase in the United States (Rodden 2009). A reason for this is the better performance of concrete roundabouts in high traffic areas where HMA roundabouts do not perform well due to excessive shoving and rutting that results in frequent maintenance activities. Although JCP roundabouts perform better than HMA roundabouts, these pavements do experience periodic maintenance activities to reseal joints and to repair joint spalls. For roundabouts serving high-volume incoming roadways, significant interruptions to traffic operations at the roundabout may not be acceptable to many transportation agencies. In Europe, low-maintenance CRCP roundabouts have been used at high-volume roadway intersections (Rens 2013; Debroux, Dumant, and Ployaert 2010). In recent years, several CRCP roundabouts have been constructed in Texas and several more are in the planning stages.

European CRCP Roundabout Use Summary

CRCP roundabout use began in the Netherlands in 1995 and many of those early roundabouts are now more than 20 years old. Since 1995, hundreds of CRCP roundabouts have been constructed in Belgium, France, and the Netherlands for heavy truck-traffic applications (Rens 2013; Debroux, Dumant, and Ployaert 2010). Those applications include entrances to industrial areas, freeway exits, and secondary roads.

Typical reinforcement used in CRCP designs for roundabouts in Belgium are summarized below (Rens 2013; Debroux, Dumant, and Ployaert 2010):

- Limit longitudinal steel diameter to 0.62 inches.
- Longitudinal steel amount: 0.6 to 0.7 percent.
- Length of longitudinal steel bar lap: 35 times the nominal diameter of the steel near the outer perimeter but reduced near the inner perimeter to minimize steel congestion. Splices should be staggered.
- Nominal diameter of transverse bars: 0.55 inches.
- Depth to top of reinforcement: 3.15 inches.

The transverse reinforcement is typically placed radially. However, in Belgium, the transverse reinforcement is placed diagonally at an angle of 60 degrees to the tangent at the outer perimeter of the pavement. Also, a 2-inch thick HMA base/interlayer is typically used to support the reinforcement and to provide the desired level of interface friction.

European CRCP roundabouts are typically constructed using forms and a vibrating screed or using slipform pavers for larger roundabouts. However, in the Netherlands, a transversely moving roller-finisher is also used for roundabouts. Depending on site accessibility limitations, concrete may be brought to the center area of the roundabout and distributed to the paver or may be pumped. A view of a European CRCP roundabout construction using a slipform paver is shown in figure 3 (Rens 2013).

Figure 3. View of a European CRCP roundabout construction.

Texas CRCP Roundabout Use Summary

Texas is one of the largest users of CRCP, with over 15,000 lane-miles of pavement throughout the state. The Texas Department of Transportation (TxDOT) and local municipalities routinely use CRCP for high-volume roadways. In 2013 and 2014, two CRCP roundabouts were constructed as part of the Alameda Avenue/Paisano Drive intersection improvement project in El Paso County. Also, two CRCP roundabouts were constructed in Walker County in 2014.

El Paso County CRCP Roundabouts

The El Paso County CRCP roundabouts (TxDOT 2016a) are located along Alameda Avenue (SH 20) at the intersection with Paisano Drive. The roundabouts were used to correct a difficult threeway interchange that included high-volume pedestrian traffic. Views of the existing interchange and the reconstructed interchange with the two CRCP roundabouts are shown in figures 4 and 5 (TxDOT 2016a).

The 2035 average daily traffic (ADT) at the Alameda Avenue roundabouts was estimated at 15,400 vehicles/day, with 4.2 percent trucks. The roundabouts were designed for a speed limit of 15 mi/hr. with pedestrian crossings at the approaches of the roundabouts. The design details are the same as those used in the two El Paso County CRCP roundabouts and are summarized below:

- Number of lanes: Two 16-ft wide travelling lanes and one 10-ft wide apron lane.
- Inside Radius: 46 ft.
- Apron pavement: 10-inch thick CRCP with No. 6 bar at 7-inch spacing (0.63 percent steel).
- Intermediate Radius at Apron: 56 ft.
- Inside traveling lane: 8-inch thick CRCP with No. 6 bar at 9-inch spacing (0.61 percent steel).
- Outside Radius: 90 ft.
- Outside traveling lane: 8-inch thick CRCP with No. 6 bar at 9-inch spacing (0.61 percent steel).
- Base/Subbase: 4-inch hot-mix asphalt concrete (HMAC) base over a 6-inch lime stabilized subgrade.

Figure 4. Previous interchange at Alameda Avenue and Paisano Drive.

Figure 5. Reconstructed interchanges at Alameda Avenue and Paisano Drive.

The steel layout for the two Alameda Avenue CRCP roundabouts includes longitudinal steel in a circular pattern, transverse steel located radially, and tie bars along longitudinal joints. Texas DOT's longitudinal steel details for CRCP roundabouts are shown in table 1 and the transverse bar and tie bar details are shown in table 2, with the attributes for the El Paso County projects highlighted in bold font.

Table 1. Texas DOT longitudinal steel for roundabout CRCP (TxDOT 2016a).

Slab Thickness T (in)	Bar Size	Regular Steel Bars Spacing (in)	First Spacing at Edge or Joint (in)	Additional Steel Bars at Transverse Construction Joint Spacing (in)	Additional Steel Bars at Transverse Construction Joint Length (in)
6.0	#5	7.5	3 – 4	15	50
6.5	#5	7.0	3 – 4	14	50
7.0	#5	6.5	3 – 4	13	50
7.5	#5	6.0	3 – 4	12	50
8.0	**#6**	**9.0**	**3 – 4**	**18**	**50**
8.5	#6	8.5	3 – 4	17	50
9.0	#6	8.0	3 – 4	16	50
9.5	#6	7.5	3 – 4	15	50

8.0-inch data shows corresponding attributes for El Paso County projects.

Table 2. Texas DOT transverse steel and tie bar for roundabout CRCP (TxDOT 2016a).

Slab Thickness (in)	Transverse Steel Bar Size	Transverse Steel Spacing (in)	Tie Bars at Longitudinal Contraction Joint Bar Size	Tie Bars at Longitudinal Contraction Joint Spacing (in)	Tie Bars at Longitudinal Construction Joint Bar Size	Tie Bars at Longitudinal Construction Joint Spacing (in)
s6.0 – 7.5	#5	48	#5	48	#5	24
8.0 – 13.0	**#5**	**48**	**#6**	**48**	**#6**	**24**

8.0 – 13.0-inch data shows corresponding attributes for El Paso County projects.

Walker County Roundabouts

The two Walker County CRCP roundabouts (TxDOT 2016b; Robbins 2016) were constructed beginning in August 2014 along the Farm-to-Market Road 1375 at the Interstate 45 frontage road intersections in New Waverly. The new roundabouts replaced existing two-way intersections, as shown in figure 6, to improve safety and relieve traffic congestion (TxDOT 2014).

© 2014 Google Earth with overlays marking old and new intersections

Figure 6. Walker County CRCP roundabouts.

The design details are the same for the two Walker County CRCP roundabouts as summarized below:

- Number of lanes: Two 16-ft wide travelling lanes and one 10-ft wide apron lane.
- Inside Radius: 51-1/2 ft.
  - Apron pavement: 9-inch thick CRCP with No. 6 bar at 6-inch spacing (0.61 percent steel).
- Intermediate Radius at Apron: 65-1/2 ft.
  - Inside travelling lane: 7-inch thick CRCP with No. 5 bar at 6.5-inch spacing (0.68 percent steel).
- Outside Radius: 89-1/2 ft.
  - Outside travelling lane: 7-inch thick CRCP with No. 5 bar at 6.5-inch spacing (0.68 percent steel).

As with the Alameda Avenue roundabouts, the steel layout for the two Walker County CRCP roundabouts includes longitudinal steel in a circular pattern, transverse steel located radially, and tie bars along longitudinal joints and followed the information presented in tables 1 and 2.

The roundabout pavement design incorporated use of support (sleeper) slabs at the joint between the approach lanes and the exterior CRCP traveling lane. The support slab was 10 inches thick and 5 ft wide. The layout of the steel and the underlying support slab are shown in figure 7, while figure 8 shows the completed concrete placement along the outer traveling lane and the steel placement for the interior traveling lane (TxDOT 2016b). Figure 9 shows the completed outer lane CRCP and the steel reinforcement for the approach roadways (TxDOT 2016b).

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Figure 7. Steel reinforcement and underlying support slab for Walker County roundabout.

Figure 8. Completed outer lane CRCP and the steel reinforcement for the inner lane of Walker County roundabout.

Figure 9. Completed outer lane of Walker County CRCP and the steel reinforcement for the approach roadways.

Performance of CRC Pavements Used in Roundabouts

The CRCP roundabouts in Belgium, France, and the Netherlands are reported to be performing well (Rens 2013; Debroux, Dumant, and Ployaert 2010). In the United States, the CRCP roundabouts in the Texas counties of El Paso and Walker are performing well after 4 to 6 years of service (Naranjo 2020).

Applications and Effectiveness

Typical Applications

CRCP roundabouts are typically used for multi-lane roundabouts that are expected to carry heavy loadings from commercial vehicles and buses. These roundabouts typically also incorporate a CRCP apron lane to carry truck wheels that encroach into the central island of the roundabout. As indicated, CRCP roundabouts are suitable for intersections that carry a high volume of truck traffic and where disruptions to traffic flow at the intersections are to be avoided. CRCP roundabouts, based on the European and the Texas experience, can provide low-maintenance, long-term service. Specifically, CRCP roundabouts are good applications for the following high-volume, heavy truck-traffic intersections:

- A current 3-way or a 4-way intersection.
- An existing roundabout with poorly performing asphalt concrete or jointed concrete pavements.

Limitations

A limitation to the use of CRCP roundabouts may be the need for full closure during the construction of the roundabout. However, since CRCP roundabouts are typically multi-lane facilities, lane-at-a-time construction typically can be used, and typically around the full roundabout. The steel (both transverse and longitudinal) is pre-placed after base completion; and the concrete curing adds a few more days before the roundabout can be opened to traffic. As a result, the construction of a CRCP roundabout typically takes place during several weeks to several months. It should be noted that the CRCP lanes can be constructed in stages while allowing traffic operation around a partially opened roundabout, but this staging approach would further delay the opening of the completed roundabout.

Pavement Design Considerations

The design considerations for CRCP roundabouts are like those for linear CRCP. The first step in the design process is to estimate the design truck traffic over the design period that would use the roundabout travelling lanes and the apron lane. Then, a State highway agency’s conventional CRCP design procedure is used to develop the following details:

- Slab thickness.
- Longitudinal steel content.
- Base type.
- Edge treatment for the outer and the apron lanes.

In addition to the CRCP roundabout pavement design for the traveling and the apron lanes, the structural design of the approach pavements and the jointing details of those pavements are also typically addressed.

Traffic Staging

Traffic staging during construction of a CRCP roundabout may depend on whether the roundabout is new construction or if an existing roundabout is being rehabilitated. Although a new roundabout construction can be staged to permit critical traffic flow along part of the intersection, roundabouts typically are constructed using detours at the intersection to allow for unrestricted roundabout construction, like the approach used for the Walker County CRCP roundabouts discussed previously and shown in figure 6. For rehabilitation of an existing HMA or JCP roundabout, the CRCP roundabout lanes can be constructed in stages while allowing traffic operation around part of the existing roundabout, but this staging approach could delay the opening of the completed roundabout.

Structural Thickness Design

A roundabout CRCP is typically designed for a service life of 40 years or longer. The CRCP design focuses on managing the crack spacing and crack width to reduce the structural distress that may develop as a result of traffic and environmental loadings. These distresses include deteriorated cracking, steel rupture, spalling at crack locations, and punchouts. CRCP design involves determining the 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. While most of these features are common to all good pavement designs, longitudinal reinforcement details are unique and critical to a CRCP.

The crack spacing in CRCP is significantly impacted by the concrete strength at early ages and the longitudinal steel characteristics (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 within a few years most cracks that develop should be spaced between 3 and 6 ft.

The design steel content for a given level of concrete strength provides a balance between the desired crack width (< 0.02 inches at the surface over the design life), the desired crack spacing (3 to 6 ft) over the design life, and the desired crack load transfer efficiency (>90 percent load transfer over the design life). During construction, the concrete strength should be targeted to be close to the assumed design strength in the design process. Achieving higher concrete strength in the field may result in longer crack spacing and wider cracks, while achieving lower than the design strength may result in shorter crack spacing with a higher risk of punchouts.

One design procedure for CRCP is the AASHTOWare Pavement™ ME Design software (AASHTO 2020; Roesler and Hiller 2013), although its use is not required under FHWA regulations. The Pavement™ ME software minimizes the development of punchout distress. The software input includes the longitudinal steel content as a designated input. For linear CRCP, the number of punchouts is limited to about 15 per mile over the design life. For CRCP roundabouts with the outer perimeter length typically not exceeding about 500 ft, the number of punchouts expected over the design period would be less than two.

It should be noted that many State highway agencies have developed guidance on the steel amount to be used for a range of concrete slab thicknesses based on local experience. Table 3 provides a typical bar size, bar spacing, and calculated steel percentage for a range of slab thicknesses. The use of epoxy-coated bars should follow the State highway agency practice.

Table 3. Typical longitudinal steel use in CRCP (FHWA 2019).

Slab Thickness, inches	Bar Size & Spacing, inches	Percent Steel
9	No. 6 @ 7.0	0.70
10	No. 6 @ 6.0	0.73
11	No. 6 @ 5.5	0.73
12	No. 6 @ 5.0	0.70
12	No. 7 @ 7.0	0.71

In general, a higher steel percentage keeps transverse cracks tighter and allows for good load transfer over the long life of CRCP. A tight crack also keeps out incompressible material and water, minimizes crack spalling, and greatly reduces the potential for development of punchouts in the CRCP. For slab thickness of 12 inches or larger, the change in bar size from No. 6 to No. 7 allows the longitudinal steel bars to be spaced farther apart, facilitating concrete placement and flow around the steel bars. Bars spaced too tightly in one horizontal plane may cause concrete consolidation issues.

Nominal steel contents of 0.70 to 0.75 percent are commonly used by State highway agencies in linear CRCP design (Roesler, Hiller, and Brand 2016; FHWA 2019). Adding additional steel may lead to concrete consolidation concerns because of the congestion caused by the additional bars. Typical U.S. practice is to place the longitudinal steel bars between about one-third to one-half of the slab thickness from the surface.

Concrete Materials and Mixture Design

From a technical standpoint, concrete mixture design for CRCP is similar to that used by State highway agencies for jointed concrete pavements. However, concrete workability is important in CRCP to ensure that the fresh concrete flows well through the steel reinforcement and that it can be easily consolidated to eliminate honeycombing. Typical concrete specifications for CRCP are as follows (Kosmatka and Wilson 2016; ACI 2017):

- Concrete strength (at 14 or 28 days):
  - Flexural strength for design purposes – 650 psi.
  - Compressive strength for acceptance purposes – 4,000 psi.
- Maximum water-cementitious materials ratio – 0.42 for CRCP exposed to cycles of freezing and thawing, 0.45 for CRCP in non-freeze-thaw areas.
- Air content (entrained) – As appropriate for the maximum aggregate size used and severity of exposure (climatic region).
- Durability – Concrete should be durable and should not be susceptible to materials-related distress, such as alkali-silica reactivity, sulfate attack, or D-cracking.
- Optimized aggregate gradation to ensure good workability and a dense matrix to ensure low permeability.
- Slump – 1 to 2 inches for slipform paving; 3 to 4 inches for fixed-form paving.
- Coefficient of Thermal Expansion (COTE) – Some State highway agencies limit the COTE of the concrete to less than 6.0×10^{-6} inch/inch/°F.

It should be noted that as part of the design process, the stab thickness, the percent steel, and the concrete strength have been matched. Therefore, during construction, achieving higher or lower concrete strength and thicker or thinner concrete slabs can affect the development of crack spacing and impact performance. Higher concrete strengths or thicker concrete slabs can lead to longer crack spacing and wider joint opening, while lower concrete strengths or thinner concrete slabs can lead to shorter crack spacing and a higher risk of punchouts.

Longitudinal Steel Lap Splices

It should be noted that the longitudinal steel used is bendable and can accommodate circular bending for roundabouts. Steel bars typically come in lengths of 60 ft and can be lap-spliced to form a continuous longitudinal mat around the roundabout. The lap-splicing patterns used are either staggered or skewed to avoid a weakened plane across the concrete pavement. Common U.S. practice is to use a lap length of 26 times the diameter of the longitudinal steel to ensure sufficient bond development length.

Transverse (Radial) Steel

Transverse, or radial steel in roundabouts, is used to position the longitudinal steel at the desired depth and spacing. Transverse steel may be supported on chairs placed on steel plates or transverse bar assemblies (TBAs) may be used. A TBA is a transverse bar with welded steel supports, which serve as chairs and include U-shaped clips. The use of TBAs speeds up the placement of the longitudinal steel bars. Both the chair supports and the TBAs should have sufficient bearing on the base to prevent overturning and to avoid penetration into the HMA base during warm weather. The transverse bars also serve to keep tight any longitudinal cracking that may develop. The following details are typical for transverse bars:

- No. 5 bars at 3-ft spacing at the outer perimeter.
- No. 6 bars at 4-ft spacing at the outer perimeter.

By the nature of the roundabout geometry and the placement of the transverse bars radially, the transverse bar spacing along the inner perimeter of each lane will be reduced by a few inches.

Because there is no possibility of lane drift for roundabout lanes, there is no need to use tie bars along longitudinal joints and there is no need to continue transverse bars across longitudinal joints into the adjacent lanes. The transverse bar layout for each lane can be developed independently from adjacent lanes.

Edge Support

For CRCP roundabouts, the following edge support features could be used depending on the functional use of the roundabout.

- Exterior lane:
  - Use of a curb placed along the CRCP edge.
  - Use of a curb and gutter adjacent to the lane.
  - Use of an asphalt or a concrete shoulder in rural settings.
- Interior lane:
  - Use of a transition curb between the lane and the apron lane.
- Apron lane:
  - Use of a transition curb between the apron lane and the central island.

Longitudinal Joint Details

In concrete roundabouts, deformed tie bars are often used to tie the interior concrete curb and gutter of the truck apron to the circulatory lane (see figure 10). Tie bars are also used to tie the truck apron to the concrete curb of the central island and to tie the outside curb/gutter to the outside circulatory lane. The tie bars are used to maintain alignment and restrain movement at tied "longitudinal" contraction and construction joints. Typical tie bar considerations during construction include (ACPA 2017):

- Tie bars are placed at mid-depth of the slab across the joint. These are typically No. 4 or No. 5 bars, 30 inches long, and spaced on 30-inch centers.
- Tie bars can be placed and aligned during concrete placement using various means including positioned on chairs or baskets, through proprietary systems that attach to formwork, the use of a tie bar inserter if the pavement is slipformed, or manually drilled into the existing slab and anchored with a grout or epoxy material.

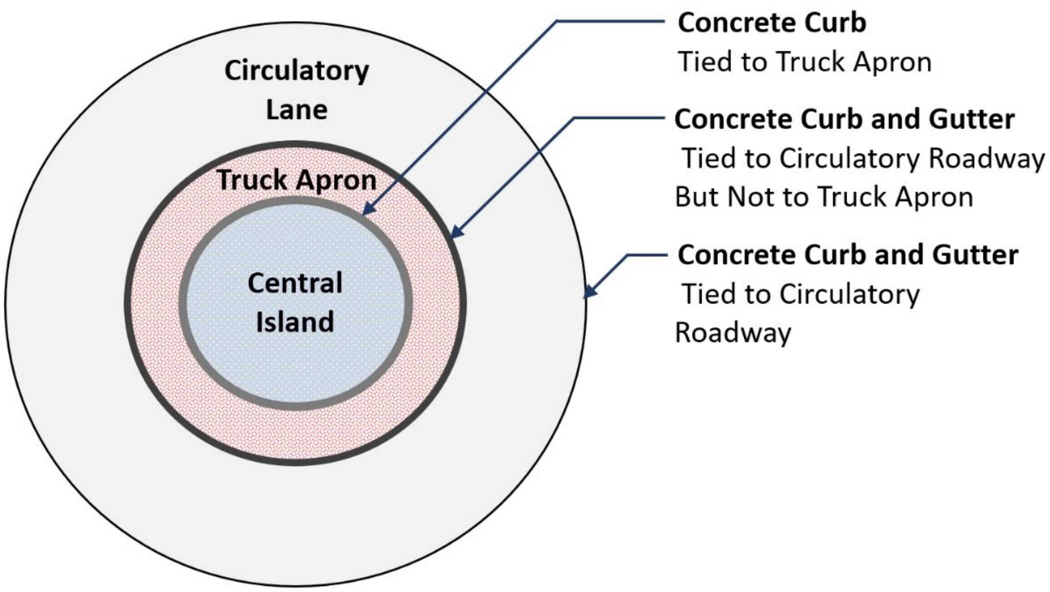


Figure 10. Tie bar locations for concrete roundabout designs.

It is possible to construct the roundabout without tie bars at these locations. This is because slab drifting or migration is unlikely to occur since the pavement is constrained by its geometric layout and by the dowel bars provided in the transverse joints. The resulting free edge condition of untied longitudinal joints may lead to slight increases in the thickness of the slabs used in the circulatory lane.

Base Support

The following base types are commonly used under linear CRCP and may be used for roundabout CRCP:

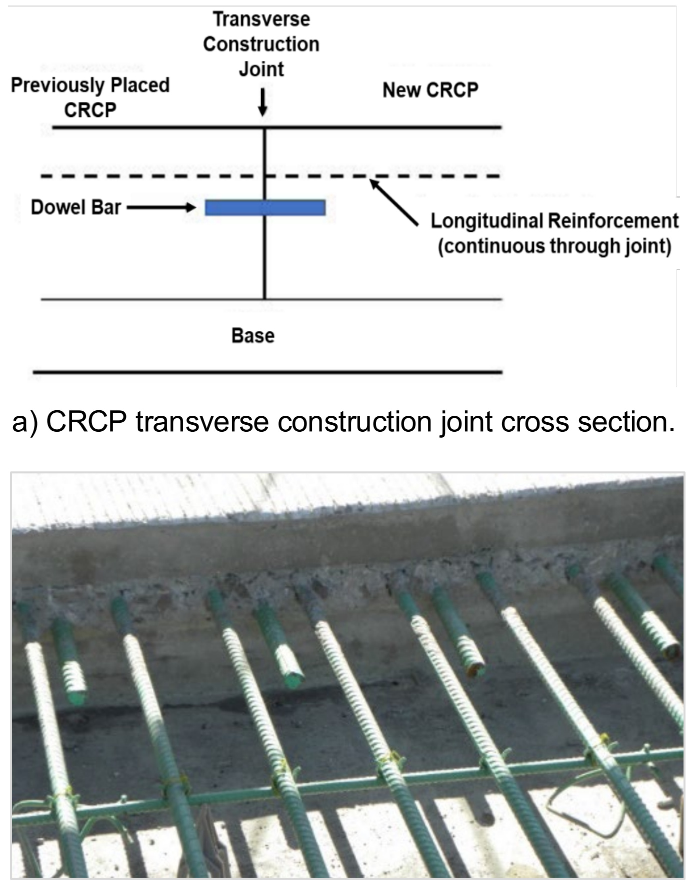
- Granular base – for lower levels of truck traffic (< 60 trucks/day).
- Hot-mixed asphalt (HMA) base – for higher levels of truck traffic.
- Cement-treated base (CTB) with an HMA interlayer – for higher level of truck traffic.

Pavement monitoring data have shown that permeable bases do not perform well under CRCP designs (Heckel 1997).

Granular, HMA, and cement-treated bases all provide a stable working platform during construction for steel and concrete placement. A well-graded base ensures a smooth pavement surface, and the base texture/bonding characteristic is also important to performance. The base surface should result in just enough friction at the concrete slab/base surface interface to promote concrete cracking at the desired spacing of 3 to 6 ft. If there is too much slab/base friction or bonding, it will lead to shorter crack spacing, while if there is too little friction, it will lead to longer and more variable crack spacing (FHWA 2019). Both an HMA base or a CTB with an HMA interlayer perform well in linear CRCP (Roesler, Hiller, and Brand 2016) and can be expected to do so for roundabout CRCP.

Transverse Construction Joint Details

By the nature of construction, a roundabout CRCP lane has at least one transverse construction joint, at the start of concrete placement. Additional 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). For CRCP, the transverse construction joint design involves maintaining the continuity of the longitudinal steel and provision for adequate load transfer across the joint, which has smooth faces. Poorly designed and constructed transverse construction joints are potential locations of early-age punchouts or other deterioration. In the past, practice was 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. The typical approach is to ensure necessary load transfer across the smooth joint faces is provided by use of dowel bars, as shown in figure 11, designed similarly to load transfer for jointed concrete pavement (FHWA 2019).



a) CRCP transverse construction joint cross section.

b) CRCP transverse construction joint.

Figure 11. CRCP transverse construction joint design.

A minimum of four dowel bars is typically used in each wheel path. Dowel bars may be smooth or deformed. The longitudinal bars that cross the joint are sufficient to maintain the joint tightly closed, like the tight cracking maintained by the same longitudinal bars. The need for extra "steel" at the joint is so that the necessary load transfer is available at this smooth-faced joint. The construction joint should be at least 12 ft from the last construction joint, and the distance from the construction joint to the nearest longitudinal bar splice should be at least 42 inches.

Isolation Joints and Roadway Transitions

The CRCP roundabout pavement is typically constructed in a circular pattern. The approach and existing roadways may consist of HMA pavement, JCP, or CRCP.

For the case of the approach and exiting HMA pavements, the termination portion of the roadways at the roundabout should be a jointed concrete pavement and an expansion joint should be used around the outside perimeter of the exterior roundabout CRCP lane at the location of the juncture with the approach and the exiting roadways. Also, a support slab (as shown previously in figure 7) should be used under the CRCP section and the ends of the approach and exiting roadways to reduce deflections as heavy vehicles cross the juncture. The same transition detail is applicable if the approach and exiting roadways consist of JCP.

For the case of CRCP approach and exiting roadways, a linear CRCP terminal expansion joint design can be used. Details for the terminal expansion joint design are discussed elsewhere (Roesler, Hiller, and Brand 2016). Also, depending on the site condition and other factors, the approach CRCP lanes may be continued (paved-through) around a partial length of the roundabout. Discussion of this design approach is beyond the scope of this Tech Brief.

Truck Apron

As shown in figure 1, the truck apron is the area between the circulating roadway and center island whose purpose is to provide a paved surface for wheel tracking of trailer axles as long trucks pass through the roundabout. Colored concrete or stamped patterns are among the options used to differentiate the appearance of the truck apron from the circulatory roadway, but in some cases these may discourage truck drivers from using the apron (ITE 2008).

The truck apron may be CRCP, JCP, or, in some cases, block pavers, with an expansion joint used to isolate it from the back of curb of the circulatory pavement. If the truck apron is JCP, some standard detail drawings (e.g., SDD 13C18-e, WisDOT 2018) show the truck-apron transverse joints without dowels, which may satisfy most design situations. State or local highway agencies may choose not to place dowels in the truck apron if it is assumed that few if any trucks could traverse the transverse joints. Alternatively, dowels could be used along the full length of transverse joints in the truck apron, especially for smaller-diameter roundabouts, if it is assumed that a significant number of trucks could traverse them. Similarly, a logical design detail for transverse joints in the truck apron could also show dowels along the outer half of the transverse joint if this is assumed to be the portion of the transverse joint that could be subjected to a significant volume of truck traffic.

Construction of CRCP Roundabouts

Introduction

Construction of CRCP for roundabouts is like linear CRCP construction, except that there are no end treatments. The following subsections highlight important CRCP roundabout construction factors.

Subgrade Preparation

For a new roundabout construction at an existing intersection or a relocated intersection, construction can start with the preparation of the subgrade. The subgrade should provide uniform support to the CRCP. Problematic soils, including those that are expansive or susceptible to frost heave, can be addressed by removing and replacing the soil or through the use of chemical stabilization (lime or cement) to reduce swell potential. Some State highway agencies may specify the use of geogrid or geotextile for cases of poor subgrade or when the potential for migration of fines into the engineered layers exists.

For rehabilitation of an existing roundabout, it may not be necessary to re-work the subgrade.

Subbase and Base Preparation

For CRCP, it is desirable for the support under the concrete slab to be stable and uniform. This is achieved using subbase and base layers. The subbase is commonly an unstabilized, granular material that is used to improve drainage and/or provide protection against expansion or heave. With respect to the base, as discussed previously, several options are available:

- HMA base – for higher levels of truck traffic.
- CTB with an HMA interlayer – for higher level of truck traffic.

The base for the CRCP provides uniform support to the concrete slab and contributes to the development of crack spacing in the typical range of 3 to 6 ft. Isolated areas of poor/marginal support can lead to early failures/punchouts. Any variability in the stability of the base support can increase the risk of punchouts in the areas of the weak support.

The base material is typically placed wider than the specified concrete pavement width to ensure uniform slab support at the edge of the pavement and to provide support for concrete forms or slipform paver tracks. The standard State highway agency practices should be followed to construct the subbase and base. The base surface should be stable enough to carry the weight of the pre-placed reinforced steel.

When an existing HMA or JPC roundabout is being rehabilitated using CRCP, part of the base may be reused and with only grade correction and compaction if the existing base is granular.

Reinforcing Odd-Shaped Slabs

The CRCP roundabout layout may result in several odd-shaped slabs at the junctions with the approach roadways. These odd-shaped slabs utilize reinforcement to mitigate cracking that may occur because of their geometry and size. It is typical practice to use steel in both directions (along the longer dimension and along the direction perpendicular to the longer direction). The cross-sectional area of steel should be between 0.15 and 0.20 percent, obtained using welded wire fabric or a grid of small diameter rebar (e.g., No. 3 bars). The steel is generally positioned in the top half of the slab with adequate cover (typically 2.5 to 3 inches), held in place on chairs or dobies, and terminated 6 inches from the perimeter. Care is exercised during concrete hand-placement to avoid stepping on the steel and forcing it to the bottom of the slab.

Isolating Drainage and Utility Manholes

The design layout of a CRCP roundabout typically eliminates the location of utilities within the CRCP lanes. If utility manholes are to be located within a CRCP lane, the manhole should be isolated and additional longitudinal reinforcement, equal to the diameter of the manhole, should be provided along each side of the manhole to replace the bars that are cut to accommodate the manhole. Blockouts are used at the manhole locations and compressible board type material is used to isolate the manhole from the slab. The blockouts typically are covered during concrete placement.

Drainage inlets are located along the outer perimeter of the roundabout and can be incorporated within the curb and gutter or in the shoulder. During construction, any drains or inlets should be protected before paving to prevent concrete from getting into the drainage system.

Steel Placement

As discussed previously, longitudinal steel is placed on transverse bars, oriented radially, that are placed manually on chairs or on TBAs that rest on the base. The steel placement for a CRCP roundabout is like the steel placement for linear CRCP, except for the circular alignment of the longitudinal steel bars. The practice is discussed in detail elsewhere (Roesler, Hiller, and Brand 2016) and should follow the State highway agency's requirements for steel placement inspection and tolerances. If chairs are used to support the transverse bars over an HMA base or an HMA interlayer, plates typically are used under the chairs during warm weather to prevent the chairs from sinking into the base layer. Views of the steel placement at the Walker County, Texas, CRCP roundabouts are shown in figures 7 and 9.

Concrete Placement

The placement of concrete for CRCP roundabouts is typically done using fixed-form paving and one-lane-at-a-time construction. The outer travelling lane is constructed first, followed by the inner lane and the apron lane. A bridge deck type vibratory screed together with a roller screed was used at the Walker County, Texas, CRCP roundabout project. Figure 12 shows the formwork for the Walker County project (Robbins 2016). Forms used for CRCP roundabout concrete placements are typically made of wood, but plastic forms are another option. Forms should be adequately supported at the edge and base to provide support for placing and finishing equipment and to resist bulging during concrete placement. The concrete is delivered from the side using ready-mixed concrete trucks and chutes or the concrete may be pumped.

For large radius CRCP roundabouts, slipform paving may be used. The use of a slipform paver incorporates a leave-out length to allow the paver to move to the next lane. A closure placement would be used to close-out the leave-out after all lanes are constructed. It should be noted that the leave-out results in one or two additional construction joints.

Figure 12. Formwork for the Walker County CRCP roundabout.

All slipform paving, especially when being used for the construction of roundabouts, has upfront planning and, at a minimum, the following items can be addressed:

- Paver entrance and exit paths (at least one leave-out area).
- Width of paving and features included (i.e. one lane or lane and curb/gutter, etc.).
- Concrete placement method – The concrete may be deposited in front of the paver using side discharge from ready-mixed concrete trucks using chutes or using a belt placer located on the shoulder or on a completed lane. The concrete may also be deposited in front of the paver using pumped concrete.

Whether a slipform paver is used or a fixed-form method is used, the concrete is proportioned to be workable so the concrete can flow through the reinforcement and can be consolidated adequately without honeycombing or segregation. In addition, concrete placed using a slipform paver typically is low-slump concrete that will not result in edge slump.

As discussed previously, the CRCP roundabout concrete pavement will result in at least one transverse construction joint at the start of the concrete placement. The transverse construction joint is formed using a header board using conventional practice. Concrete at each side of the construction joint should be well consolidated.

Surface Finishing and Curing

Typically, the pavement surface is textured to provide adequate surface friction for the roundabout facility. As vehicle speeds in roundabout are relatively low, adequate surface friction is commonly obtained by using broom finishing or exposed aggregate finish. However, many State highway agencies use transverse or longitudinal tining that is usually manually applied. Curing practices should be no different than conventional practice for concrete pavement construction and should follow State highway agency approved methods.

Summary

CRCP is a suitable pavement type for roundabout facilities designed to carrying heavy truck traffic and buses. CRCP typically does not need maintenance and repair during the initial 15 to 20 years of service, so minimal disruptions to traffic can be anticipated. Like other pavements, if CRCP roundabout pavements are built smooth they stay smooth longer.

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Contact—For more information, contact:

Federal Highway Administration (FHWA)
Office of Preconstruction, Construction and Pavements
Sam Tyson (sam.tyson@dot.gov)

Researcher—This Tech Brief was developed by Shiraz Tayabji (Advanced Concrete Pavement Consultancy, LLC) and prepared under FHWA's Pavement Roundabouts project (693JJ320F000070). Applied Pavement Technology, Inc. of Urbana, Illinois served as the contractor to FHWA.

Distribution—This Tech Brief is being distributed according to a standard distribution. Direct distribution is being made to the Divisions and Resource Center.

Availability—This Tech Brief may be found at https://www.fhwa.dot.gov/pavement.

Key Words—roundabout, pavement design, construction

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MARCH 2021 FHWA-HIF-20-081