CHAPTER 12
PRICIPLES OF DESIGN FOR RIGID PAVEMENT INTERSECTIONS

12.1 Introduction

The construction and reconstruction of urban intersections utilizing Portland Cement Concrete Pavement (PCCP) needs to be given serious consideration by the designer. PCCP in an intersection offers many advantages, such as long life, reduction in maintenance costs, and elimination of wash boarding and rutting caused by the braking action of all types of traffic, especially heavy buses and trucks. PCCP in an intersection will eliminate the distress caused in asphalt pavements due to rolling traffic loads and the deceleration/acceleration forces.

12.2 Design Considerations

The distance from the intersection where deformation such as rutting and shoving occurs varies depending on the traffic situation, types of traffic, speed and stopping distance, and the number of vehicles per lane stopped at the intersection. Several approaches can be used. In some applications, PCCP can extend the full width for several hundred feet on each side of the intersection. In other situations, the concrete lanes approaching the intersection extend 250 feet (deceleration lane), while those going away terminate about 60 feet (acceleration lane) beyond the curb return. These approaches can be used for both high volume streets and bus stops. For more moderate traffic, 50 to 100 feet on each side of the intersection is likely to be adequate. This distance can be based on an evaluation of the existing traffic and pavement conditions.

Dowels should be placed in the transverse joints of the dominant traffic stream, as well as, the cross street transverse joints. Tie bars should be placed in the longitudinal joints of the dominant traffic stream and cross street sections past the intersection.

Class P concrete is recommended for rigid pavements. If it is desirable to fast track an intersection reconstruction, Class E concrete can be used. Class E concrete is designed to achieve a minimum of 2,500 psi in 12 hours or as required. It is possible to remove existing pavement, recondition the base materials, place Class E concrete, and have the roadway open for traffic within 24 hours.

12.3 Design Period

The destructive effect of repeated wheel loads and the impacts of braking action are the major factors that contribute to the failure of highway pavement at the intersections. Since the magnitude of the load, the number of its repetitions, and the braking actions are important, provisions are made in the design procedure to allow for the effects of braking actions and the number and weight of all axle loads expected during the design period. **The design period for new rigid pavement construction and reconstruction is 30 years.**

12.4 Traffic Analysis

When two roadways intersect there are two streams of traffic that exert loads on the pavement. The total of the historic design 18,000-pound equivalent single axle loads (18k ESAL) for each stream of traffic should be used in the calculation for the intersection's pavement thickness. In any pavement, the destructive effect of repeated wheel loads is the major factor that contributes to the pavement failure. Design traffic will be the 18k ESAL obtained from the Traffic Analysis Unit of the Division of Transportation Development, http://dtdapps.coloradodot.info/Otis/TrafficData. The actual projected traffic volumes for each category are weighted by the appropriate load equivalence factors and converted to a historic cumulative total 18k ESAL number to be entered into the rigid pavement design equation. Since different load equivalence factors apply to different pavement types, the designer must inform the Traffic Analysis Section that the intended use of the historic 18k ESAL is for a rigid pavement design.

Another source of traffic load data can be Weigh-In-Motion (WIM) data. Although these devices are not as plentiful, they are usually more accurate for measurements of traffic load in the present year. Projections for future traffic loads can be calculated similarly using growth factors provided by the DTD Traffic Analysis Unit.

12.5 Design Methodology

Design methodologies for rigid intersections are similar to those found in **CHAPTER 7, Principles of Design for Rigid Pavement.**

12.6 Rigid Pavement Joint Design for Intersections

Joints are used in PCCP to aid construction and eliminate random cracking. There are two types of longitudinal joints. The first are longitudinal weakened plane joints that relieve stresses and control longitudinal cracking. They are spaced to coincide with lane markings, and are formed by sawing the hardened concrete to a depth of $^1/_3$ the pavement thickness. Longitudinal construction joints perform the same functions and also divide the pavement into suitable paving lanes. These construction joints should be tied with deformed reinforcing steel bars to hold the slabs in vertical alignment. Stresses in a slab are reduced when the slab is tied to adjacent slabs. Keyed joints may be used in a longitudinal construction joint, but tying the slabs is preferable.

- **The Key** may be formed by attaching a keyway at the mid-depth of a side form. With a slip form paver, the keyway can be formed as the paver advances. For detailed layout refer to the CDOT's *Standard Plans, M & S Standards*, July 2012.

- **Transverse Joints** are spaced at short intervals in the slab. A maximum of 12 feet is recommended to insure crack control and ease of construction. The joint should be sawed to a depth of at least $^1/_3$ the pavement thickness.

- **Dowel Bars** in the first three transverse joints where PCCP abuts an asphalt pavement can prevent progressive slab movement.

- **Expansion Joints** are not required except at intersections.

The following summarizes the general design guides and information for constructing rigid pavement joints:

- Joints are used in PCCP to aid construction and minimize random cracking.
    - Odd shaped slabs and acute angles of less than 60 degrees should be avoided.
    - Longitudinal joint spacing should be approximately 12 feet. Longitudinal joints should be tied to hold adjacent slabs in vertical alignment, as well as, curb and gutter.
    - Transverse joint spacing should be at regular 12 foot intervals with no more than a 15 foot spacing. Transverse joints should be carried through the curb.
    - Thinner slabs tend to crack at closer intervals than thicker slabs. Long narrow slabs tend to crack more than square slabs.
    - All contraction joints must be continuous through the curb and have a depth equal to $^1/_3$ of the pavement thickness.
    - Expansion joint filler must be full-depth and extend through the curb.

- The normal backfill behind the curb constrains the slabs and holds them together.
    - Offsets at radius points should be at least 18 inches wide.
    - Minor adjustments in joint location made by skewing or shifting to meet inlets and manholes will improve pavement performance.
    - When pavement areas have many drainage structures (particularly at intersections) place joints to meet the structures whenever possible.
    - Depending on the type of castings, manhole and inlet frames may be boxed out and isolated using expansion joint filler. The frames may be wrapped with expansion joint filler or the frames may be cast rigidly into the concrete.

- CDOT designs their PCCP using the JPCP (Jointed Plain Concrete Pavement) method. For a detailed illustration, see CDOT's CDOT *Standard Plans, M & S Standards*, July 2012, M-412-1 Concrete Pavement Joints and as revised.

Following the previous design of a new intersection near Sugarloaf Reservoir, the following steps and points should be followed to design slabs and location of joints:

- **Step 1**. Draw all edge of pavement lines on a plan view. Plot all utility manholes, catch basins, water valve, etc. on the plan view (see **Figure 12.1**).

- **Step 2.** Draw lines, which define the median, travel lanes, and turning lanes. These lines define the longitudinal joints (See **Figure 12.2**).

- **Step 3**. Determine locations in which the pavement changes width (i.e. channelization tapers, turning lane tapers and intersection radius returns). Joints at these locations are necessary to isolate irregular shapes. Triangles or circles, which are left intact with a

rectangular portion of a slab, will create a plane of weakness that will break during temperature movements of the slab. Concrete simply likes to be square (see **Figure 12.3**).

- **Step 4.** Draw transverse lines through each manhole or other utility. Joints need to be placed through utility structures in the pavement, or movement of the pavement will be restricted and cracking will result. When structures are located near a joint placed according to the steps above, isolation can be provided by adjusting the joint to meet the structure. By doing this, numerous short joints will be avoided. Add transverse joints at all locations where the pavement changes width, extending the joints through the curb and gutter. Create an "intersection box". Do not extend joints that intercept a circumference-return-return line, except at the tangent points. The joints at the tangent point farthest from the mainline becomes an isolation joint in the cross road for T and unsymmetrical intersections (see **Figure 12.4**).

- **Step 5**. The intermediate areas between the transverse joints placed in Steps 3 and 4 may also require transverse joints. These joints are placed using a standard joint spacing. There is an old rule of thumb for joint placement in plain concrete pavements that says, the joint spacing, in feet, should be no greater than two to two and a half times the slab thickness, in inches. However, in no case should the joint spacing exceed 15 feet (see **Figure 12.5**).

- **Step 6.** Where an intersection is encountered, intermediate joints must be placed. This is done by extending the radius line of each turning radius three feet beyond the back of curb. The extension is made at approximately the 45 degree line for small radii, and at approximately the 30 and 60 degree lines for larger radii. Joints are then connected to each of these points.

- **Step 7.** Expansion joints are needed adjacent to any structure, i.e., bridges, buildings, etc., and at T intersections. T intersections are isolated at the radius return to the intersecting street. The same layout discussed in Step 6 is used at that location.

- **Step 8.** If there are manholes or other structures, which cannot be intersected by a joint, they must be isolated. These structures can be isolated by boxing out the structure during paving. Manholes can also be isolated by using a telescoping manhole, which can be poured integral with the pavement. The area around the structure should be reinforced to control cracking. The joints that form a box out should be expansion joints to allow some movement.

- **Step 9**. Check the distances between the “intersection box” and the surrounding joints (see **Figure 12.6**).

- **Step 10**. Lightly extend lines from the center of the curve(s) to the points defined by the “intersection box” and point(s) along any island. Add joints along these radius lines. Finally, make slight adjustments to eliminate dog legs in mainline edges (see **Figure 12.7**).

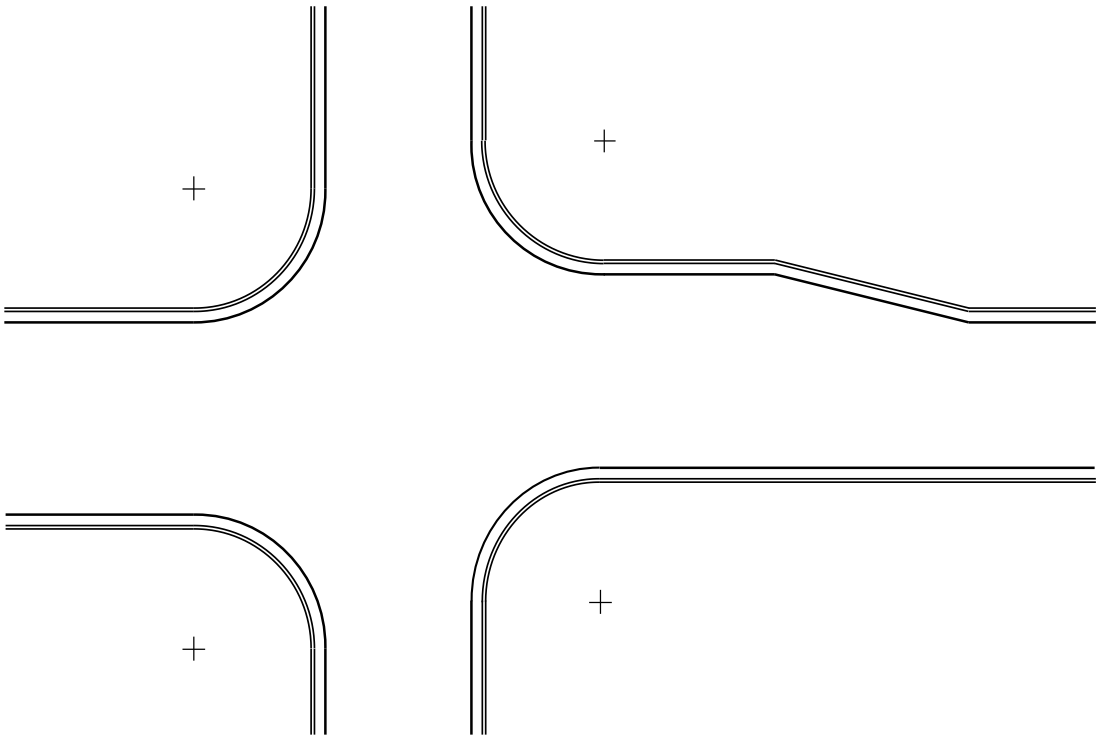


Figure 12.1 Typical Joint Layout for a Rigid Pavement Intersection
(Shows Lane Configuration, Step 1)

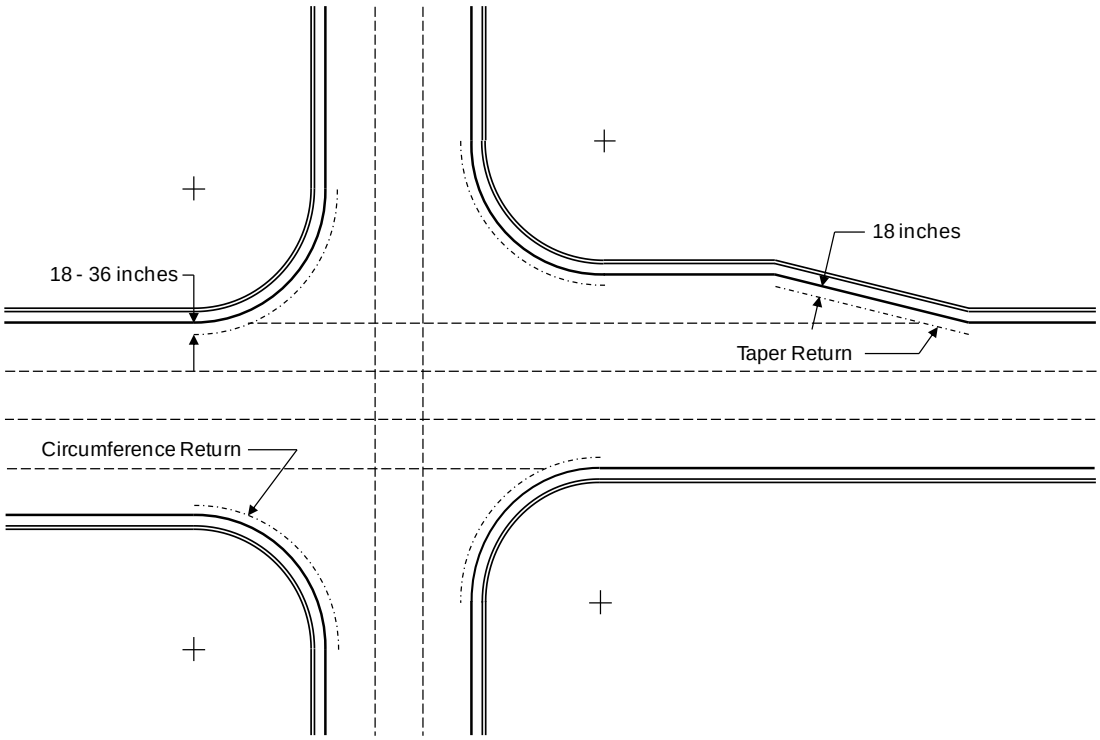


Figure 12.2 Typical Joint Layout for a Rigid Pavement Intersection
(Shows Lane Configuration, Step 2)

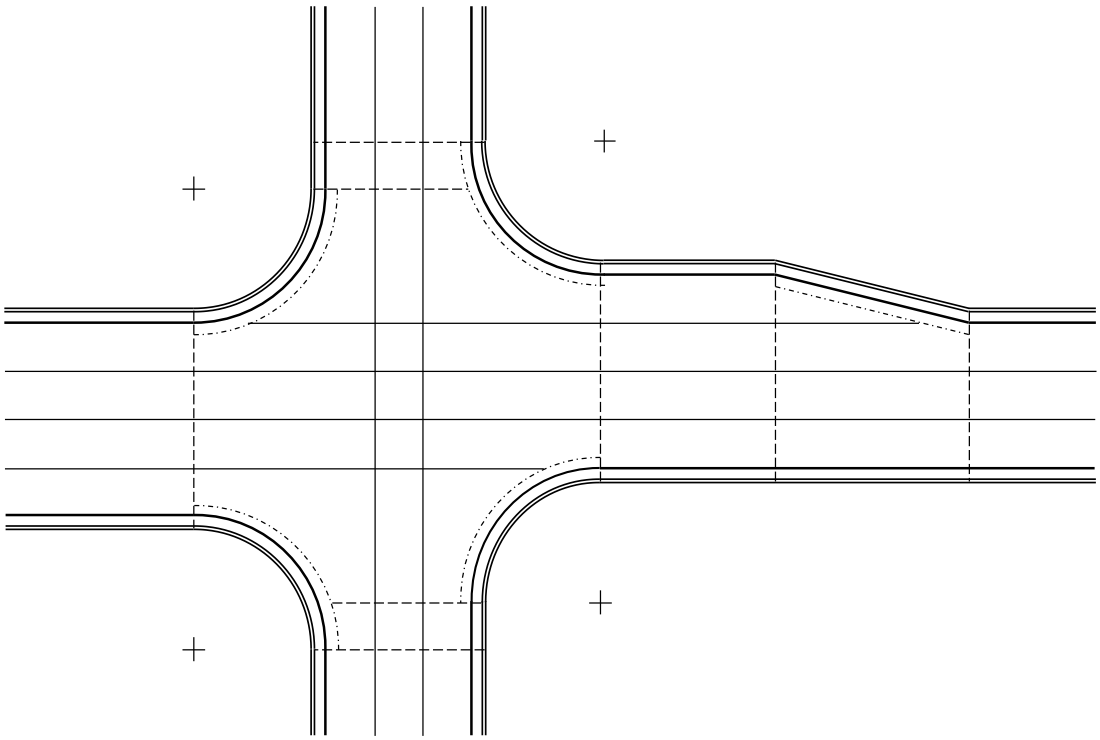


Figure 12.3 Typical Joint Layout for a Rigid Pavement Intersection
(Shows Lane Configuration, Step 3)

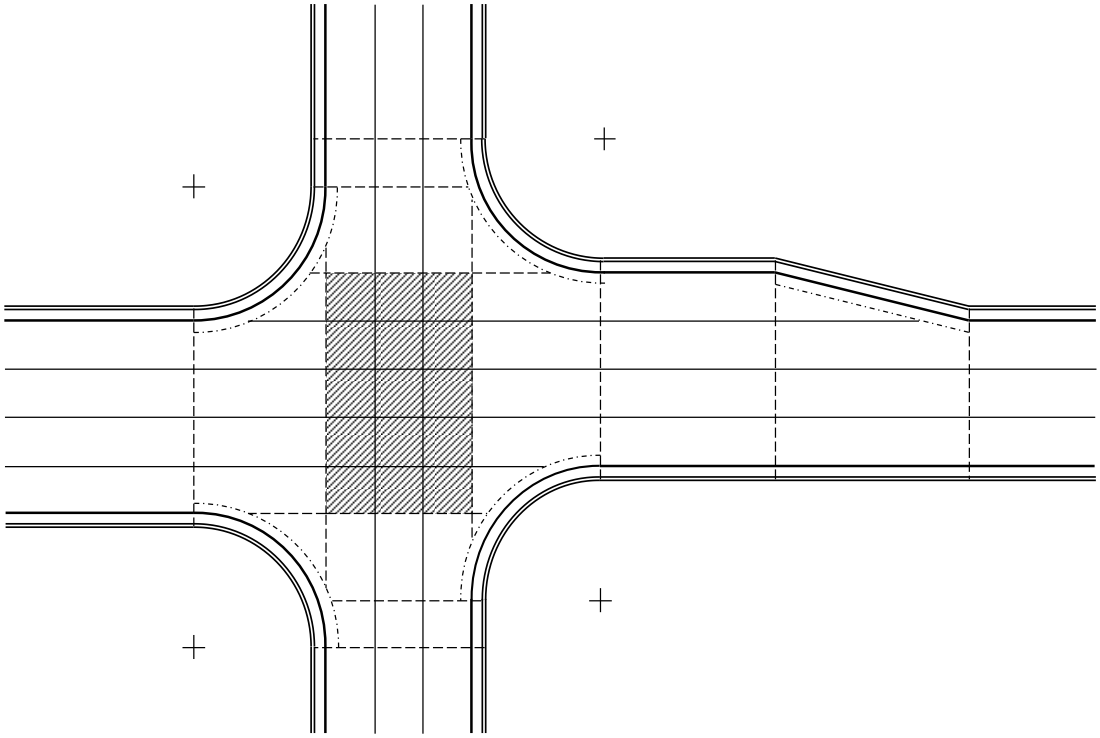


Figure 12.4 Typical Joint Layout for a Rigid Pavement Intersection
(Shows Lane Configuration, Step 4)

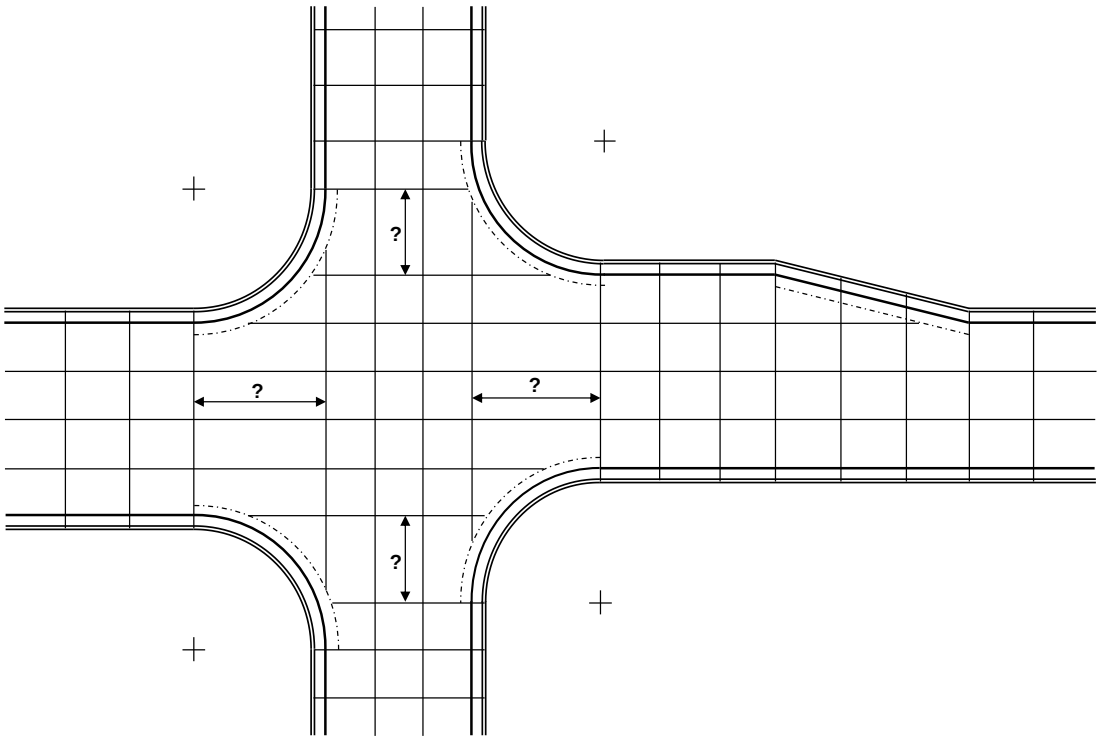


Figure 12.5 Typical Joint Layout for a Rigid Pavement Intersection
(Shows Lane Configuration, Steps 5 thru 8)

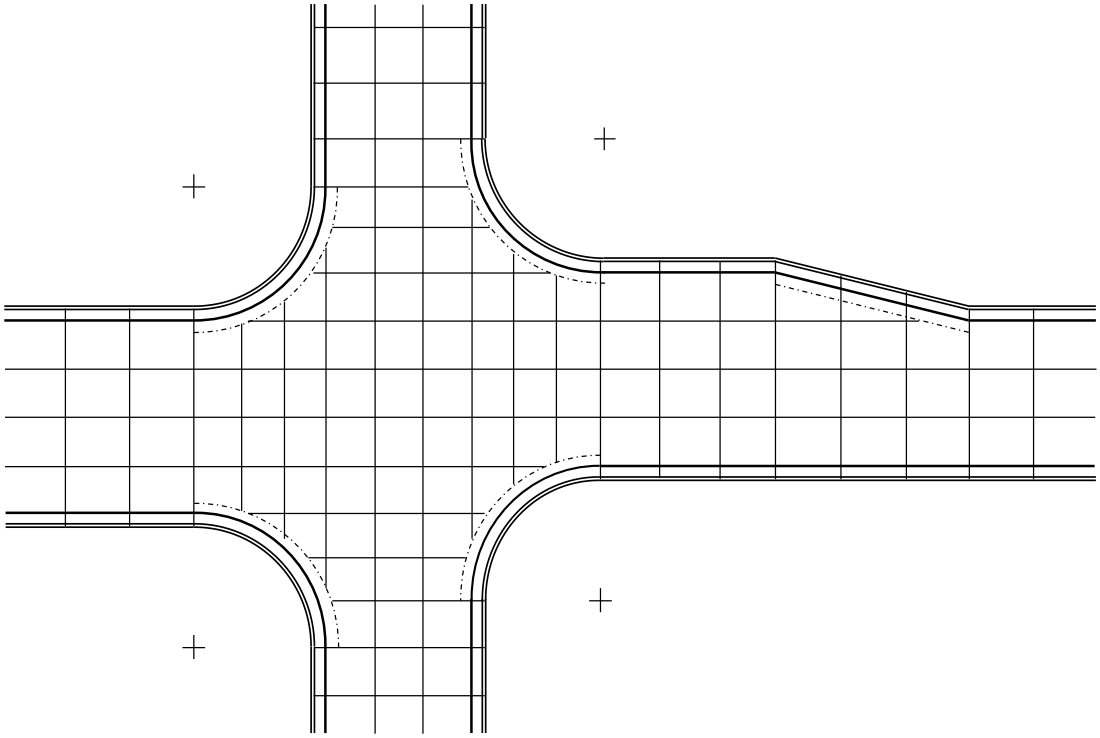


Figure 12.6 Typical Joint Layout for a Rigid Pavement Intersection
(Shows Lane Configuration, Step 9)

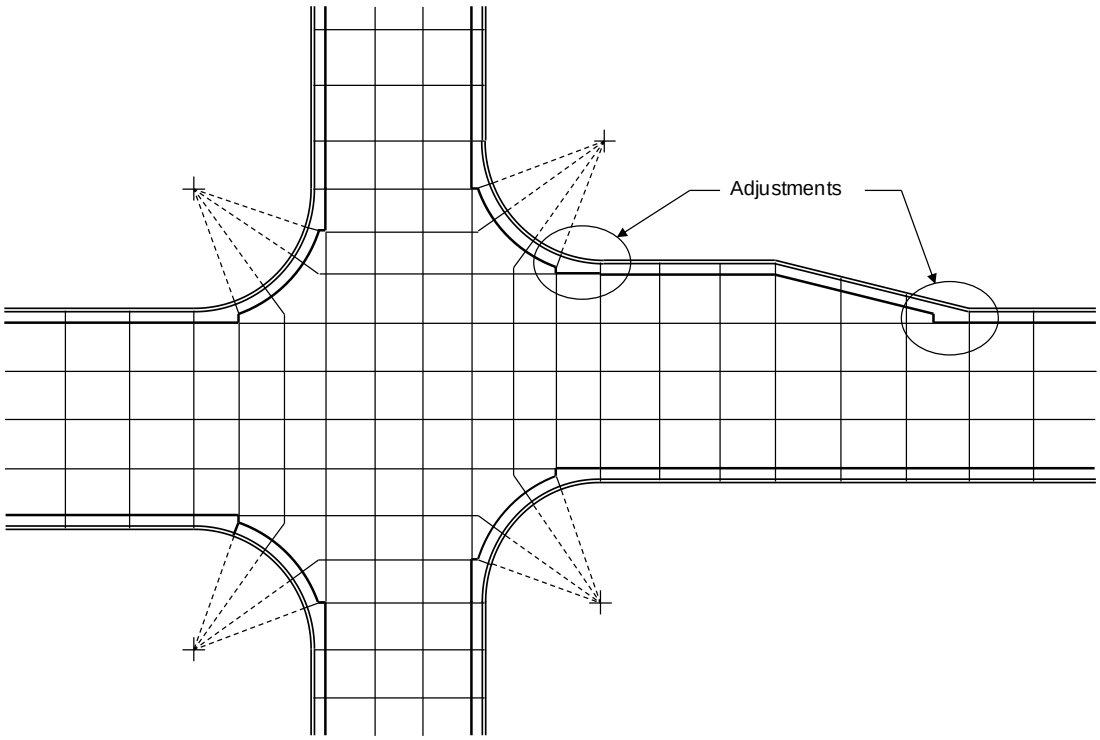


Figure 12.7 Typical Joint Layout for a Rigid Pavement Intersection
(Shows Lane Configuration, Step 10)

12.7 Assessing Problems with Existing Intersections

A successful rigid pavement intersection rehabilitation project is dependent on proper project scoping. The keys to proper scoping include the following:

- Identifying the problem with the existing intersection
- Removing enough of the pavement section to encompass the entire problem
- Designing and reconstructing with a full depth PCCP especially formulated for high traffic volume intersections. Special caution should be exercised in concrete overlay intersections (using PCCP overlay and not a full depth PCCP design).

12.8 Detail for Abutting Asphalt and Concrete

When joining asphalt and concrete slabs refer to the schematic layout given in **Figure 12.8 Detail of Asphalt and Concrete Slab Joint**. The figure shows how at least three consecutive machine-laid concrete slabs will be constructed and doweled at the transverse construction joints to prevent creeping or curling. The size of the dowels will conform to * Assumes 90 degree angles between entries and roundabouts with four or fewer legs.
CDOT's *Standard Plans, M & S Standards*, M-412-1 Concrete Pavement Joints and as revised (use the larger required dowel diameter in joining 2 different pavement thicknesses), will be 18 inches long, and spaced under the wheel paths as shown on CDOT's *Standard Plans, M & S*

Standards, July 2012, M-412-1 Concrete Pavement Joints. A hand-poured concrete slab with a rough surface finish and a depth equal to the design thickness will be constructed and joined to the first of three machine-laid concrete slabs numbered 1, 2 and 3. Concrete Slab Number 1 will have a depth of design thickness plus 2 inches. Concrete slabs 2 and 3 will be constructed with a depth equal to the design thickness.

The bottom of the hand-poured concrete slab will be flush with the bottom elevation of concrete Slab 1 leaving a 2-inch vertical drop from the adjacent concrete slab's finish elevation. The HMA paving operation will terminate in the area of the hand-poured concrete slab that will be overlaid with a HMA overlay to fill the 2-inch vertical drop.

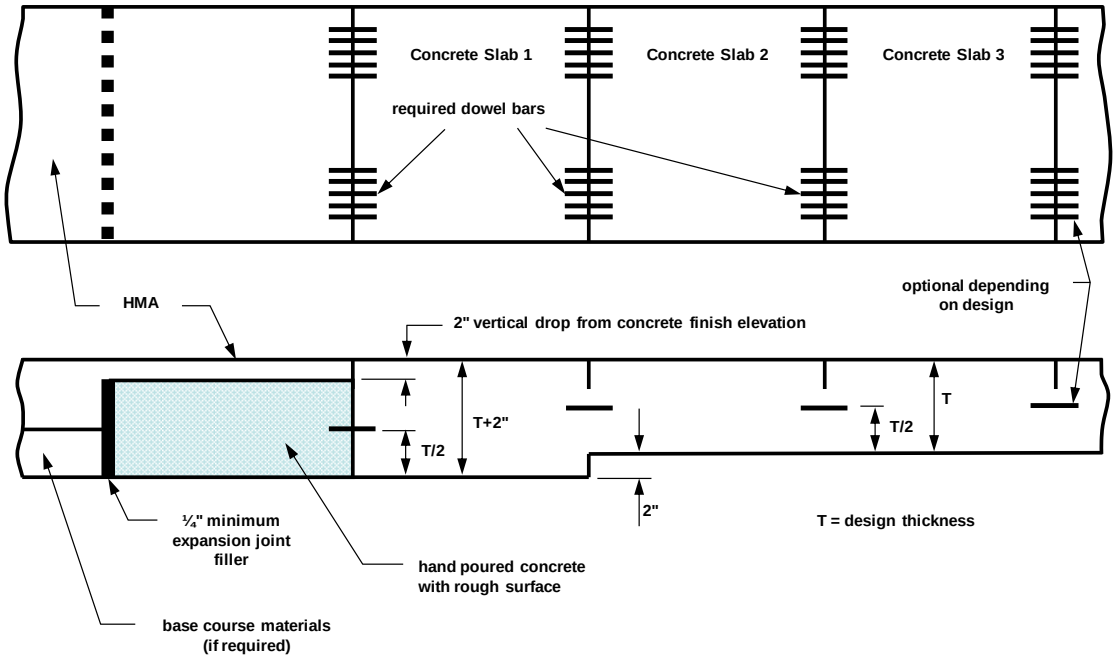


Figure 12.8 Detail of Asphalt and Concrete Slab Joint

12.9 Roundabout Pavement Design

Roundabouts are circular intersections with specific design and traffic control features. These features include yield control to entering traffic, channelized approaches, and appropriate geometric curvature to ensure travel speeds on the circulatory roadway are typically less than 30 mph. Thus, roundabouts are a subset of a wide range of circular intersection forms. Circular intersections that do not conform to the characteristics of modern roundabouts are called "traffic circles" (1).

Roundabouts have been categorized according to size and environment to facilitate discussion of specific performance or design issues. There are six basic categories based on environment, number of lanes, and size:

- Mini-roundabouts
- Urban compact roundabouts
- Urban single-lane roundabouts
- Urban double-lane roundabouts
- Rural single-lane roundabouts
- Rural double-lane roundabouts

The most likely categories CDOT will use are the urban and rural double-lane roundabouts. The double-lane roundabouts can be expected to handle the increased traffic volumes of a state highway. The following chapter sections will address the double-lane categories.

13.9.1 Roundabout Geometry

12.9.1.1 Minimum Radius

The minimum radius geometry of a roundabout is dependent on several variables including vehicle path radii, alignment of approaches and entries, entry width, circulatory roadway width, size of the central island, entry and exit curves, size of the design vehicle, and land constraints. The designer must incorporate the needs of all the aforementioned items for proper design (see **Figure 12.9 Basic Geometric Elements of a Roundabout).** The AASHTO publication, *A Policy on Geometric Design of Highways and Streets* (2) provides the dimensions and turning path requirements for a variety of common highway vehicles. FHWA's *Roundabouts: An Informational Guide*, Publication No. FHWA-RD-00-067, June 2010 (3) provides guidelines in choosing an appropriate minimum radius.

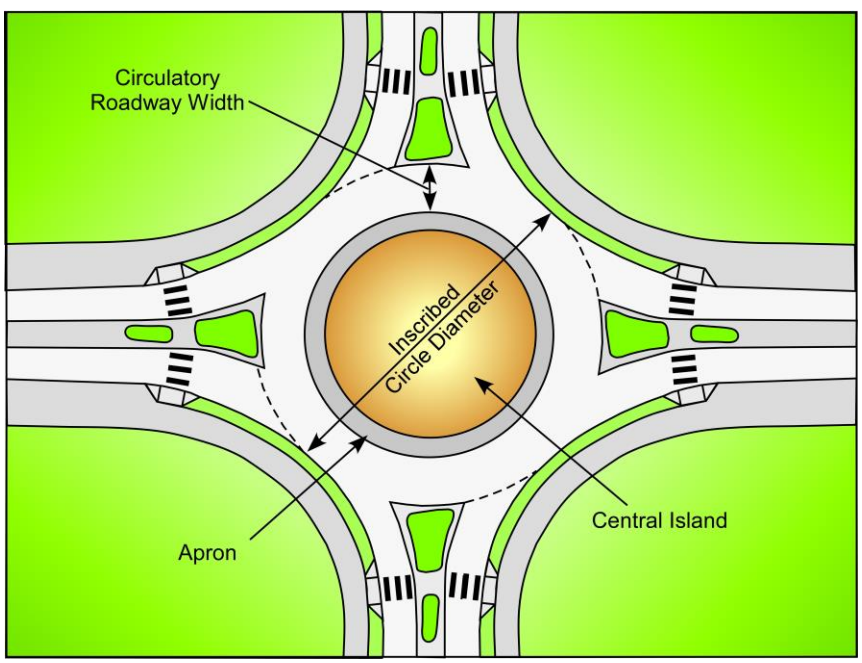


Figure 12.9 Basic Geometric Elements of a Roundabout
(Modified from Exhibit 6-2, *Basic Geometric Elements of a Roundabout, Roundabouts: An Informational Guide*, Federal Highway Administration, Publication No. FHWA-RD-00-067, June 2000 (3))

12.9.1.2 Inscribed Circle Diameter

Figure 12.9 Basic Geometric Elements of a Roundabout shows the inscribed circle diameter, which is the distance across the circle inscribed by the outer curb of the circulatory roadway. In general, smaller inscribed diameters are better for overall safety because they help maintain lower speeds. Larger inscribed diameters allow for a better approach geometry, decreased vehicle approach speeds, and a reduced angle between entering and circulating vehicle paths. Thus, roundabouts in high-speed environments may require diameters that are somewhat larger than those recommended for low-speed environments. Very large diameters (greater than 200 feet) should not be used because they will have high circulating speeds resulting in greater severity crashes.

Table 12.1 Recommended Inscribed Circle Diameters
(From Exhibit 6-19, *Recommended Inscribed Circle Diameter Ranges, Roundabouts: An Informational Guide, Federal Highway Administration,* Publication No. FHWA-RD-00-067, June 2010 (3))

Site Category	Inscribed Circle Diameter Range* (feet)
Mini-Roundabout	45-80
Urban Compact	80-100
Urban Single Lane	100-130
Urban Double Lane	150-180
Rural Single Lane	115-130
Rural Double Lane	180-200
Note: * Assumes 90 degree angles between entries and roundabouts with four or fewer legs.	

12.9.1.3 Circulatory Roadway Width

The required width of the circulatory roadway is determined from the width of the entries and turning requirements of the design vehicle. In general, it should always be at least as wide as the maximum entry width. Suggested lane widths and roundabout geometries are found on Exhibit 6-22 of FHWA's *Roundabouts: An Informational Guide*, Federal Highway Administration, Publication No. FHWA-RD-00-067, dated June 2010 (3).

12.9.1.4 Central Island

The central island of a roundabout is the center area encompassed by the circulatory roadway. Central islands should be circular in shape with a constant radius so drivers can maintain a constant speed. Islands should be raised, not depressed, as depressed islands are difficult for approaching drivers to recognize. An apron may be added to the outer edge of the central island when right-of-way, topography, or other constraints do not allow enlargement of the roundabout. An apron provides an additional paved area for larger vehicles, such as trucks, to negotiate the roundabout. An expansion joint should be used between the truck apron and the circular roadway.

12.9.2 General Joint Layout

The pavement designer may choose from two layout approaches. One is to isolate the circle from the legs and the other is to use a pave through layout, **Figure 12.10 Isolating the Circle** and **Figure 12.11 Pave-Through Layout**. Once the approach layout is decided, a sequenced step-by-step procedure is utilized.

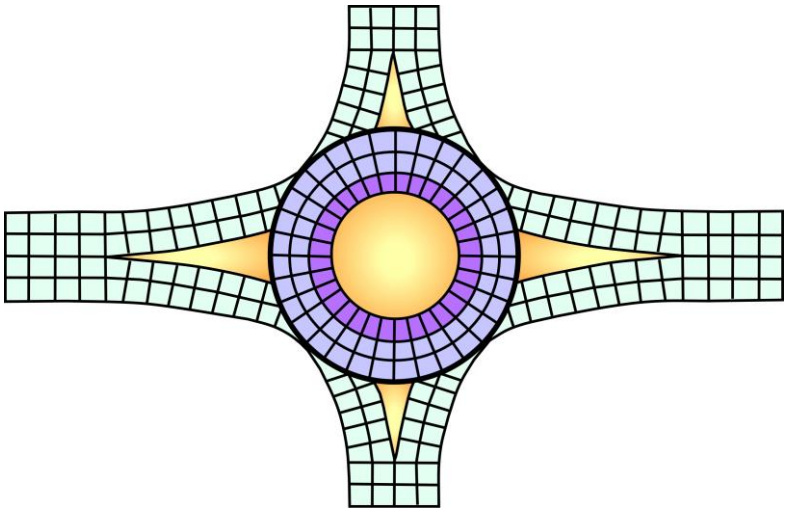


Figure 12.10 Isolating the Circle
(From Figure 1, Joint Layout for Roundabout, Isolating Circle from Legs,
Concrete Roundabouts: Rigid Pavement Well-Suited for Increasing Popular Intersection Type,
ACPA, June 2005(4))

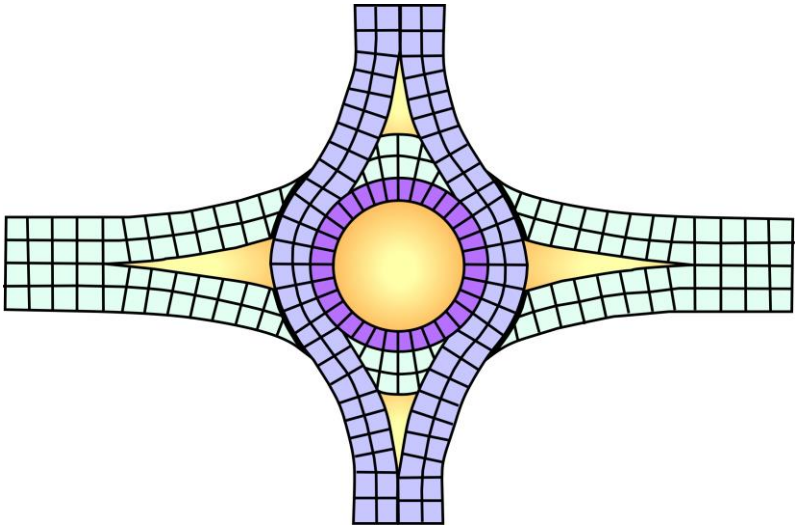
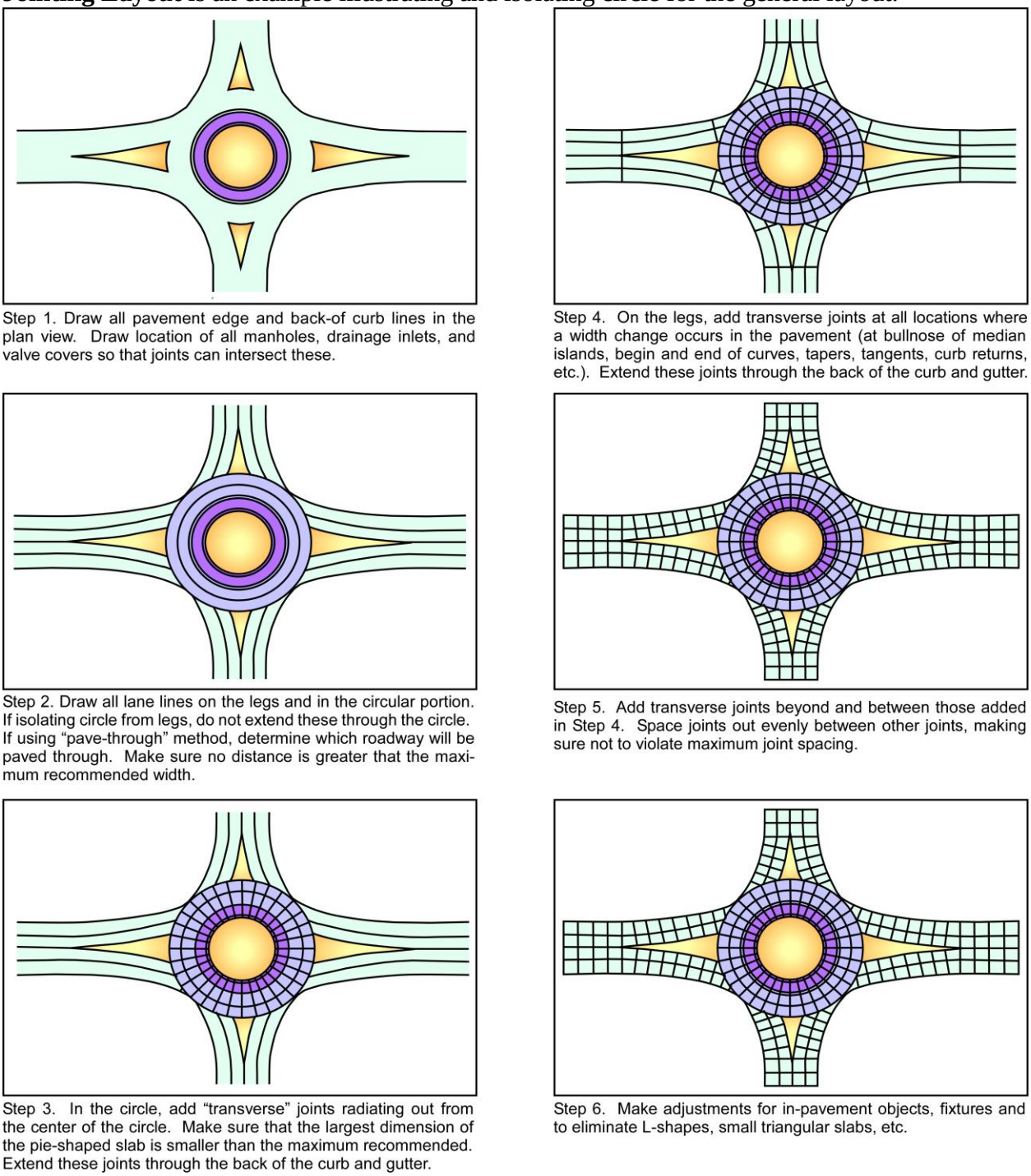


Figure 12.11 Pave-Through Layout
(From Figure 2, Joint Layout for Roundabout, Isolating Circle from Legs,
Concrete Roundabouts: Rigid Pavement Well-Suited for Increasing Popular Intersection Type,
ACPA, June 2005(4))

ACPA recommends a six step process on constructing joint layouts. **Figure 12.12 Six Step Jointing Layout** is an example illustrating and isolating circle for the general layout.



Step 1. Draw all pavement edge and back-of curb lines in the plan view. Draw location of all manholes, drainage inlets, and valve covers so that joints can intersect these.

Step 2. Draw all lane lines on the legs and in the circular portion. If isolating circle from legs, do not extend these through the circle. If using "pave-through" method, determine which roadway will be paved through. Make sure no distance is greater that the maximum recommended width.

Step 3. In the circle, add "transverse" joints radiating out from the center of the circle. Make sure that the largest dimension of the pie-shaped slab is smaller than the maximum recommended. Extend these joints through the back of the curb and gutter.

Step 4. On the legs, add transverse joints at all locations where a width change occurs in the pavement (at bullnose of median islands, begin and end of curves, tapers, tangents, curb returns, etc.). Extend these joints through the back of the curb and gutter.

Step 5. Add transverse joints beyond and between those added in Step 4. Space joints out evenly between other joints, making sure not to violate maximum joint spacing.

Step 6. Make adjustments for in-pavement objects, fixtures and to eliminate L-shapes, small triangular slabs, etc.

Figure 12.12 Six Step Jointing Layout

(From Page 3, Six Steps, *Concrete Roundabouts: Rigid Pavement Well-Suited for Increasing Popular Intersection Type*, ACPA, June 2005 (4))

12.9.3 Details of PCCP Joints

Additional detailing of the joints is necessary to achieve long lasting, crack free pavements. **Figure 12.13 Basic Joints and Zones of a Roundabout**, shows a roundabout broken into three zones based on joint layout; the central, approach, and transition zones. The central zone consists of concentric circles (longitudinal joints) intersected by radial, transverse joints. The longitudinal joints are tied to minimize outward migration of the slabs. Slabs should be square or pie shaped with a maximum width of 14 feet and a maximum length of 15 feet. If possible, establish uniform lane widths to accommodate a slip-form paver. The transition zone generally consists of irregular shaped slabs and is usually tied to the central zone. Joint angles should be greater than 60 degrees. In cases where odd shapes occur, dog legs through curve radius points may be needed to achieve an angle greater than 60 degrees. An expansion joint should be used to properly box out fixtures such as manholes and inlets. An expansion joint is usually placed between the transition and approach zones to act as a buffer from the radial outward movement of the roundabout and the inward movement of the approach roads. All transverse or horizontally moving joints should extend through the curb and gutter sections to ensure their movement remains unrestricted and does not induce cracking in the adjoining slab. Generally, transverse joints are placed at 10 foot intervals in curb and gutter, however, since roundabout curb and gutter sections are tied or poured monolithically and the thickness is the same as the pavement thickness, the jointing may be increased to match the slab joint spacing. Longitudinal joints should be located close to, but offset from lane lines or pavement markings. Vehicles tend to track towards the center of the roundabout, thus, joints would be better placed inside lane lines.

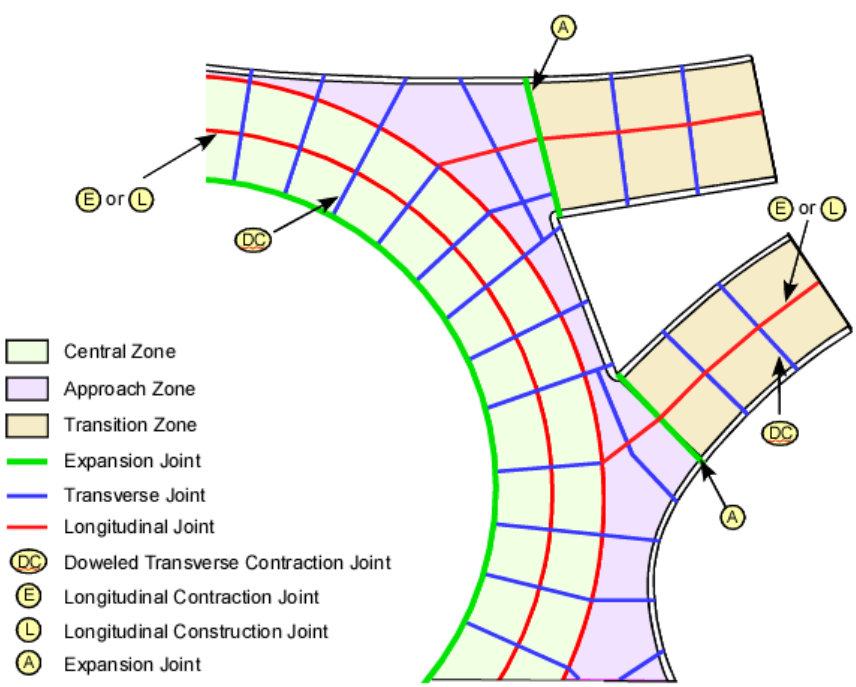


Figure 12.13 Basic Joints and Zones of a Roundabout

(Modified from Figure 4, Roundabout Zones, *Concrete Roundabout Pavements: A Guide to their Design and Construction*, Doc. No. TP-GDL-012, March 2004 (5))

Typically, state highway projects use load transfer devices (dowel bars) and tie-bars. These reinforcements must be detailed throughout the roundabout intersection. The dowel bars should be evenly distributed across the lane width and are generally spaced every 12 inches. The tie-bars are located in the longitudinal joints and are usually spaced every 36 inches. Tie bar requirements and pull out testing are specified in Section 412.13 of CDOT's *Standard Specifications for Road and Bridge Construction* (6). Dowel bar and tie-bar joints to be used in the roundabouts are detailed in CDOT's *Standard Plans, M & S Standards*, July 2012, M-412-1, Concrete Pavement Joints and as revised.

12.9.4 Typical Section

The concrete pavement thickness is calculated by adding the truck traffic for each stream of traffic going through the roundabout intersection. Structural components include the curb and gutter sections as detailed in CDOT's *Standard Plans, M & S Standards*, July 2012, 2012 M-609-1, Curb, Gutters, and Sidewalks and as revised. It is recommended to use Curb Type 2 (6 inch barrier) (Section B) for the inner most ring curb barrier adjacent to the in-field, Curb and Gutter Type 2 (Section IIM) (6 inch mountable – 2 foot gutter) for the middle ring curb barrier, and Curb and Gutter Type 2 (Section IIB) (6 inch barrier – 2 foot gutter) for the outer ring barrier. The gutter thickness has been increased to the thickness of the pavement and tie-bars are used to tie the gutters to the pavement. This mimics a monolith pour. Refer to **Figure 12.14 Typical Section of an Urban Double-Lane Roundabout** and **Section 7.14 Lane Edge Support Condition (E)** for more information.

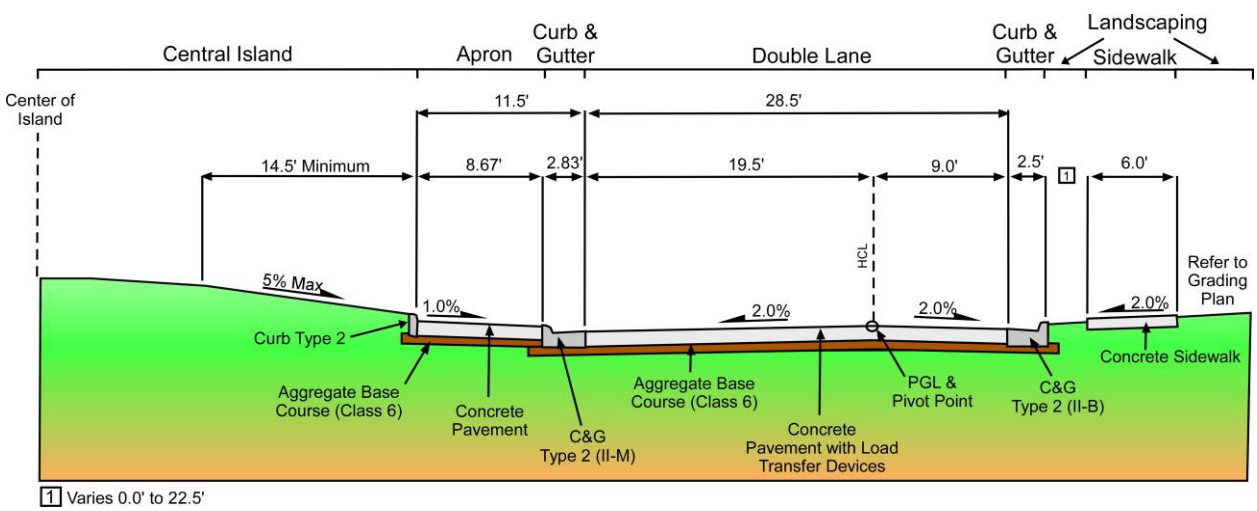


Figure 12.14 Typical Section of an Urban Double-Lane Roundabout

References

1. *Roundabouts: An Informal Guide*, FHWA-RD-00-067, Federal Highway Administration, Turner-Fairbanks Highway Research Center, June 2000.

2. *A Policy on Geometric Design of Highways and Streets*, Washington, D.C, AASHTO, 1994.

3. *Roundabouts: An Informational Guide*, Publication No. FHWA-RD-00-67, U.S. Department of Transportation, Federal Highway Administration, Robinson, June 2010. http://www.fhwa.dot.gov/publications/research/safety/00067/000676.pdf

4. *Concrete Roundabouts: Rigid Pavement Well-Suited for Increasing Popular Intersection Type*, Number 6.03, R & T Update, Concrete Pavement Research & Technology, American Concrete Pavement Association, Skokie, IL, June 2005.

5. *Concrete Roundabout Pavements, A Guide to their Design and Construction*, Document No. TP-GDL-012, Pavements Branch of the Road Network Infrastructure, TechMedia Publishing Pty Ltd., 2005.