CHAPTER 19
ROUNDABOUTS

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19.0 INTRODUCTION

A roundabout is a form of a circular intersection in which traffic travels counterclockwise around a central island where entering traffic must yield to circulating traffic. Roundabouts feature, among other things, a central island, a circulatory roadway, and splitter islands on each approach. Roundabouts rely upon two basic and important operating principles:

1. Speed reduction at the entry and through the intersection will be achieved through geometric design and,

2. The yield-at-entry rule, which requires traffic entering the intersection to yield to traffic that is traveling in the circulatory roadway.

Benefits of roundabouts are:

- Fewer conflict points typically result in fewer collisions with less severity. Over half of vehicle to vehicle points of conflict associated with intersections are eliminated with the use of a roundabout. Additionally, a roundabout separates the points of conflict which eases the ability of the users to identify a conflict and helps prevent conflicts from becoming collisions.
- Roundabouts are designed to reduce the vehicular speeds at intersections. Lower speeds lessen the vehicular collision severity. Likewise, studies indicate that pedestrian and bicyclist collisions with motorized vehicles at lower speeds significantly reduce their severity.
- Roundabouts allow continuous free flow of vehicles and bicycles when no conflicts exist. This results in less noise and air pollution and reduces overall delays at roundabout intersections.

The following is a list of locations where a roundabout may be feasible:

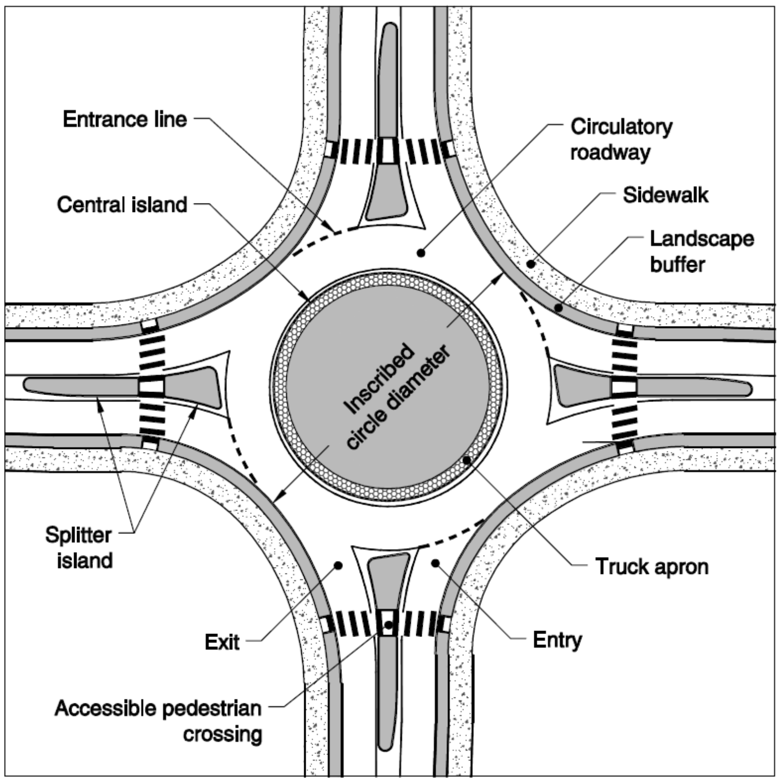
- Intersections with a high-crash rate or a higher severity of crashes
- High-speed rural intersections
- Freeway ramp terminals
- Transitions in functional class or desired speed change (including rural to urban transitions)
- Existing intersections that are failing operationally
- Intersections where aesthetics is an objective
- Four-leg intersections with entering volumes less than 5,000 vph or approximately 50,000 ADT
- Three-leg intersections
- Intersection of two signalized progressive corridors where turn proportions are heavy (random arrival is better than off-cycle arrival)
- Closely spaced intersections where signal progression cannot be achieved
- Replacement of all-way stops
- Intersections near schools

The contents of this chapter are intended to serve as design guidance only.

Roundabout intersections on the Colorado State Highway System must be developed and evaluated in accordance with National Cooperative Highway Research Program (NCHRP) Report 672 (1) entitled "Roundabouts: An Informational Guide, 2nd ed." (NCHRP Guide 2) dated October 2010, or latest edition.

Roundabout considerations, planning, operational analysis and safety are not covered in this chapter. Signs, striping and markings at roundabouts are to comply with the MUTCD latest edition.

Figure 19-1 depicts the typical nomenclature associated with roundabouts.



Note: This figure is provided to only shown nomenclature and is not to be used for design details.

Figure 19-1 [NCHRP Report 672 Exhibit 6-1 (1)] Roundabout Geometric Elements

19.1 ROUNDABOUT CATEGORIES

Roundabouts are separated into three basic categories according to the size and number of lanes used at the roundabout. The three categories of roundabouts are: mini-roundabouts, single-lane roundabouts, and multilane roundabouts. Table 19-1 summarizes and compares some fundamental design and operational elements for each roundabout category.

Design Element	Mini-Roundabout	Single-Lane Roundabout	Multilane Roundabout
Desirable maximum entry design speed	15 to 20 mph (25 to 30 km/h)	2 to 25 mph	25 to 30 mph
Maximum number of entering lanes per approach	1	1	2+
Typical inscribed circle diameter	45 to 90 ft	90 to 180 ft	150 to 300 ft
Central island treatment	Fully traversable	Raised (may have traversable apron)	Raised (may have traversable apron)
Typical daily service volumes on 4-leg roundabout below which may be expected to operate without requiring a detailed capacity analysis (veh/day)*	Up to approximately 15,000	Up to approximately 25,000	Up to approximately 45,000 for two-lane roundabout
*Operational analysis needed to verify upper limit for specific applications or for roundabouts with more than two lanes or four legs.			

Table 19-1 [NCHRP Report 672 Exhibit 1-9 (1)] Roundabout Category Comparison

19.1.1 Mini-Roundabout

Mini-roundabouts are small single-lane roundabouts with a fully traversable central island. They are most commonly used in low-speed urban environments with average operating speeds of 30 mph or less. Figure 19-2 illustrates a typical mini-roundabout and the important characteristics. Mini-roundabouts can be useful in such environments where conventional roundabout design is precluded by right-of-way constraints. In retrofit applications, mini-roundabouts are relatively inexpensive because they typically require minimal additional pavement at the intersecting roads and minor widening at the corner curbs. They are mostly recommended when there is insufficient right-of-way to accommodate the design vehicle with a traditional single-lane roundabout. Because they are small, mini-roundabouts are perceived as pedestrian-friendly with short crossing distances and very low vehicle speeds on approaches and exits.

A fully traversable central island is provided to accommodate large vehicles and serves one of the distinguishing features of a mini-roundabout. The mini-roundabout is designed to accommodate passenger cars without requiring them to traverse over the central island. The overall design of a mini-roundabout should align vehicles at entry to guide drivers to the intended path and minimize running over of the central island to the extent possible.

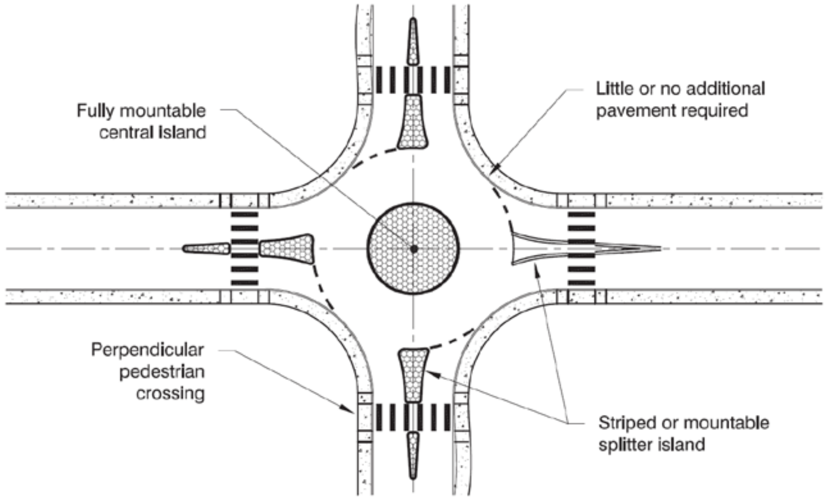


Figure 19-2 [NCHRP Report 672 Figure 1-10 (1)] Typical Mini-Roundabout

19.1.2 Single-Lane Roundabout

This type of roundabout is characterized as having a single-lane entry at all legs and one circulatory lane. Figure 19-3 illustrates the features of a typical single-lane roundabout. They are distinguished from mini-roundabouts by their larger inscribed circle diameters and non-traversable central islands. Their design allows slightly higher speeds at the entry, on the circulatory roadway, and at the exit. The geometric design typically includes raised splitter islands, a non-traversable central island, crosswalks, and a truck apron. The size of the roundabout is largely influenced by the choice of design vehicle and available right-of-way.

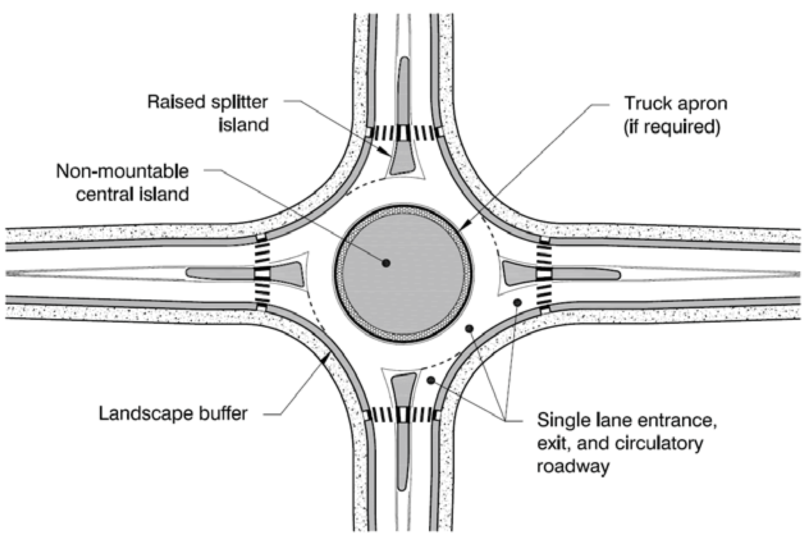


Figure 19-3 [NCHRP Report 672 Figure 1-12 (1)] Typical Single-Lane Roundabout

19.1.3 Multilane Roundabout

Multilane roundabouts have at least one entry with two or more lanes. In some cases, the roundabout may have a different number of lanes on one or more approaches. They also include roundabouts with entries on one or more approaches that flare from one to two or more lanes. These require wider circulatory roadways to accommodate more than one vehicle traveling side by side. Figure 19-4 provide an example of a typical multilane roundabout. The speeds at the entry, on the circulatory roadway, and at the exit are similar or may be slightly higher than those for the single-lane roundabouts. The geometric design will include raised splitter islands, truck apron, a non-traversable central island, and appropriate entry path deflection.

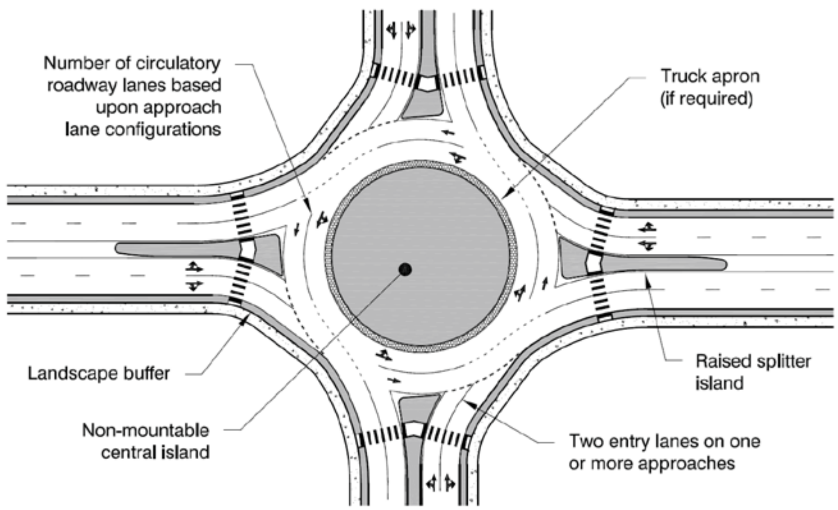


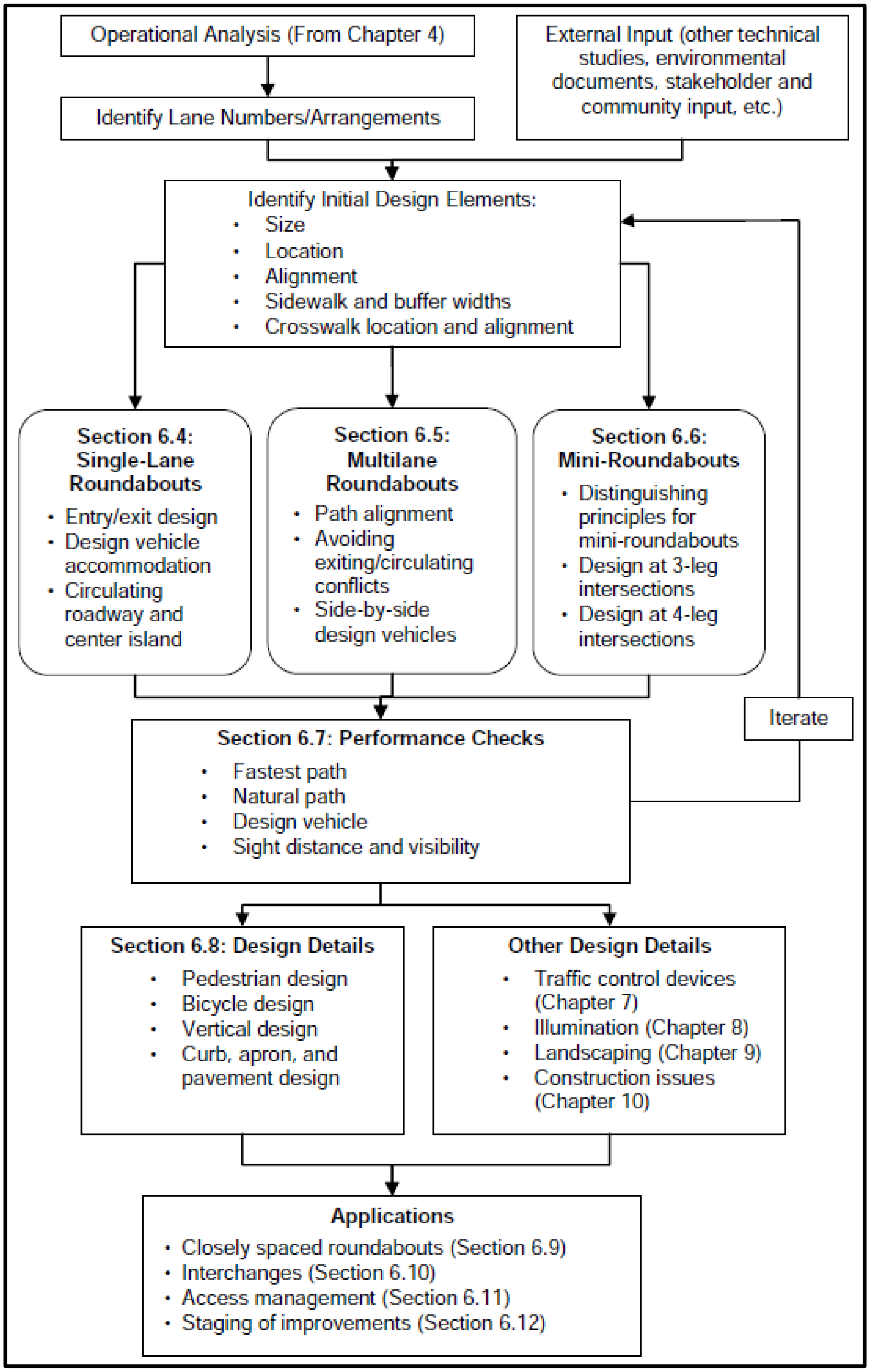
Figure 19-4 [NCHRP Report 672 Figure 1-14 (1)] Typical Multilane Roundabout

19.2 ROUNDABOUT DESIGN PROCESS

19.2.1 Roundabout Design Process

Roundabout design is an iterative process where a variety of design objectives must be considered and balanced within site-specific constraints. Maximizing the operational performance and safety for a roundabout requires the engineer to think through the design rather than rely upon a design template. The basic design should be laid out based upon the principles to a level that allows the engineer to verify that the layout will meet the design objectives. The key is to conduct enough work to be able to check the design and identify whether adjustments are necessary. Once enough iteration has been performed to identify an optimum size, location, and set of approach alignments, additional detail can be added to the design.

Figure 19-5 provides a general outline for the roundabout design process, incorporating elements of project planning, preliminary design, and final design into an iterative process. Information from the operational analysis is used to determine the required number of lanes for the roundabout (single or multilane), which dictates the required size and many other design details. The basic design should be laid out based upon the principles identified in this chapter and the *NCHRP Report 672* to a level that allows the engineer to verify that the layout will meet the design objectives.



Note: Section numbers refer to NCPRP Report 672

Figure 19-5 [NCHRP Report 672 Exhibit 6-1 (1)] General Roundabout Design Process

19.2.2 General Design Considerations

Throughout this chapter and the *NCHRP Report 672* **(1),** ranges of typical values are given for many of the different geometric elements to provide guidance in the design of individual roundabout components. The use of a design technique not explicitly included or a value that falls outside of the ranges presented does not automatically create an unsafe condition if a few basic design principles can be achieved. The following list of principles should be the objective of any roundabout design:

- Provide slow entry speeds and consistent speeds through the roundabout by using deflection.
- Provide the appropriate number of lanes and lane assignment to achieve adequate capacity, lane volume balance, and lane continuity.
- Provide smooth channelization that is intuitive to drivers and results in vehicles naturally using the intended lanes.
- Provide adequate accommodation for the design vehicles.
- Design to meet the needs of pedestrians and cyclists.
- Provide appropriate sight distance and visibility for driver recognition of the intersection and conflicting users.

Each of the principles described above affects the safety and operations of the roundabout. When developing a design, the trade-offs of safety, capacity, cost, and so on must be recognized and assessed throughout the design process. Favoring one component of design may negatively affect another. A common example of such a trade-off is accommodating large trucks on the roundabout approach and entry while maintaining slow design speeds. Increasing the entry width or entry radius to better accommodate a large truck may simultaneously increase the speeds that vehicles can enter the roundabout. Therefore, the engineer must balance these competing needs and may need to adjust the initial design parameters.

19.3 GEOMETRIC DESIGN

The following geometric design elements are a general set of guidelines to be considered when first laying out a roundabout. These are not to be interpreted as a standard or rule, but general best practices. As described above, roundabout design is an iterative process where a variety of design objectives must be considered and balanced within site-specific constraints.

19.3.1 Identify Initial Design Elements

19.3.1.1 Roundabout Size

The inscribed circle diameter is the overall outside diameter of a roundabout, which is the distance across the circle inscribed by the outer curb (or edge) of the circulatory roadway, as illustrated previously in Figure 19-1. The inscribed circle diameter is determined by a number of design objectives, including accommodation of the design vehicle and providing speed control.

The inscribed circle diameter typically needs to be at least 105 feet to accommodate a WB-50 design vehicle. Smaller roundabouts can be used for some constrained urban intersections, where the design vehicle may be a bus or single-unit truck. For locations that must accommodate a larger WB-67 design vehicle, a larger inscribed circle diameter will be required, typically in the range of 130 to 150 feet. In situations with more than four legs, larger inscribed circle diameters may be appropriate. Truck aprons are typically needed to keep the inscribed circle diameter reasonable while accommodating the larger design vehicles. Generally, the inscribed circle diameter of a multilane roundabout ranges from 150 to 250 feet. For two-lane roundabouts, a common starting point is 160 to 180 feet. Roundabouts with three- or four-lane entries may require larger diameters of 180 to 330 feet to achieve adequate speed control and alignment. Mini-roundabouts serve as a special subset of roundabouts and are defined by their small inscribed circle diameters. With a diameter less than 90 feet, the mini-roundabout is smaller than the typical single-lane roundabout. The small diameter is made possible by using a fully traversable central island to accommodate large vehicles.

Table 19-2 provides typical ranges of inscribed diameters for various roundabout configurations.

Roundabout Configuration	Typical Design Vehicle	Common Inscribed Circle Diameter Range*
Mini-Roundabout	SU-30	45 to 95ft
Single-Lane Roundabout	B-40	90 to 150 ft
	WB-50	105 to 150 ft
	WB-67	130 to 180 ft
Multilane Roundabout (2 lanes)	WB-50	105 to 220 ft
	WB-67	165 to 220 ft
Multilane Roundabout (3 lanes)	WB-50	200 to 250 ft
	WB-67	220 to 300 ft

* Assumes 90° angles between entries and no more than 4 legs. List of possible design vehicles in not all-inclusive.

Table 19-2 [NCHRP Report 672 Exhibit 6-9 (1)] Typical Inscribed Diameter Ranges

19.3.1.2 Alignment of Approaches

The alignment of the approach legs plays an important role in the design of a roundabout. The alignment affects the amount of deflection (speed control) that is achieved, the ability to accommodate the design vehicle, and the visibility angles to adjacent legs. The optimal alignment is generally governed by the size and position of the roundabout relative to its approaches. Various options for approach alignment are summarized in Figure 19-6.

A common starting point in design is to center the roundabout so that the centerline of each leg passes through the center of the inscribed circle (radial alignment). This location typically allows the geometry of a single-lane roundabout to be adequately designed such that vehicles will maintain slow speeds through both the entries and the exits. The radial alignment also makes the central island more conspicuous to approaching drivers and minimizes roadway modification required upstream of the intersection.

Another frequently acceptable alternative is to offset the centerline of the approach to the left (i.e., the centerline passes to the left of the roundabout's center point). This alignment will typically increase the deflection achieved at the entry to improve speed control. However, engineers should recognize the inherent tradeoff of a larger radius (or tangential) exit that may provide less speed control for the downstream pedestrian crossing. Especially in urban environments, it is important to have drivers maintain sufficiently low vehicular speeds at the pedestrian crossing to reduce the risk for pedestrians. The fastest-path procedure provided in Section 19.7.1 identifies a methodology for estimating speeds for large radius (or tangential) exits where acceleration may govern the attainable speed.

Approach alignments that are offset to the right of the roundabout's center point typically do not achieve satisfactory results, primarily due to a lack of deflection and lack of speed control that result from this alignment. An offset-right alignment brings the approach in at a more tangential angle and reduces the opportunity to provide sufficient entry curvature. Vehicles will usually be able to enter the roundabout too fast, resulting in more loss-of-control crashes and higher crash rates between entering and circulating vehicles. However, an offset-right alignment alone should not be considered a fatal flaw in a design if speed requirements and other design considerations can be met.

Like signalized and stop-controlled intersections, the angle between approach legs is also an important design consideration. Although it is not necessary for opposing legs to align directly opposite one another (as it is for conventional intersections), it is generally preferable for the approaches to intersect at perpendicular or near-perpendicular intersection angles. If two approach legs intersect at an angle significantly greater than 90°, it will often result in excessive speeds for one or more right-turn movements. Alternatively, if two

Entry Alignment

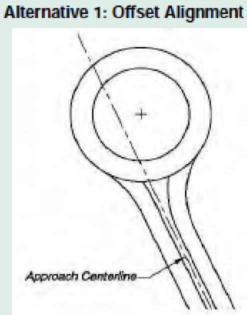
Question

Should the approach alignment run through the center of the inscribed circle? Or is it acceptable to offset the approach centerline to one side?

Design Principle

The alignment does not have to pass through the center of the roundabout; however, it has a primary effect on the entry/exit design. The optimal alignment allows for an entry design that provides adequate deflection and speed control while also providing appropriate view angles to drivers and balancing property impacts/costs.

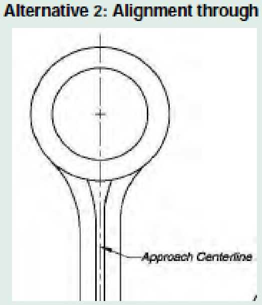
Alternative 1: Offset Alignment to the Left of Center



ADVANTAGES:
- Allows for increased deflection
- Beneficial for accommodating large trucks with small inscribed circle diameter—allows for larger entry radius while maintaining deflection and speed control
- May reduce impacts to right-side of roadway

TRADE-OFFS
- Increased exit radius or tangential exit reduces control of exit speeds and acceleration through crosswalk area
- May create greater impacts to the left side of the roadway

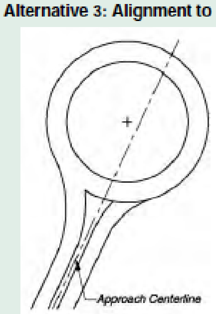
Alternative 2: Alignment through Center of Roundabout



ADVANTAGES:
- Reduces amount of alignment changes along the approach roadway to keep impacts more localized to intersection
- Allows for some exit curvature to encourage drivers to maintain slower speeds through the exit

TRADE-OFFS
- Increased exit radius reduces control of exit speeds/acceleration through crosswalk area
- May require a slightly larger inscribed circle diameter (compared to offset-left design) to provide the same level of speed control

Alternative 3: Alignment to Right of Center



ADVANTAGES:
- Could be used for large inscribed circle diameter roundabouts where speed control objectives can still be met
- Although not commonly used, this strategy may be appropriate in some instances (provided that speed objectives are met) to minimize impacts, improve view angles, etc.

TRADE-OFFS
- Often more difficult to achieve speed control objectives, particularly at small diameter roundabouts
- Increases the amount of exit curvature that must be negotiated

Figure 19-6 [NCHRP Report 672 Exhibit 6-10 (1)] Entry Alignment Alternatives

approach legs intersect at an angle significantly less than 90°, then the difficulty for large trucks to successfully navigate the turn is increased. Providing a large corner radius to accommodate trucks may result in a wide portion of circulatory roadway resulting in increased speeds and may also lead to reduced safety performance if the circulatory roadway width is mistakenly interpreted by drivers to be two lanes.

Designing the approaches at perpendicular or near-perpendicular angles generally results in relatively slow and consistent speeds for all movements. Highly skewed intersection angles can often require significantly larger inscribed circle diameters to achieve the speed objectives. Approaches that intersect at angles greater than approximately 105° can be realigned by introducing curvature in advance of the roundabout to produce a more perpendicular intersection.

Other possible geometric modifications include changes to the inscribed circle diameter or modifications to the shape of the central island to manage vehicle speeds. For roundabouts in low-speed urban environments, the alignment of the approaches may be less critical.

19.3.1.3 Design Vehicle

The design vehicle will dictate many of the roundabout's dimensions and the designer should consider the largest design vehicle to normally use that facility. Consult Chapter 2, Design Controls and Criteria, for more information regarding the appropriate design vehicle.

Because roundabouts are intentionally designed to slow traffic, narrow curb-to-curb widths and tight turning radii are typically used. However, if the widths and turning requirements are designed too tight, it can create difficulties for large vehicles. Large trucks and buses often dictate many of the roundabout's dimensions, particularly for single-lane roundabouts. Nearly all roundabouts feature truck aprons, which provides additional paved surface to accommodate the wide path of the trailer, but keeps the actual circulatory roadway width narrow enough to maintain speed control for smaller passenger cars.

19.4 SINGLE-LANE ROUNDABOUTS

This section presents general guidelines for the design of individual geometric elements at a single-lane roundabout. Many of these same principles also apply to the design of multilane roundabouts; however, there are some additional complexities to the design of multilane roundabouts that are described in detail in Section 19.5.

19.4.1 Splitter Islands

Splitter islands (also called separator islands or median islands) should be provided on all single-lane roundabouts. Their purpose is to provide refuge for pedestrians, assist in controlling speeds, guide traffic into the roundabout, physically separate entering and exiting traffic streams, and deterring wrong-way movements.

When performing the initial layout of a roundabout's design, a sufficiently sized splitter island envelope should be identified prior to designing the entry and exits of an approach. This will ensure that the design will eventually allow for a raised island that meets the minimum dimensions (offsets, tapers, length, widths).

The total length of the splitter island will vary based on terrain, access considerations, site-specific mainline and crossroad operational speeds, and the stepdown speeds to the final desired entry speed. However, the raised island should be at least 50 feet in length (100 feet is desirable) to provide sufficient protection for pedestrians and to alert approaching drivers to the geometry of the roundabout. On higher speed roadways, splitter island lengths of 150 feet or more are often beneficial. Additionally, the splitter island should extend beyond the end of the exit curve to prevent exiting traffic from accidentally crossing into the path of approaching traffic. The splitter island width should be a minimum of 6 feet at the crosswalk to adequately provide refuge for pedestrians. Figure 19-7 shows the minimum dimensions for a splitter island at a single-lane roundabout, including the location of the pedestrian crossing.

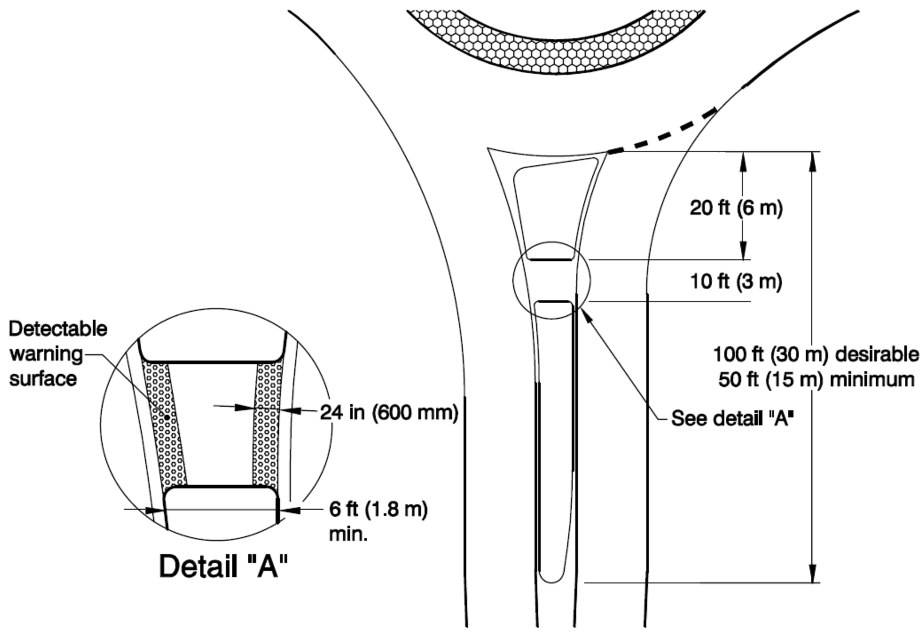


Figure 19-7 [NCHRP Report 672 Exhibit 6-12 (1)] Minimum Splitter Island Dimensions

While Figure 19-7 provides minimum dimensions for splitter islands, there are benefits to providing larger islands. An increase in the splitter island width results in greater separation between the entering and exiting traffic streams of the same leg and increases the time for approaching drivers to distinguish between exiting and circulating vehicles. This results in better gap acceptance and can help reduce confusion for entering motorists. A larger splitter island width also supports better pedestrian refuge.

Standard AASHTO guidelines for island design should be followed for the splitter island. This includes using larger nose radii at approach corners to maximize island visibility and offsetting curb lines at the approach ends to create a funneling effect. The funneling treatment also aids in reducing speeds as vehicles approach the roundabout. Figure 19-8 shows typical minimum splitter island nose radii and offset dimensions from the entry and exit traveled ways.

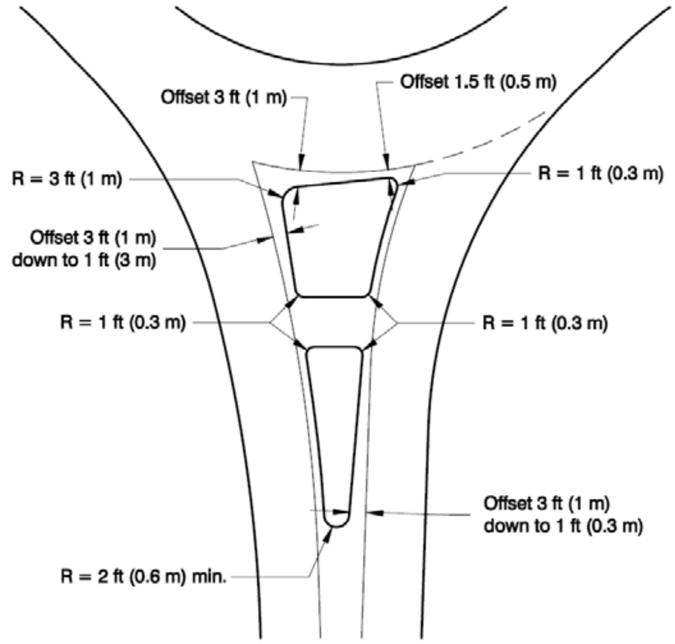


Figure 19-8 [NCHRP Report 672 Exhibit 6-13 (1)] Typical Minimum Splitter Island Nose Radii and Offsets

19.4.2 Entry Width

Typical entry widths for single-lane roundabout entrances range from 14 to 18 feet. These entries are often flared from upstream approach widths. However, values higher or lower than this range may be appropriate for site-specific design vehicle and speed requirements for critical vehicle paths. A 15-foot entry width is a common starting value for a single-lane roundabout. Care should be taken with entry widths greater than 18 feet or for those that exceed the width of the circulatory roadway, as drivers may mistakenly interpret the wide entry to be two lanes when there is only one receiving circulatory lane. Figure 19-9 shows a typical single-lane roundabout entry design.

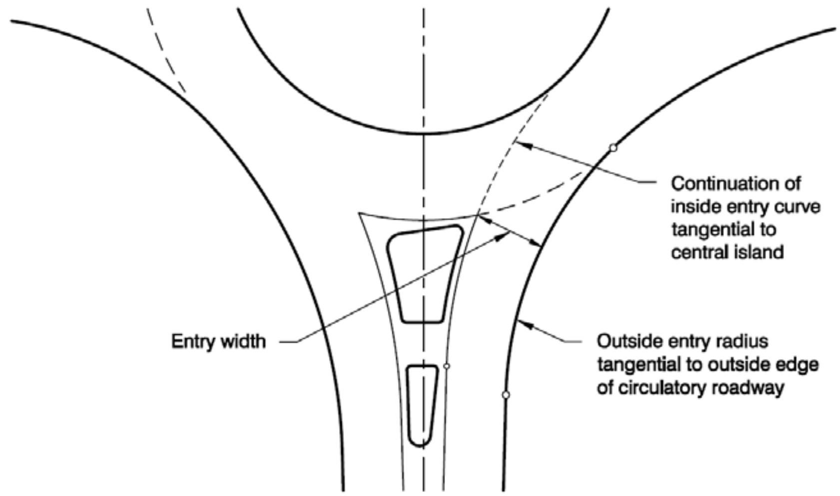


Figure 19-9 [NCHRP Report 672 Exhibit 6-14 (1)] Single-Lane Roundabout Entry Design

19.4.3 Circulatory Roadway Width

The circulating width should be at least as wide as the maximum entry width and up to 120% of the maximum entry width. For single-lane roundabouts, the circulatory roadway width usually remains constant throughout the roundabout. Typical circulatory roadway widths range from 16 to 20 feet for single-lane roundabouts. Care should be taken to avoid making the circulatory roadway width too wide within a single-lane roundabout because drivers may think that two vehicles are allowed to circulate side-by-side. Typically, the circulatory roadway width should typically be designed to accommodate the swept path of a bus design vehicle without use of the truck apron to avoid jostling bus passengers by running over the truck apron.

19.4.4 Central Island & Truck Apron

The central island of a roundabout is the raised, mainly non-traversable area surrounded by the circulatory roadway. It may also include a traversable truck apron. The island is typically landscaped for aesthetic reasons and to enhance driver recognition of the roundabout upon approach. Raised central islands for roundabouts are preferred over depressed central islands on the Colorado State Highway system.

Truck aprons should be designed such that they are traversable to trucks but discourage passenger vehicles from using them. Truck apron width is dictated by the swept path of the design vehicle using a CAD-based vehicle turning path simulation software (see Figure 19-10). Truck aprons should generally be 3 to 15 feet wide and have a cross slope of 1% to 2% away from the central island. To discourage use by passenger vehicles, the outer edge of the apron should be raised approximately 2 to 3 inches above the circulatory roadway surface. The apron should be constructed of a different material than the pavement to differentiate it from the circulatory roadway.

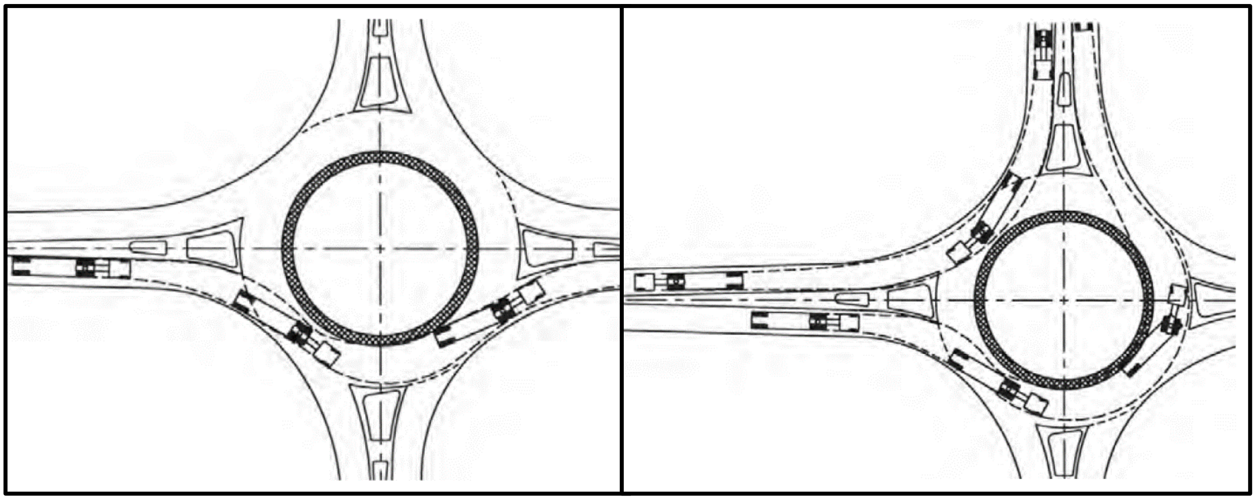


Figure 19-10 [NCHRP Report 672 Exhibits 6-17 & 6-18 (1)] Typical Swept Path of a Large Design Vehicle through a Single-Lane Roundabout

19.4.5 Entry Design

At single-lane roundabouts, a single-entry curb radius is typically adequate. For approaches on higher speed roadways, the use of compound curves may improve guidance by lengthening the entry arc.

The entry curb radius, in conjunction with the entry width, the circulatory roadway width, and the central island geometry, controls the amount of deflection imposed on a vehicle's entry path. Excessively large entry curb radii have a higher potential to produce faster entry speeds than desired.

Entry radii at urban single-lane roundabouts typically range from 50 to 100 feet. A common starting point is an entry radius in the range of 60 to 90 feet; however, a larger or smaller radius may be needed to accommodate large vehicles or serve small diameter roundabouts, respectively. Larger radii may be used, but it is important that the radii not be so large as to result in excessive entry speeds.

The entry geometry should provide adequate horizontal curvature to channelize drivers into the circulatory roadway to the right of the central island. It is also often desirable for the splitter island to have enough curvature to block a direct path to the central island for approaching vehicles. To achieve the proper amount of deflection for each approach to a roundabout, an entry angle usually between 20° and 40° is desirable. Not only does the entry angle aid in the slowing the vehicle entry speed, it also helps so vehicles don't hit broadside in the event of a collision. Figure 19-11 depicts the roundabout entry angle.

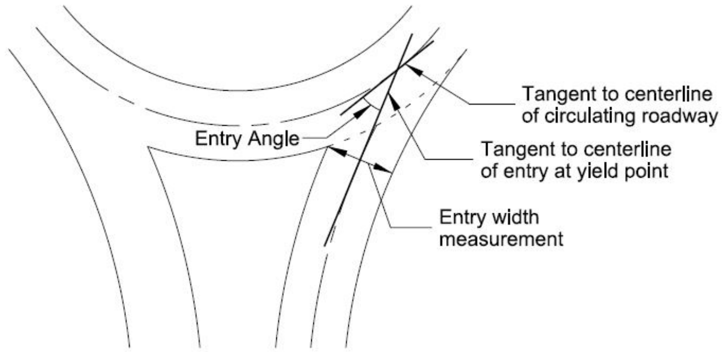


Figure 19-11 Roundabout Entry Angle

19.4.6 Exit Design

The exit curb radii are usually larger than the entry curb radii in order to minimize the likelihood of congestion and crashes at the exits. This, however, is balanced by the need to maintain slow speeds through the pedestrian crossing on exit. The exit design is also influenced by the design environment (urban versus rural), pedestrian demand, the design vehicle, and physical site constraints.

The exit curb is commonly designed to be curvilinearly tangential to the outside edge of the circulatory roadway. Likewise, the projection of the inside (left) edge of the exit roadway is commonly curvilinearly tangential to the central island. Generally, exit curb radii should be no less than 50 feet, with values of 100 to 200 feet being more common. Figure 19-12 shows a typical exit layout for a single-lane roundabout.

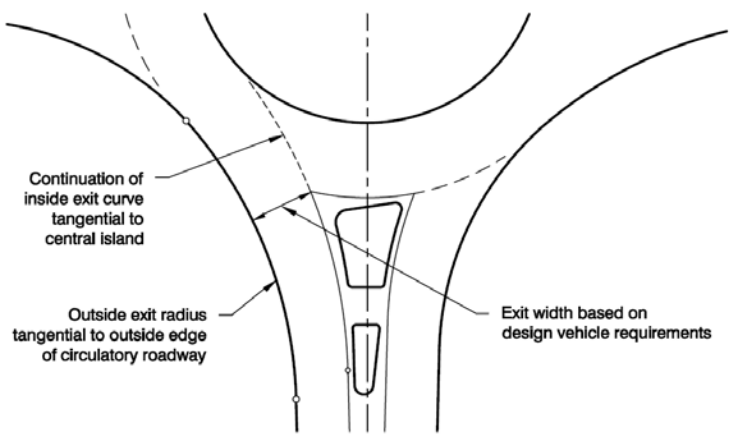


Figure 19-12 [NCHRP Report 672 Exhibit 6-15 (1)] Single-Lane Roundabout Curvilinear Exit Design

For designs using an offset-left approach alignment, the exit design may require much larger radii, ranging from 300 to 800 feet or greater. Larger exit radii may also be desirable in areas with high truck volumes to provide ease of navigation for trucks and reduce the potential for trailers to track over the outside curb. These radii may provide acceptable speed through the pedestrian crossing area given that the acceleration characteristics of the vehicles will result in a practical limit to the speeds that can be achieved on the exit. Figure 19-13 depicts the larger radius exit design of a single-lane roundabout.

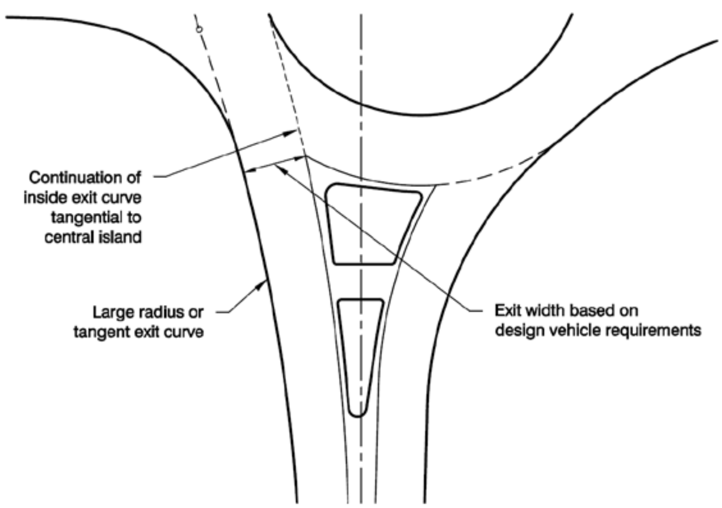


Figure 19-13 [NCHRP Report 672 Exhibit 6-16 (1)] Single-Lane Roundabout Larger Radius Exit Design

19.4.7 Right-Turn Bypass Lanes

Right-turn bypass lanes are a proven way to increase the "life" of a single-lane roundabout by removing traffic that would otherwise enter the roundabout and reduce the available capacity to other movements. Extending the life of a single-lane roundabout is desirable given the stronger safety performance in comparison to multilane roundabouts due to the smaller size and slower speeds that are achieved. To determine if a right-turn bypass lane should be used, the appropriate capacity and delay calculations should be performed.

A right-turn bypass lane should be implemented only where needed. In urban areas with heavy bicycle and pedestrian activity, a right-turn bypass lane should be used with caution. The entries and exits of the bypass lane can increase conflicts with bicyclists and with merging maneuvers on the downstream leg. The generally higher speeds of bypass lanes and the lower expectation of drivers to stop may increase the risk of collisions with pedestrians. They also introduce additional complexity for pedestrians with visual impairments who are attempting to navigate the intersection. However, in locations with minimal pedestrian and bicycle activity, or where bicycle and pedestrian concerns can be addressed through design solutions, right-turn bypass lanes can be used to improve capacity when heavy right-turning traffic exists. Figure 19-14 shows a sample layout of a right-turn bypass lane for a single-lane roundabout.

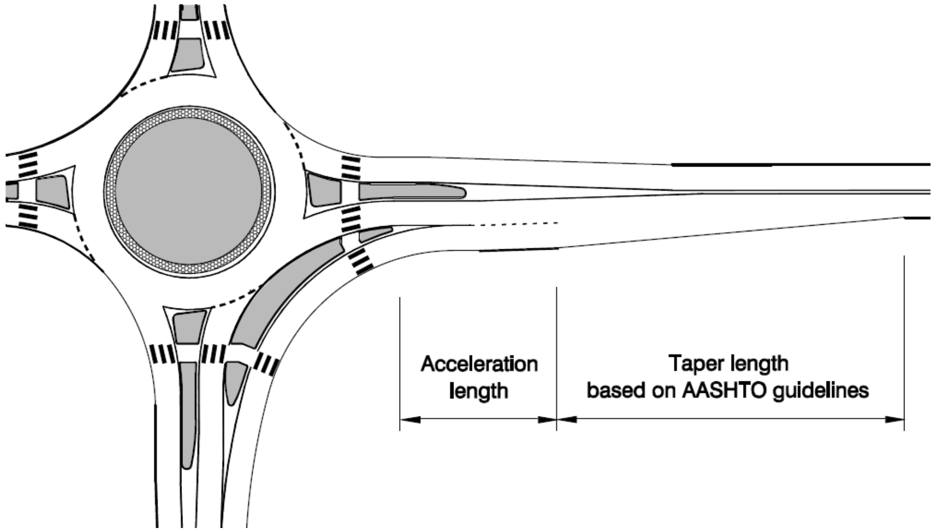


Figure 19-14 [NCHRP Report 672 Exhibit 6-72 (1)] Sample Layout of Right-Turn Bypass Lane with Acceleration Lane

19.5 MULTILANE ROUNDABOUTS

The principles and design process described previously for single-lane roundabouts also apply to multilane roundabouts but in a more complex way. Because multiple traffic streams may enter, circulate through, and exit the roundabout side-by-side, the engineer should consider how these traffic streams interact with each other. The geometry of the roundabout should provide adequate alignment and establish appropriate lane configurations for vehicles in adjacent entry lanes to be able to negotiate the roundabout geometry without competing for the same space.

The number of lanes within the circulatory roadway may vary depending upon the number of entering and exiting lanes. The important principle is that the design requires continuity between the entering, circulating, and exiting lanes such that lane changes are not needed to navigate the roundabout. The driver should be able to select the appropriate lane upstream of the entry and stay within that lane through the roundabout to the intended exit without any lane changes.

The number of lanes provided at the roundabout should be the minimum needed for the existing and anticipated demand as determined by the operational analysis. The engineer is discouraged from providing additional lanes that are not needed for capacity purposes as these additional lanes can reduce the safety effectiveness at the intersection. If additional lanes are needed for future conditions, a phased design approach should be considered that would allow for future expansion.

19.5.1 Entry Width

A typical entry width for a multilane roundabout ranges from 24 to 30 feet for a two-lane entry and from 36 to 45 feet for a three-lane entry. Typical widths for individual lanes at entry range from 12 to 15 feet. The entry width should be primarily determined based upon the number of lanes identified in the operational analysis combined with the turning requirements for the design vehicle. Excessive entry width may not produce capacity benefits if the entry width cannot be fully used by traffic.

At locations where any of the intersection approach legs is a 2-lane roadway, but a multilane roundabout capacity is required to meet the operational needs, there are generally two options for developing the second roundabout entry lane:

1. Adding a full lane upstream of the roundabout and maintaining parallel lanes through the entry geometry (Figure 19-15)
2. Widening the approach by gradually flaring through the entry geometry (Figure 19-16).

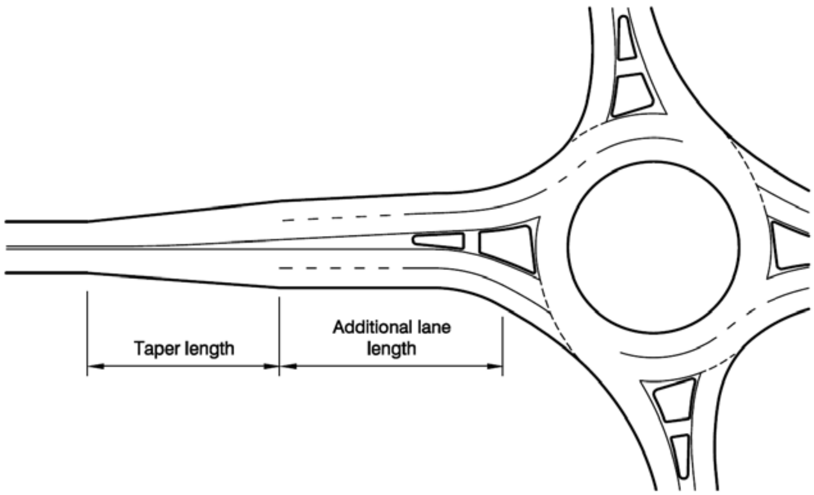


Figure 19-15 [NCHRP Report 672 Exhibit 6-24 (1)] Approach Widening by Adding a Full Lane

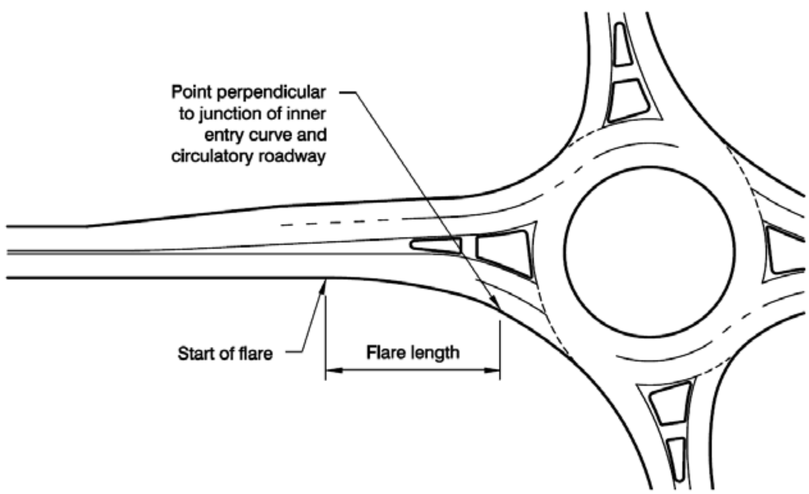


Figure 19-16 [NCHRP Report 672 Exhibit 6-25 (1)] Approach Widening by Entry Flaring

19.5.2 Circulatory Roadway Widths

The circulatory roadway width for multilane roundabouts is usually governed by the design criteria relating to the types of vehicles that may need to be accommodated adjacent to one another. If the entering traffic is predominantly passenger cars and single-unit trucks (AASHTO P and SU design vehicles, respectively) and semi-trailer traffic is infrequent, it may be appropriate to design the width for two passenger vehicles or a passenger car and a single-unit truck side-by-side. If semi-trailer traffic is relatively frequent (greater than 10%), it may be necessary to provide sufficient width for the simultaneous passage of a semi-trailer in combination with a P or SU vehicle.

Multilane circulatory roadway lane widths typically range from 14 to 16 feet. Use of these values results in a total circulating width of 28 to 32 feet for a two-lane circulatory roadway and 42 to 48 feet total width for a three-lane circulatory roadway.

A constant width is not required throughout the entire circulatory roadway. It is desirable to provide only the minimum width necessary to serve the required lane configurations within that specific portion of the roundabout. A common combination is two entering and exiting lanes along the major roadway, but only single entering and exiting lanes on the minor street (Figure 19-17).

In some instances, the circulatory roadway width may need to be wider than the corresponding entrance that is feeding that portion of the roundabout. For example, in situations where two consecutive entries require exclusive left turns, a portion of the circulatory roadway will need to contain an extra lane and spiral markings to enable all vehicles to reach their intended exits without being trapped or changing lanes (Figure 19-18).

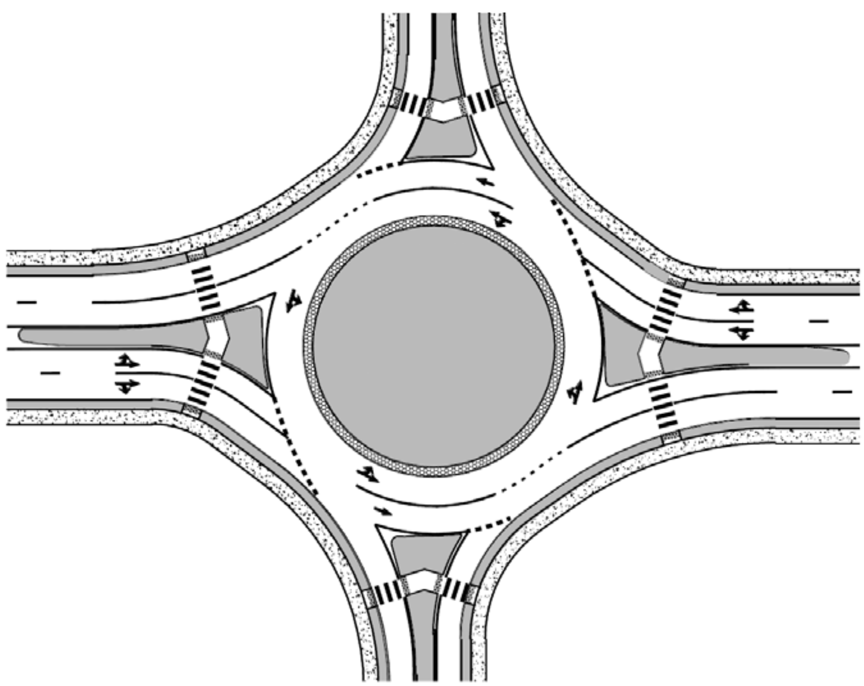


Figure 19-17 [NCHRP Report 672 Exhibit 6-26 (1)] Multilane Major Street with Single-Lane Minor Street

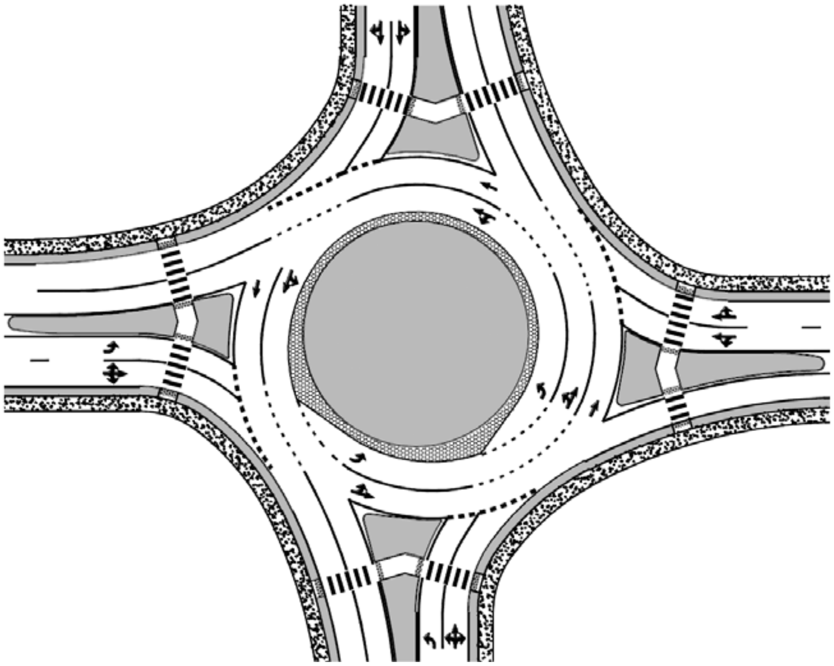


Figure 19-18 [NCHRP Report 672 Exhibit 6-27 (1)] Two-Lane Roundabout with Consecutive Double-Lefts

19.5.3 Entry Geometry and Approach Alignment

Entry radii for multilane roundabouts should typically exceed 65 feet to encourage adequate natural paths and avoid sideswipe collisions on entry. Engineers should avoid the use of overly tight geometrics in order to achieve the fastest-path objectives. Overly small (less than 45 feet) entry radii can result in conflicts between adjacent traffic streams, which may result in poor lane use and reduced capacity. Similarly, the R_1 fastest-path radius should also not be excessively small. If R_1 is too small, vehicle path overlap may result, reducing the operational efficiency and increasing potential for crashes. Values for R_1 in the range of 175 to 275 feet are generally preferable. This results in a design speed of 25 to 30 mph. Refer to Section 19.7.1 for more discussion on the fastest path guidelines.

One possible technique to promote good path alignment is shown in Figure 19-19 using a compound curve or tangent along the outside curb. The design consists of an initial small-radius entry curve set back from the edge of the circulatory road-way. A short section of a large-radius curve or tangent is provided between the entry curve and the circulatory roadway to align vehicles into the proper circulatory lane at the entrance line.

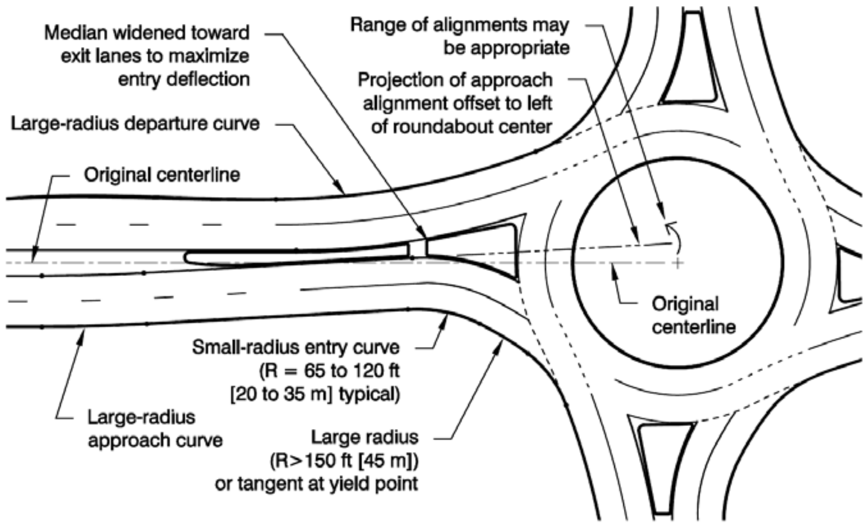


Figure 19-19 [NCHRP Report 672 Exhibit 6-30 (1)] Example Minor Approach Offset to Increase Entry Deflection

For the method illustrated in Figure 19-19, entry curve radii commonly range from approximately 65 to 120 feet and are set back at least 20 feet from the edge of the circulatory roadway. A tangent or large-radius (greater than 150 feet) curve is then fitted between the entry curve and the outside edge of the circulatory roadway.

19.5.3.1 Entry Geometry and Design Vehicle Considerations

Where the design dictates the need to accommodate large design vehicles within their own lane, there are a number of design considerations. A larger inscribed circle diameter and entry/exit radii may be required to maintain speed control and accommodate the design vehicle. A common technique that can be used is to provide gore striping between the two entry lanes to help center the vehicles within the lane and allow a cushion for off-tracking by the design vehicle. This technique is illustrated in Figure 19-20.

Another technique for accommodating the design vehicle within the circulatory roadway is to use a wider lane width for the outside lane and a narrower lane width for the inside lane. This could provide an extra buffer of circulating width for trucks in the outside lane. Large trucks in the inside lane would use the truck apron to accommodate any off-tracking. Eliminating all overlap for the outside lane may not always be desirable or feasible, as this may dictate a much larger inscribed circle diameter than desired for overall safety performance for all vehicle types and the context.

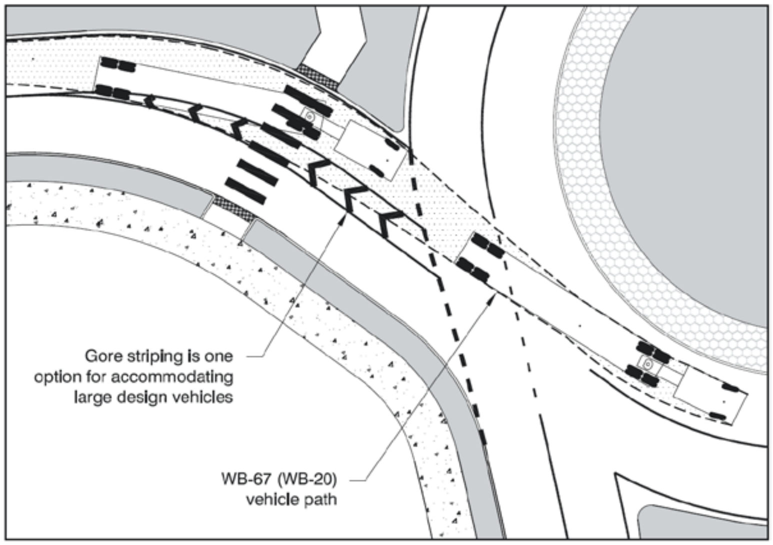


Figure 19-20 [NCHRP Report 672 Exhibit 6-37 (1)] Truck Path with Gore Striping at Entry

19.5.4 Path Overlap

In a multilane roundabout, the designer should avoid a design that aligns an entering vehicle at the incorrect lane in the circulatory roadway which will create path overlap (see Figure 19-21). As a vehicle enters the circulating roadway it should be headed directly toward its respective lane within the circulating roadway. Figure 19-22 illustrates the design vehicle path alignment of a multilane roundabout.

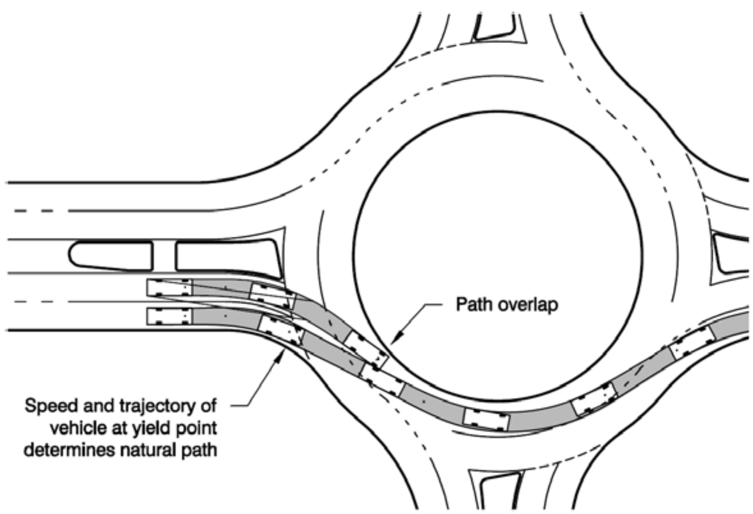


Figure 19-21 [NCHRP Report 672 Exhibit 6-28 (1)] Entry Vehicle Path Overlap

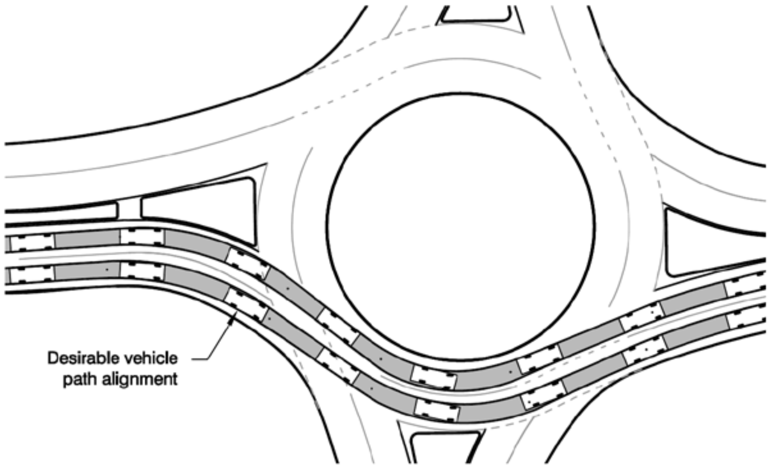


Figure 19-22 [NCHRP Report 672 Exhibit 6-29 (1)] Desirable Vehicle Path Alignment

19.5.5 Exit Curves

Conflicts can occur between exiting and circulating vehicles if appropriate lane assignments are not provided. Inadequate horizontal design of the exits can also result in exit vehicle path overlap, similar to that occurring at entries. The radii of exit curves are commonly larger than those used at the entry because of other factors (entry alignment, diameter, etc.); larger exit curve radii are also typically used to promote good vehicle path alignment. However, the design should be balanced to maintain low speeds at the pedestrian crossing at the exit.

To promote good path alignment at the exit, the exit radius at a multilane roundabout should not be too small. At single-lane roundabouts, it is acceptable to use a minimal exit radius in order to control exit speeds and maximize pedestrian safety. However, if the exit radius on a multilane exit is too small, traffic on the inside of the circulatory roadway will tend to exit into the outside exit lane on a more comfortable turning radius.

Problems can also occur when the design allows for too much separation between entries and subsequent exits. Large separations between legs causes entering vehicles to join next to circulating traffic that may be intending to exit at the next leg, rather than crossing the path of the exiting vehicles. This can create conflicts at the exit point between exiting and circulating vehicles, as shown in Figure 19-23.

While it would be possible to provide a low-cost solution by modifying the lane arrangements using a combination of striping and other physical modifications, a better solution would be to realign the approach legs to have the paths of entering vehicles cross the paths of the circulating traffic (rather than merging) to eliminate the conflict as shown in Figure 19-24.

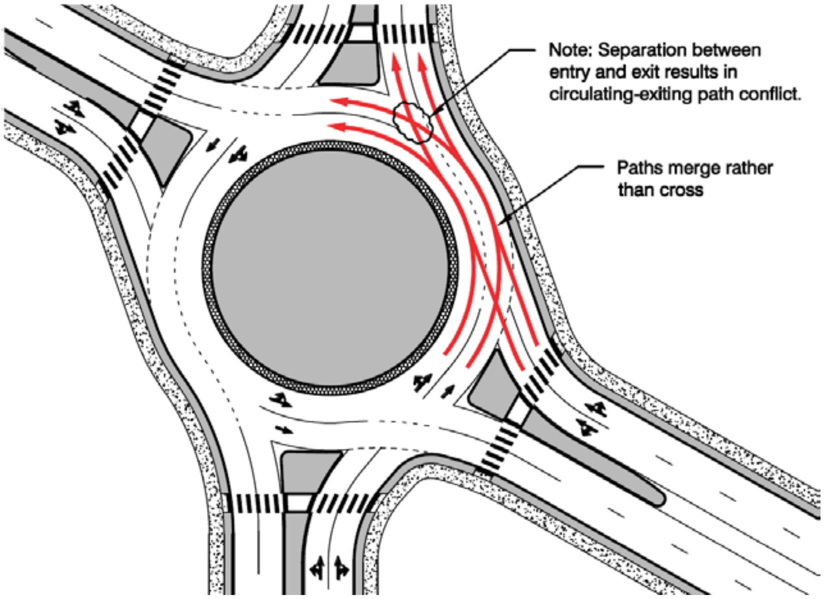


Figure 19-23 [NCHRP Report 672 Exhibit 6-33 (1)] Exit-Circulating Conflict Caused by Large Separation between Legs

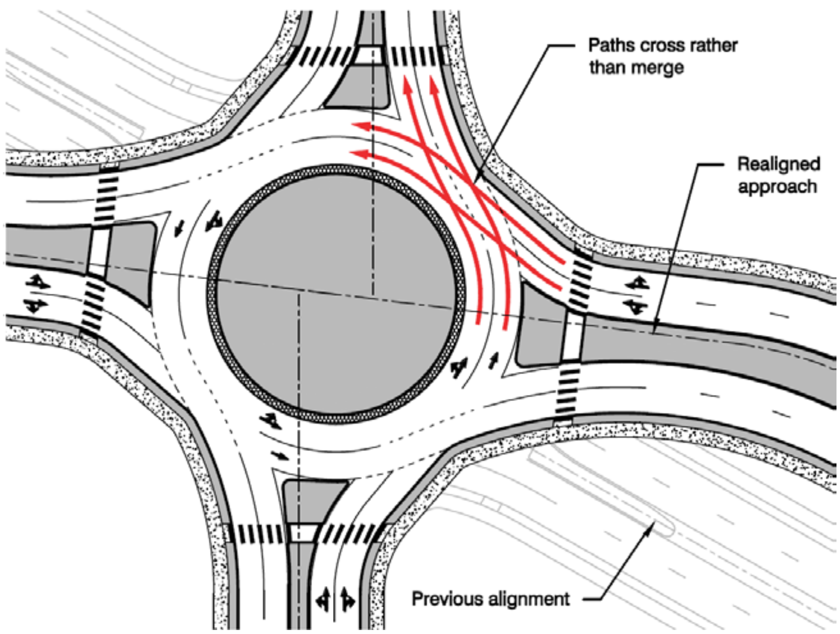


Figure 19-24 [NCHRP Report 672 Exhibit 6-35 (1)] Realignment to Resolve Exit-Circulating Conflicts

19.6 MINI-ROUNDABOUTS

As discussed in Section 19.1.1, Mini-roundabouts are small single-lane roundabouts with a fully traversable central island that are most commonly used in low-speed urban environments with average operating speeds of 30 mph or less. Given that the central island of a mini-roundabout is fully traversable, the overall design should provide channelization that naturally guides drivers to the intended path. Sub-optimum designs may result in drivers turning left in front of the central island (or driving over the top of it), improperly yielding, or traveling at excess speeds through the intersection.

Mini-roundabouts should be made as large as possible within the intersection constraints. However, a mini-roundabout inscribed circle diameter should generally not exceed 90 feet. Above 90 feet, the inscribed circle diameter is typically large enough to accommodate the design vehicles navigating around a raised central island. A raised central island provides physical channelization to control vehicle speeds, and therefore a single-lane design is preferred where a diameter greater than 90 feet can be provided.

As with single-lane and multilane roundabouts, it is desirable to accommodate buses within the circulatory roadway to avoid jostling passengers by running over a traversable central island. However, for very small inscribed circle diameters, the bus turning radius is typically too large to navigate around the central island, thus requiring buses to travel over it. For mini-roundabouts with larger inscribed circle diameters, it may be possible to accommodate the swept path of a bus vehicle within the circulatory roadway. The potential trade-off to designing for a bus instead of a passenger car is that the design may result in a wider circulatory roadway and smaller central island.

Composed of asphalt concrete, Portland cement concrete, or other paving material, the central island should be domed using 5% to 6% of cross slope, with a maximum height of 5 inches. Although fully traversable and relatively small, it is essential that the central island be clear and conspicuous. Islands with a mountable curb should be designed in a similar manner to truck aprons on normal roundabouts.

19.6.1 Splitter Islands

As with larger roundabouts, splitter islands are generally used at mini-roundabouts to align vehicles, encourage deflection and proper circulation, and provide pedestrian refuge. Splitter islands are raised, traversable, or flush depending on the size of the island and whether trucks will need to track over the top of the splitter island to navigate the intersection. In general, raised islands are used where possible, and flush islands are generally discouraged. The following are general guidelines for the types of splitter islands under various site conditions

Consider a raised island if:

- All design vehicles can navigate the roundabout without tracking over the splitter island area,
- Sufficient space is available to provide an island with a minimum area of 50 ft^2, and/or
- Pedestrians are present at the intersection with regular frequency.

Consider a traversable island if:

- Some design vehicles must travel over the splitter island area and truck volumes are minor, and
- Sufficient space is available to provide an island with a minimum area of 50 ft^2.

Consider a flush (painted) island if:

- Vehicles are expected to travel over the splitter island area with relative frequency to navigate the intersection,
- An island with a minimum area of 50 ft^2 cannot be achieved, and
- Intersection has slow vehicle speeds.

19.6.2 Pedestrian and Bicycle Treatments

At conventional intersections, pedestrian ramps and crosswalks are typically located near the curb returns at the corners of the intersection. When converting to a mini-roundabout, these corner pedestrian-crossing locations may require relocation. The crosswalk is recommended to be located 20 feet upstream of the entrance line to accommodate one vehicle stopped between the crosswalk and the entrance line. Where a minimum splitter island width of 6 feet is available on the approach, a pedestrian refuge should be provided within the splitter island.

Bicyclists are encouraged to navigate through a mini-roundabout like other vehicles. Where bicycle lanes are provided on the approaches to a mini-roundabout, they should be terminated to alert motorists and bicyclists of the need for bicyclists to merge. Bike lanes should be terminated at least 100 feet upstream of the entrance line.

19.6.3 Vertical Design

Mini-roundabouts should be designed to be outward draining to place the central island at the highest point of the intersection for maximum visibility.

19.7 PERFORMANCE CHECKS

Performance checks are a vital part of the roundabout design process in order to help an engineer determine whether the design meets its performance objectives. The following are the critical performance checks that need to be performed prior to finalizing any roundabout design:

- Fastest Path
- Path Alignment
- Sight Distance
- Angles of Visibility

19.7.1 Fastest Path

The fastest path allowed by the roundabout geometry determines the negotiation speed for that particular movement into, through, and exiting the roundabout. It is the smoothest, flattest path possible for a single vehicle, in the absence of other traffic and ignoring all lane markings. The fastest path does not represent expected vehicle speeds, but rather theoretical attainable entry speeds for design purposes.

Maximum entering design speeds based on a theoretical fastest path of 20 to 25 mph are recommended at single-lane roundabouts. At multilane roundabouts, maximum entering design speeds of 25 to 30 mph are recommended. These speeds are influenced by a variety of factors, including the geometry of the roundabout and the operating speeds of the approaching roadways. As a result, speed management is often a combination of managing speeds at the roundabout itself and managing speeds on the approaching roadways.

There are five critical path radii that must be checked for each roundabout approach (Figure 19-25) as follows:

- **R_1** - the entry path radius, is the minimum radius on the fastest through path prior to the entrance line.
- **R_2** - the circulating path radius, is the minimum radius on the fastest through path around the central island.
- **R_3** - the exit path radius, is the minimum radius on the fastest through path into the exit.
- **R_4** - the left-turn path radius, is the minimum radius on the path of the conflicting left-turn movement.
- **R_5** - the right-turn path radius, is the minimum radius on the fastest path of a right-turning vehicle.

It is important to note that these vehicular path radii are not the same as the curb radii. The R_1 through R_5 radii measured in this procedure represent the vehicle centerline in its path through the roundabout.

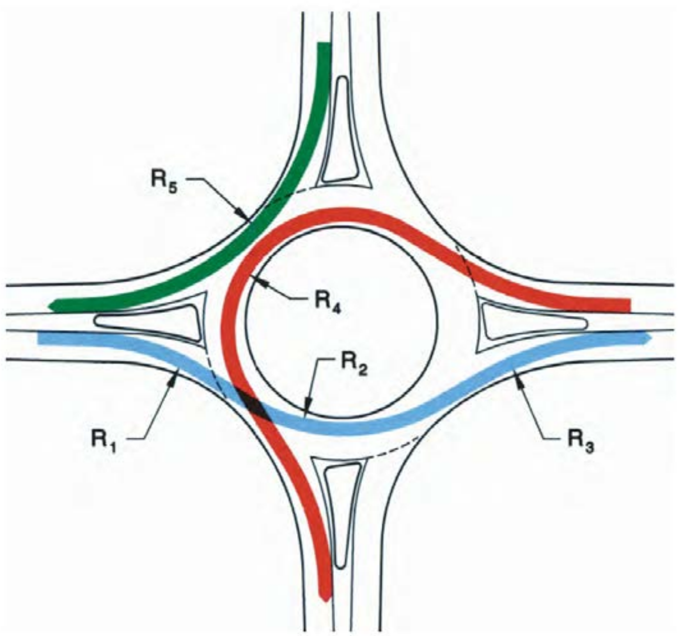


Figure 19-25 [NCHRP Report 672 Exhibit 6-46 (1)] Fastest Path Radii

Once a conceptual roundabout design is complete, the engineer should draw out the fastest path alignment to determine the speed of the roundabout. The design speed of the roundabout is determined from the smallest radius along the fastest allowable path. The smallest radius usually occurs on the circulatory roadway as the vehicle curves to the left around the central island.

A vehicle is assumed to be 6 feet wide and maintain a minimum clearance of 2 feet from a roadway centerline or concrete curb and flush with a painted edge line. Thus, the centerline of the vehicle path is drawn with the following distances:

- 5 feet from the face (flowline) of a concrete curb
- 5 feet from a roadway centerline

- 3 feet from a painted edge line

Figure 19-26 illustrates the construction of the fastest vehicle path alignment at a multilane roundabout.

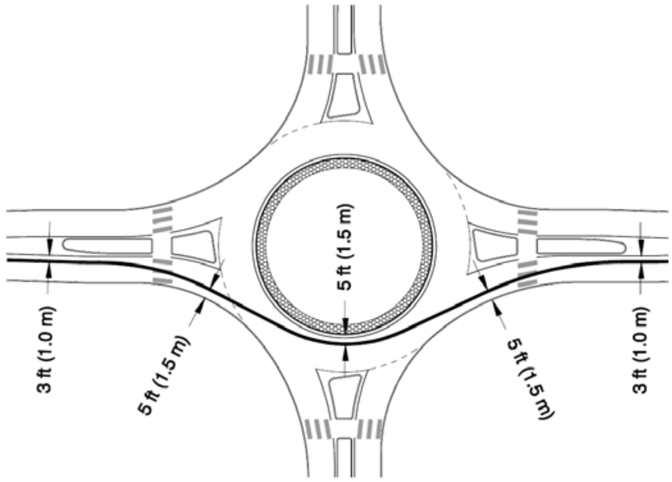


Figure 19-26 [NCHRP Report 672 Exhibit 6-48 (1)] Fastest Path Radii

The relationship between travel speed and horizontal curvature is documented in the *PGDHS* **(2).** Both superelevation and the side friction factor affect the speed of a vehicle. Side friction varies with vehicle speed and can be determined in accordance with AASHTO guidelines. The most common superelevation values encountered are +0.02 and −0.02, corresponding to 2% cross slope. Figure 19-27 depicts the speed-to-radius relationship in a graphical format.

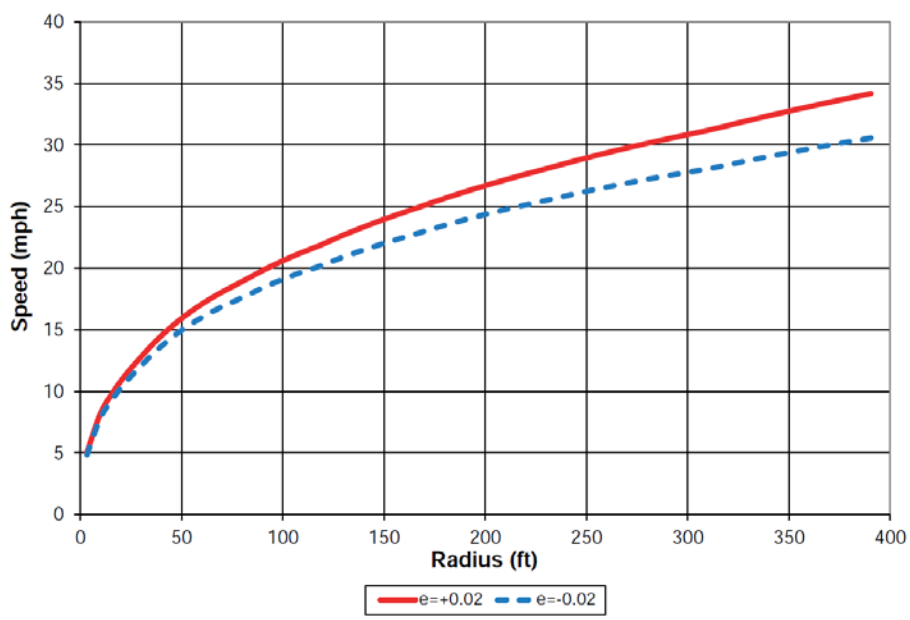


Figure 19-27 [NCHRP Report 672 Exhibit 6-52 (1)] Speed-to-Radius Relationship

The speed–radius relationship given above generally provides a reasonable prediction for the left-turn and through movement circulating speeds. However, this method does not consider the effects of deceleration and acceleration and therefore may overpredict entry and exit speeds in cases where the path radius is large

Consistency between the speeds of various movements within the intersection can help to minimize the crash rate between conflicting traffic streams. Relative speeds between conflicting traffic streams and between consecutive geometric elements should be minimized such that the maximum speed differential between movements should be no more than approximately 10 to 15 mph. These values are typically achieved by providing a low absolute maximum speed for the fastest entering movements. As with other design elements, speed consistency should be balanced with other objectives in establishing a design.

The desirable maximum R_1 radius is 150 feet for single-lane roundabouts and 250 feet for multilane roundabouts. Generally, for urban roundabouts with pedestrian accommodations a lower speed entry is desirable. Rural roundabouts typically allow slightly higher entry speed than urban roundabouts. The R_1 and R_2 should be used to control exit speed. Typically, the speed relationships between R_1, R_2, and R_3 as well as between R_1 and R_4 are of primary interest. Along the through path, the desired relationship is $R_1 > R_2 < R_3$, where R_1 is also less than R_3. Similarly, the relationship along the left-turning path is $R_1 > R_4$. For most designs, the $R_1 – R_4$ relationship will be the most restrictive for speed differential at each entry. However, the $R_1 – R_2 – R_3$ relationship should also be reviewed, particularly to ensure the exit speed is not overly restrictive. Design criteria in past years advocated relatively tight exit radii to minimize exit speed, however, recent best practice suggests a more relaxed exit radius for improved drivability.

19.7.2 Path Alignment (Natural Path) Considerations

As discussed in Section 19.7.1, the fastest path through the roundabout is drawn to ensure a safe design speed is achieved. In addition to evaluating the fastest path, at multilane roundabouts the engineer should also consider the natural vehicle paths. These are the paths approaching vehicles will naturally take through the roundabout geometry, assuming there is traffic in all approach lanes.

The key consideration in drawing the natural path is to remember that drivers cannot change the direction or speed of their vehicle instantaneously. This means that the natural path does not have sudden changes in curvature; it has transitions between tangents and curves and between consecutive reversing curves. Secondly, it means that consecutive curves should be of similar radius. If a second curve has a significantly smaller radius than the first curve, the driver will be traveling too fast to negotiate the turn and may not be able stay within the lane. If the radius of one curve is drawn significantly smaller than the radius of the previous curve, the path should be adjusted. As a rule of thumb, the design should provide at least one car length of large radius or tangent to adequately align vehicles into the correct lane within the circulatory roadway. Figure 19-28 illustrates a sample sketch of the natural path through a multilane roundabout.

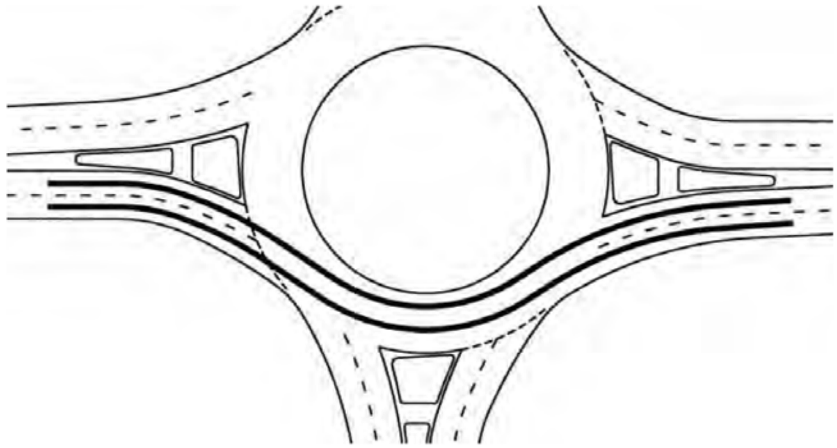


Figure 19-28 [NCHRP Report 672 Exhibit 6-53 (1)] Natural Vehicle Path Sketched through Roundabout

19.7.3 Sight Distance

The roundabout design should be checked to ensure adequate sight distance is achieved. The two most relevant aspects of sight distance for roundabouts are stopping sight distance and intersection sight distance. Stopping sight distance and intersection sight distance should be measured using an assumed height of the driver's eye of 3.5 feet and an assumed object height of 2 feet.

19.7.3.1 Stopping Sight Distance

Stopping sight distance should be provided at every point within a roundabout. *NCHRP Report 400: Determination of Stopping Sight Distance* recommends the formula given in Equation 19-1 for determining stopping sight distance.

$$\boldsymbol{d = (1.468)(t)(V) + 1.087\, V^2/a} \qquad [19\text{-}1]$$

where,

d = stopping sight distance, ft;

t = perception–brake reaction time, assumed to be 2.5 s;

V = initial speed, mph; and

a = driver deceleration, assumed to be 11.2 ft/s^2

Table 19-3 gives stopping sight distances computed from the above equations.

Speed (km/h)	Computed Distance* (ft)
10	46.4
15	77
20	112.4
25	152.7
30	197.8
35	247.8
40	302.7
45	362.5
50	427.2
55	496.7
* Assumes 2.5 s perception-breaking time, 11.2 ft/s^2 driver deceleration	

Table 19-3 [NCHRP Report 672 Exhibit 6-53 (1)] Stopping Sight Distance

At roundabouts, a minimum of three critical types of locations should be checked for stopping sight distance:

3. Approach sight distance (Figure 19-29),
4. Sight distance on circulatory roadway (Figure 19-30), and
5. Sight distance to crosswalk on exit (Figure 19-31).

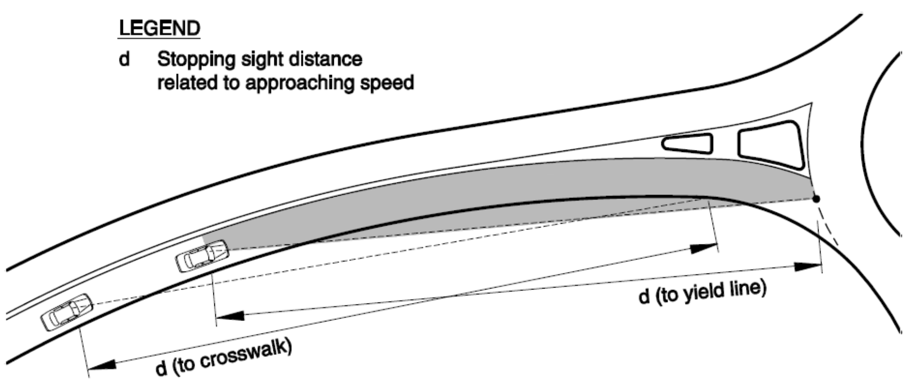


Figure 19-29 [NCHRP Report 672 Exhibit 6-55 (1)] Stopping Sight Distance on Approach

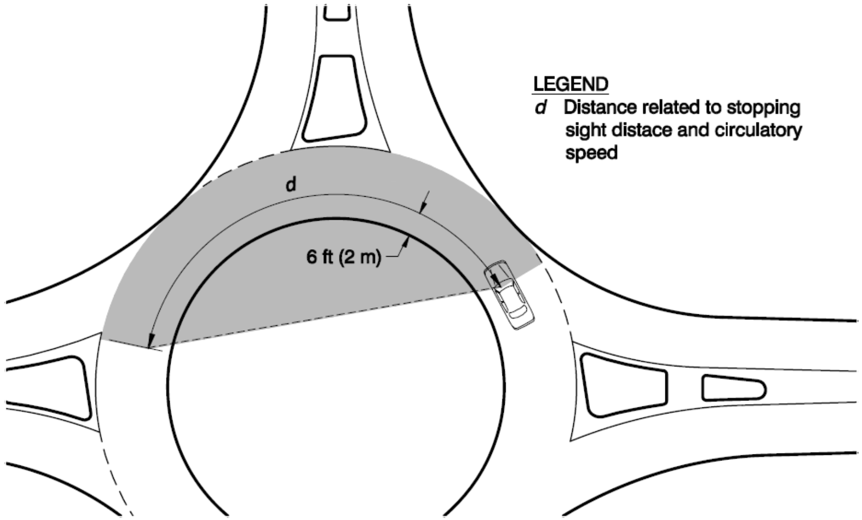


Figure 19-30 [NCHRP Report 672 Exhibit 6-56 (1)] Stopping Sight Distance on Circulatory Roadway

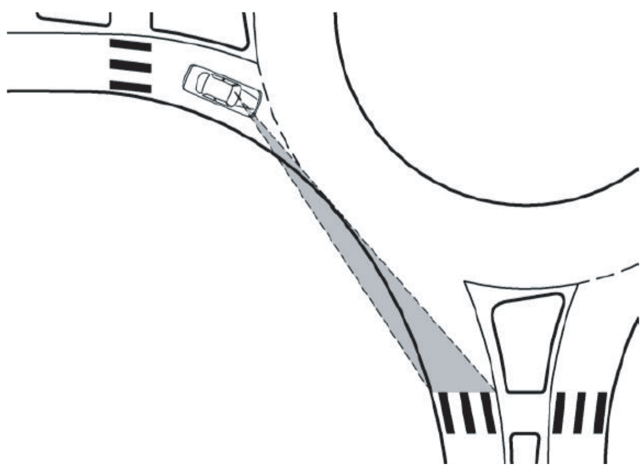


Figure 19-31 [NCHRP Report 672 Exhibit 6-57 (1)] Sight Distance to Crosswalk on Exit

19.7.3.2 Intersection Sight Distance

Intersection sight distance must also be verified for any roundabout design to ensure that sufficient distance is available for drivers to perceive and react to the presence of conflicting vehicles, pedestrians, and bicyclists. At roundabouts, the only location requiring evaluation of intersection sight distance is at entry of the roundabout.

Intersection sight distance is achieved by establishing sight triangles where the triangle is bounded by a length of roadway defining a limit away from the intersection on each of the two approaches and by a line connecting those two limits. For roundabouts, these legs should be assumed to follow the curvature of the roadway, and thus distances should be measured not as straight lines but as distances along the vehicular path as shown in Figure 19-32.

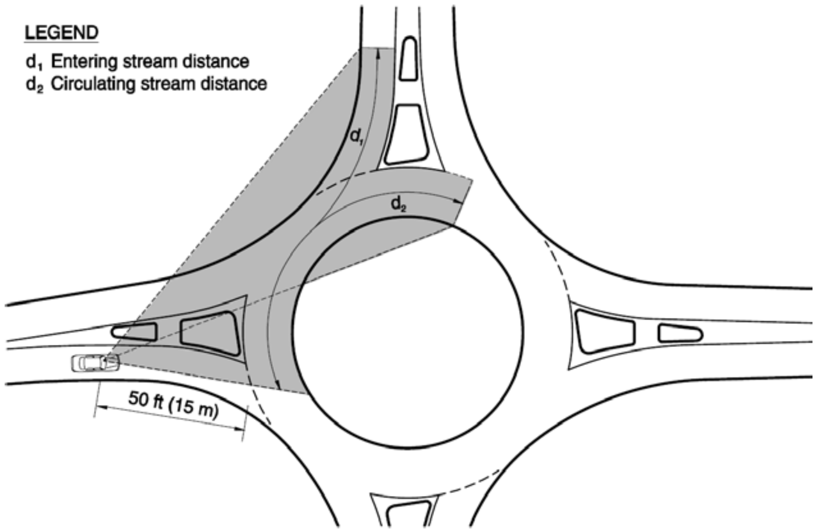


Figure 19-32 [NCHRP Report 672 Exhibit 6-58 (1)] Intersection Sight Distance

The approach leg of the sight triangle should be no more than 50 feet as shown in Figure 19-32. International research shows that excessive intersection sight distance can lead to higher vehicle speeds and a higher frequency of crashes. In most cases, it is best to provide no more than the minimum required intersection sight distance. Landscaping within the central island can be effective in restricting sight distance to the minimum requirements.

As shown in Figure 19-32, a vehicle approaching an entry to a roundabout faces two conflicting traffic streams; the entering stream of the immediate upstream entry (d_1) and the circulating stream (d_2). Vehicle speeds for the entering stream can be approximated by taking the average of the theoretical entering (R_1) speed and the circulating (R_2) speed. Vehicle speeds for the circulating stream can be approximated by taking the speed of the left-turning vehicles (R_4). The length of the conflicting leg is calculated using Equation 19-2 and Equation 19-3.

$$d_1 = (1.468)(V_{major,entering})(t_c) \quad [19\text{-}2]$$

$$d_2 = (1.468)(V_{major,circulating})(t_c) \quad [19\text{-}3]$$

where,

d_1 = length of entering leg of sight triangle, ft;

d_2 = length of circulating leg of sight triangle, ft;

V_{major} = design speed of conflicting movement, mph; and

t_c = critical headway for entering the major road, s, equal to 5.0 seconds

The critical headway for entering the major road is based on the amount of time required for a vehicle to safely enter the conflicting stream. The critical headway value of 5.0 seconds given in Equation 19-2 and Equation 19-3 is based upon the critical headway required for passenger cars. Table 19-4 shows computed length of the conflicting leg of an intersection sight triangle.

Conflicting Approach Speed (mph)	Computed Distance (ft)
10	73.4
15	110.1
20	146.8
25	183.5
30	220.2
Note: Computed distances are based on a critical headway of 5.0 s.	

Table 19-4 [NCHRP Report 672 Exhibit 6-59 (1)] Computed Length of Conflicting Leg of Intersection Sight Triangle

19.7.4 Angles of Visibility

The intersection angle between consecutive entries must not be overly acute in order to allow drivers to comfortably turn their heads to the left to view oncoming traffic from the immediate upstream entry. The intersection angle between consecutive entries, and indeed the angle of visibility to the left for all entries, should conform to the same design guidelines as for conventional intersections. Guidance for designing for older drivers and pedestrians recommends using 75° as a minimum intersection angle.

At roundabouts, the intersection angle may be measured as the angle between a vehicle's alignment at the entrance line and the sight line required according to intersection sight distance guidelines. Figure 19-33 illustrates an example where the angle of visibility is poor and the intersection needs to be improved. Figure 19-34 shows an example of a possible correction to improve the angle of visibility.

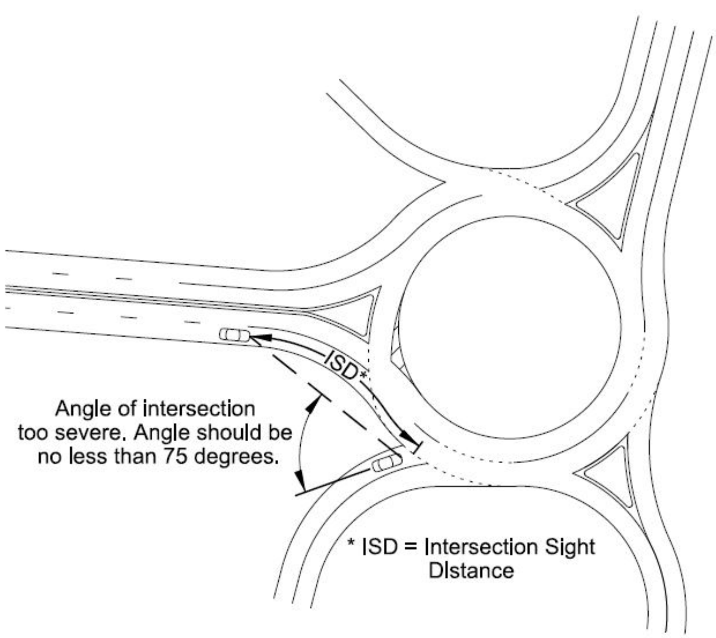


Figure 19-33 Roundabout Example with Poor Angle of Visibility

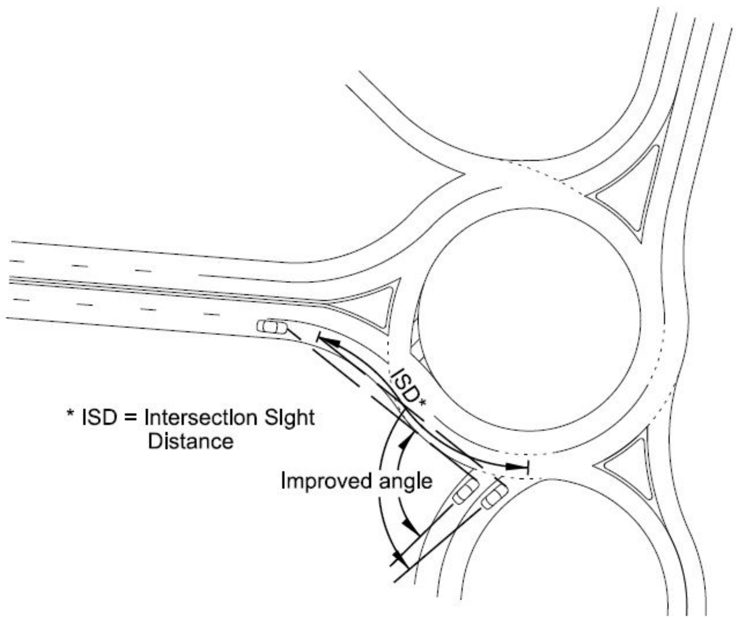


Figure 19-34 Roundabout Example with Improved Angle of Visibility

19.8 DESIGN DETAILS

The following are a general set of design detail guidelines to be considered at roundabouts. These are not to be interpreted as a standard or rule, or to be a complete set of design detail elements to considered. They are, however, a general set of best practices that the engineer should strive to achieve.

19.8.1 Sidewalk Considerations

Wherever possible, sidewalks at roundabouts should be set back from the edge of the circulatory roadway with a landscape strip, as shown in Figure 19-35. A recommended set back distance of 5 feet should be used (2-foot minimum), and it is best to plant low shrubs or grass in the area between the sidewalk and curb.

The recommended sidewalk width at roundabouts is 6 feet (5 feet minimum). In areas with heavy pedestrian volumes, sidewalks should be as wide as necessary to accommodate the anticipated pedestrian volume. At any roundabout where ramps provide sidewalk access to bicyclists, the sidewalk should be a minimum of 10 feet wide to accommodate shared use by pedestrians and bicyclists. Examples of sidewalk setback are shown in Figure 19-35 and Figure 19-36.

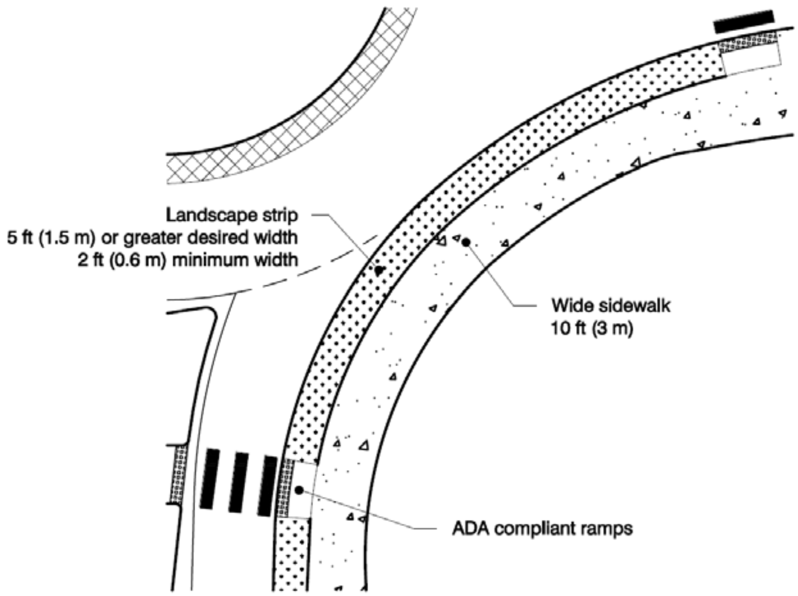


Figure 19-35 [NCHRP Report 672 Exhibit 6-63 (1)] Example Roundabout Sidewalk

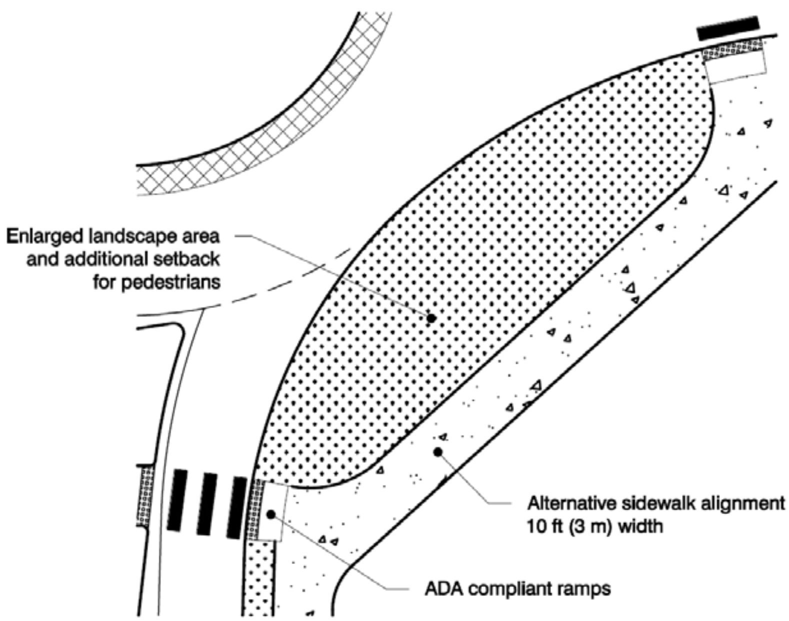


Figure 19-36 [NCHRP Report 672 Exhibit 6-64 (1)] Alternative Roundabout Sidewalk Treatment

19.8.2 Crosswalk Considerations

Pedestrian crosswalk placement at roundabouts requires consistency, based on a balance between pedestrian convenience, pedestrian safety, and roundabout operations. Pedestrian crosswalks should be designed as follows:

- The raised splitter island width should be a minimum of 6 feet at the crosswalk to adequately provide pedestrian refuge.
- A typical and minimum crosswalk setback of 20 feet is recommended (see Figure 19-7). This is the length of one vehicle without any additional distance to account for the gap between vehicles. At some roundabouts, it may be desirable to place the crosswalk two or three car lengths (45 feet to 70 feet) back from the edge of the circulatory roadway.
- The walkway through the splitter island should be cut-through instead of ramped. This is less cumbersome for wheelchair users and allows the cut-through walkway to be aligned with the crosswalks, providing guidance for all pedestrians, but particularly for those who are blind or who have low vision. The cut-through walkway should be approximately the same width as the crosswalk, ideally a minimum width of 10 feet.

Raised crosswalks (speed tables with pedestrian crossings on top) are another design treatment that can encourage slow vehicle speeds where pedestrians cross. Refer to Chapter 14 for additional information regarding pedestrian crossings at roundabouts.

19.8.3 Bicycle Design Considerations

When designing a roundabout, the engineer should provide bicyclists with similar options to negotiate roundabouts as they have at other intersections. Consider how they navigate either as motor vehicles or pedestrians depending on the size of the intersection, traffic volumes, their experience level, and other factors.

Bicyclists are often comfortable riding through single-lane roundabouts in low-volume environments in the travel lane with motor vehicles, as speeds are comparable and potential conflicts are low. At larger or busier roundabouts, cyclists may be more comfortable using ramps connecting to a sidewalk around the perimeter of the roundabout as a pedestrian. Roundabouts can be designed to simplify this choice for cyclists.

Where bicycle lanes or shoulders are used on approach roadways, they should be terminated at least 100 feet in advance of the circulatory roadway of the roundabout. Bicycle lanes should not be located within the circulatory roadway of roundabouts. Terminating the bike lane helps remind cyclists that they need to merge. At roundabout exits, an appropriate taper should begin after the crosswalk, with a dotted line for the bike lane through the taper. The solid bike lane line should resume as soon as the normal bicycle lane width is available.

Because some cyclists may not feel comfortable traversing some roundabouts in the same manner as other vehicles, bicycle ramps can be provided to allow access to the sidewalk or a shared use path at the roundabout. Bicycle ramps at roundabouts have the potential to be confused as pedestrian ramps, particularly for pedestrians who are blind or who have low vision. Therefore, bicycle ramps should only be used where the roundabout complexity or design speed may result in less comfort for some bicyclists. In general, bicycle ramps should not normally be used at urban, single-lane roundabouts, however, they may be appropriate if traffic speeds or other conditions (e.g., a right-turn bypass lane) make circulating like other vehicles more challenging for bicyclists.

Where bicycle ramps are provided at a roundabout, consideration should be given to providing a shared-use path or a widened sidewalk at the roundabout as discussed in 19.8.1. Bicycle ramps should be placed at the end of the full-width bicycle lane where the taper for the bicycle lane begins. Cyclists approaching the taper and bike ramp will thus be provided the choice of merging left into the travel lane or moving right onto the sidewalk. Bike ramps should not be placed directly in line with the bike lane or otherwise placed in a manner that appears to cyclists that the bike ramp and the sidewalk is the recommended path of travel through the roundabout.

Wherever possible, bicycle ramps should be placed entirely within the planting strip between the sidewalk and the roadway as shown in Figure 19-37. In these locations, the bicycle ramps should be placed at a 35° to 45° angle to the roadway and the sidewalk to enable cyclists to use the ramp even if pulling a trailer, but to discourage them from entering the sidewalk at high speed. The bike ramp can be fairly steep, with a slope potentially as high as 20%. If placed within the sidewalk area itself, the ramp slope must be built in a manner so that it is not a tripping hazard.

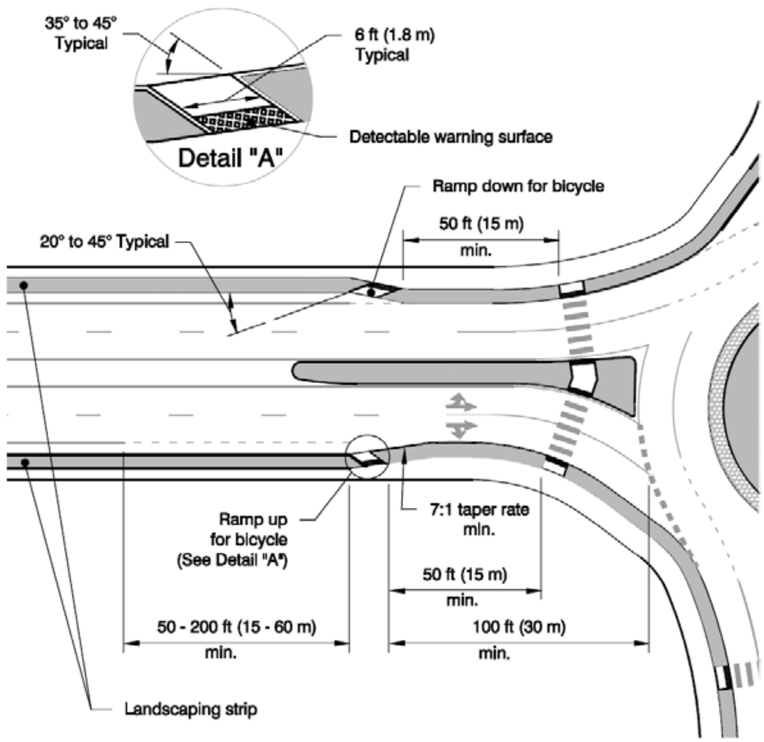


Figure 19-37 [NCHRP Report 672 Exhibit 6-67 (1)] Possible Treatments for Bicycles at Roundabouts

Since bike ramps can be confusing for pedestrians with vision impairments, detectable warnings should be included on the ramp. Where the ramp is placed in a planter strip, the detectable warning tile should be placed at the top of the ramp since the ramp itself is part of the vehicular area for which the detectable warning is used. If the ramp is in the sidewalk itself (as shown as one of the options in Figure 19-38), the detectable warning should be placed at the bottom of the ramp. Refer to Chapter 14 for additional information regarding bicycles at roundabouts.

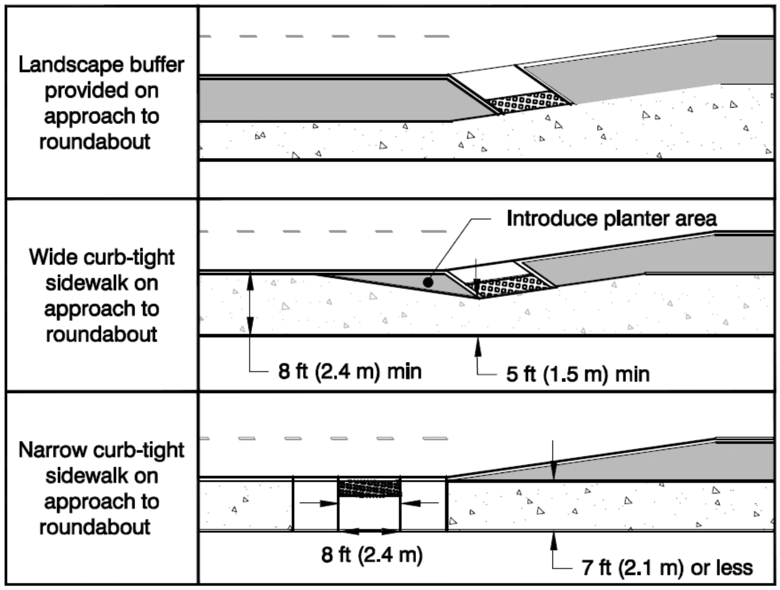


Figure 19-38 [NCHRP Report 672 Exhibit 6-68 (1)] Bicycle Ramp Design Options

19.8.4 Parking and Bus Stop Considerations

Parking in the circulatory roadway is not conducive to efficient and safe roundabout operations and should typically be prohibited. Parking on entries and exits should also be set back far enough so as not to hinder roundabout operations or to impair the visibility of pedestrians. AASHTO recommends that parking should end at least 20 feet from the crosswalk of an intersection. Curb extensions or bulb-outs are recommended to clearly mark the limit of permitted parking and reduce the width of the entries and exits.

For safety and operational reasons, bus stops should be located sufficiently far away from entries and exits and never in the circulatory roadway.

19.8.5 High-Speed Approach Considerations

An important feature affecting safety at rural intersections is the visibility of the intersection itself. Where possible, the geometric alignment of approach roadways should be constructed to maximize the visibility of the central island and the shape of the roundabout. Where adequate visibility cannot be provided solely through geometric alignment, additional treatments (signing, pavement markings, advanced warning beacons, etc.) should be considered.

On open rural highways, changes in the roadway's cross section can be an effective means to help approaching drivers recognize the need to reduce their speed. Rural highways typically have no outside curbs with wide paved or gravel shoulders. Narrow shoulder widths and curbs on the outside edges of pavement, on the other hand, generally give drivers a sense they are entering a more controlled setting, causing them to naturally slow down. Thus, when installing a roundabout on an open rural highway, curbs should be provided at the roundabout and on the approaches, and consideration should be given to reducing shoulder widths.

Another effective cross-section treatment to reduce approach speeds is to use longer splitter islands on the approaches. Splitter islands should generally be extended upstream of the entrance line to the point at which entering drivers are expected to begin decelerating comfortably. A minimum length of 200 feet is recommended for high-speed approaches.

Another method to achieve speed reduction that reduces crashes at the roundabout while minimizing single-vehicle crashes is the use of successive curves (chicanes) on approaches, as shown in Figure 19-39. These approach curves should be successively smaller in order to minimize the reduction in speed between successive curves.

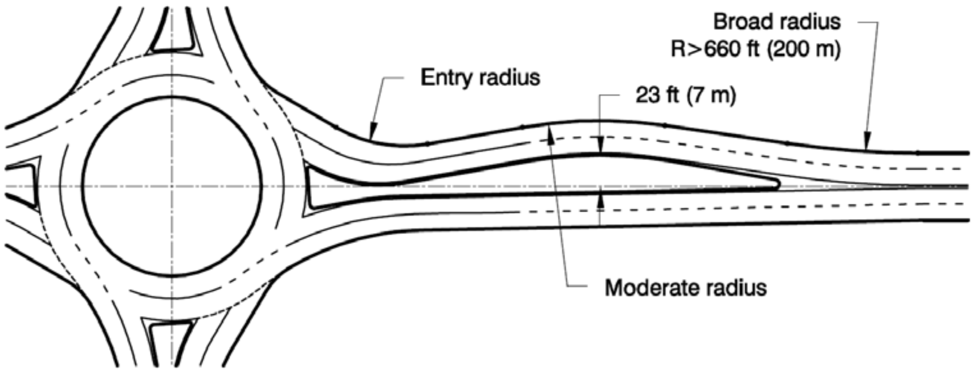


Figure 19-39 [NCHRP Report 672 Exhibit 6-40 (1)] Use of Successive Curves on High-Speed Approaches

19.8.6 Vertical Considerations

The vertical design of a roundabout begins with the development of the approach roadway and central island profiles. The development of each profile is an iterative process that involves tying the elevations of the approach roadway profiles into a smooth profile around the central island.

Each approach profile should be designed to the point where the approach baseline intersects with the central island as shown in Figure 19-40. A profile for the central island is then developed that passes through these four points (in the case of a four-legged roundabout). The approach roadway profiles are then readjusted as necessary to meet the central island profile.

It is generally not desirable to place roundabouts in locations where grades through the intersection are greater than 4%, although roundabouts have been installed on grades of 10% or more. At locations where a constant grade must be maintained through the intersection, the circulatory roadway may be constructed on a constant-slope plane. This means, for instance, that the cross slope may vary from +3% on the high side of the roundabout (sloped toward the central island) to −3% on the low side (sloped outward). On approach roadways with grades steeper than −4%, it is more difficult for entering drivers to slow or stop on the approach. At roundabouts on crest vertical curves with steep approaches, a driver's sight lines may be compromised, and the roundabout may violate driver expectancy.

Entry grade profiles (approximately two car lengths from the outer edge of the circulatory roadway) should not exceed 3%, with 2% being the desirable maximum. It is desirable to match the exit grades and the entry grades; however, the exit grade may be steeper but should not exceed 4%. Adjustments to the circulatory roadway cross slope may be required to meet these criteria but should be balanced with the effects on the circulatory roadway.

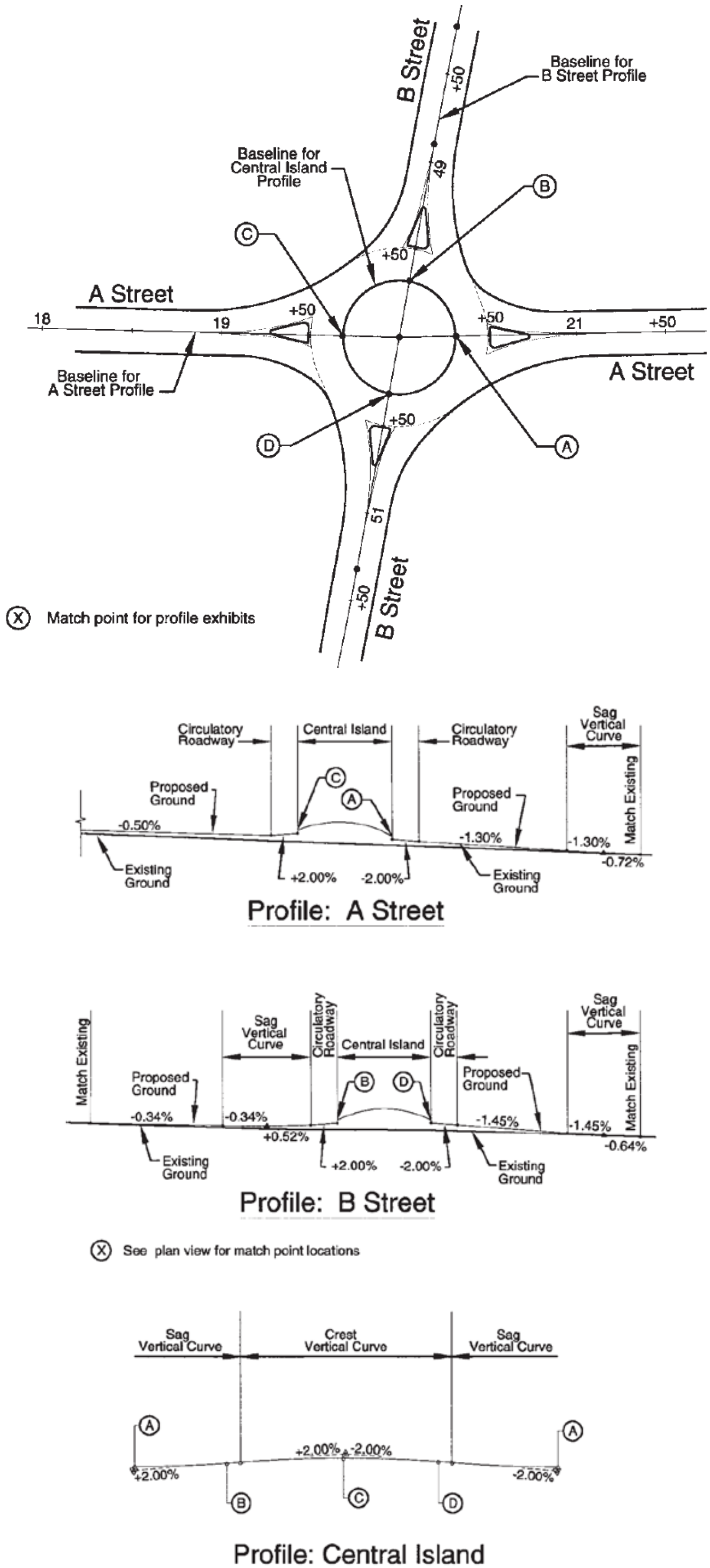


Figure 19-40 [NCHRP Report 672 Exhibit 6-75 (1)] Sample Central Island Profile

19.8.7 Cross Slope

As a general practice, a cross slope of 2% away from the central island should be used for the circulatory roadway on single-lane roundabouts. This is most practical in relatively flat terrain, however, roundabouts in hilly terrain may require the engineer to warp the profile to get the vertical design to work. It should be noted that excessive negative superelevation can result in an increase in single-vehicle crashes and loss-of-load incidents for trucks, particularly if speeds are high.

One method, primarily intended for consideration at multilane roundabouts, is to crown the circulatory roadway. The circulatory roadway is crowned with approximately two-thirds of the width sloping toward the central island and one-third sloping outward. This may alternatively be reversed so that half of the circulatory roadway slopes toward the central island. The maximum recommended cross slope is 2%. Asphalt paving surfaces are recommended under this type of application to produce a smoothed crown shape.

19.8.8 Truck Apron

Where truck aprons are used, the slope of the apron should generally be no more than 2%. Greater slopes may increase the likelihood of loss-of-load incidents. It is preferred to slope truck aprons away from the central island toward the outside of the roundabout, however, some locations have also implemented roundabouts with truck aprons sloped inward (toward the central island) to minimize water shedding across the roadway and to minimize load shifting in trucks.

The vertical design of the truck apron should be reviewed to confirm that there is sufficient clearance for low-boy type trailers, some of which may have only 6 to 8 inches between the roadway surface and bottom of the trailer. The vertical clearance can be reviewed by drawing a chord across the apron in the position where the trailer would sweep across. In some cases, warping of the profile along the circulatory roadway can create high spots that could cause trailers to drag or scrape along the truck apron. This should be checked during final design.

Between the truck apron and the circulatory roadway, a curb is required to accommodate a change in vertical elevation. As discussed in Section 19.4.4, the outer edge of the apron should be raised approximately 2 to 3 inches above the circulatory roadway surface. The apron should be constructed of a different material than the pavement to differentiate it from the circulatory roadway.

19.8.9 Drainage

With the circulatory roadway sloping away from the central island, inlets will generally be placed on the outer curb line of the roundabout. Inlets can usually be avoided on the central island for a roundabout designed on a constant grade through an intersection. As with any intersection, care should be taken to ensure that low points and inlets are placed upstream of crosswalks.

19.8.10 Concrete Jointing Patterns

If concrete pavement is used, joint patterns should be concentric and radial to the circulating roadway within the roundabout. Ideally the joints should not conflict with pavement markings within the roundabout, although concrete panel sizes may control this. On multilane roundabouts, circumferential joints within the circulating roadway should follow the lane edges to the extent practical.

19.8.11 Access Management

It is preferable to avoid locating driveways where they must take direct access to a roundabout. Nonetheless, site constraints sometimes make it necessary to consider providing direct access into a roundabout.

Public and private access points near a roundabout often have restricted operations due to the channelization of the roundabout. Driveways between the crosswalk and entrance line complicate the pedestrian ramp treatments and introduce conflicts in an area critical to operations of the roundabout. Driveways blocked by the splitter island will be restricted to right-in/right-out operation and are best avoided altogether unless the impact is expected to be minimal and/or no reasonable alternatives are available.

Queuing from nearby intersections (the roundabout or others nearby) should be checked to see if the operation of the access point will be affected.

19.8.12 Illumination

To improve the users' understanding of the roundabout's operations, the illumination should be designed to create a break in the linear path of the approaching roadway and emphasize the circular aspect of the roundabout

Illumination is recommended for all roundabouts, including those in rural environments. However, it can be costly to provide if there is no power supply in the vicinity of the intersection. Where lighting is not provided, the intersection should be well signed and marked (including the possible use of reflective pavement markers) so that it can be correctly perceived by day and night, recognizing that signing and markings alone cannot correct for the limited view of headlights when circulating.

In areas where only the roundabout is illuminated (no lighting is provided on the approach roadways), the scope of illumination needs to be carefully considered. Any raised channelization or curbing should be illuminated. A gradual illumination transition zone should be provided beyond the final trajectory changes at each exit. This helps drivers adapt their vision from the illuminated environment of the roundabout back into the dark environment of the existing roadway.

REFERENCES

1. NCHRP. *NCHRP 672, Roundabouts: An Informational Guide, 2nd ed. (NCHRP Guide 2)*, Transportation Research Board, National Academy Press, Washington D.C., 2010.

2. AASHTO. *A Policy on Geometric Design of Highways and Streets*, American Association of State Highway and Transportation Officials, Washington, D.C.: 2011.