Roundabout Design Reference Guide

TN TDOT Department of Transportation

Roadway Design Division

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Part 1 - Roundabout Design Process

The control type for a given intersection should be chosen based on an Intersection & Interchange Evaluation (IIE) screening process as outlined in the *Highway System Access Manual* (TDOT, 2021) or another form of feasibility study. Should a roundabout be selected, this process should also identify whether a mini, single-lane, or multi-lane roundabout is most appropriate for the site and the specific lane configuration for the intersection. Given the detailed grading, paving, and curb work that is required for a roundabout, the Designer (planner) should consider the future capacity needs of the roundabout and consider provisions for appropriate expansion.

Once the roundabout capacity and number of lane need is finalized, the design process can begin. The design process should be considered an iterative process, involving design checks and review points which may trigger revisions to earlier steps in the process. There may be several acceptable designs for a given location that will meet the desired performance however, this is rarely achieved on the first design iteration. Because of this, it is advisable that the Designer prepare the preliminary layout drawings to a “sketch” level of detail. Design components are interrelated and changing one affects others, so it is important that the Designer evaluate the performance of the entire intersection design as changes are made to ensure that the individual components are compatible. If a change is made to one component of a roundabout design, such as the Inscribed Circle Diameter (ICD) size, angle of approaches, or lane width, the Designer must verify that other components of the roundabout will still meet the design criteria.

The flow chart in Figure 1-1 provides the general procedure and steps for designing a typical roundabout:

- Prepare a preliminary layout to a “sketch” level of detail; validate that the initial planimetric roundabout design satisfies all design checks (Part 4).
- After successfully passing the initial design review, the roundabout layout can then be finalized, including detailed alignments, profiles, and drainage elements.
- This finalized roundabout layout should undergo another round of the same design checks to confirm that they are still satisfied, after which point the non-geometric design elements such as lighting, and landscaping can be added and sight distance must be checked one final time.
- The roundabout design is then ready for a final design review.

Should the roundabout at any point fail to pass the design checks or either review, the Designer must revise the design and repeat the review steps as appropriate.

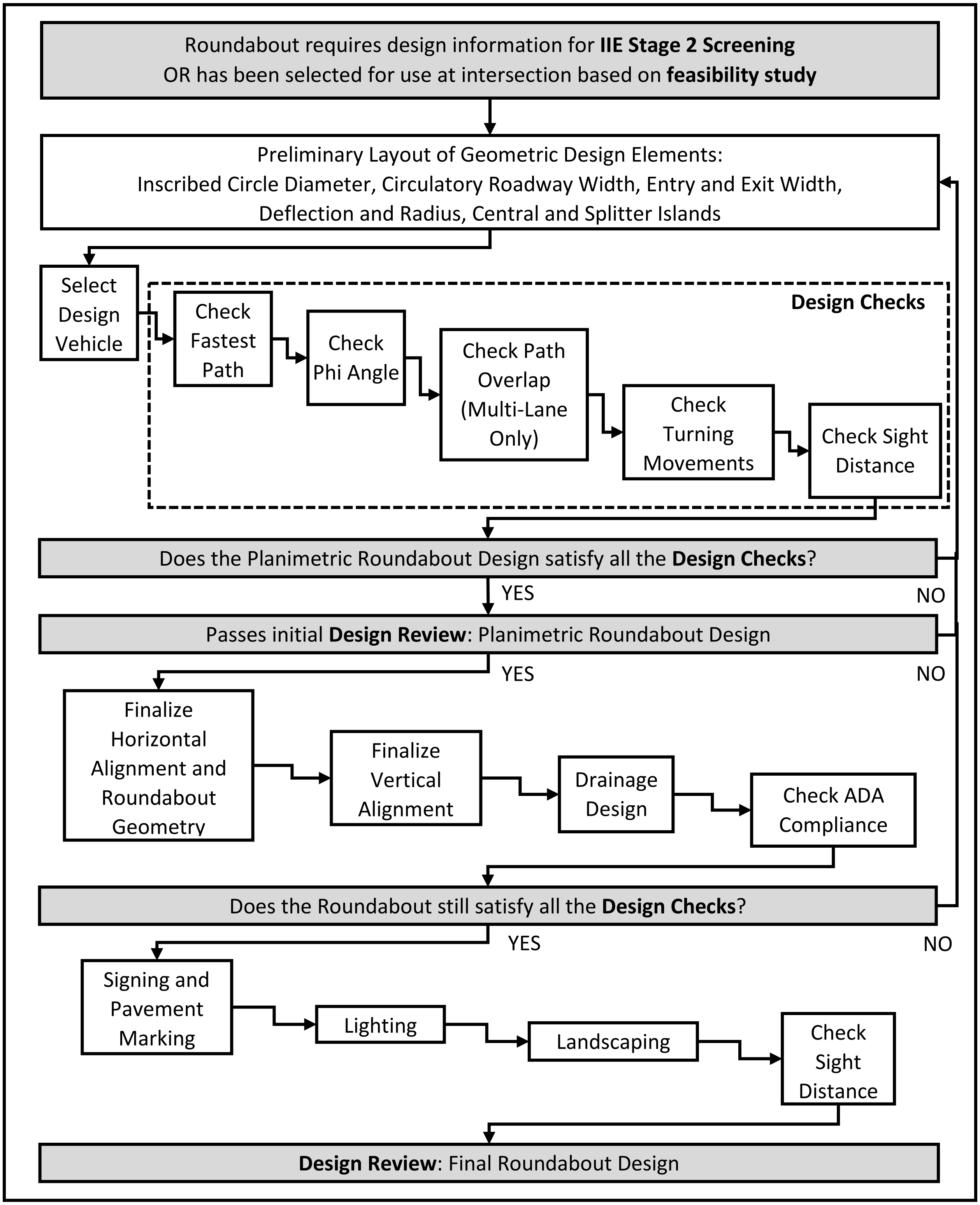


Figure 1-1
Typical Roundabout Design Procedure

Part 2 - General Roundabout Design Considerations

2.01 - Design and Control Vehicle Selection for Roundabouts

The size of vehicle to accommodate at a roundabout should be based on the type of roadway, volume and type of vehicles expected, and the intersection location. There are two types of vehicles that are important to accommodate in the design of a roundabout:

The *design vehicle* is the largest vehicle that is expected to use the intersection regularly and should be accommodated completely within the circulating lanes. With the exception of mini-roundabouts, all roundabouts should be designed to accommodate the design vehicle within the traveled way, without overtracking onto any truck apron and while maintaining separation between the truck and the face of curb. **Both AASHTO WB-40 trucks and BUS-45 motorcoaches should typically be used as the design vehicle.** Roundabouts should also be able to accommodate smaller vehicles within the traveled way such as single-unit trucks and all classes of school buses, transit buses, and emergency vehicles serving the surrounding area, including articulated buses where used by local transit authorities.

The *control vehicle* is the largest vehicle that the intersection must be able to accommodate, albeit on an infrequent basis, and as such may be accommodated by using both the circulating lanes and any provided truck aprons to traverse the roundabout. For the purpose of most designs, **the AASHTO WB-67 vehicle should be used as the control vehicle for designing roundabouts**, especially those located on the state highway system, including movements between state routes and at freeway or other controlled-access facility ramp terminals. A WB-67 control vehicle may also be appropriate in areas where a high percentage of truck traffic is expected, such as intersections on routes accessing industrial sites that are not the intersection of two state routes. The Designer should consider if a larger control vehicle is appropriate due to oversized trucks or other specialty vehicles serving nearby land uses. In situations that do not meet the above criteria, such as for roundabouts on local streets or in areas away from freeways or designated truck routes, a WB-50 or smaller control vehicle may be appropriate based on local conditions, approval of design waiver request will be needed.

Under no circumstances shall a design or control vehicle need to track across sidewalk or shared-use path facilities to traverse a roundabout.

The Designer should be aware that for multi-lane roundabouts, large trucks rarely track within the circulatory lanes marked on the pavement and may utilize both lanes, or possibly both lanes and the truck apron, while attempting to navigate through the intersection. The degree to which control vehicles are accommodated at multi-lane roundabouts can be categorized in one of the following cases:

Case 1: Trucks encroach into adjacent lane and/or truck apron as they both enter and circulate the roundabout. This should be considered only when trucks will not frequently use the intersection.

Case 2: Approach lane widths are wide enough to accommodate trucks in-lane as they enter the roundabout, but trucks may encroach into adjacent lanes while circulating. This should be considered where moderate truck volumes are expected in order to minimize the risk of side-swipe collisions along the approaches.

Case 2B: A more accommodating form of Case 2, where trucks may encroach into the adjacent circulating lane but adequate width remains within the adjacent circulating lane for a typical passenger vehicle to circulate next to the truck, totaling approximately 8-10 feet of residual space. This should be considered in situations where there is expected to be a more balanced mix of truck and passenger vehicle traffic and higher volumes, such as at a ramp terminal.

Case 3: Trucks accommodated in-lane as they traverse the entire roundabout. This should be considered when heavy volumes of both trucks and passenger vehicles are expected.

A roundabout should be designed according to the case best suited to the volume of truck traffic and the balance between trucks and passenger vehicles expected at the intersection, as each successive case provides greater separation between truck traffic and other vehicles but requires a correspondingly larger intersection footprint. The level of truck accommodations should be determined in conjunction with the Regional Traffic office prior to commencing preliminary layout of geometric elements.

In general, Designers should consider using a Case 2 or Case 2B design rather than Case 1 when the roundabout is expected to service 120 trucks per hour per approach or more. Below this threshold, the Designer should consider using a Case 1 design, particularly in urban areas where the smaller circle and tighter radii of a Case 1 design are desirable for pedestrian safety. A Case 3 design requires the largest roundabout footprint but should only be considered where warranted by heavy truck and passenger vehicle volumes.

2.02 - Horizontal Alignment Considerations for Roundabouts

It is preferred that approaching roadway centerlines should be offset left of the center of the roundabout. An offset left layout allows entry lanes to include more horizontal deflection and speed control, as shown in Figure 2 and detailed further in Section 3.05. The Designer should attempt to achieve this configuration on most projects. Where this is not possible at an approach, the Designer may allow the approach centerline to pass near the center of the proposed circle, at close to a 90-degree angle when projected across the intersection, although in this situation the entry radius must be carefully chosen to provide adequate speed control within the roundabout.

It is not recommended that any approach leg to a roundabout be offset to the right of the circle's center. A right offset layout will result in the alignment entering at a greater tangential angle and may lead to higher entry speeds, greater potential for vehicle rollover, and increased pedestrian conflicts.

Designing roundabout approaches with an offset left layout may require an iterative process. Figure 2 shows the conceptual steps in establishing proper entry offset:

1. Select desired Inscribed Circle Diameter (ICD, see Section 3.02) and place on intersection to create an initial circle layout. Note that the ICD does not need to be

centered on the intersection and can be shifted to account for right-of-way or other site constraints, as noted in RDG Chapter 2, Section 1005.01.

2. Offset the ICD to create circulating lane(s) (see Section 3.03) and add large exiting radii for all approaches (see Section 3.07).
3. Offset the exit lanes to create preliminary linework for the splitter island and entry lanes. In this way, a large exiting radius creates space that allows the entering lanes to be "pulled" to the left to create entry deflection.
4. Complete the entry lanes by constructing an entry radius that is tangent to the offset lines from Step 3 and the circulating lanes.

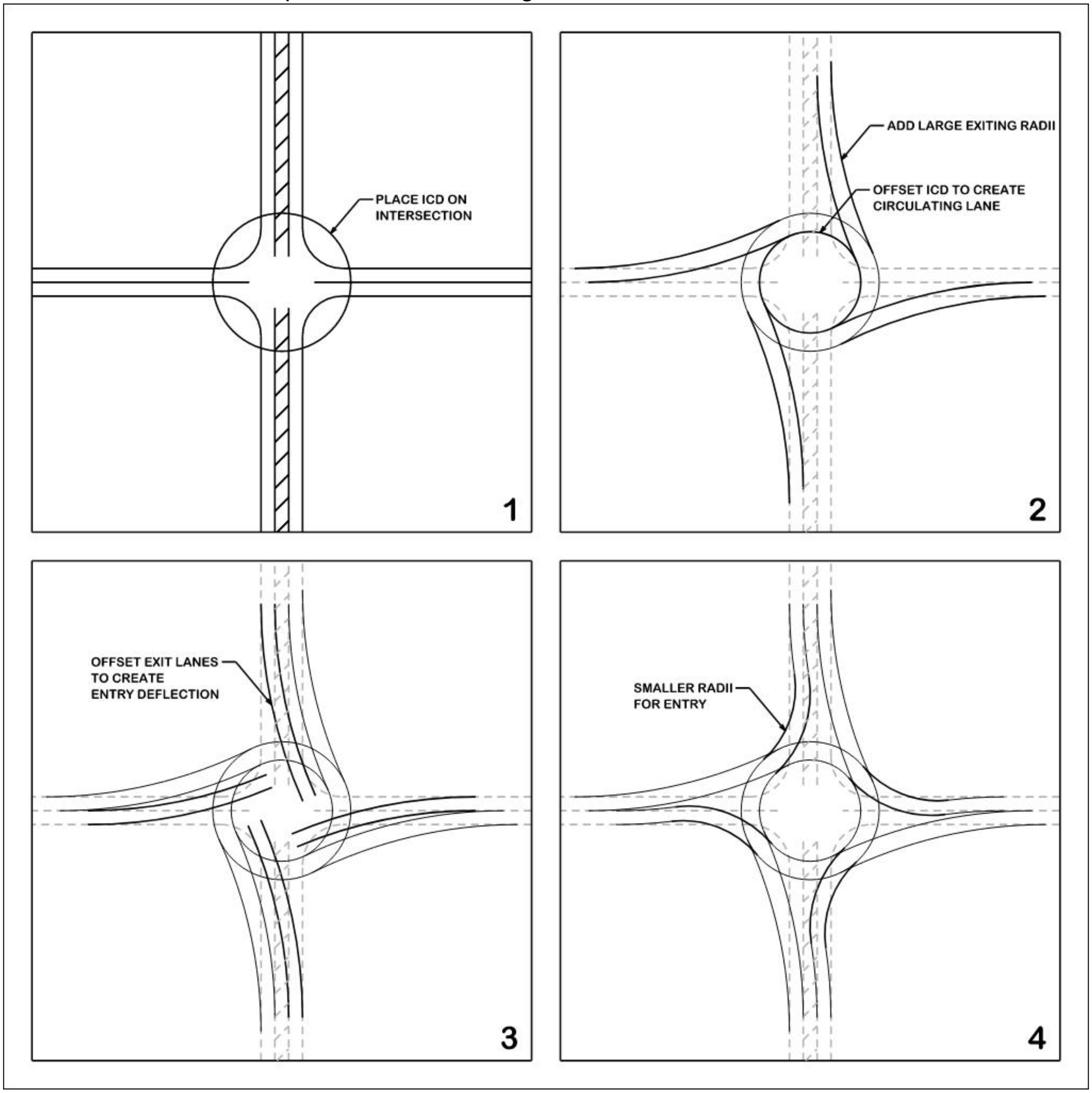


Figure 1
Desired Entry Offset and Exit Alignment Roundabout Design Process

Where feasible, the Designer should attempt to equally space entries into the circulatory roadway. At multi-lane roundabouts with a large separation between adjacent legs, the lane configuration must be carefully chosen to avoid conflicts between circulating traffic and exiting traffic, as shown in Figure 2. For new facilities, adjustments to the approaches in advance of the roundabout may be required. For urban roundabouts, the ability to provide equally spaced entries may not always be possible, especially when existing intersecting roadways are skewed from the mainline. When considering adjustment to approaches, the proposed right-of-way cost should be factored into the final design decision.

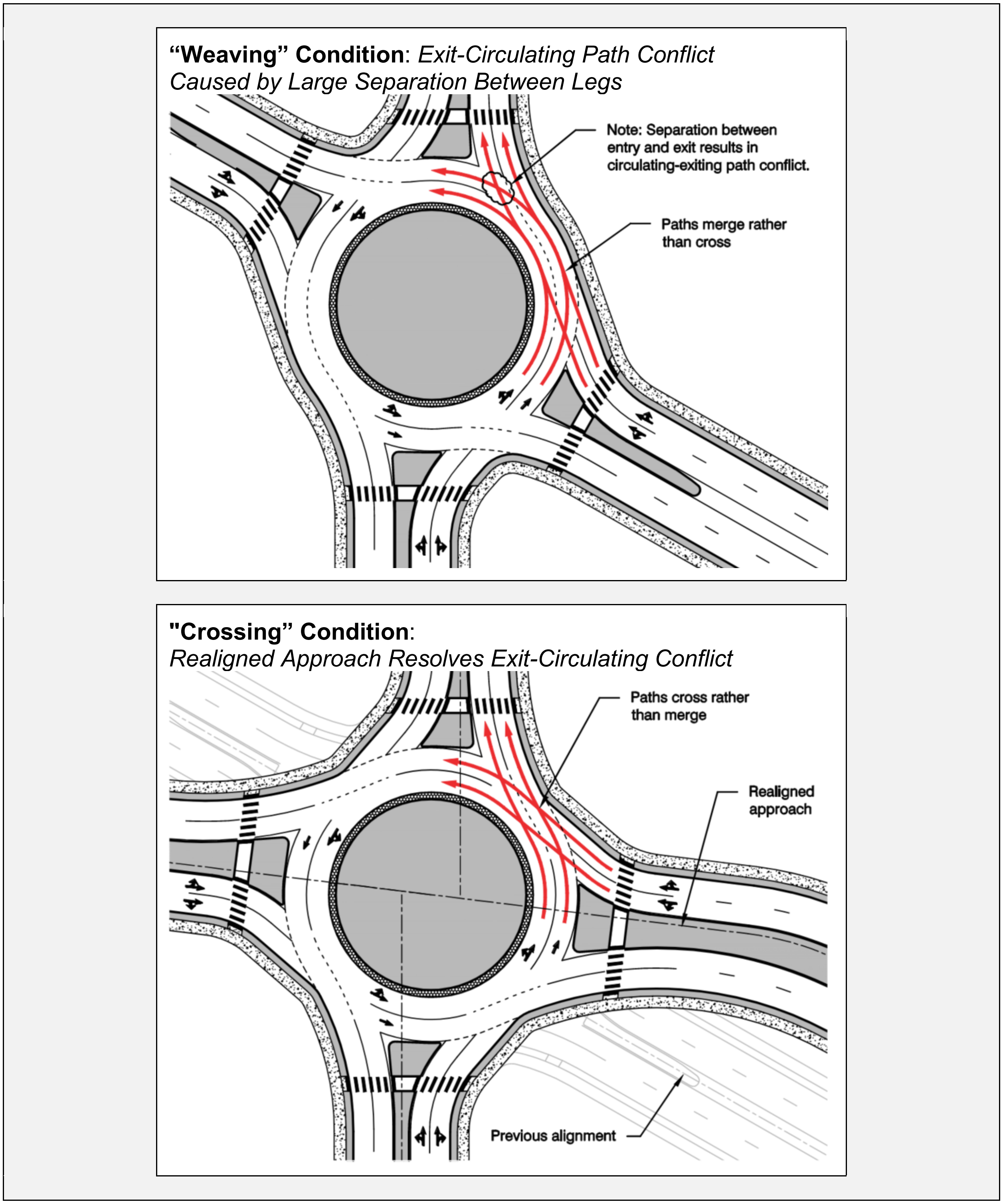


Figure 2
Example of Vehicle Exit-Circulating Path Conflict and Desirable Path Alignment
Adapted from: *Roundabouts: An Informational Guide, Second Edition* (NCHRP, 2010)

2.03 - Vertical (Profile) Grade Considerations for Roundabouts

An important factor when determining the optimum location of a roundabout is the longitudinal (profile) grade passing through the intersection. A relatively flat area with minor grade changes needed for drainage is preferred. The longitudinal grade through a roundabout should be limited to a maximum of 4 percent, though flatter longitudinal grades are preferred. Longitudinal grades in excess of 4 percent are not desirable due to the increased potential for load shifting within semi-trailers traversing the intersection, especially on the down-slope side of the central island, which can result in overturning of the vehicle.

Where a longitudinal grade cannot be designed less than 4 percent, the Designer should consider benching the roundabout into a localized flat area and steepening the roadway approaches to the intersection. The design should accommodate for the steeper approach grades by providing adequate braking distance.

Large differences in grades through and around a roundabout can create sight distance problems; refer to the sight distance design criteria in Section 4.06.

2.04 - Right-of-Way Requirements for Roundabouts

Right-of-way may be a determining factor when locating a roundabout. As compared to a traffic signal or a stop-controlled intersection, roundabouts usually require more right-of-way closer to the intersection and less right-of-way further away. Roundabouts designed in tight urban areas where building and/or right-of-way corners are close to the intersection may require additional right-of-way so that required sight distances are achieved. Additional right-of-way may also be required to alleviate skewed entries, accommodate multi-lane roundabouts, or provide for right-turn bypass lanes.

Designers should take advantage of the fact that a roundabout's center point does not need to coincide with the point of intersection of the two roadways. As discussed in RDG Chapter 2-1005.01, shifting the center point can lessen the right-of-way impacts at one or more intersection quadrants.

The Designer may consider designing the roundabout to the future condition with provisions for expanding the initial roundabout included in the design. Expansion should normally be inward, so the Designer should provide an adequately sized inscribed circle diameter and splitter islands if future expansion is expected.

2.05 - Considerations for High-Speed Approaches and Rural Locations for Roundabouts

High speed approaches and rural roundabout locations require additional attention because of the need for speed reduction of the approaching vehicles. Any approach to a roundabout with a posted speed of 45 mph or greater should be considered a high-speed approach, even if the project site is located in an urbanizing area. At these locations, drivers may not be anticipating an intersection or any other type of speed interruption. Drivers should be able to discern the impending intersection configuration and react to changing operational needs.

Providing fundamental features such as an extended splitter island, entry deflection, signage, and lighting are important design parameters for roundabouts with high-speed approaches.

At high-speed approaches or rural locations, the Designer should consider additional speed reducing design elements such as the following:

- Provide signage warning of the roundabout or ensure that the roundabout is visible from a greater distance.
- Increase the visual impact of the roundabout by raising the central island. Raising the central island also limits visibility across the roundabout, thereby reducing the possibility that drivers attempt to proceed directly through the intersection. Recommended grading guidance for the central island is in Section 2.06.
- Add reverse curvature at the high-speed approach leg, consistent with practices for offset left entry approaches and entry deflection discussed in Sections 2.02 and 3.05. The reverse curves should have a broad radius at the first curve, moderate at the second, and a sharp radius at the last curve before the yield line.
- Add alignment and cross-sectional cues to alert drivers of the pending change in geometry, such as longer splitter islands for additional deceleration length (see *A Policy on Geometric Design of Highways and Streets, Seventh Edition* [AASHTO, 2018], Section 3.2.2 for required braking distance), adding curb or curb and gutter to both sides of the approach beyond the curbed section at the roundabout, and/or a transition section where the shoulders narrow for the curbed section.
- Extend splitter islands in excess of minimum lengths to provide a visual “tunneling” effect along the approach, potentially up to 150-200 feet in length. Landscaping elements within the splitter island can enhance this “tunneling” effect if the splitter island is of sufficient size to permit landscaping based on the guidance in RDG Chapter 2 Section 1009.00.
- Incorporate larger nose radii at splitter island approaches to maximize island visibility. Splitter island guidance is included in RDG Chapter 2, Section 1005.08.
- Add additional signs and pavement markings to supplement geometric features, landscaping features to produce a tunneling effect, and roadway lighting.

Bicycle routes and lanes that sometimes are found at rural intersections should be accommodated by the roundabout. Detail on bicycle accommodations at roundabouts is included in Section 3-409.00.

2.06 - Grading and Drainage Considerations for Roundabouts

The optimum grading scheme for a roundabout is to slope the circulatory roadway away from the central island so that the center of the central island is the highest point in the intersection. This will increase the visual impact of the central island to the approaching motorist but will inherently create mildly adverse superelevation for left turning and through vehicles traversing the circulatory roadway. The Designer should accept this adverse superelevation given that the low travel speeds along these movements will mitigate the potential for rollovers or other safety risks of adverse superelevation.

Typical sections through a single- and multi-lane roundabout are provided in Standard Drawings RD18-RTS-1 AND RD18-RTS-2 respectively. While each location will be unique, grading a roundabout to slope away from the central island should follow these general guidelines:

The central island earthen area for single- and multi-lane roundabouts should always be raised, not depressed. A raised central island increases the visual impact of the roundabout to approaching drivers and is desired to limit sight lines across the roundabout, as discussed in Section 4.06. As shown in Standard Drawings RD18-RTS-1 AND RD18-RTS-2 the highest point of the central island should sit between 3.5 to 6.0 feet above the finished grade of the perimeter of the circulating lanes, and the ground slope of the central island should not exceed 6H:1V per the *Roadside Design Guide* (AASHTO, 2011). Note that mini-roundabouts typically have mountable central islands rather than curbed, landscaped central islands and as such should be paved and graded using the standards of a truck apron as noted below.

The slope of the truck apron should not exceed 4 percent and should normally be between 2 and 3 percent, sloping away from the central island. When the entire intersection is placed on a constant longitudinal grade, special attention should be given to ensure that the slope of the truck apron on the down-grade side of the center circle does not exceed 4 percent. Apron cross-slopes greater than 4 percent may lead to rollovers or load shifting within trucks.

Roadway cross slope of the circulatory roadway should be a maximum of 2 percent sloping away from the central island. Superelevation sloping toward the central island will normally result in increased vehicle speeds and the need to place stormwater inlets along the truck apron, neither of which are desired.

The maximum grade in any direction of travel along the circulatory roadway should not exceed 4 percent.

The Designer should note that by sloping the entire intersection away from the central island, visibility of the roundabout is improved since the center of the circle becomes the highest point in the intersection. Sloping the roadway inward is not recommended unless dictated by site constraints.

Stormwater runoff should be controlled to minimize sheet flow across the roundabout. The Designer should consider the vehicle wheel path traveling through the roundabout when considering placement of catch basins and inlets. The most desirable location of stormwater inlets is between adjacent legs of the roundabout. Additional inlets in the roundabout may be required and installed above the splitter islands. Concentrated storm drainage that is directed towards a roundabout should be intercepted (where practical) prior to entering the circulatory roadway. The Designer should not place inlets or low points within crosswalks.

Drainage for the circulatory roadway should typically be toward the exterior of the intersection, away from the central island. Inlets should be placed in the outer curb line of the roundabout, away from and up-slope of crosswalks. When the roundabout is placed on a roadway with a constant grade that passes completely through the intersection, the Designer may be required to place an inlet adjacent to the central island. Drainage of the central island should be considered in the overall drainage plan. In cases where the central island is large enough and/or contains complex landscaping plans, the Designer should consider whether area drains, or drainage inlets are appropriate within the central island to minimize runoff to the roadway or stormwater infiltration into the subgrade.

Part 3 - Geometric Design Elements for Roundabouts

3.01 - Introduction

A roundabout intersection incorporates a different group of geometric elements than a controlled (signal or stop) intersection. Some locations may require the Designer to deviate from the given design ranges on an as-needed basis while still adhering to the fundamental performance principles of roundabouts.

The following sections provide guidance on geometric features that are generally considered the most basic design elements for a roundabout intersection.

3.02 - Inscribed Circle Diameter (ICD)

Inscribed Circle Diameter (ICD) is the basic diameter of the roundabout circle. The ICD is measured from striped edge line to edge line across the largest part of the circle. The ICD size can vary at different parts of the circle due to spirals on the inside lanes (see Section 3.04). Smaller ICDs are desired to reduce circulating speeds. Determining the optimal ICD size is typically an iterative process using software applications such as Auto Trac. The Designer may consider making minor changes in the size of the ICD but should also be cautioned from deviating too much from the ICD assumptions used during Roundabout Design Procedure (RDG Figure 2-35). Recommended ICD ranges are shown in Standard Drawings RD18-RTS-1 AND RD18-RTS-2.

The use of a smaller ICD may not adequately allow for the control vehicle to make a left or U-turn. Ultimately, the design and control vehicles selected will have a direct influence on the ICD, especially for single-lane roundabouts, when the ICD is most influenced by the vehicle selected. While a truck apron is required at all roundabouts, the width of the truck apron may be larger for a smaller ICD.

3.03 - Circulatory Roadway Width

Circulatory Roadway Width is the travelled way width of the roadway for vehicles circulating around the central island. This width is typically measured from the solid yellow line at the central island to the solid white line at the right edge of the ICD, or the edge of pavement if a solid white line is not provided. The width of the circulatory lanes should typically be 16’ wide. This width strikes a balance between accommodating larger vehicles within the lane while not giving the appearance of multiple lanes at a single-lane roundabout. The circulatory roadway width does not include the mountable truck apron.

3.04 - Spirals

Spirals are used to lead vehicles into their proper lane within the circulating roadway and are effective in keeping vehicles in the proper lane as they traverse the roundabout. A spiral is either a hard raised surface, such as an extended curb, or painted line that develops at the central island and continues “spiraling out” until it ties into a circulating lane. Spirals should generally be an extended curb unless other design criteria prevail, such as turning movement sweeps of vehicle classes frequently using the roundabout. Spirals especially should be considered for use when multiple left-turning lanes are present so that turning movements and through movements do not weave.

Figure 3 depicts a multi-lane roundabout with spiraling. The spiral creates a second circulating lane for left-turning traffic by way of a dashed lane line which spirals outward. In this example, the spiral directs eastbound left-turning vehicles into the outside lane, allowing them to depart the roundabout to the right at the appropriate exit point.

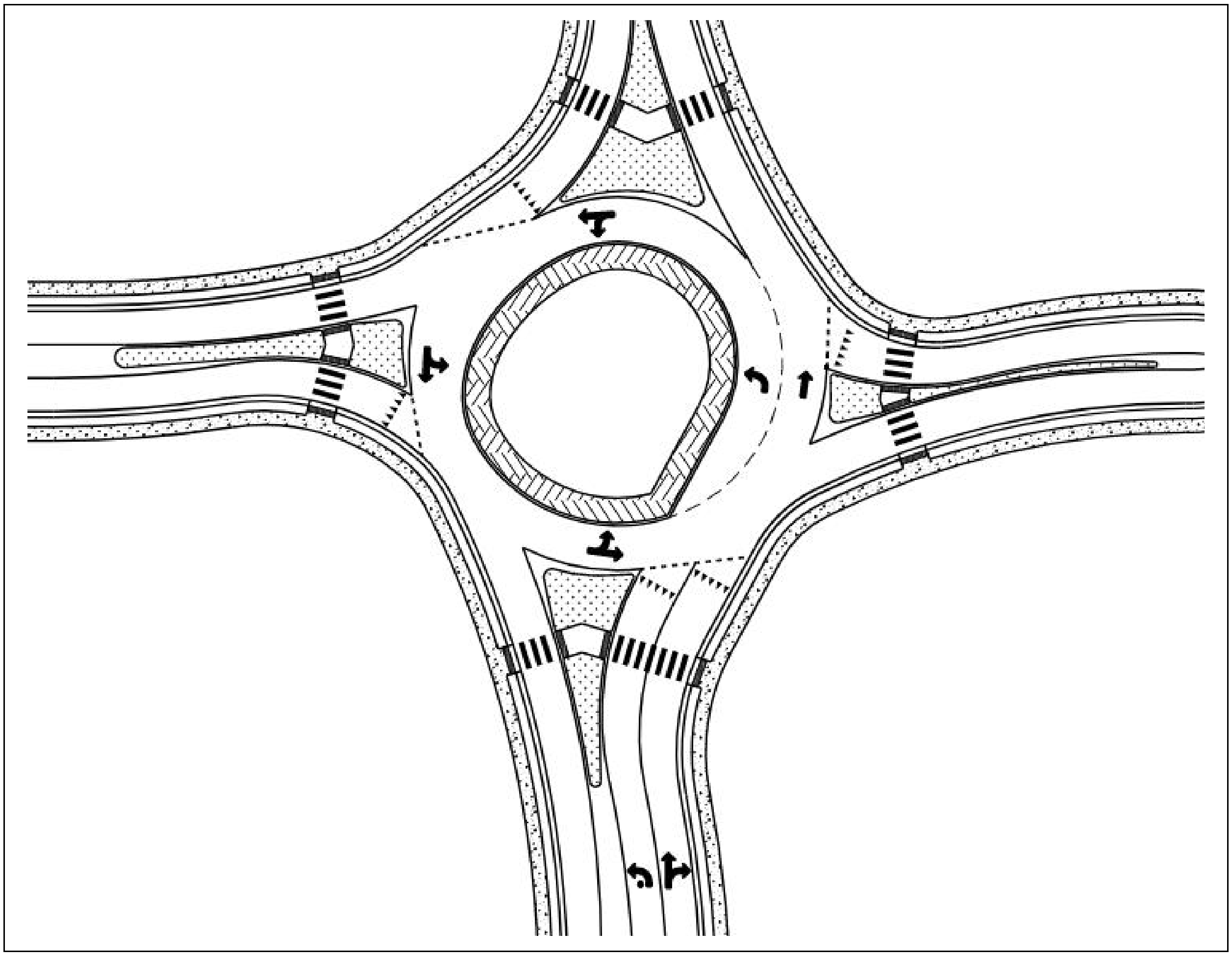


Figure 3
Typical Spiral for Multi-Lane Roundabouts

3.05 - Entry Deflection

Entry Deflection is the curvature (deflection) of the roadway as the roadway enters the roundabout. Deflection is used as a passive speed control measure for entering vehicles and should be applied prior to the yield line. Entry deflection has a direct correlation with fastest path speeds, phi angle, truck turning movements, and path overlap, and will ultimately affect all aspects of a roundabout.

Proper and adequate entry deflection causes vehicles approaching the roundabout to slow, thereby reducing speeds throughout the roundabout by ensuring a low entry speed (see Section 4.02, Fastest Path). Deflection also positions the entering vehicle so that the driver can see the circulating vehicles already in the roundabout (see Section 4.03, Phi Angle). Properly designed deflection at a multi-lane roundabout will also create good lane alignment between the entry lanes and the circulating lanes, reducing the likelihood of path overlap and lane departure collisions within the roundabout (see Section 4.04, Path Overlap). Deflection is also critical for preventing wrong way movements at the entries.

If the computed speed at the entry is high (see Section 4.02, Fastest Path), the Designer should consider increasing the entry deflection. Increased entry deflection is generally correlated with smaller entry radii and larger exit radii, both of which are desirable. To gain additional area for entry deflection, the Designer can offset the roadway alignment of the approach leg to the left of the circle center as discussed in Section 2.02 and illustrated in Figure 1. When used, a left-of-center offset is particularly beneficial to achieving desired deflection at roundabouts with small ICD's.

3.06 - Entry Width

Entry Width is the width of the entering travelled way as it approaches the roundabout after the flare length has ended (flare length is the distance from approach width to entry width). Entry width is the largest determinant of a roundabout's capacity and has a direct correlation to the fastest path measurement and truck turning movements. The most accurate location for measuring entry width is typically at the end of the splitter island, beginning at the intersection of the yield line (or wide dotted white line tangent to the ICD if a yield line is not provided at a single-lane roundabout) and the left edge of the travel way and extending to the right edge of travel way. This measurement should be taken perpendicular to the right edge of pavement and should be measured between the solid yellow line at the left edge of the travel way and the solid white line at the right edge, or the edge of pavement if a solid white line is not provided.

Design ranges for entry width are shown in Standard Drawings RD18-RTS-1 AND RD18-RTS-2. A 15' entry width per lane is a common starting point for design, but the total entry width should not exceed the width of the circulatory roadway typically 16' wide. At single-lane approaches, the entry width should remain at 18' or less to prevent drivers from treating the approach as two lanes.

3.07- Entry Radius

Entry Radius is the radius of the curve that leads vehicles into the roundabout. The entry radius is measured at the solid white line at the right edge of the traveled way. The Designer should use a radius that is small enough to reduce vehicle speeds, but not so small that vehicle turning movements are compromised. Designers should be aware of the relationship between entry radius, entry deflection (see Section 3.05 and fastest paths (see Section 4.02). Acceptable ranges for entry radius are shown in Standard Drawings RD18-RTS-1 AND RD18-RTS-2.

3.08 - Exit Width

Exit Width is the width at the exit roadway from a roundabout and is measured between the solid yellow line at the left edge of the travel way and the solid white line at the right edge, or the edge of pavement if a solid white line is not provided. The exit width should correlate with the upstream entries and circulating roadway width to ensure that it is wide enough. The Designer should ensure that the exit width provided is not too narrow for vehicles as they attempt to leave the roundabout, resulting in possible delays. In general, the exit width will taper from the width of the circulating lanes to the full width cross-section of the receiving roadway and should therefore be slightly less than the lane width of the circulatory roadway.

3.09 - Exit Radius

Exit Radius is the radius of the curve that leads a vehicle out of the roundabout. Exit radii are generally significantly larger than entry radii to allow for smoother exits and minimize the potential for delays or stopped vehicles within the circulating lanes. Large exit radii provide increased capacity at the exit compared to a roundabout's entrances or circulatory roadway, thereby assuring that assuring that vehicles can freely exit the circulating lanes when there is not conflicting pedestrian traffic.

The larger the exiting radius can be, the more left offset is possible on the entry lanes. This facilitates speed control at the entrance to a roundabout by providing room for greater entry deflection and smaller entry radii, as discussed in Section 2.02, Horizontal Alignment Considerations, and illustrated in Figure 1. For this reason, the exit and exit radius are typically designed in conjunction with the entry radii.

The exit radius is measured along the solid white line at the right edge of the traveled way. The exit curve should be tangential to the circulatory roadway. Design ranges for exit radius are shown in Standard Drawings RD18-RTS-1 AND RD18-RTS-2.

3.10 - Right-Turn Bypass Lane (Slip Lane)

Right-Turn Bypass Lanes, or right-turn "slip lanes", are exclusive, channelized lanes used to accommodate a high-volume right-turn movement, allowing right-turning traffic to bypass the roundabout's circulating lanes. No more than one right-turn bypass lane is permitted per approach.

There are two acceptable treatments possible at the exit from a right-turn bypass lane, both of which are shown in Figure 4:

Yield-controlled right-turn bypass lanes have yield control at the exit from the bypass lane onto the adjacent exit roadway. The yield point should be designed using similar principles to a traditional roundabout approach lane, including phi angle, crosswalk spacing, and striping.

Free-flow right-turn bypass lanes continue into an added lane on the departure leg, generally using a higher radius curve to meet the adjacent exit roadway at a tangent alignment. Free-flow configurations should only be used where the added lane continues for an appropriate length of acceleration distance and taper ratio before merging into the adjacent lane, consistent with the "Lane Drop After Intersections" guidance in the *Highway System Access Manual Volume 3, "Design Criteria"* (TDOT, 2021).

In areas that have a high volume of pedestrian traffic, additional attention should be given to the design of the right-turn bypass lane to allow for pedestrians to have the right-of-way. The Designer should consider other options for accommodating anticipated right-turn volumes prior to using a bypass lane in an urban environment due to the potential for high pedestrian volumes. However, in some cases, the need for a multi-lane roundabout may be eliminated by providing a right-turn bypass lane on one or more critical approaches. When used at locations with a high volume of pedestrian traffic, right-turn bypass lanes should be designed with yield control at the exit rather than free flow to reduce vehicle speeds at the pedestrian crossing points.

For rural roundabouts, right-turn bypass lanes may be considered when their need is warranted based on capacity or queuing considerations. When used, the Designer should expect greater vehicle speeds in the bypass lane and an increased risk to pedestrians crossing the quadrant of the intersection where the bypass lane is to be located. The Designer should examine the present and projected pedestrian and bicycle demand at the rural location under consideration and properly design pedestrian crossings, signalization, and signing at the bypass lane.

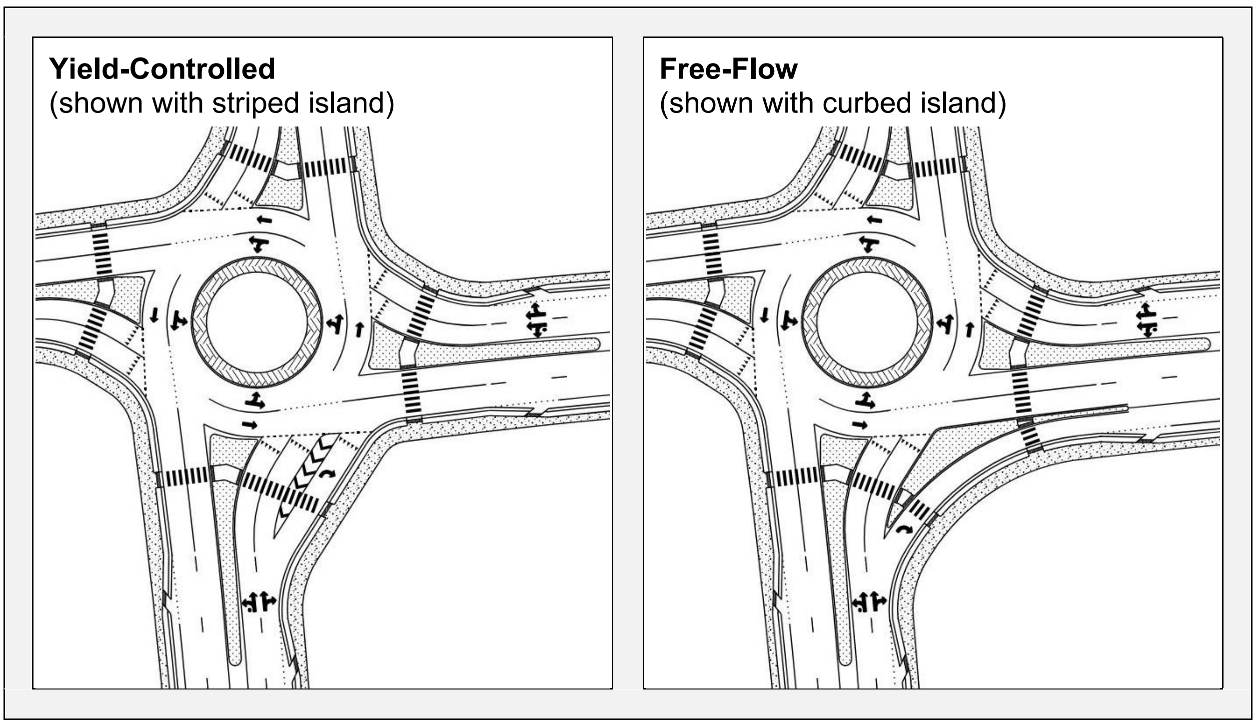


Figure 4
Typical Right-Turn Bypass Lanes

Where a bypass lane is used, the following design criteria should be considered:

Run a fastest path check through the bypass lane, using the general methodology for R1 and R5 control radii (see Section 4.02, Fastest Path), to ensure that the bypass lane does not produce excessive speeds. Vehicle speeds in the bypass lane should be similar to those in the roundabout.

- A buffer island should be provided between the bypass lane and the general-purpose lanes along a given approach to prevent access back into the circulatory roadway once a vehicle is committed to using the bypass lane. A raised, curbed island is preferred to establish this buffer.
- Minimizing the radius of the bypass lane may provide greater safety for crossing pedestrians; however, the design vehicle and control vehicle should be checked on all aspects of the bypass lane geometry. Mountable aprons should be used as needed to accommodate the control vehicle (see 3.11, Truck Apron); the design vehicle must be accommodated within the travel lane.
- Traffic exiting the roundabout should be given the right-of-way over traffic exiting any bypass lanes for both yield-controlled and free flow bypass lane configurations.
- For yield-controlled bypass lanes, the Phi angle at the yield point should be evaluated to ensure appropriate visibility for yielding drivers looking over their left shoulder (see 4.03, Phi Angle).
- In rural locations where right-of-way is available and pedestrian volumes are low, an acceleration lane with appropriate taper rates based on AASHTO guidelines is the preferred merging method at the end of the bypass lane.
- Pedestrian crossing points should be designed based on the guidance regarding Pedestrian, Bicycle, and Accessibility Considerations in Section 3-409.00.
- Proper lighting should be provided where applicable.

Bypass lanes can potentially add a significant amount of required right-of-way area to the intersection design. The final decision to use a bypass lane should consider pedestrian and right-of-way constraints. Proper analysis should ensure all right-turn bypass lanes have been justified prior to proceeding with a detailed design.

3.11 - Truck Apron

A Truck Apron is a mountable area used to accommodate turning movements of larger vehicles. The truck apron is designed to allow the rear tires of large vehicles to traverse the apron as they are making through and left turn movements due to their wider swept paths. At mini-roundabouts, the entire central island likely needs to be mountable and therefore designed using the standards of a truck apron.

The truck apron should be included at the central island of roundabouts, typically taking the form of a circular region extending out from the central island. Final truck apron width should be based on truck turning analysis for the control vehicle plus a recommended buffer of 2 feet in width to account for driver imprecision. When used at central islands, a truck apron should be a minimum of 6 feet wide.

Perimeter truck aprons may also be appropriate along the exterior of a roundabout, most commonly in between closely spaced approaches to accommodate right-turning vehicles that would otherwise need to make a 450-degree turn to avoid running up on the curb. For any perimeter truck aprons, the width and extent of the apron should be based on truck turning analysis for the control vehicle plus a recommended buffer of 2 feet in width.

The truck apron shall not be flush with the traffic lanes nor merely painted on the roadway surface. Truck aprons are not intended for passenger vehicles or small trucks; therefore, a sloping curb that provides enough vertical grade difference shall be used at the perimeter of a truck apron so as to appear unappealing to the driver of a smaller vehicle and prevent them from cutting across the apron. Sloping curbs are discussed in RDG Chapter 2-1005.09; a detail of the preferred 4” Sloping Detached Concrete Curb is included on Standard Drawing RP-SC-1.

The truck apron itself should provide positive drainage away from the central island, with slopes as noted in Standard Drawings RD18-RTS-1 AND RD18-RTS-2.

It is preferable that the design of the truck apron provide a color and surface texture contrast from the circulatory roadway and to that of any surrounding sidewalks so as to not be confused with a pedestrian path. Approved pavements and surface treatments for truck aprons and other mountable areas are discussed in RDG Chapter 2-1005.10.

Part 4 - Roundabout Design Check process

4.01 - Introduction

Design checks are measurements that are taken on various geometric elements of a roundabout to verify that the design will have sufficient entry angles, proper deflection and speed reduction, adequate area for turning movements, and adequate sight distance. Design checks are also necessary to show that the desired capacity and speed will be maintained for the types of vehicles that are expected to use the intersection. The design check process is essential to a roundabout design and is included at multiple points in the design process as discussed in RDG Chapter 2-1001.00 and outlined in RDG Chapter 2, Figure 2-35. The design check process is also iterative, and checks must be re-run to confirm acceptable results if any portion of the geometric design is modified. Verifying the design through the use of design checks can be a tedious process but is necessary for proper roundabout design.

The following design checks should be performed for proper roundabout design.

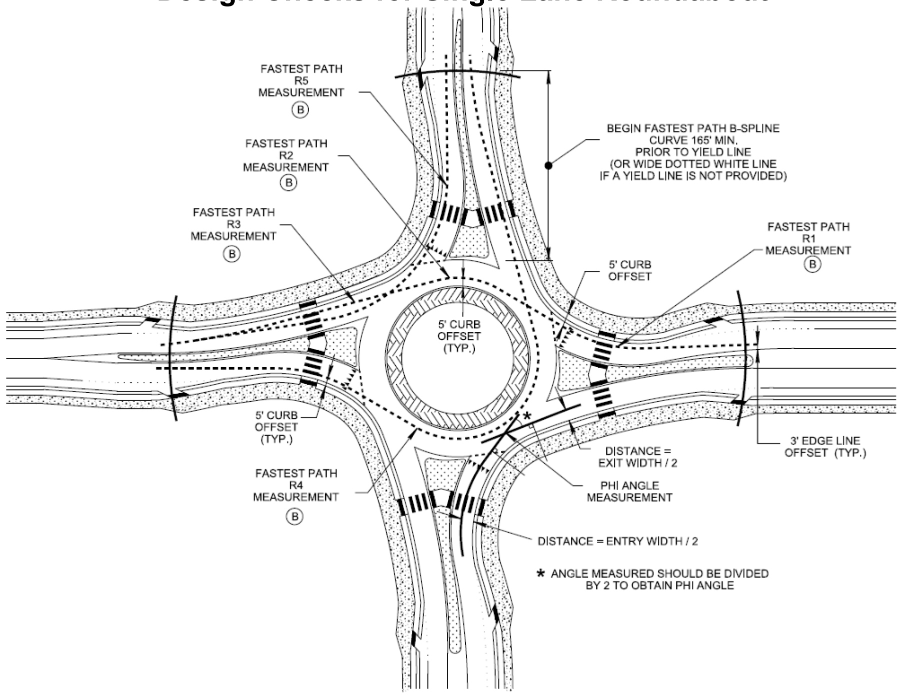
4.02 - Fastest Path Design Check

A roundabout operates most effectively when the final design results in low and consistent speeds being maintained throughout the intersection. Controlling the maximum allowable speed is fundamental to attaining desired operational and safety performance at roundabout intersections.

The design speed of a roundabout is determined from the fastest vehicle path allowed by the geometry and is a function of radius size along the fastest path in combination with vehicle acceleration and deceleration characteristics. Roundabout geometry, lane alignment, and other design elements should be properly selected and checked to ensure speeds are appropriately reduced at the approach, entry, circulating lanes, and exit of the intersection, although it should be noted that due to vehicle acceleration characteristics, a tight radius that controls speeds at one point along a vehicle path can incur speed reduction benefits upstream and downstream. A combination of all design elements working together is ultimately how the final design speed will be dictated.

The process for conducting fastest path design checks is outlined in Figure 2-5 & 5A and discussed in detail in the following subsections. Recommended design speed ranges for all turning movements within a mini, single-lane, and multi-lane roundabout are included in Table 1.

Design Checks for Single Lane Roundabout



Design Checks for Multi-Lane Roundabout

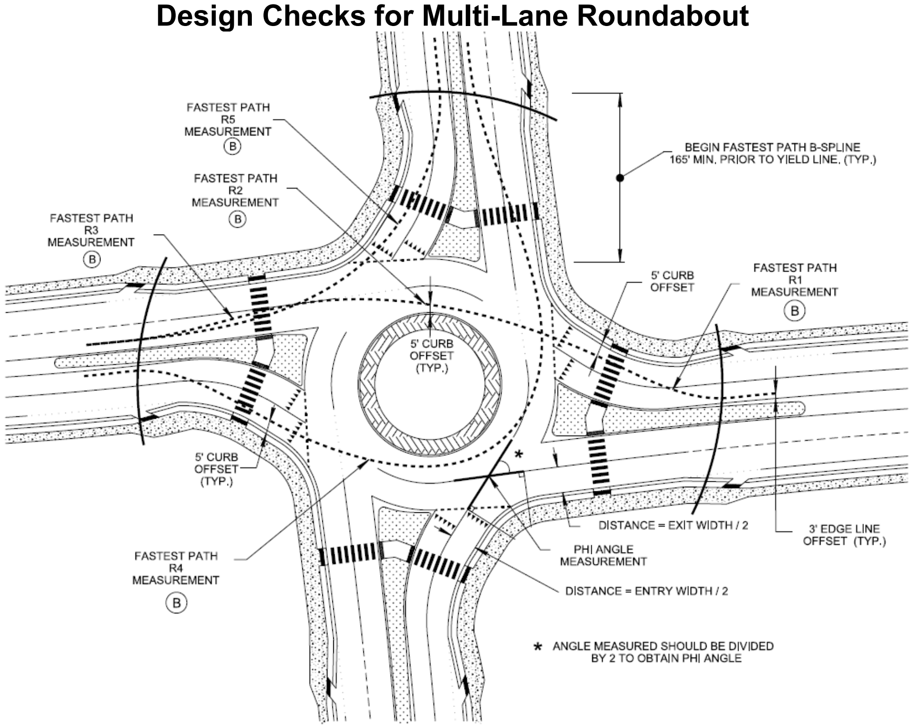


Figure 5

Design Checks for Single and Multi-Lane Roundabouts

Adapted from: *Roundabouts: An Informational Guide, Second Edition* (NCHRP, 2010)

Fastest Path Design Check Methodology
(to be repeated for all intersection approaches)

Step 1: Construct Fastest Path Splines
for Left, Through, and Right Turn Movements

Step 2: Identify Critical Radii:
- *R1*: Entry Path Radius
- *R2*: Circulating Path Radius
- *R3*: Exit Path Radius
- *R4*: Left-Turn Path Radius
- *R5*: Right-Turn Path Radius

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Step 3: Calculate Base Speeds, $V\#_{base}$
Speeds based on Path Radii, *R#*,
and Superelevation, *e*

$$V\#_{base} = \begin{cases} 3.4415 \times R\#^{0.3861}, \text{for } e = +0.02 \\ 3.4614 \times R\#^{0.3673}, \text{for } e = -0.02 \end{cases}$$

(graphical speed curves in Figure 6)

Step 4: Determine Practical Speeds, $V\#$,
in sequence by incorporating vehicle acceleration and/or deceleration from adjacent constraining radii

***V1*: Practical Entering Speed** $V1 = min \begin{cases} V1_{base} \\ {}^{1}/_{1.47} \times \sqrt{(1.47 \times V2_{base})^2 - 2a'_{12}d_{12}} \end{cases}$

(Deceleration from *R1* to *R2*, a'_{12} = -4.2 ft/s²;
d_{12} = distance along vehicle path from *R1* midpoint to *R2* midpoint, in feet)

***V2*: Practical Circulating Speed** $V2 = min \begin{cases} V2_{base} \\ {}^{1}/_{1.47} \times \sqrt{(1.47 \times V1)^2 + 2a_{12}d_{12}} \end{cases}$

(Acceleration from *R1* to *R2*, a_{12} = +6.9 ft/s²;
d_{12} = distance along vehicle path from critical *R1* point to midpoint of *R2*, in feet)

***V3*: Practical Exiting Speed** $V3 = min \begin{cases} V3_{base} \\ {}^{1}/_{1.47} \times \sqrt{(1.47 \times V2)^2 + 2a_{23}d_{23}} \end{cases}$

(Acceleration from *R2* to *R3*, a_{23} = +6.9 ft/s²;
d_{23} = distance along vehicle path from *R2* midpoint to critical *R3* point, in feet)

***V4*: Practical Left Turn Speed** $V4 = min \begin{cases} V4_{base} \\ {}^{1}/_{1.47} \times \sqrt{(1.47 \times V1)^2 + 2a_{14}d_{14}} \end{cases}$

(Acceleration from *R1* to *R4*, a_{14} = +6.9 ft/s²;
d_{14} = distance along vehicle path from critical *R1* point to midpoint of *R4*, in feet)

***V5*: Practical Right Turn Speed** $V5 = V5_{base}$

Step 5: Assess Speed Consistency and Compare to Recommended Speed Ranges
If consecutive speeds are inconsistent or any Practical Speed > Recommended Speed,
consider redesigning *R1* or other controlling radius (see Table 1 for recommended speeds)

Figure 5A
Fastest Path Design Check Methodology

Step 1: Construct Fastest Path Splines

The fastest possible paths for a vehicle to traverse a roundabout will follow the smoothest, and generally shortest, path that traverses the entry, travels around the central island, and through the exit. Fastest paths should be constructed given the absence of any other traffic within the roundabout and assuming that the driver ignores all lane markings on the approach, circulating lanes, and exit. Fastest paths should assume that the driver complies with all curbs, including sloped curbs lining truck aprons or other designated mountable areas.

In order for the Designer to determine the maximum expected vehicle speeds at the roundabout, splines representing all vehicle paths through the roundabout must first be constructed. Separate paths should be drawn at all approaches to a roundabout and should include path analysis for all left-turn, right-turn, and through movements at the intersection, making a total of 12 measurements for a 4-leg intersection. In most cases the critical path for a given approach will be the through movement; however, all paths must be analyzed because it is possible under certain geometries for the critical speed to occur on a left- or right-turn movement. Representative left, through, and right paths for a 4-leg roundabout are illustrated in Figure 5, “Design Checks for Single & Multi-Lane Urban and Rural Roundabouts”; note that the remaining nine paths at the intersection are omitted for clarity.

Fastest paths are typically created by constructing a b-spline (polyline) curve in a CADD program. The b-spline curve should represent the centerline of a vehicle that is attempting to traverse the roundabout at the highest rate of speed possible, ignoring other vehicles, pedestrians, pavement markings, and signing but complying with curbs. The Designer should begin the b-spline curve a minimum of 165 feet prior to the yield line (or wide dotted white line tangent to the ICD if a yield line is not provided at a single-lane roundabout) and continue for a minimum of 165 feet after exiting the circulating lanes, as noted in Figure 5.

When laying out a b-spline curve, the Designer should use an assumed vehicle width of 6 feet and maintain a minimum of 2 feet of clearance from the roadway centerline or any curb face. These assumptions result in the following minimum offset distances between the fastest path centerline and the roundabout’s geometric elements:

5 feet offset from the face of curb (2 feet clearance + 3 feet to center of vehicle)
3 feet offset from channelization striping, if no curb is present (half width of vehicle)
5 feet offset from roadway centerlines, if no splitter island or painted gore area is present (2 feet clearance + 3 feet to center of vehicle)

The through movement b-spline curve will be constructed to represent a vehicle entering a roundabout, passing to the right of the central island, and exiting the roundabout on the opposite side of the circle. The left-turn movement b-spline curve will be constructed to represent a vehicle entering a roundabout and making a left turn around the central island. The right-turn movement b-spline curve will be constructed to represent a vehicle entering a roundabout and then making an immediate right turn out of the roundabout. These movements are depicted in Figure 5 “Design Checks for Single & Multi-Lane Urban and Rural Roundabouts”.

Step 2: Identify Critical Radii

Once the Designer has constructed fastest path curves for the through, left-turn, and right-turn movements for each approach to the roundabout, the critical (minimum) radii can be measured off of the b-spline curves. Each approach in a roundabout has five critical path radii, described below and noted on Figure 5:

R1, Entry Path Radius: The minimum radius on the through movement b-spline curve measured at the entry, typically prior to the yield line (or wide dotted white line tangent to the ICD if a yield line is not provided at a single-lane roundabout) near the crosswalk

R2, Circulating Path Radius: The minimum radius on the through movement b-spline curve measured in the circulatory lanes around the central island

R3, Exit Path Radius: The minimum radius on the through movement b-spline curve measured at the exit to the roundabout

R4, Left-Turn Path Radius: The minimum radius on the left-turn b-spline curve measured in the circulatory roadway around the central island

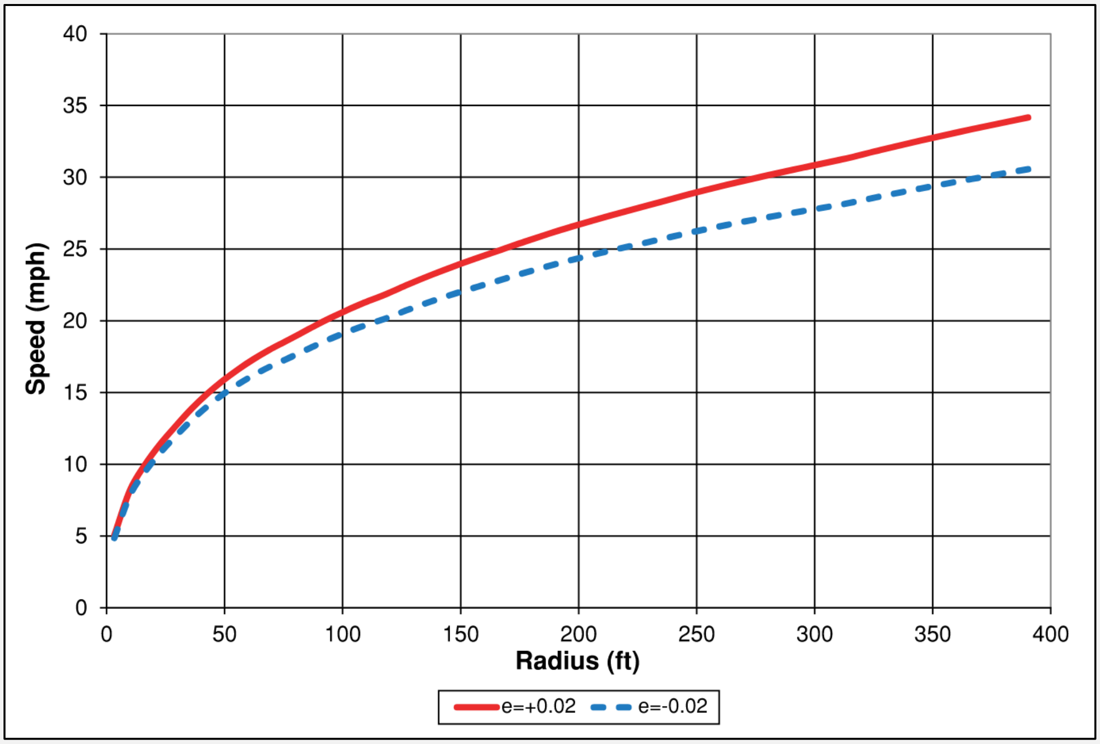
R5, Right-Turn Path Radius: The minimum radius on the right-turn b-spline curve measured at the tightest point

It should be noted that the critical path radius does NOT equal curb radius. Each critical path radius should be measured in a CADD program, most commonly by fitting an arc with a length of 65 to 80 feet on top of the b-spline curve at each critical point and measuring the radius of each arc.

Step 3: Calculate Base Speeds

Once all critical path radii are measured, the Designer can determine the corresponding theoretical speed associated with each critical path radius using the methodology in NCHRP 672, *Roundabouts: An Informational Guide, Second Edition* (NCHRP, 2010). The resulting theoretical speeds, or "base speeds" (V_{base}), are based solely on the critical path radii and superelevation and must be adjusted in Step 4 to account for vehicle acceleration and deceleration characteristics in order to reflect the practical speeds that are achievable by a vehicle traversing the roundabout.

Figure 6 shows the correlation between the measured radius and the base speed using the NCHRP methodology. The positive superelevation curve (e = +0.02) should be used for measurements at the entry and exit (*R1*, *R3*, and *R5*); the negative superelevation curve (e = -0.02) should be used for off-camber maneuvers around the central island (*R2* and *R4*).



Fitted Curves: $V_{base} = \begin{cases} 3.4415 \times R^{0.3861}, \text{for } e = +0.02 \text{ (at } R1, R3, R5) \\ 3.4614 \times R^{0.3673}, \text{for } e = -0.02 \text{ (at } R2 \text{ and } R4) \end{cases}$

where V_{base} = theoretical speed (mph), *R* = critical radius (ft), *e* = superelevation (ft/ft)

Figure 6
Speed-Radius Relationship
Adapted from: *Roundabouts: An Informational Guide, Second Edition* (NCHRP, 2010)

Step 4: Determine Practical Speeds

The base speeds computed in Step 3 are based solely on path radii and superelevation and may not reflect speeds that are achievable by normal vehicles due to acceleration and deceleration limitations. For instance, if a roundabout exit has *R3* = 1,000 feet, the corresponding $V3_{base}$ = 50 mph would be unacceptable for pedestrian safety and other reasons. However, if the upstream radius and corresponding speed along the fastest path is lower, say with *R2* = 125 feet and $V2_{base}$ = 20.4 mph, acceleration over the distance between *R2* and *R3* will limit the Practical Speed for R3.

In this way, a tight radius that controls speeds at one point along a vehicle path can incur speed reduction benefits elsewhere along the vehicle path. Once speeds are low, speeds generally stay low. Typical vehicles require substantial distances to accelerate to speed, even in straight lines; therefore, it is critical to evaluate the relationship of fastest path geometrics in series to each other as opposed to in isolation.

To account for this phenomenon, for all approaches the Designer must calculate the practical speed (*V*) at each critical radius in sequence using the methodology outlined in Step 4 of Figure 5. For instance, *V1*, the practical entering speed, is determined by taking the minimum value of A) $V1_{base}$, the theoretical speed at *R1*, versus B) the calculated maximum speed at *R1* which would allow the vehicle to safely decelerate to $V2_{base}$, the theoretical radius-limited speed at *R2*. *V2*, *V3*, and *V4* are then built incrementally by comparing the theoretical speed at each location to the potential speed a vehicle could accelerate to by that point and taking the minimum achievable speed. *V5* is not limited by any other critical radii and is set equal to $V5_{base}$.

Step 5: Assess Speed Consistency and Compare to Recommended Speed Ranges

Once all practical speeds are determined, the practical speeds should be compared to the recommended speed ranges for each critical point which are noted in Table 1. The practical speeds also should be assessed for speed consistency.

Fastest Path Check	Mini-Roundabout	Single-Lane RAB	Multi-Lane RAB
Speed at Entry (*V1*)	15-20 mph	15-25 mph	20-30 mph
Speed on Circulating Path (*V2*)	15-25 mph	15-25 mph	15-25 mph
Speed at Exiting Crosswalk (*V3*)	25 mph or less	25 mph or less	25 mph or less
Speed on Left Turn Path (*V4*)	10-20 mph	10-20 mph	10-20 mph
Speed on Right Turn Path (*V5*)	15-25 mph	15-25 mph	15-25 mph

Table 1
Recommended Speed Ranges for Fastest Path Critical Points

Note: Speed ranges are provided for each fastest path check. Lower speeds are generally desired; speeds at the higher end of the range should only be considered at sites with negligible pedestrian/bicycle demand. Speeds lower than the noted ranges are acceptable if speed consistency is achieved.

Speed consistency is critical and should be checked across all fastest path measurements. The Designer should attempt to minimize variations in vehicular speeds within the intersection, since a large speed differential between movements can lead to an increased incidence of crashes. The speed differential between conflicting traffic streams and between consecutive geometric elements should be no more than 10 to 15 mph, with a speed differential of no more than 6 mph being preferred. These values are typically achieved by providing a low absolute maximum speed for the fastest entering movements, which will in turn limit the maximum achievable speed at any point in the roundabout due to acceleration limitations. It is generally preferable for the entrance to have the lowest speed, with *V1* smaller than *V2* and *V4*, and *V2* smaller than *V3*.

When the initial design will not produce adequate speed consistency, the Designer has several options for consideration to remedy the situation. The following is a list of strategies that the Designer may consider correcting a speed control problem:

Adjust the size of the inscribed circle diameter a few feet, either making it smaller or larger as needed.

Adjust the entry radius by a few feet by either making it smaller or larger.

Re-design the entry or exit so that the entry angle changes, thus creating more or less deflection as needed.

Move the entire circle in one direction to increase or decrease the entry deflection.

Re-evaluate the modeling to determine if a different lane configuration will be acceptable.

Designers should be aware that any change to a geometric element will affect the previously computed roundabout design checks and all checks will need to be re-evaluated after geometric changes are made.

4.03 - Phi Angle Design Check

The Phi (Φ) angle is measured between the entering and exiting roadways. Phi angle is typically measured as a design check to verify that the angle of the entering roadway relative to the circulating lanes allows a driver to see oncoming traffic within the circle without the driver having to turn their head in an uncomfortable position. When a driver approaches the yield line, the roundabout geometry should allow for the driver to see oncoming vehicles within the circle without having to look over their left shoulder excessively.

Values for the Phi angle typically range from 16 to 40 degrees, with greater than 30 degrees considered optimal.

At most roundabouts, an approach and the subsequent exit are located close together such that the entering and exiting traffic paths cross at a single point. In this case, the angle measured between the tangent paths is equal to twice the Phi angle (2Φ). Specific procedures to construct the tangent paths are shown in Figure 5, "Design Checks for Single & Multi-Lane Urban and Rural Roundabouts".

Note that directly measuring the Phi angle between adjacent tangents will not be possible at roundabouts where the subsequent exit is sufficiently far from a given approach that entering traffic must merge with the circulating lanes before the exiting traffic can diverge from the roundabout, in contrast to the more traditional crossing conflict point described above and illustrated in Figure 5. This merging configuration is most commonly found at three-legged roundabouts but is also possible at four-legged locations with unevenly spaced legs, an example of which was shown in Figure 2. In this situation, the Designer should construct a "dummy" exiting tangent which can then be used to measure the Phi angle as described previously.

The Phi angle design check should also be applied to the design of yield-controlled right-turn bypass lanes, measured relative to the exiting lane that traffic within the bypass lane must yield to.

4.04 - Path Overlap Design Check

A critical design issue for multi-lane roundabouts occurs when the natural paths of entering and exiting vehicles in adjacent lanes overlap or cross each other. This occurs when a vehicle enters a roundabout and is directed into an adjacent lane once inside the circulatory roadway as shown in Figure 7. The existence of path overlap should be checked at both the entrance and exits.

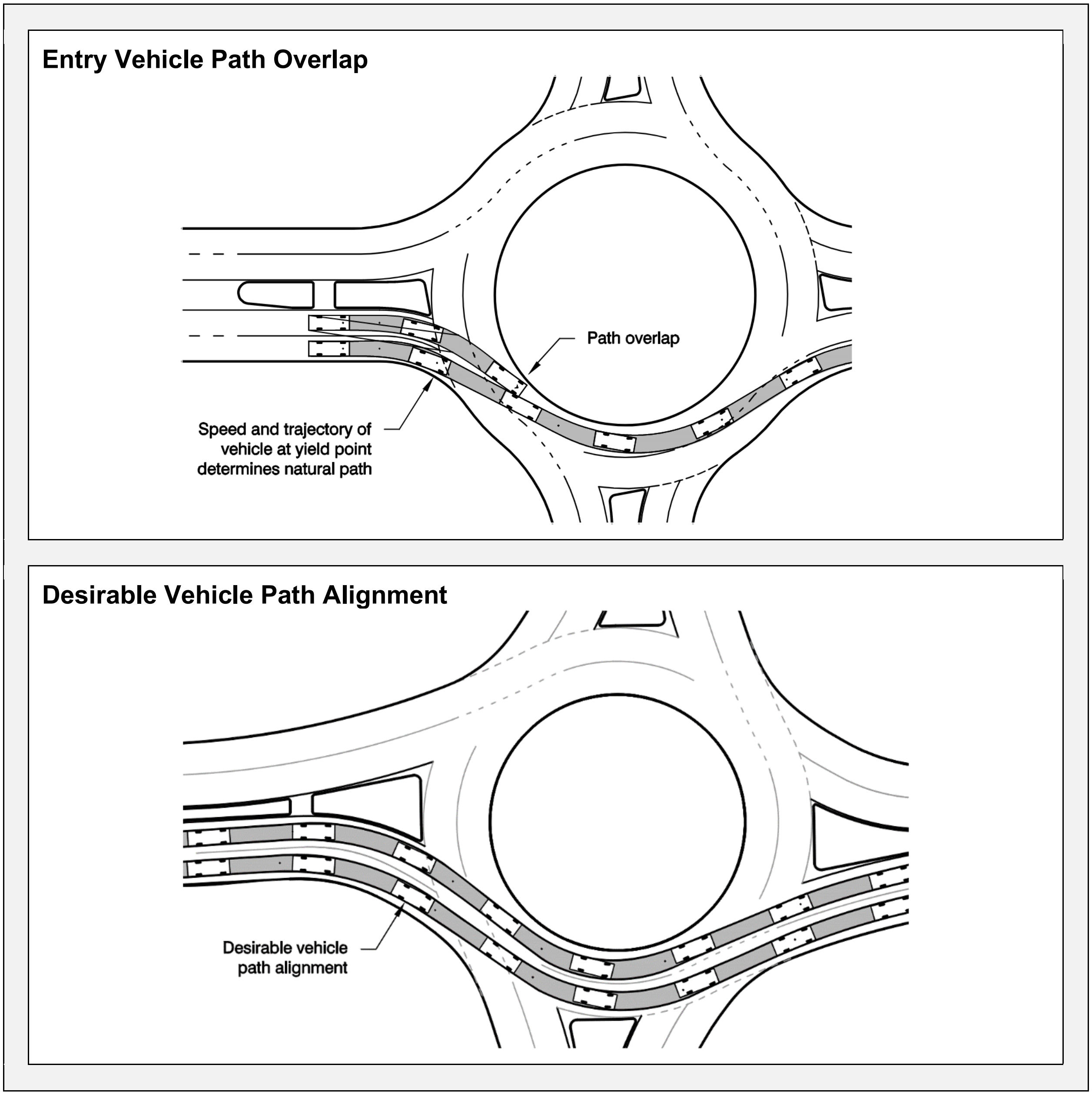


Figure 7
Example of Vehicle Path Overlap and Correct Path Alignment into a Multi-Lane Roundabout
Adapted from: *Roundabouts: An Informational Guide, Second Edition* (NCHRP, 2010)

Larger exit radii and/or tangential exits will aid in reducing the potential for exit path overlap. The Designer can minimize the potential for entry path overlap by providing adequate entry deflection and ensuring multi-lane vehicle entry paths are properly aligned with the circulatory lanes ahead at the yield line. To accomplish this, the Designer should locate the entry curve so that the projection of the inside entry lane at the yield line connects tangentially, or nearly tangentially, to the curb line ahead at the central island.

Multi-lane roundabouts shall be designed to minimize the potential for entry and exit path overlap which can result in significant safety concerns, particularly a higher rate of side-swipe collisions, as well as reduced operational performance and adverse capacity impacts due to unbalanced lane utilization on the approach. NCHRP 672, *Roundabouts: An Informational Guide, Second Edition* (NCHRP, 2010) provides additional suggestions for eliminating path overlap at a multi-lane roundabout.

4.05 - Truck Turning Movements Design Check

Truck movements shall be reviewed for all roundabout designs to verify that the design vehicle can properly navigate all required turns. Roundabouts shall be designed to accommodate the design vehicle and control vehicles according to accommodation case, as discussed in Section 2.01. Design vehicles should be accommodated within the travel lanes while larger "control vehicles" may need to use the truck apron at the central island and any other mountable areas to negotiate the roundabout. All roundabouts, with the exception of mini-roundabouts due to their small size, should be designed to accommodate buses and emergency vehicles within the traveled way without overtracking onto the truck apron.

The right-turn movement tends to be the most challenging movement for a truck. The roundabout should be designed so that truck tires do not track over the exterior concrete curbing or combined curb and gutter for the right-turn movement, nor over the splitter island curbing at the entry and exits. Mountable right-side overtracking areas, also known as perimeter truck aprons and constructed using similar techniques to the central island truck apron, can be used to accommodate right-turn movements by larger "control vehicles", discussed in Section 2.01, when warranted by site conditions. Control vehicles that are continuing through the roundabout or making a left turn can use the truck apron within the central island.

4.06 - Stopping and Intersection Sight Distance Design Check

There are four critical types of stopping sight distance that shall be measured at roundabout intersections:

- Approach Stopping Sight Distance, measured from the approaching vehicle to both the yield line and crosswalk
- Circulatory Roadway Stopping Sight Distance, measured along the circulating lanes as a vehicle travels around the roundabout
- Stopping Sight Distance to Crosswalk at Exit, measured from an entering or circulating vehicle to the crosswalk on an exiting leg
- Intersection Sight Distance, measured between an approaching vehicle and opposing vehicles along the circulatory roadway and at other entrances

These sight distances are shown in Standard Drawing RD11-SD-8, "Sight Distance for Urban and Rural Roundabouts". These distances are normally measured to verify that there are no obstructions within the sight lines, also referred to as sight triangles. Refer to NCHRP 672, *Roundabouts: An Informational Guide, Second Edition* (NCHRP, 2010) for diagrams on the proper method for measuring stopping sight distance.

When measuring intersection sight distance for a vehicle entering the roundabout, sight distances must be checked along two approach paths, namely intersection sight distance with the conflicting upstream entry and intersection sight distance within the circulatory roadway. Each should be checked independently, and each should be measured along the expected vehicular path on the roadway, not as a straight line.

Studies have shown that providing the minimum intersection sight distance as opposed to unlimited sight distance aids in speed reduction by creating a confining visual effect that calms traffic. Speed should be primarily controlled with geometric and other design elements; however, providing minimum intersection sight distance can support geometric and other physical controls, particularly on entry to roundabouts.

Stopping sight distance to crosswalks shall be verified for both the entry and exit of the roundabout, especially at the exit crosswalk. Studies collected within NCHRP 572: *Roundabouts in the United States* (NCHRP, 2007) show that a higher percentage of drivers do not yield to pedestrians at the exit when compared to the entry. The proper design of the exit is essential to ensure adequate sight lines are provided between the driver and the pedestrian and that speeds are held to the desired amount. The Designer should consider additional design features that will provide improved safety to pedestrians at crosswalks.

Any areas identified by the sight distance checks as being required to maintain proper sight lines must be designed without significant visual obstructions. For design consistency, the outer 6 feet of the central island greenspace is designated as the Perimeter Landscaped Zone and should also be reserved for sight distance even if not required for sight lines. As discussed in RDG Chapter 2-1009.00, any landscaping in this sight distance space should be under 2 feet in height. Space within the central island not reserved for sight distance and not within the outermost 6 feet is part of the Inner Landscaped Zone and can include taller plantings and landscaping. This advantageously restricts sight across the center island, which can reduce speeds of approaching vehicles and reduce headlight glare from oncoming traffic, while also maximizing the visual impact of the roundabout. Unlimited intersection sight distance is not desirable through a roundabout but adequate minimum stopping sight distance must be provided.