OCTOBER 2024

Texas Department of Transportation

INNOVATIVE INTERSECTIONS DESIGN AIDS

High-Speed Approaches to Roundabouts

OVERVIEW

As an extension of TxDOT's Roadway Design Manual Chapter 14, this aid provides designers with both geometric and non-geometric design guidance for roundabouts on roadways where at least one approach has a posted speed limit of 45mph or higher. Roundabout design in a rural high-speed context requires an understanding of human factors involved in the detection, recognition, and reaction to a roundabout while approaching at a high rate of speed. This document provides high speed geometric design fundamentals as well as performance-based design, which responds to human factors, forward sight distance and other aspects of the driving task.

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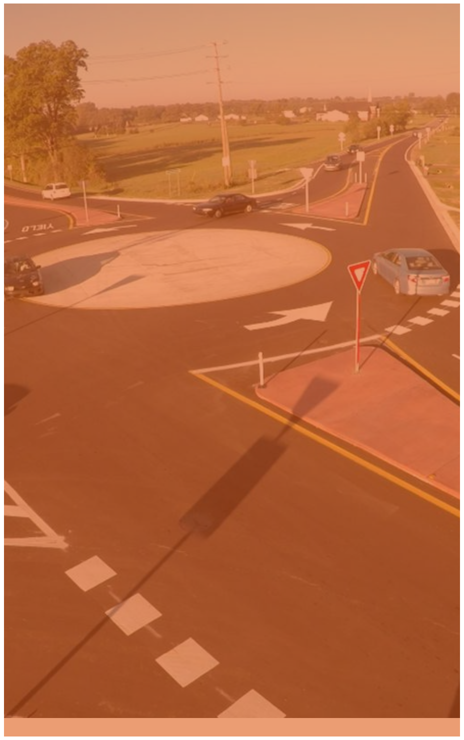

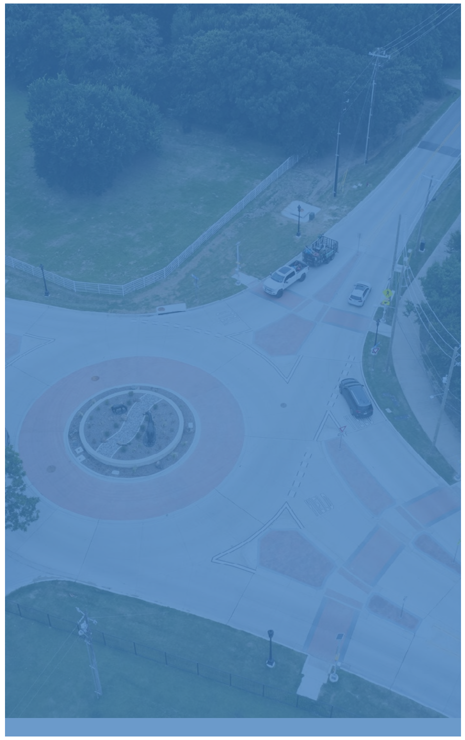

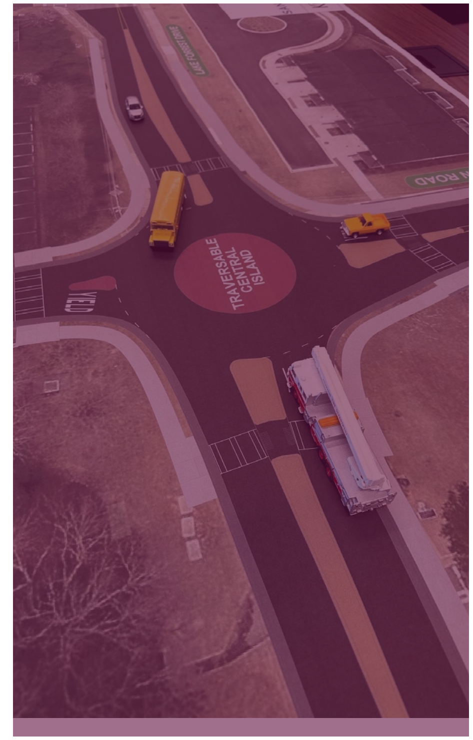

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INTRODUCTION

The principles behind design considerations for rural high-speed locations can be summarized as follows:

- Recognize information handling zones and place information to correspond with the driving task.
- Develop a 'visibility package' on high-speed approaches consisting of geometric and non-geometric elements.
- Simplify the driving tasks by spreading task demands.
- Minimize detection, interpretation, and processing time by identifying the most meaningful information and locating it with regard for information handling zones.

Roundabout visibility and the ability of a driver to detect and react to an approaching condition is critical. Horizontal layout considerations, forward visibility, central island design, and speed change demands play a role in the safety of high-speed roundabout facilities. However, the designer must also consider the traffic information system consisting of signs and markings. Intersection and transition lighting are also vital components of a 'visibility package'.

The underlying principles of this design aid are coupled with a distillation of national and regional best practices (Appendix A). A 'toolbox' of treatments in categories of geometric design, traffic control and visibility package enhancements is provided in Appendix B. The treatment of high-speed, superelevated approaches is given detailed attention in this design aid. A combination of AASHTO provisions and TxDOT RDM super-elevation requirements are applied in several worked examples in Appendix C. The worked examples apply super-elevation requirements of high-speed roads in transition to low-speed conditions and illustrate the application of the TxDOT RDM Chapter 14 for curves with high and low alignment deflection.

SAFETY BENEFITS OF ROUNDABOUTS ON HIGH-SPEED FACILITIES

National Statistics show that the fatality rate on rural non-interstate roads is nearly three times higher than urban non-interstate roadways. Nearly 40% of those fatalities (2,830) are at rural intersections (Isebrands et al). At seventeen rural roundabout installations with high-speed approaches, the average injury crash frequency was reduced by 84%, angle crashes were reduced by 86%, and **fatal crashes were eliminated** (Isebrands, 2009). The number of successful roundabout installations on high-speed highways has reached a critical mass of evidence supporting the conversion of high-speed stop control intersections to roundabouts. Appendix A provides a sample listing, with map links, of prominent sites located across the U.S.

> ***Rural intersections with a poor safety history are prime candidates for a roundabout. Investing in an intersection alternative that lowers speeds and significantly reduces the risk of someone in your community getting injured, is an intersection alternative worth constructing.***
> *(Isebrands et al, 2013)*

HUMAN FACTORS AS DESIGN PRINCIPLES FOR HIGH-SPEED APPROACHES

Designing a roundabout approach at a rural intersection in a high-speed (>45mph) context requires an understanding of the foundational human factors that impact a driver's ability to recognize an approaching condition. Applying Positive Guidance, a concept framed by FHWA in the 1980's is the most effective way to ensure a driver is aware of an upcoming condition and can efficiently detect, process and react to the changes in their driving environment. Minimizing the detection and processing time allows drivers to respond instantaneously to an upcoming condition.

NCHRP 737, Design Guidance for High-Speed to Low-Speed Transition Zones for Rural Highways states the following: *Fundamentally, higher speeds mean a driver travels a greater distance during the perception and reaction time compared to a lower speed. Therefore, higher speeds can have an effect on requisite sight distance values, which, in turn, can increase the nominal dimensions of design elements. Therefore, selecting an appropriate target speed and understanding the potential inferred speeds of a facility can provide designers with more flexibility and precision in selecting design values for those geometric features that are directly influenced by design speed. Ultimately, this approach could provide designers with more flexibility to meet desired performance targets through their informed geometric design decisions.*

REACTION TIME AND DRIVING TASK INFORMATION LOAD

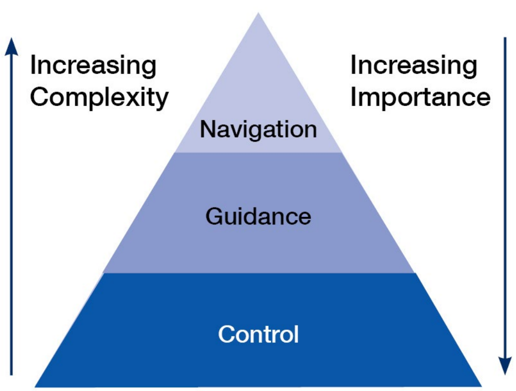
When designing high speed approaches to roundabouts, designers must recognize that inconsistent or unrecognized conditions can extend decision time, adding risk to the driving task. This is especially important for high-speed approaches where the demand on the driver for speed reduction and recognition of the intersection condition ahead is paramount.

Information presented to a driver can be categorized into “bits”. A “bit” is the information needed to resolve uncertainty between two likely responses. These can take the form of signs, pavement markings, geometric changes, or any other characteristics that may alert a driver of an upcoming condition. Most drivers can comfortably process up to 4 bits while driving (A User’s Guide to Positive Guidance, FHWA-SA-90-017). As the number of bits presented to a driver increases, so does their reaction time to respond to the condition. Minimizing the number of bits and presenting them in a familiar way to the driver ensures the condition is expected and easy to respond to. This should give designers a clue as to where vital information regarding the conditions ahead should be placed relative to the distance from the condition and the speed that the motorist is traveling.

INFORMATION HANDLING ZONES FOR ROUNDABOUTS

The driving task may be broken down into three key components: navigation, guidance, and control (A User’s Guide to Positive Guidance, FHWA-SA-90-017). Per **Figure 1**, navigation is the most complex of the three components as it requires a driver to recognize their surroundings and make directional judgments to reach their destination. Guidance, afforded by the roadway, roadside and traffic information system allows drivers to see their choices and react efficiently. Control is the most important component, but it should also be the simplest for a driver to respond to since it is based on conditioning and experience. Control stems from driver expectancy and practical design of roadways or intersections.

FIGURE 1 – Driving Task Components (FHWA-SA-90-017)



In the design of high-speed approaches to roundabouts, the three components are associated with the three information handling zones as described in A User’s Guide to Positive Guidance, FHWA-SA-90-017. The three information handling zones – the advance zone, the approach zone, and the transition zone – are defined in geometric categories by the decision sight distance, stopping sight distance, and deceleration distances required for the approach design speed. For convenience, **Table 1** provides values for decision sight, stopping sight and comfortable braking distances per **AASHTO Greenbook 7th Edition, 2018**. The zones associated with decision sight, perception-reaction time, deceleration and stopping sight are depicted on **Figure 2**. Note that sight distance should always be larger than deceleration distance. Deceleration distance accounts for a comfortable change in speed, not for the time it takes for drivers to identify a condition and react.

Given the need to separate navigation from guidance and control decisions, the designer must be aware of the information handling zones and the most meaningful information to relay to the driver in that zone. The three information handling zones include the advance zone, the approach zone, and the transition zone. Each zone has different driving task priorities that the design must elicit for the driver to make an error-free approach to a roundabout. These priorities correspond to approach travel speeds and target speeds for each zone.

These elements are the basis for determining how approach curvature, super-elevation and profiling is applied near roundabouts. It also gives designers clues as to where geometric curvature, warning and guide signs should be placed to supplement the visibility of the roundabout ahead. Typically, warning and guide signs should be visible upstream of the Transition Zone. If letter heights and symbol sizes are selected based on approach speed and 5 seconds of reading time then guide signs can be placed just upstream of the Transition Zone, but if spacing needs are considered, signs can spread well into the approach zone.

Approach curvature is best applied across the transition zone, with visual clues, such as a small deflection and taper in the approach zone. Approaches with substantial curvature require more detailed treatment of superelevation transition. This is addressed in a subsequent section with guidance and case study examples in **Appendix C**.

The Advance Zone - Minimal Guidance Required for A Typical Roundabout

The advance zone is defined as any stretch of roadway outside of unique conditions where decision or stopping sight distance is not a primary design parameter. It is located beyond the decision sight distance as defined in TxDOT RDM Table 4-25. The advance zone requires little to no guidance for a typical roundabout, and the driver's expectancy is met using standard highway geometric design for the prevailing design speed and roadway conditions.

The Approach Zone – Navigation and Guidance

The approach zone develops between the limits of decision sight distance and stopping sight distance for a unique condition. Decision sight distance and stopping sight distance should be determined per TxDOT RDM Table 4-25 and TxDOT RDM Table 4-23. In the approach zone, drivers are presented with 'bits' of information related to a navigation choice. Near the end of the approach zone, guidance information becomes primacy. The most meaningful information in this zone influence guidance-related driving task choices. Some of these may include speed, direction, and path selection. Forward sight of the roundabout must be free of distractions or physical impediments such as vertical or horizontal curves that can 'hide' a roundabout entry.

The Transition Zone – Control

The transition zone is the final opportunity to present drivers with information regarding the condition ahead. In this zone, drivers rely on their own experience and react most effectively to the 'feel' of the roadway (i.e., the geometric design). It is represented by the Stopping Sight Distance, which is described as the sum of two distances: (1) the distance traversed by the vehicle from the instant the driver sights an object necessitating a stop to the instant the brakes are applied, and (2) the distance needed to stop the vehicle from the instant brakes are applied. These are referred to as brake reaction distance and braking distance, respectively. In regard to TxDOT roundabout designs, the design Transition Zone length is slightly extended by accommodating the brake reaction time based on comfortable braking (AASHTO Figure 2-34) versus the average braking distance (-11.2 ft./ sec2) that is normally used per the AASHTO reported stopping sight values (TxDOT RDM Table 4-23). Since braking distances can be longer for large vehicles and less skilled drivers, the values used from AASHTO Figure 2-34 are appropriate to establish speed contours per TxDOT RDM Figure 14-10. The stopping sight distance may be measured from the crosswalk or from the yield line when a crosswalk is not present.

TABLE 1 – Speed and Sight Distance Parameters

Speed and Sight Distance Parameters				
	Approach Zone	Transition Zone		
Approach Design Speed	**Start of Decision Sight Distance** TxDOT RDM Table 4-25 Maneuver C	**Stopping Sight Distance** TxDOT RDM Table 4-23 (Sum of P-R + Decl. @ -11.2 ft./ sec. 2)	**Deceleration Distance*** Between- 11.2ft/sec.2 and AASHTO Figure 2-34** E= 0mph	**Perception-Reaction Distance** (2.5sec.)
75	1180	820	540-650	275
70	1105	730	470-575	255
65	1050	645	406-500	240
60	990	570	346-460	220
55	865	495	290-415	200
50	750	425	290-375	185
45	675	360	240-310	165
40	600	305	194-260	145
35	525	250	154-225	130
30	450	200	118-175	110

**Deceleration on flat profiles.*

***Figure 2-34 represents rates that govern the selection of curves and super-elevation data for long braking distances of lower performance drivers and vehicles, e.g., a loaded truck or bus.*

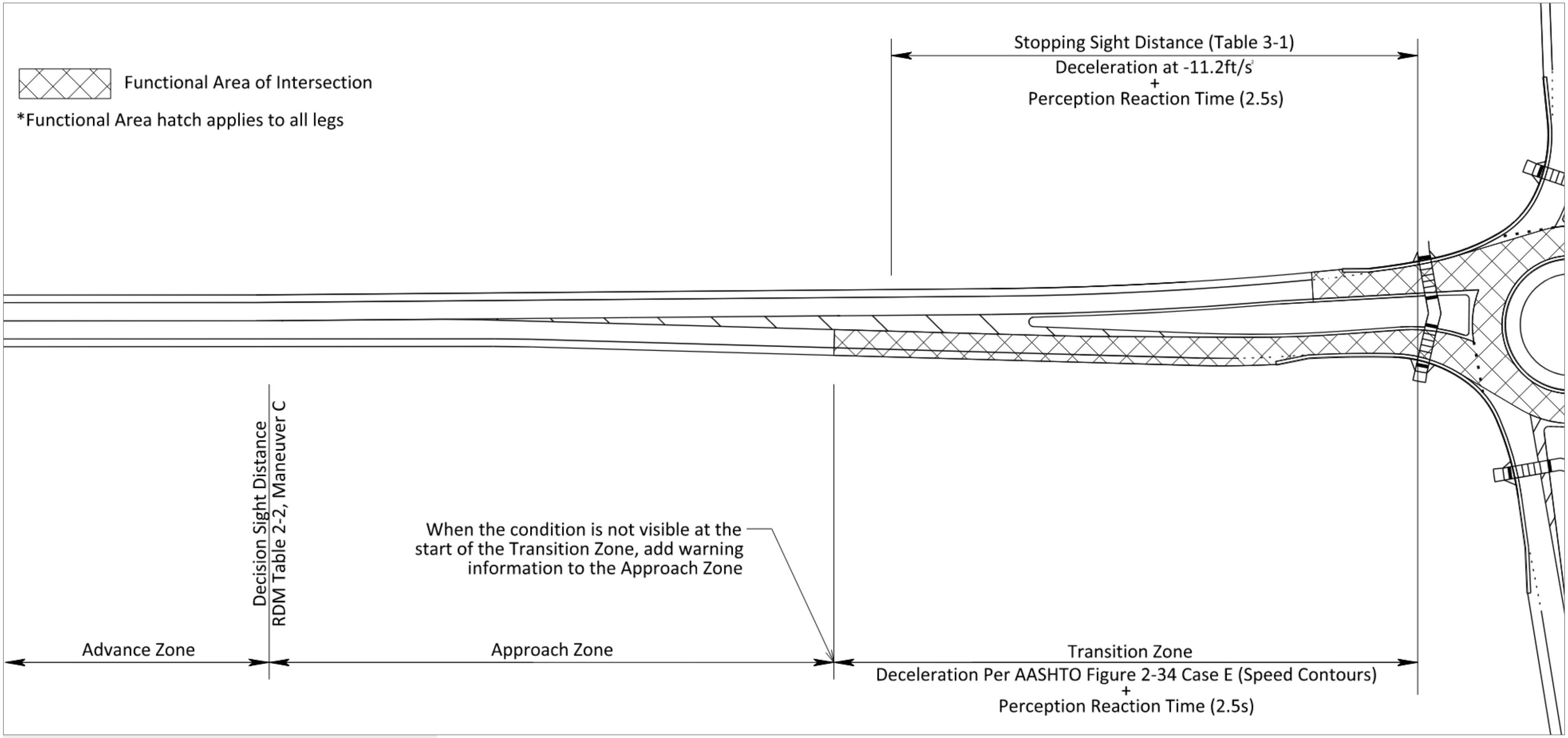


FIGURE 2 – Information Handling Zone, (AASHTO 2018 and FHWA-SA-90-017)

ROUNDABOUT GEOMETRIC DESIGN TREATMENTS

A primary goal of roundabout design is to make drivers aware of the roundabout with enough distance to gradually decelerate to a slow entry speed. This is especially necessary in rural areas where driver expectancy was previously free flow operation. Approach geometry should build driver expectation to reduce speed gradually and yield or stop at entry. Geometric design of approaches that is safe and practical generally exhibits these principles:

- **Approach Alignment** – Left-offset from the center of the circle.
- **Forward Sight Distance** (Stopping Sight Distance) – Based on approach design speed.
- **Central Island Visibility** – Approaches should be aligned horizontally and vertically to make the central island and yield point as conspicuous as possible.

A 'toolbox' of proven geometric design elements is tabulated in **Table 2** and detailed in **Appendix B**. These elements are best combined with non-geometric design elements to form a 'visibility package'. **Table 2** elements are listed in general priority, based on the anticipated benefits. Geometric elements such as circle size, left-offset, splitter island length and reverse curvature are generally sufficient to provide the necessary visual clues in the approach zone, however, the addition of lighting, signs, landscaping and transverse markings are considered to be part of the overall 'visibility package'.

TABLE 2 – Candidate Geometric Design Elements Associated with Information Handling Zones

Geometric Design Element	Approach Zone	Transition Zone
Splitter Island Extension	Minimum 200ft.; can be based on AASHTO deceleration length. Overlaps transition zone if length needs to exceed deceleration distance, e.g., curved approach.	
Reverse Curvature on Approach	Successively smaller radii that are sized based on the design speed and speed contours (see Figure TxDOT RDM Figure 14-10). Include a tangent between successive curves, especially if radii are small or require super-elevation run-off.	
Mounded Central Island	A highly visible central island can be seen from the approach zone beyond stopping sight distance. Make the central island conspicuous by mounding up to 6-feet high.	
Left-Offset Approach Alignment	Requires a deflection to the left in the approach zone. Often combined with reverse curves to initiate deceleration.	Fully developed in the transition zone. Improves entry curve for more gradual speed reduction
Inscribed Circle Diameter	Contributes to increased left-offset on approach	Creates longer radii close to the roundabout entry, which creates more gradual speed reduction.
Curb and Gutter	Rural cross-section unless approach curves or drainage dictate curb extension	Provide 6-inch vertical face curbs within at least 150-feet of the roundabout entries and exits
Sight Distance Screening	N/A	Reducing sight to the left has been shown to reduce entry-circulating crashes (TRL Report LR1120)

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DESIGNING FOR APPROACH CURVATURE AND INTEGRATING SUPER-ELEVATION IN THE TRANSITION AREA

Reverse curved approaches to roundabouts use successively smaller curve radii to gradually reduce approach speeds. Successively smaller radii are sized based on the speed contour and expected speed change of 15 to 20 mph per successive horizontal curve. Within the transition/deceleration zone of a roundabout approach, selection of a horizontal curve radius, and vertical curve K-value should be based on the speed contour closest to the center of the curve; see TxDOT RDM Figure 14-10 below. See also Exhibit 10.109, NCHRP 1043. Speed contours are drawn to reflect deceleration distances presented in AASHTO Figure 2-34. The deceleration distances represent passenger vehicles approaching intersections and are adjusted to depict lower-powered (compact) cars, loaded trucks, and buses for suitable design application.

Designers should note that in NCHRP 1043, Exhibit 10.108, which is adapted from AASHTO Table 10-6, provides longer braking distances than shown in **Table 1**. In practice, many drivers can and will decelerate later in the path to an intersection. Since braking distances can be shorter, shorter values used from AASHTO Figure 2-34 to establish speed contours per TxDOT RDM Figure 14-10, are appropriate.

Speed contours span the approach and transition areas (**Figure 2**) as shown below on RDM Figure 14-10. The placement of speed contours assumes comfortable braking (Figure 2-34 in the AASHTO Green Book, 2018) to a potential stop at the crosswalk (or the yield line in the absence of a crosswalk).

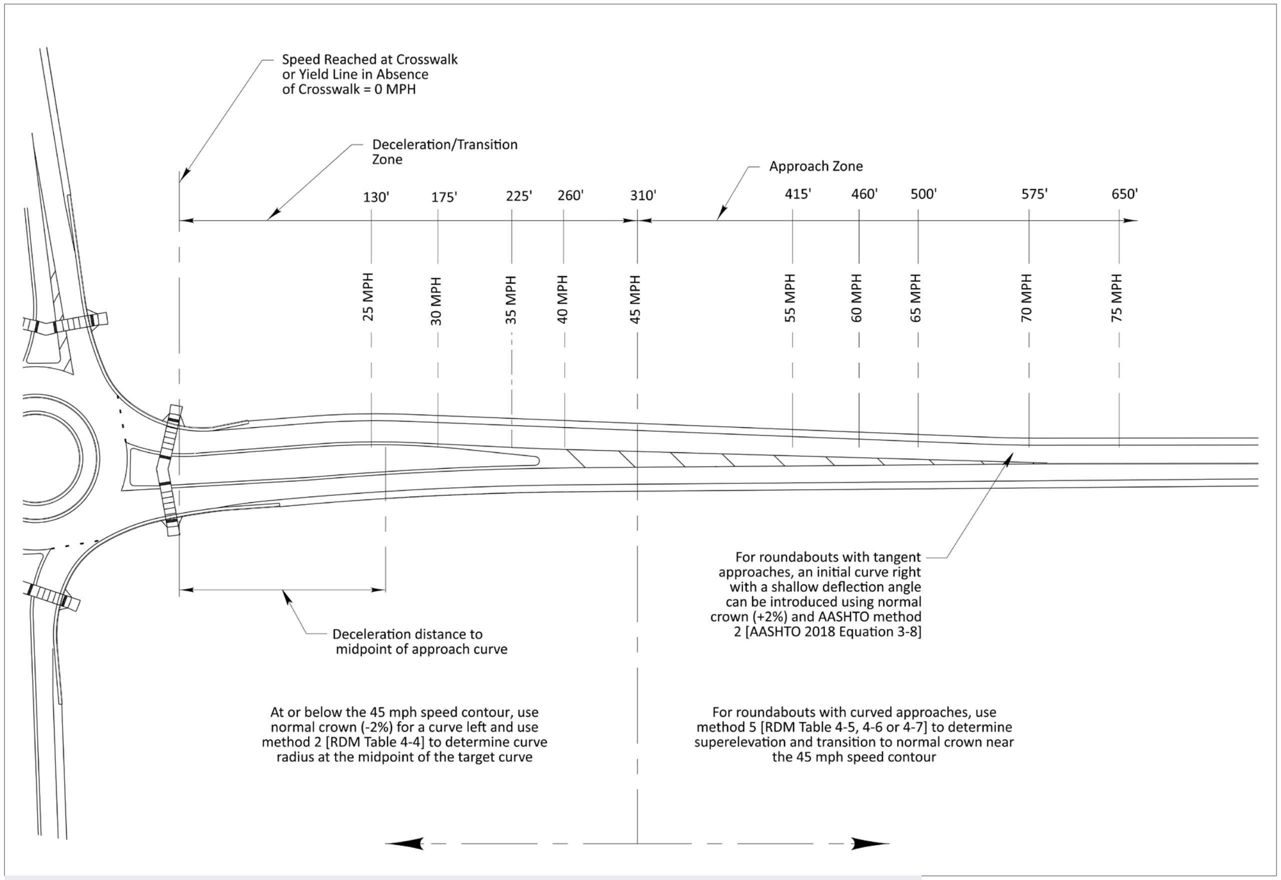

FIGURE 3 – TxDOT RDM Figure 14-10 – High-Speed Approach Design Approach and Deceleration Zones

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Super-elevation for curves within the transition zone (below a speed contour of 45 mph) should be selected from the TxDOT RDM Table 4-4 (Table 3-13 AASHTO Greenbook, 2018) Minimum Radii and Super-elevation for Low-Speed Streets in Urban Areas. The intent of reducing curve design criteria to low-speed urban (TxDOT RDM Table 4-4 (Table 3-13 AASHTO Greenbook, 2018)), is to introduce more lateral acceleration to the driver implying the need to reduce speed as they approach a roundabout.

For approaches with existing super-elevation before the start of the transition zone, apply Equation 3-8, AASHTO 2018, if the approach deflection is small. If there is a significant deflection in the approach zone it is likely that the horizontal curve will overlap the transition zone at the 45mph. In such cases, the curve selection and super elevation criteria are governed by TxDOT RDM Table 4-6 (Table 3-9 AASHTO Greenbook, 2018). Likewise, if the center of the curve is upstream of the 45mph speed contour, the higher speed super-elevation (SE) parameters apply, TxDOT RDM Table 4-6 (Table 3-9 AASHTO Greenbook, 2018), for larger deflections and TxDOT RDM Table 4-4 (Table 3-13 AASHTO Greenbook, 2018) for small deflections, e.g., less than 5 degrees.

A curve needing super-elevation in the approach zone must be transitioned to the lower speed transition zone where TxDOT RDM Table 4-4 (Table 3-13 AASHTO Greenbook, 2018) governs curve choice and SE. Therefore, the super-elevation applied in the approach zone, for a curve centered in the approach zone, must apply TxDOT RDM Table 4-6 (Table 3-9 AASHTO Greenbook, 2018) or TxDOT RDM Table 4-7 (Table 3-10 AASHTO Greenbook, 2018) for curve selection. The super-elevation transition from the approach zone to the transition zone must apply TxDOT super-elevation run-off parameters for the portion of super-elevation in the tangent section. Generally, 70% to 90% of the run-off can be applied in the tangent section per TxDOT RDM, Table 4-10.

In **Appendix C** there are several project examples of how RDM Chapter 14, Figure 14-10 is to be applied for the development of superelevation on curved approaches to roundabouts. In most cases, tangents between successive reverse curves should be applied. Tangents, preferably the length of the design vehicle, minimize swaying of large truck loads and loss of control roadway departure crashes. This was shown to be a factor in very high-speed approaches with small reverse curves that had no 'intervening' tangent to 'right' the truck, before it was affected by the next downstream curve. **Appendix D** provides the calculation parameters used in the case studies.

NON-GEOMETRIC DESIGN

Geometric design is a crucial component of high-speed roundabout approaches, but non-geometric considerations play an important role in a driver's ability to detect an upcoming condition and react appropriately. Non-Geometric design elements are given in **Table 3**. These alert a driver to upcoming geometric changes which may not match their expectation on a high-speed facility.

These elements are best combined with geometric design elements (**Table 2**) to form a 'visibility package' (Isebrands et al). **Table 3** elements are listed in general priority, based on the perceived benefits **Appendix B** provides detailed guidance and examples of each element including their benefits, guidance on application and the empirical basis to support their use.

TABLE 3 – Candidate Non-Geometric Design Elements Associated with Information Handling Zones

Geometric Design Element	Approach Zone	Transition Zone
Transition Illumination	NCHRP 1043, Section 14.2.4 with eye adaption and approach visibility considerations. Minimum length of transition = 262-ft. per IES guidelines. Often coincides with the length of splitter island	Same as intersection illumination requirements (IES RP-8-18). Lighting to begin where raised curb and gutter begins/ends.
Diagrammatic Guide Signs (D1-5) and Overhead Signs (multilane)	Placed within the approach zone. Capital letter heights for >45mph should be a minimum of 10.67-inches (See Roundabout Sign Strings Design Aid for additional Information)	Destination signs (D1-3) are optional. Place overhead lane signs for multilane approaches to maximize target value. *(See Roundabout Sign Strings Design Aid for additional Information)*
Advanced Roundabout Warning Sign with Flashers or Additional W2-6	In addition to W2-6 Roundabout Ahead sign on approaches with very high speed or on approaches with curves or poor forward visibility, i.e., lacking decision sight distance.	N/A
Transverse Pavement Markings (Rumble Strips)	See TxDOT RS(5)-23 and Roundabout Sign Strings Design Aid for guidance on placement and spacing.	Markings cross into the transition zone (See TxDOT RS(5)-23)

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APPENDIX A – LOCATIONS OF ROUNDABOUTS ON HIGH-SPEED ROADS

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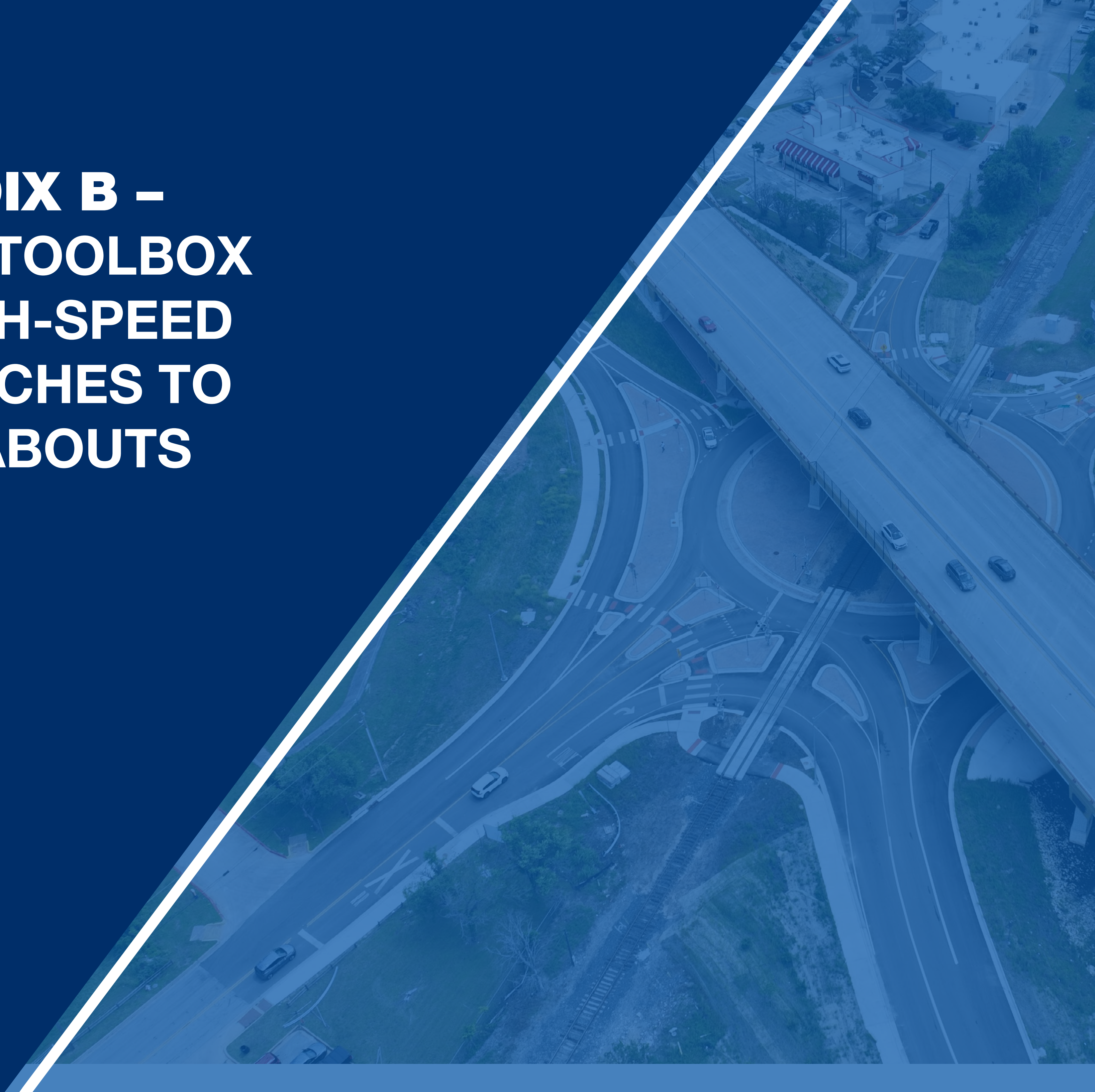
1. Ramps at I-45 and FM 1375, New Waverly, Tx
   https://maps.app.goo.gl/M3nVxTJ6TFGHva658
2. US 10 and State Route 13/State Route BB, Marshfield, WI
   https://goo.gl/maps/yahpb9Ekxitg3WWp6
3. US 141 (Main Street) and Verlin Road, Green Bay, WI
   https://goo.gl/maps/FKF7vQuc9puVVegV7
4. US 18 and Bennett Road, Dodgeville, WI
   https://goo.gl/maps/GtrisLjsMhff9Nsf7
5. M-5 (Martin Parkway) and N Pontiac Trail, MI
   https://goo.gl/maps/ym5Z4jKN8daSyiVE6
6. US 41 and Hospital Drive, US 41 and 7th Street, Marquette, MI (2 locations 55mph) https://goo.gl/maps/zfuz7b2hSFwkH6Br6
7. State Route 539 and River Road, State Route 539 and Wiser Lake Road, WA (2 locations) https://goo.gl/maps/KTa6RoUTSXXPKyGS6
8. State Route 539 and State Route 544, State Route 539 and Ten Mile Road, WA (2 locations) https://goo.gl/maps/Lp6dds23oM3ndoSCA
9. Route 8 and Smythe Street, Fredericton, NB
   https://goo.gl/maps/j3tkvMwogakFXSPa8
10. US 2 and Belknap Street, Superior, Wisconsin
    https://maps.app.goo.gl/uqX8YNqsimBxgY2W7
11. 18 ½ Mile Road and Van Dyke Avenue, Sterling Heights, Michigan
    https://maps.app.goo.gl/ESNjEEWdTGaxvsj96State Route 3 (19) and State Route 26, Ellaville, Georgia https://maps.app.goo.gl/2et257myFQXtftrc7
12. Hwy. 260 Corridor of seven (7) multilane roundabouts with 55mph speed limit
    https://maps.app.goo.gl/JPGyTShreGmTfEQg8
13. State Route 89 and Willow Lake Road, Prescott, Arizona
    https://maps.app.goo.gl/P7TPiMT3Ge5sgqQx5
14. US 97 corridor (McDonald Rd & Becker Rd, Jones Rd); 55mph; Toppenish & Wapato, WA (2 constructed with 5 more planned)
    https://maps.app.goo.gl/7p3XDCgtDcfLZe8JA
15. Mendon NY
    https://www.google.com/maps/@42.99061,-77.5782,590m/data=!3m1!1e3
16. Guide Meridian, WA (3 more north of here):
    https://goo.gl/maps/zGj2mynpEcK2
17. K-68 at Old KC Road, Paola, KS (65 and 55 mph, 6,900 vpd, 20% trucks):
    https://goo.gl/maps/qfKkhKxMYsT2
18. N Jct US-59 and US-169, Garnet, KS (65 and 60 mph, 5,800 vpd, 20% trucks):
    https://goo.gl/maps/1XD1eNUUxqJ2
19. US-50 and US-77, Florence, KS (65 and 55 mph, 4,800 vpd, 50% trucks):
    https://goo.gl/maps/CAckusLs31o
20. US-77 and US-56, Marion, KS (65 mph, 4,000 vpd, 35% trucks):
    https://goo.gl/maps/RkUFPbKeoZU2
21. US-75 and K-268, Lyndon, KS (65 mph, 8,600 vpd, 10% trucks):
    https://goo.gl/maps/Fdr4ranBcKL2
22. US-77 and US-166, Arkansas City, KS (65 and 55 mph):
    https://goo.gl/maps/Uc5gs4ckGKP2
23. US-400 and K-47, Fredonia, KS (65 mph):
    https://goo.gl/maps/SqCV6aWasmM2
24. US-400 and K-66, Riverton, KS (65 and 45 mph):
    https://goo.gl/maps/5MS41b1d6jN2
25. Hoosier Heartland Highway (SR 25) in Tippecanoe County, IN:
    https://goo.gl/maps/ojq1ZBQSC1u
26. I-587, Kingston, NY
    https://goo.gl/maps/ueeegBhpe7N2 https://www.kingston-ny.gov/filestorage/8395/16365/18849/881126_render_master_102417.pdf https://goo.gl/maps/bgwC3jhhrqz
27. SR 539 corridor (River Rd, Wiser Lake Rd, SR 544, Ten Mile Rd); 50mph; Lynden, WA
    https://maps.app.goo.gl/ZfCRL4KjHFu48iXCA
28. SH 60 at FM 2668, Bay City, TX
    https://www.google.com/maps/search/SH+60+at+FM+2668,+Bay+City,+TX/@28.9402281,-95.9668429,17z?entry=ttu&g_ep=EgoyMDI0MDkyOS4wIKXMDSoASAFQAw%3D%3D

APPENDIX B – DESIGN TOOLBOX FOR HIGH-SPEED APPROACHES TO ROUNDABOUTS

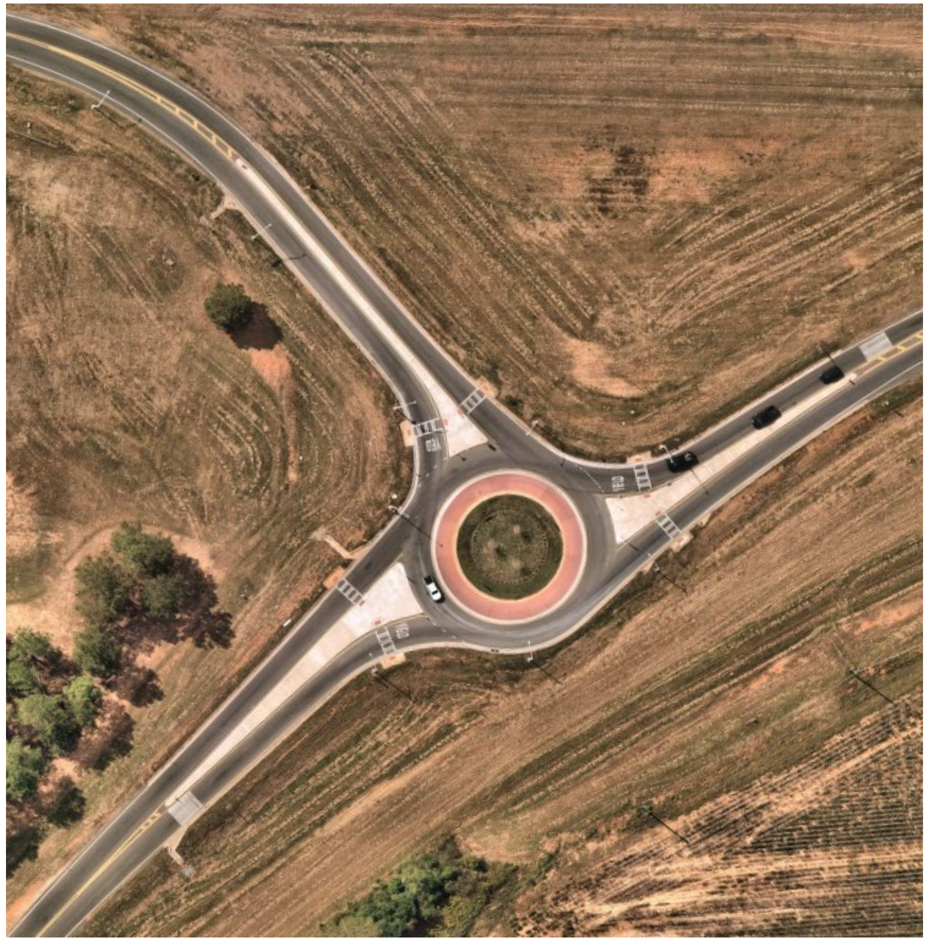


Appendix B

Design Toolbox for High-Speed Approaches to Roundabouts

Splitter Island/Curb

A splitter island is a raised, curbed dividing island on a roundabout approach. It is used to separate entering from exiting traffic, deflect and slow entering traffic. It also provides a central median refuge for pedestrians crossing a roundabout approach in two stages.



Applicability (where to use):

- >200’ for approaches of 45 mph or higher

Guidance:

- Splitter islands should extend upstream of the yield line to the point at which entering drivers are expected to begin decelerating. A minimum length of 200-ft is recommended for high-speed approaches.
- Splitter island cross-sections can be monolithic (slab) or curb and gutter
- Height is normally 6-in. but to accommodate over-tracking of OSOW vehicles a 4-in. semi mountable curb profile is recommended.
- Pedestrian refuges (crosswalk) can be ramped or flush depending on refuge width (min. 6-ft.)

Effectiveness:

- Introducing raised curbs is associated with speed reduction when compared to sections with no curbs

Location Considerations:

- Increase in maintenance if landscaping is added
- Driveways near a roundabout may require median break or depressed section for a driveway opening

Reverse Curves on Approach

A slight chicane at approaches of 45mph or higher, arranged in a series of reverse curves with opposite deflections. The reverse curves alert the driver to a changing condition ahead to induce gradual, transitional speed reduction.

Guidance:

- Guidance provided in NCHRP Report 1043, Section 10.14 but using TxDOT RDM Figure 14-11 indicates splitter island length, horizontal curves, and superelevation to treat roundabouts in a high-speed context.
- The use of a tangent of between horizontal curves is recommended unless the two reverse curves have large radii and there is no required superelevation of either curve. A common tangent length is 100ft. which aids braking for two-wheeled motorists, especially on wet pavement.

Location Considerations:

- Radius of approach curve – see speed contour diagram RDM Ch. 14, Figure 14-11
- Length of splitter Island – minimum 200ft.
- Roadway width – number of lanes
- Vertical curves and visibility of median
- Preserve forward SSD by avoiding excessive splitter island width

Effectiveness:

- As the driver approaches the roundabout, successive curves have smaller radii such that the speed differential between successive curves is 15 to 20mph.
- The use of a tangent between reverse curves has been shown to eliminate truck rollovers where curves are relatively small for a high posted speed approach (>55mph).

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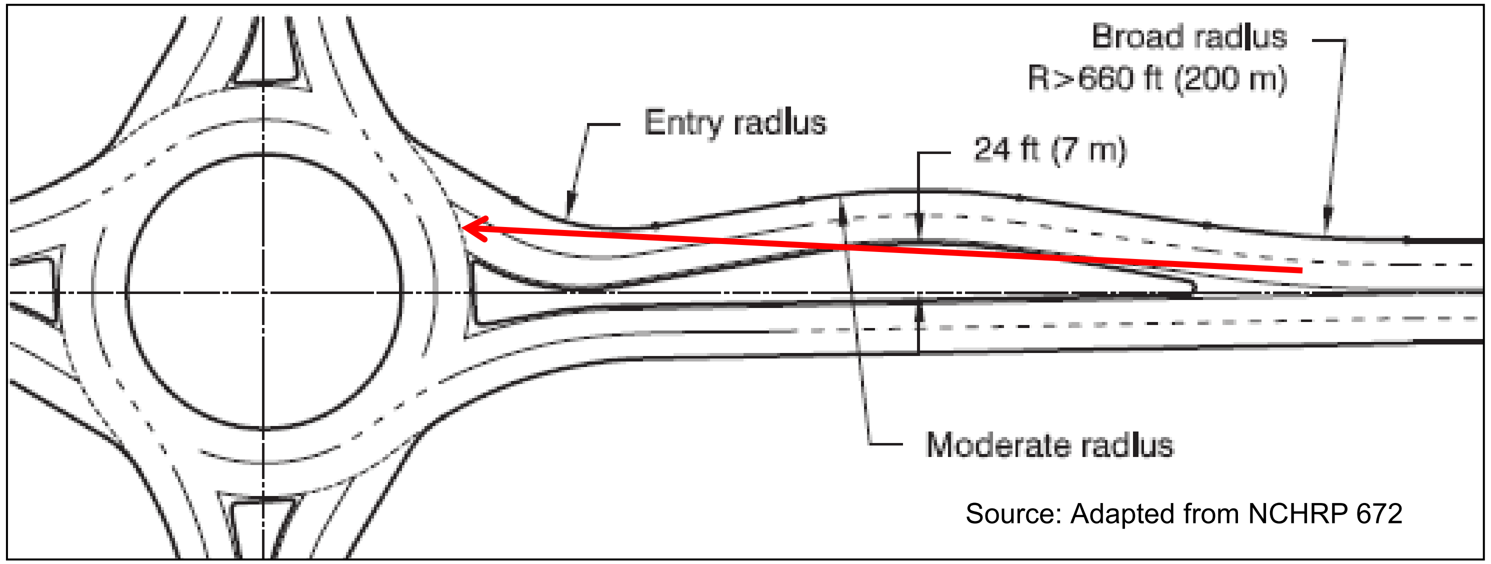
Reverse Curves on Approach



Source: Adapted from NCHRP 672

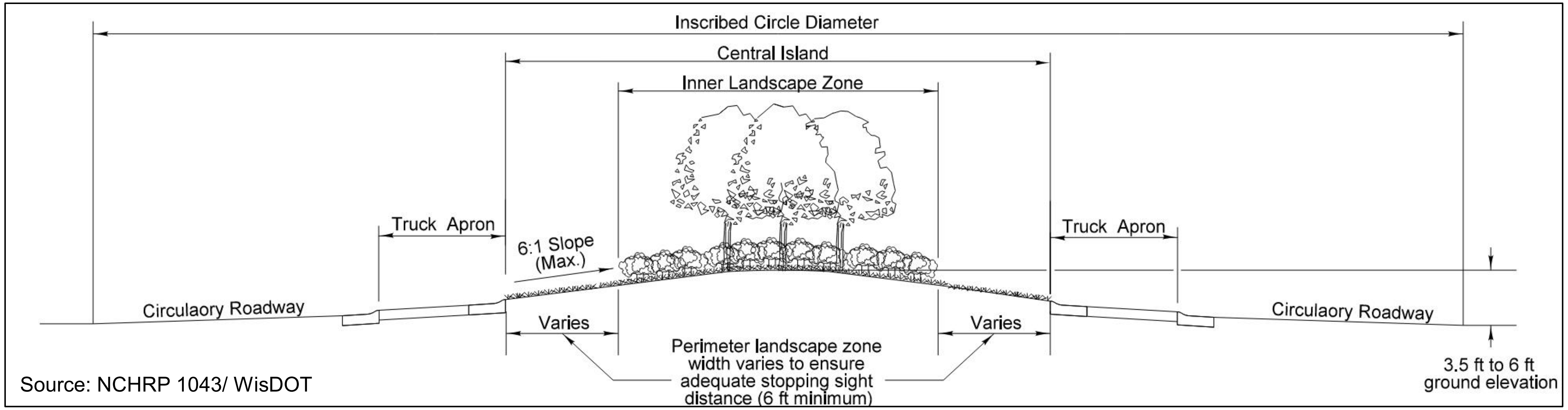
Guidance:

- Guidance provided in NCHRP 672 (diagram above) indicates a 24ft. offset was recommended. ***This guidance was removed from NCHRP 1043. The width of the offset can impede forward sight.***
- The illustration to the right shows the forward sight impediment that a modest offset can produce, which is exacerbated by plantings.
- The width of the splitter island offset to build the reverse curves must consider forward visibility at the posted speed. Increase the curve radii or minimize the width of splitter island to preserve SSD.

Above: The splitter island 'bump-out' is so wide that it deprives the driver of forward sight

Raised (Mounded) Central Island

The central island of a roundabout is the raised, non-traversable area surrounded by the circulatory roadway. It may also include a traversable truck apron. The island is typically mounded to between 3.5ft.. and 6ft. and landscaped, to enhance driver recognition of the roundabout from at least stopping sight distance.



Benefits:

- Promote intersection visibility (terminal vistas) on approach and maintain adequate sight distance for circulating traffic
- Prevents excessive sight distance
- Avoids a ‘see-thru’ problem with drivers having too much sight and headlights shining across the circle implying a thru roadway at the intersection.

Effectiveness:

- In post-construction safety reviews of roundabouts with flat central islands, single vehicle loss of control crashes were over-represented as compared to audits of roundabouts with mounded central islands where the comparison sites had good lighting. (Georgia DOT, 2020)

Applicability (where to use):

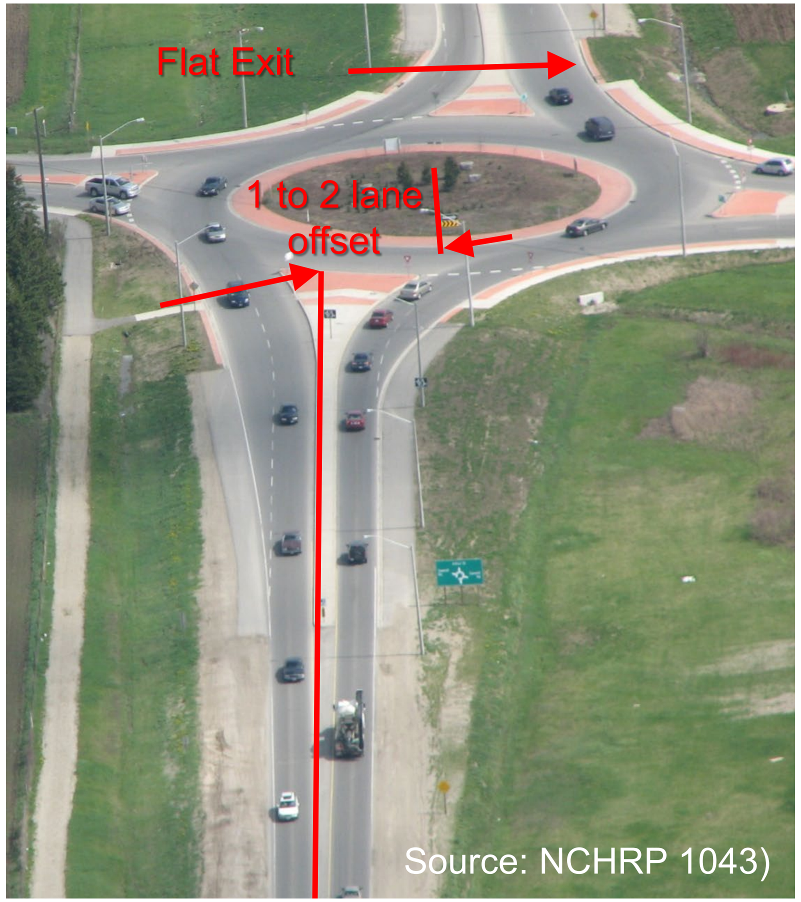
- All locations except mini roundabouts

Location Considerations:

- On-going maintenance
- Design vehicle
- Approach speed for how high to have center island
- Consider up-lighting of features on the central island to increase the target visibility

Left Offset Approach

The alignment of the approach legs affects the quality of entry path deflection (speed control) achieved, the ability to accommodate the design vehicle, and the visibility angles to adjacent legs. (NCHRP 1043, Page 10-13)



Location Considerations:

- Requires extra R/W
- Where smaller ICD is preferred
- Ideal for rural, less ideal for urban R/W

Benefits:

- Offset-left alignments (described in detail in NCHRP 1043, Section 10.3.3) can promote speed control on roundabouts with smaller ICD values.
- Accommodates large trucks with smaller ICDs—allows for larger entry radius while maintaining deflection and speed control
- Gives the approaching driver a larger view of the circle. The trajectory of the driver is to the middle of the central island, not to the right of it.

Applicability (where to use):

- Essential for multilane approaches to develop natural entry paths for two vehicles using longer arcs or compound curves
- Reverse curvature on approaches may be an outcome of left-offset.
- Approach reverse curvature can be applied to achieve similar target speeds.

Effectiveness:

- An early U.K. study showed crash reduction benefits of added entry geometric speed control (TRL Report LR 1120)

Inscribed Circle Diameter (ICD)

The diameter of the largest circle that can be inscribed within the outline of the intersection. ICD size is proportional to the number of circulating lanes required. Lane configuration requirements are typically determined by peak hour traffic volumes, but daily traffic volumes may sometimes be sufficient for planning purposes (See TxDOT TSAP Manual for checking the number of lanes needed)

Roundabout Configuration	Common ICD Ranges
Single-lane roundabout (non-traversable central island)	110-ft to 150-ft
Multilane roundabout (2 lanes circulating)	140-ft to 200-ft
Multilane roundabout (3 lanes circulating)	180-ft to 220-ft

Location Considerations & Limitations:

- Right-of-way required for larger footprints
- Larger ICD's flatter entry angles and affect sight to the left
- Geometric competition between footprint and speed control – use left-offset alignment of approaches

Guidance:

- Non-perpendicular intersection angles between approach legs can contribute to a larger ICD than perpendicular approach legs. Offset intersections or skewed approach alignments may lead to considering an elliptical, oval, peanut-shaped, or other configuration, instead of a larger conventional circle shape.
- Multileg intersections (>4 legs) require large ICDs
- With larger design vehicles, a roundabout may require a larger ICD to accommodate swept paths, especially right-turns.
- OSOW can be accommodated with larger central island truck aprons and external truck aprons.

Effectiveness:

- Large ICD's ensure longer more curvy entry path for drivers to travel causing them to slow down entering a roundabout – geometric speed control. Larger ICD's improve intersection visibility.
- An increased ICD, increased angle to the next leg, and the presence of a bypass lane are associated with a reduction in crashes. For legs with two circulating lanes, crashes decrease with increased circulating width (NCHRP 1043).

Texas Department of Transportation

Curb and Gutter

Curb and gutter help vehicles to maintain lane and reduces speeds; therefore, introduce it in the transitional and low speed segments of the approach. Graduation from paved shoulder to mountable curb to vertical face curb provides an ideal transition from rural to urban cross-section.

Guidance:

- Provide 6-inch vertical face curbs on the approaches and exits within 150 feet of the roundabout entry – longer when there is a curved approach, drainage issues or driveways.
- The remaining splitter island length should be 4-inch mountable curb.
- Where OSOWs need to over track the outside curb (external truck apron), a 4-inch mountable curb and gutter may be used in limited situations to better accommodate truck tires. Do not allow a crosswalk through the external truck apron.
- Use spillways/flumes along the gutter instead of catch basins

Effectiveness:

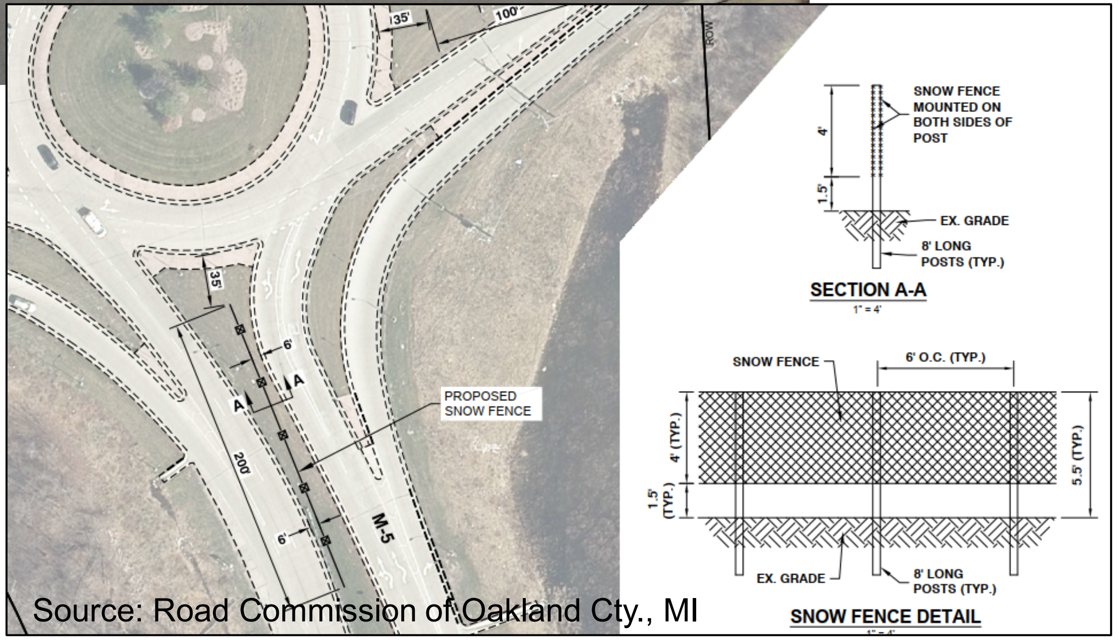
- Vertical face curbs control the fastest speed paths at the roundAabout entrances and exits.

Location Considerations:

- Rural locations that transition to built-up urban development
- Where the cost of maintaining ditches including R/W takes is more expensive than placing curb and gutter with flumes

Approach Landscaping (Screening)

The landscaping of the approaches can narrow the cone of vision for drivers giving a redirective effect, making the intersection a focal point. This includes reducing sight to the left using screening or plantings.



Source: Road Commission of Oakland Cty., MI

Benefits:

- Simple solution
- Reduces sight distance to a minimum and reduces speeds
- Breaks head light glare from oncoming vehicles

Applicability (where to use):

- Where there is a recorded history of failure to yield crashes
- Flat terrain, without vegetation on the corners

Effectiveness:

- Reducing sight to the left has been shown to reduce entry-circulating crashes (TRL Report LR1120)
- A study in Oakland County, MI showed

Location Considerations:

- On-going maintenance
- Irrigation
- Plants or natural screening versus fence or artificial screening

Texas Department of Transportation

Transition Illumination

Lighting on a roundabout approach that transitions into full intersection illumination, improves visibility of the intersection allowing drivers to anticipate the roundabout.

Guidance:

- Lighting levels at or below those in NCHRP Exhibit 14 3 for isolated roundabouts do not require transition lighting; however, at very high-speed approaches with long splitter islands, transition lighting is recommended.
- For lighting levels above those in NCHRP Exhibit 14 3 for isolated roundabouts, NCHRP Exhibit 14 4 presents the extent of necessary transition lighting. The exhibit identifies a series of zones that step away from the roundabout.
- If transition lighting is not provided on a given leg, the start of curbing within the median or outside edges of the approaching roadway should be highlighted. This includes using retroreflective signs, pavement markings, pavement markers on top of curbs, or other techniques to mark the leading edge of the splitter island as well as the start of any curbing on the outside edge of the approach roadway.

Effectiveness:

- Roundabouts need transition lighting as appropriate for the pavement type to allow time for driver eyes to adjust to the change in lighting level.
- Increased lighting has been shown to reduce crashes at all intersection types.

NCHRP 1043, Exhibit 14.3. Pavement Illuminance Criteria for Isolated Roundabouts.

Major Street AADT (veh/day)	Road Surface		Uniformity Ratio E_{avg}/E_{min}
	Portland Cement Concrete	Asphalt Concrete	
>3,500	0.6 fc (6 lux)	0.8 fc (9 lux)	3.0
1,500-3,500	0.4 fc (4 lux)	0.6 fc (6 lux)	4.0
<1,500	0.3 fc (3 lux)	0.4 fc (4 lux)	6.0

Location Considerations:

- Maintenance cost
- Operating cost
- Power supply
- Light pole placement

Texas Department of Transportation

Advanced Roundabout Warning Sign with Flashers

A Roundabout Ahead sign (W2-6) that has flashing lights to inform drivers that they are approaching a roundabout.

Advanced Roundabout Warning Sign without Flashers

A Roundabout Ahead sign (W2-6) is used to convey to a driver that they are approaching an intersection with the form of a roundabout. *Source: NCHRP 1043*

Applicability (where to use):

- Rural areas or on the outer edge of urban areas
- Posted speeds > 55mph
- Curved approaches or vertical profile interrupting decision sight – add a second W2-6 or one with flashers

Benefits:

- Allows drivers to slow down before roundabout approach in the decision sight approach zone

Effectiveness:

- Research shows a decrease in speed on rural roadways.

Location Considerations:

- Clear zone, median space and lateral clearance
- Beacon maintenance
- Power source
- Double or single indicated (2 or 1)

Texas Department of Transportation

D1-5 and Overhead Signage

Used to provide clear and concise navigation guidance on leg choice and lane choice to minimize driver confusion while alerting drivers they are approaching a multilane roundabout.

(See Sign Strings Design Aid for letter heights)

D1-5 Advance Diagrammatic Guide Sign
(See Sign Strings Design Aid for letter heights)

Guidance:

- Give drivers advanced warning of leg choice and lane choice of upcoming roundabout
- High target value for conspicuity
- D1-5 is placed in the Approach Zone for Decision Sight criteria.
- Destination signs (D1-3) are optional.
- Spread signs for conspicuity, and comprehension. Place overhead lane signs for multilane approach to maximize target value.

Applicability (where to use):

- All multilane roundabouts (D1-5 on single lane)
- Multi-lane roundabouts with posted speeds > 45mph
- Designation of exclusive right or left lanes (lane drops)

Effectiveness:

- Anticipation of lane choice reduces lane changes and incorrect turning movements (FHWA Pooled Fund Study FHWA-HRT-23-02)

Location Considerations:

- Space for the sign supports
- Guardrail placement
- Duplicate placement with a second series closer to the roundabout (<300ft.)
- Placed in approach zone based on DSD and speed contour.
- Letter heights for >45mph = >8-in. upper case/ >6-in. lower case letters

Rezoning Approach Posted Speed

Intended to have drivers at a lower speed near the approach and transition zones of the roundabout

Benefits:

- May compensate for a geometric variance such as a tight curve that cannot be properly superelevated near a roundabout.

Applicability (where to use):

- Approaches where the entry to the roundabout is not visible from the decision sight distance or stopping sight distance at the previous posted speed.
- Where a traffic signal is converted to a roundabout, but intersection visibility is marginal without signal heads high above the pavement.

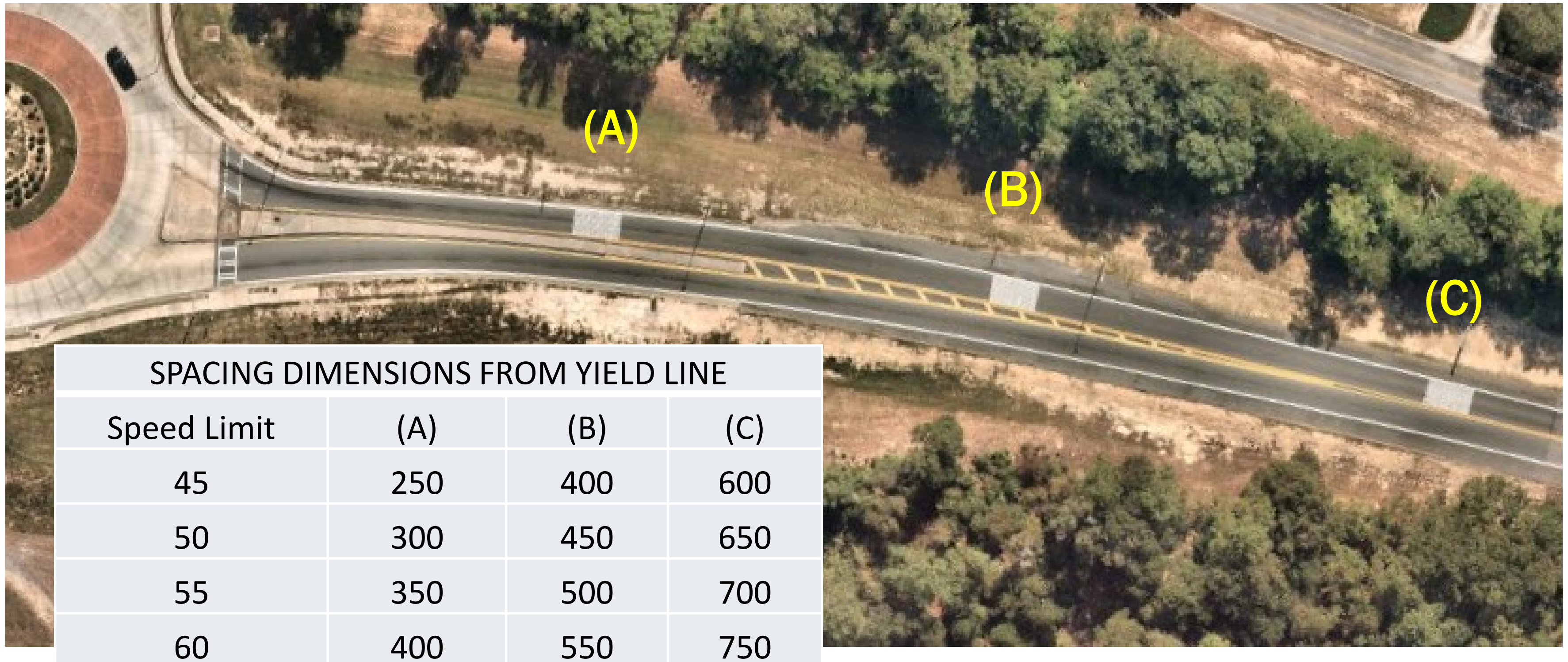
Effectiveness:

- Research studies report speed reductions between 3 and 8 mph
- Not suitable as an artificial speed limit – unenforceable

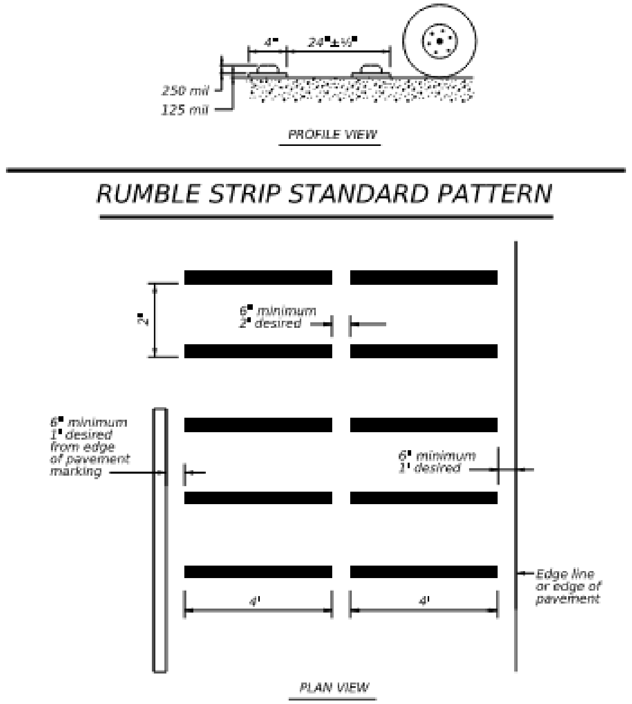
Texas Department of Transportation

Transverse Painted Rumble Strips

Geometric design is the primary contributor to speed transition; however, rumble strips support deceleration to the roundabout. It is a safety feature designed to alert inattentive drivers by creating vibration and rumbling noise. A rumble strip is typically installed across the direction of travel, to alert drivers to slow down.



SPACING DIMENSIONS FROM YIELD LINE			
Speed Limit	(A)	(B)	(C)
45	250	400	600
50	300	450	650
55	350	500	700
60	400	550	750
65	450	600	800
70	550	700	900
75	600	750	950



TxDOT RS(5)-23 Specification

Effectiveness:

- Studies have found that the treatment can reduce injury crashes by approximately 50% Source: CMF Clearinghouse

Guidance:

- Pavement markings, usually transverse (TxDOT RS(5)-23) guidance
- Do not place transverse bars on an urban cross-section, i.e. between curbs. Bicyclists have no path around the markings except where there is a paved shoulder.
- Spacing based on speed limit, placing the farther set of bars between DSD and SSD.

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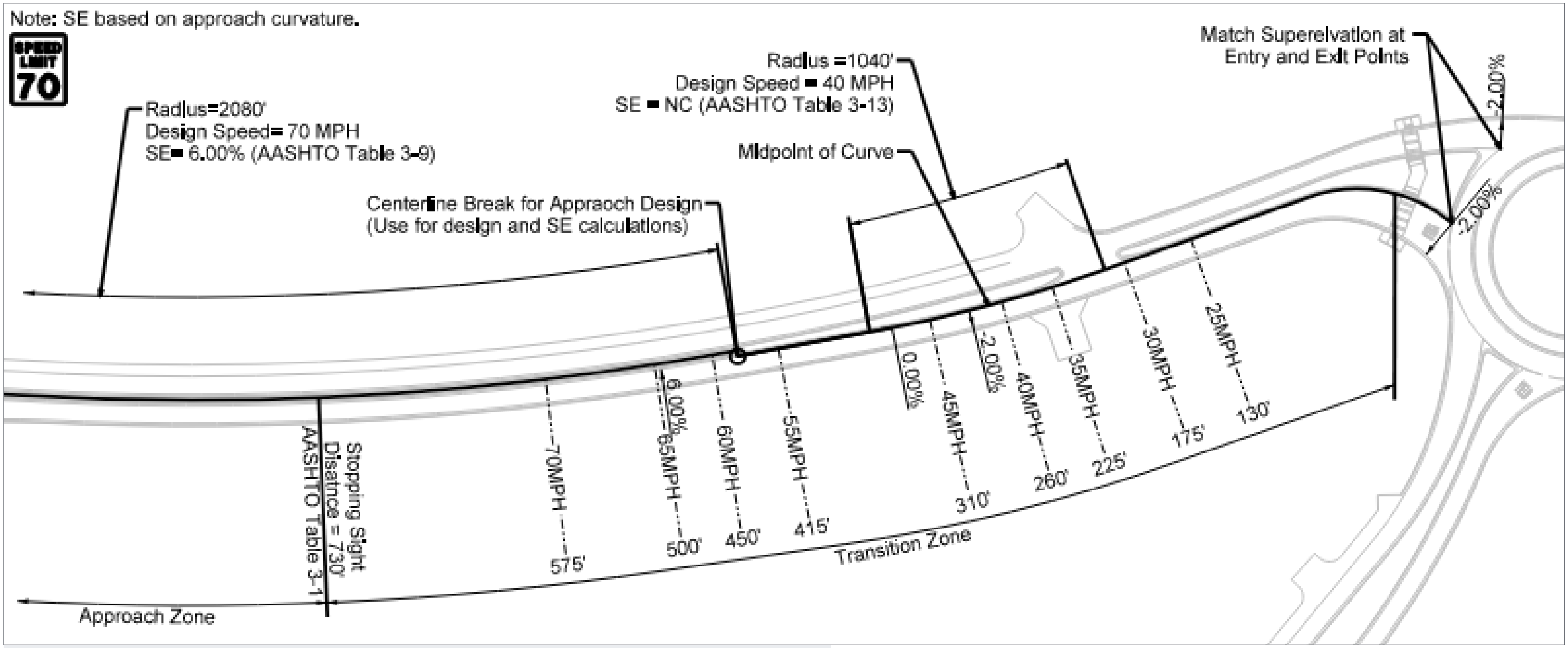
APPENDIX C – EXAMPLES APPLYING RDM CHAPTER 14, FIGURE 14-10 FOR CURVE APPROACHES



EXAMPLE 1 – 70mph Posted Speed with a Curve to the Left near the Roundabout

Note: The splitter island edge of pavement alignment is the reference line applied for approach curve radii and SE selection. The proportion of runoff length placed on the tangent for this example is 67%. Use local guidelines to determine the appropriate proportion to use in design.

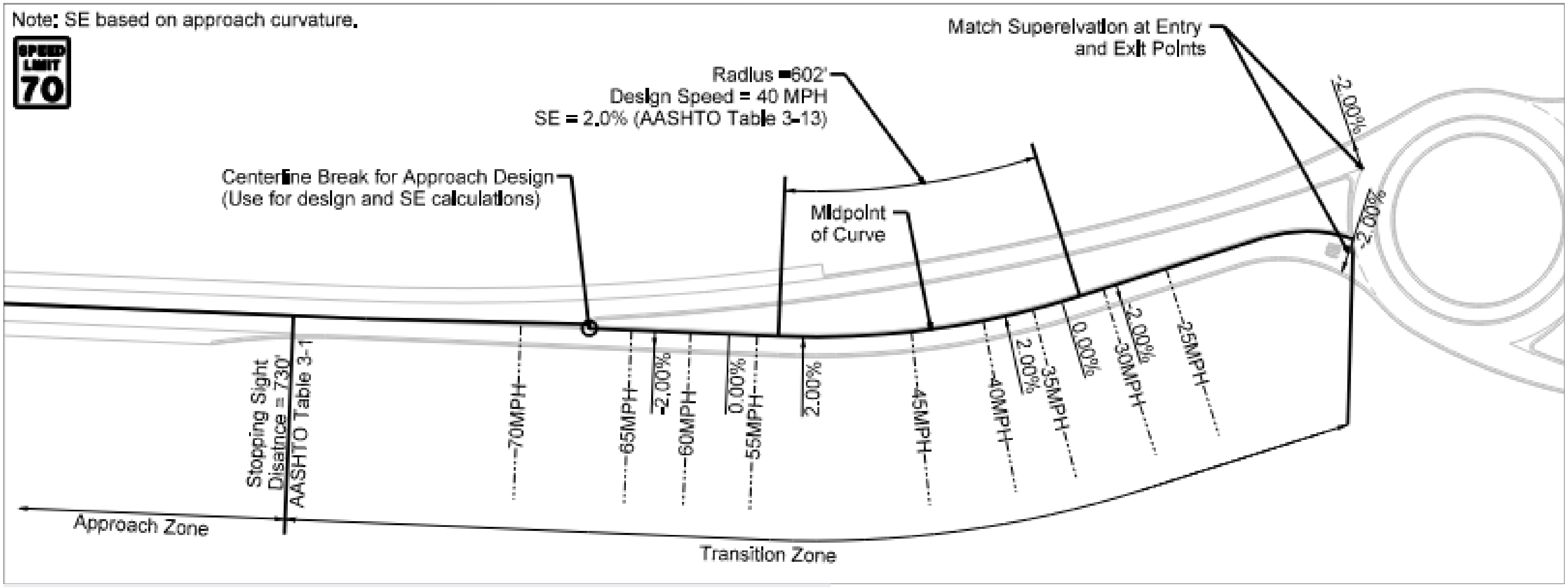
Workflow

- Locate the midpoint of the curve to pick the design speed from the speed contour (the closest deceleration distance to the midpoint of the curve is the applicable speed contour)
- Determine if the midpoint of the curve is above or below the 45mph speed contour to choose either TxDOT RDM Table 4-4 (Table 3-13 AASHTO Greenbook, 2018) (Low Speed urban SE criteria) or if the curve is in the transition zone but the region above 45mph, where Table 3-9 applies.
- In this example, the approach curve midpoint is in the 40mph speed contour. Per Table 3-13, normal crown is acceptable for R = 1040ft.
- Because a large high-speed curve is present on the approach, it becomes the driving factor for super-elevations.
- Curve Lr and Lt based on AASHTO using 60mph on the approach side of the curve:

L_r=160ft (AASHTO Table 3-16a - 1 lane; 60mph; e_d=6%)

$L_t = 160 \left(\frac{2.0\%}{6.0\%}\right)$

L_t=53ft



» EXAMPLE 2 – 70mph Posted Speed with a Curve to the Left near the Roundabout

Note: The splitter island edge of pavement alignment is the reference line applied for approach curve radii and SE selection. The proportion of runoff length placed on the tangent for this example is 67%. Use local guidelines to determine the appropriate proportion to use in design.

Workflow

- Locate the midpoint of the curve to pick the design speed from the speed contour (the closest deceleration distance to the midpoint of the curve is the applicable speed contour)
- Determine if the midpoint of the curve is above or below the 45mph speed contour to choose either TxDOT RDM Table 4-4 (Table 3-13 AASHTO Greenbook, 2018) (Low Speed urban SE criteria) or if the curve is in the transition zone but the region above 45mph, where Table 3-9 applies.
- In this example, the curve midpoint is at 40mph speed contour. Table 3-13 SE = 2% for R = 602ft.
- Curve Lr and Lt based on AASHTO using 55mph on the approach side of the curve:

  L_r = 51ft (AASHTO Table 3-16a – 1 lane; 55mph; e_d=2%)

  $L_t = 51\left(\frac{2.0\%}{2.0\%}\right)$

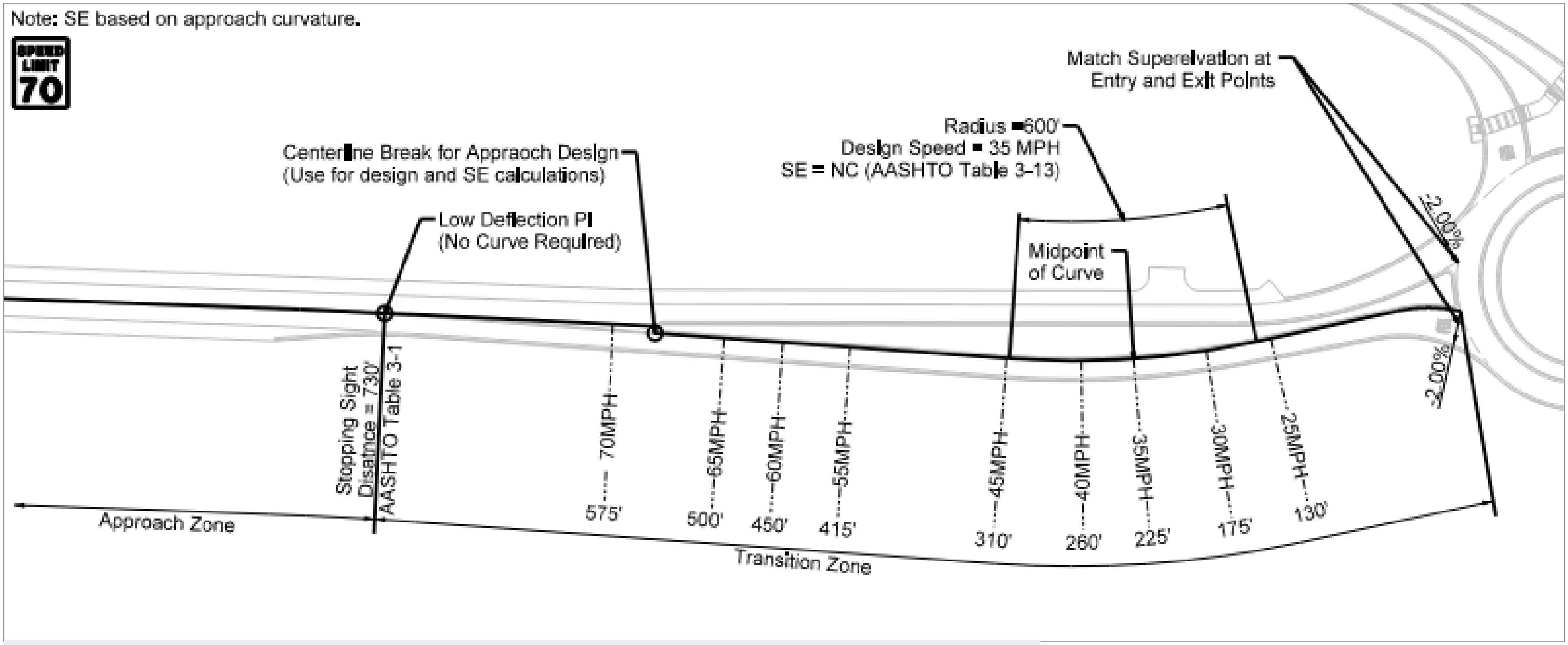
  L_t= 51ft
- Curve Lr and Lt based on AASHTO using 35mph on the departure side of the curve:

  (L_r calculated using the appropriate speed factor where $R \geq R_{min}$ for SE= -2% TxDOT RDM Table 4-4 (Table 3-13 AASHTO))

  L_r = 39ft (AASHTO Table 3-16a – 1 lane; 35mph; e_d=2%)

  $L^t = 39\left(\frac{2.0\%}{2.0\%}\right)$

  L_t= 39ft

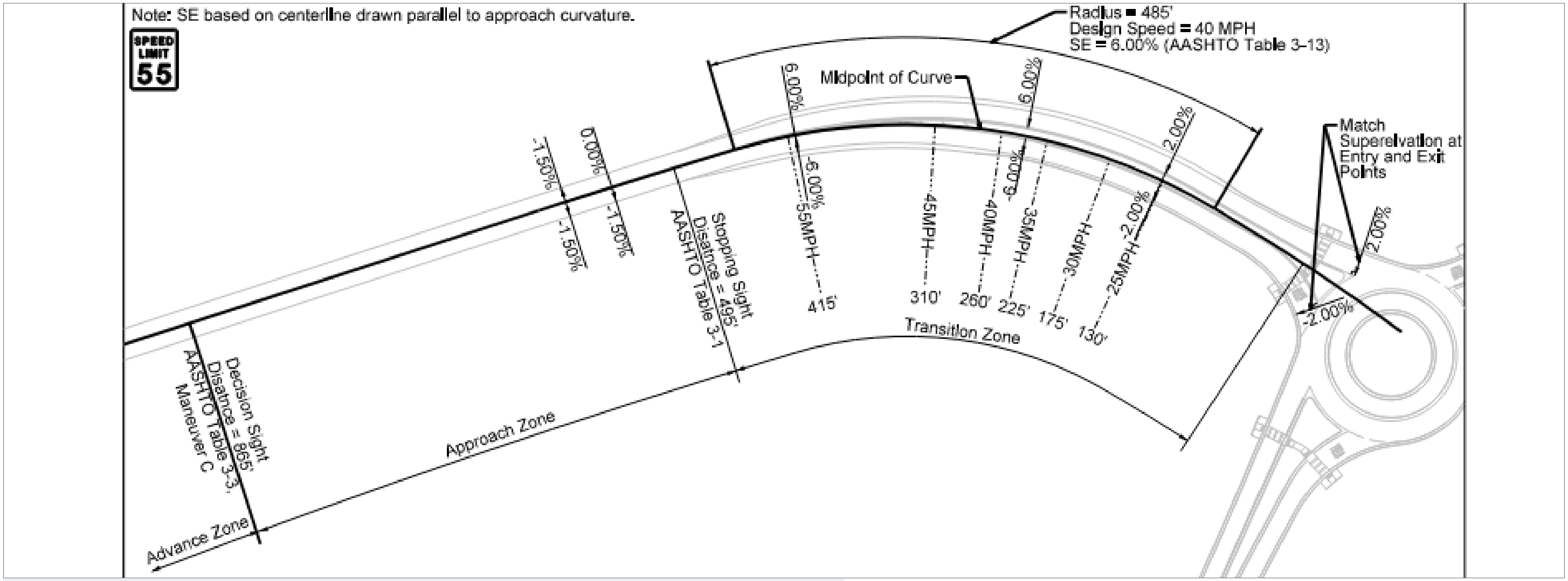


EXAMPLE 3 – 70mph Posted Speed with a Low Deflection PI and Curve to the Left near the Roundabout

Note: The splitter island edge of pavement alignment is the reference line applied for approach curve radii and SE selection.

Workflow

- The design includes a low deflection PI with a change in direction less than 2°. This PI does not require a curve or super-elevation.
- Locate the midpoint of the curve to pick the design speed from the speed contour (the closest deceleration distance to the midpoint of the curve is the applicable speed contour)
- Determine if the midpoint of the curve above or below the 45mph speed contour to choose either TxDOT RDM Table 4-4 (Table 3-13 AASHTO Greenbook, 2018) (Low Speed urban SE criteria) or if the curve is in the transition zone but the region above 45mph, where Table 3-9 applies.
- In this example, the curve midpoint is at 35mph speed contour, and super-elevation is not required. Table 3-13 SE = NC for R = 600ft.



» **EXAMPLE 4 –** 55mph Posted Speed with a Curve to the Right near the Roundabout

Note: The centerline alignment is the reference line applied for curve radii and SE selection based on being parallel to the splitter island. The proportion of runoff length placed on the tangent for this example is 67%. Use local guidelines to determine the appropriate proportion to use in design.

Workflow

- Locate the midpoint of the curve to pick the design speed from the speed contour (the closest deceleration distance to the midpoint of the curve is the applicable speed contour)
- Determine if the midpoint of the curve is above or below the 45mph speed contour to choose either TxDOT RDM Table 4-4 (Table 3-13 AASHTO Greenbook, 2018) (Low Speed urban SE criteria) or if the curve is in the transition zone but the region above 45mph, where Table 3-9 applies.
- In this example, the curve midpoint is closer to the 40mph speed contour. Table 3-13 SE = 6% for R = 485ft.
- Curve Lr and Lt based on AASHTO using 55mph on the approach side of the curve:

  L_r = 153ft

  (AASHTO Table 3-16a – 1 lane; 55mph; e_d=6%)

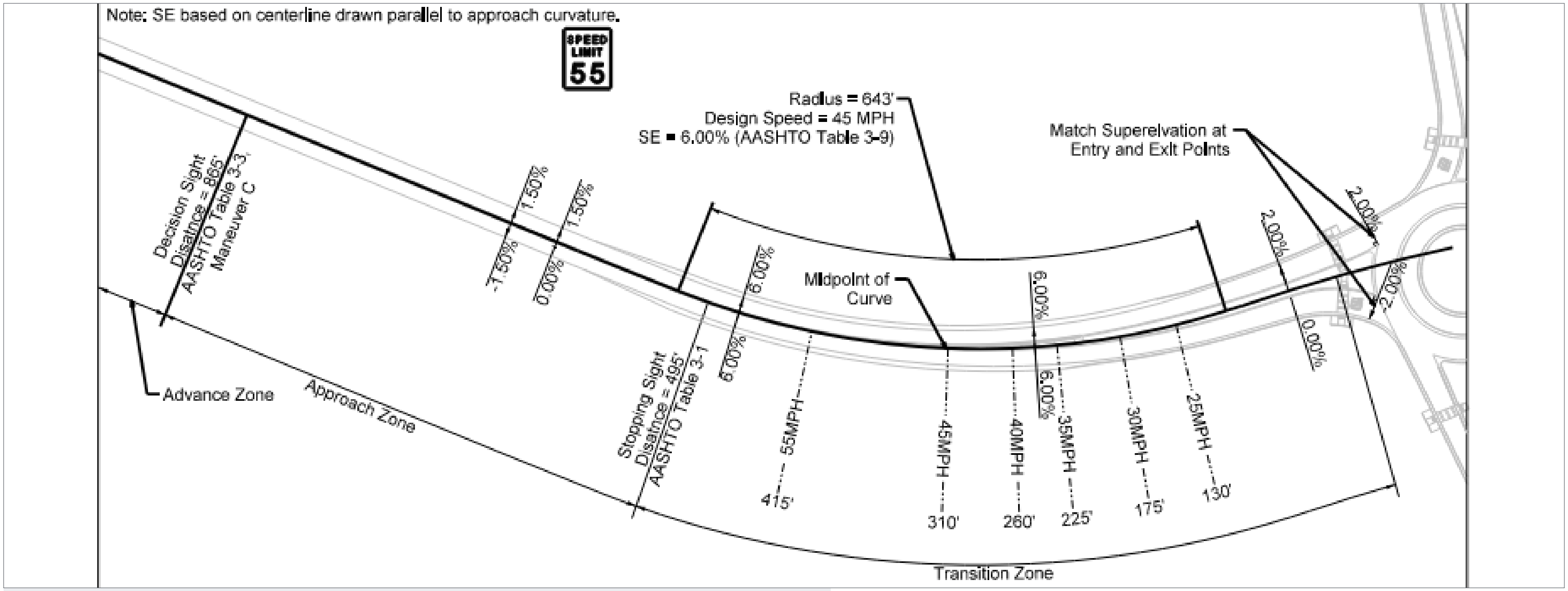
  $L_t = 153\left(\frac{1.5\%}{6.0\%}\right)$

  L_t = 39ft
- Curve Lr and Lt based on AASHTO using 55mph on the departure side of the curve:

  (Lr calculated based on the change from full super to the super-elevation needed at the roundabout exit)

  $L_r = \frac{(12)(1.5)(6\%-2\%)}{0.62}(0.83)$

  L_r =97ft



» EXAMPLE 5 – 55mph Posted Speed with a Curve to the Left near the Roundabout

Note: The centerline alignment is the reference line applied for curve radii and SE selection based on being parallel to the splitter island. The proportion of runoff length placed on the tangent for this example is 67%. Use local guidelines to determine the appropriate proportion to use in design.

Workflow

- Locate the midpoint of the curve to pick the design speed from the speed contour (the closest deceleration distance to the midpoint of the curve is the applicable speed contour)
- Determine if the midpoint of the curve is above or below the 45mph speed contour to choose either TxDOT RDM Table 4-4 (Table 3-13 AASHTO Greenbook, 2018) (Low Speed urban SE criteria) or if the curve is in the transition zone but the region above 45mph, where Table 3-9 applies.
- In this example, the curve midpoint is at 45mph speed contour. Table 3-9 SE = 6% for R = 643ft.
- Curve Lr and Lt based on AASHTO using 55mph on the approach side of the curve:

L_r = 153ft (AASHTO Table 3-16a – 1 lane; 55mph; e_d=6%)

$L_t = 153\left(\frac{1.5\%}{6.0\%}\right)$

L_t= 39ft

- Curve Lr and Lt based on AASHTO using 55mph on the departure side of the curve:

(Lr calculated using the appropriate speed factor where R ≥ Rmin for SE= -2% TxDOT RDM Table 4-4 (Table 3-13 AASHTO))

$L_r = (116)(2.5)(0.70)$

(AASHTO Table 3-16a – 2.5 lane; 35mph; e_d=6%)

L_r = 203ft

$L_t = 203\left(\frac{2.0\%}{6.0\%}\right)$

L_t= 68ft

APPENDIX D – SUPER-ELEVATION RUN-OFF CALCULATION

APPENDIX D – SUPER-ELEVATION RUN-OFF CALCULATION

AASHTO Equation 3-23

U.S. CUSTOMARY

$$L_r = \frac{(wn_1)\, e_d}{\Delta} (b_w)$$

where:

L_r = minimum length of superelevation runoff, ft

w = width of one traffic lane, ft (typically 12 ft)

n_1 = number of lanes rotated

e_d = design superelevation rate, percent

b_w = adjustment factor for number of lanes rotated

Δ = maximum relative gradient, percent

AASHTO Equation 3-24

U.S. CUSTOMARY

$$L_t = \frac{e_{NC}}{e_d} L_r$$

where:

L_t = minimum length of tangent runout, ft

e_{NC} = normal cross slope rate, percent

e_d = design superelevation rate, percent

L_r = minimum length of superelevation runoff, ft

Design Speed (mph)	Maximum Relative Gradient, G (%)	Equivalent Maximum Relative Slope
20	0.80	1:125
25	0.73	1:137
30	0.67	1:150
35	0.62	1:162
40	0.57	1:175
45	0.53	1:187
50	0.50	1:200
55	0.47*	1:213*
60	0.45*	1:223*
65	0.43*	1:233*
70	0.40*	1:250*
75	0.38*	1:264*

**The desirable maximum gradient for design speeds above 50mph is 0.50%. A maximum relative gradient of 0.50% may be used for speeds above 50mph. The above values are derived from AASHTO Greenbook Table 3-16a.*