Oregon
Department
of Transportation

Traffic Line Manual

Delivery & Operations Division | Traffic-Roadway Section

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Oregon Department of Transportation

Engineering & Technical Services Branch

Traffic-Roadway

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Preface

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Introduction Chapter 1

Pavement markings provide important information for road users. In some cases, markings are used to supplement other traffic control devices such as traffic signs or signals. Markings can also be used alone in other applications to communicate regulations, guidance, or warnings more effectively than is possible with other devices, such as no-passing zones. Uniform application of pavement markings improves roadway safety and efficiency throughout the state.

Pavement markings have limitations. They could be covered by snow, could be hard to see when wet, and could be worn away when exposed to heavy traffic. In spite of these limitations, they have the advantage of communicating warning, guidance, and other information to road users without diverting their attention away from the roadway. Audible and tactile features such as raised pavement markers or surface profile changes can be added to alert the road user that a line on the roadway is being crossed.

1.1 Scope

The Traffic Line Manual sets parameters, provides policies, establishes uniform methods, and communicates vital information about pavement markings on the Oregon State Highway System. The Traffic-Roadway Section publishes the Traffic Line Manual under the authority delegated to the state traffic-roadway engineer under Delegation Order EB-06.

This edition supersedes previous edition of the Traffic Line Manual effective January 1, 2025 and applies to all pavement marking work except in-kind maintenance of existing pavement markings on the existing pavement surface (e.g.: does not apply to re-tracing longitudinal lines, replacing worn stop bars or turn arrows, etc.), unless otherwise specified in this manual. Design parameters and figures in this manual are intended provide guidance and flexibility for a variety of roadway designs currently in service. New content presented in this edition does not imply that existing ODOT facilities, including but not limited to traffic control devices, are unsafe, nor does it mandate the initiation of improvement projects unless otherwise specified.

The Traffic Line Manual supports and complements the application of sound engineering judgement by transportation professionals. The intended audience of the Traffic Line Manual is transportation professionals practicing traffic engineering related to pavement markings on Oregon state highways.

The Traffic Manual refers to subject-specific ODOT publications when appropriate instead of duplicating information. The Traffic Line Manual does not contain roadway, signal, or signing design policies and practices; see the appropriate manuals for that information.

In support of its mission, ODOT has committed to be at the forefront of the integration of sustainable intermodal transportation. Pavement markings are some of the most fundamental traffic control devices and their use extends to nearly all modes of Oregon's transportation system. As such, this manual provides multi-modal design standards and guidance related to pavement markings – in support of the agency's mission and adopted plans – based on the latest national standards, best practices, and research.

1.2 Availability

This manual is a web-only document that can be accessed and printed in its entirety from the ODOT engineering website.

The traffic markings and sign engineer maintains the Traffic Line Manual. Send comments or questions on this document to frank.belleque@odot.state.or.us

Traffic Markings & Sign Engineer

ODOT Traffic-Roadway Section, MS#5

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1.3 Updates

This manual will be updated continually and revisions will be made as necessary, typically on a yearly basis, but could occur at any time. Contact the pavement markings and sign engineer to be placed on the notification update list.

1.4 References

This manual has been adapted primarily from the 2009 Edition of the Manual on Uniform Traffic Control Devices (MUTCD), Oregon MUTCD Supplements, ODOT policy and guidelines, and other relevant national design guides and published research. Key references used for design topics are referenced in individual sections to help identify where design parameters come from. A complete reference section of all references used in the Traffic Line Manual is provided in the Appendix.

Human Factors Chapter 2

Marking the road surface is a visual and sometimes tactile traffic control tool that communicates information about the roadway's operation (i.e.: lane uses) and path. The safety and operational benefits of pavement markings rely completely on road users' ability to see and understand the markings. Because of this limitation, it is important to understand how human factors relate to pavement markings in order to maximize effectiveness and appreciate limitations.

Road users continuously seek information from pavement markings for guidance and control of their vehicle – approximately 90 percent of all driver tasks are obtaining visual information, and visual fixation is predominantly in their own lane (*1*). Road users have limited attention and ability to process information, and their response to markings are primarily based on what they have previously experienced; design standards can enhance learned behavior expectations (*1*) (*2*). For example, road users expect a left turn lane to include a left turn arrow marked in the lane, a solid line separating the lane from through traffic, and a stop bar to show where they are expected to stop, if required to stop. When expectations are not met, road users are more likely to make mistakes (*2*).

Human factors studies estimate road users need to be able to preview the road 2 to 3 seconds ahead to maintain their lane position and 3 to 5 seconds ahead to feel comfortable with changes in the road path (*1*). For example, pavement markings communicate a curve's severity as drivers approach a curve and are best for providing short-range steering control cues once drivers enter a curve (*1*). In order for pavement markings to serve this need, road users need pavement sight distance (i.e.: object height = 0.0 feet). Not all locations can provide this sight distance, like at some vertical curves, so other devices like delineators and road alignment signing can fill in to provide additional preview of the road.

Pavement markings must be visible in a variety of driving conditions in order to provide the greatest safety benefit. Darkness, fog, rain, glare from sun or headlights, dirt and debris, ice, and snow all affect marking visibility to varying degrees or completely obscure pavement markings. For example, heavy rain that obscures pavement markings can significantly increase the standard deviation of a driver's lane position (*3*). There are strategies to address some of these issues; road users will need to rely on other traffic control devices for navigation and control during conditions that completely obscure markings.

Pavement markings become less visible as drivers age, mostly due to sensitivity to contrast and retroreflectivity (*4*). Contrast sensitivity is a key component of human vision to detect pavement markings. Contrast sensitivity is the ability to detect small differences in brightness between an object and its background. This ability tends to decline with age due to normal changes in the eye lens and higher occurrence of ocular disease; additional contrast between markings and the road surface becomes more important for these road users (*5*) (*6*). On light colored pavements like new concrete, black borders around white and yellow markings can increase contrast and improve marking visibility (*7*).

Retroreflectivity is key for nighttime visibility; it is a property of a surface that allows a large portion of the light coming from a point source to be returned directly back to a point near its origin (*8*). Retroreflectivity of pavement markings comes from glass spheres or beads on the marking's surface. Over many years of study, research is providing consistent evidence that nighttime safety can increase by specifying and maintaining adequate pavement marking retroreflectivity; however, exactly how this improves safety is still not fully understood (*9*). FHWA is working toward updating the MUTCD with minimum standards for maintenance of pavement marking retroreflectivity.

Additional information on human factors related to pavement markings is available in the support sections of this manual, NCHRP Report 600 (*1*), the Highway Safety Manual (*2*), the Handbook for Designing Roadways for the Aging Population (*5*), and other human factors – pavement marking research (*9*) (*10*).

Key References

1. Campbell, J. L., M. G. Lichty, J. L. Brown, C. M. Richard, J. S. Graving, J. Graham, M. O'Laughlin, D. Torbic, and D. Harwood. NCHRP Report 600: Human Factors Guidelines for Road Systems. 2012. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_600Second.pdf. Accessed October 23, 2012.
2. American Association of State Highway and Transportation Officials. *Highway Safety Manual*, 1st ed. AASHTO, Washington, D.C., 2010.
3. Ghasemzadeh, A., and M. M. Ahmed. Drivers' Lane-Keeping Ability in Heavy Rain: Preliminary Investigation using SHRP 2 Naturalistic Driving Study Data. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2663, 2017, pp. 99-108. https://doi.org/10.3141/2663-13.
4. Zwahlen, H. T., and T. Schnell. Visibility of Road Markings as a Function of Age, Retroreflectivity Under Low-Beam and High-Beam Illumination at Night. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1692, 1999, pp. 152-163. http://trrjournalonline.trb.org/doi/abs/10.3141/1692-16. DOI: https://doi.org/10.3141/1692-16
5. Brewer, M., D. Murillo, and A. Pate. Handbook for Designing Roadways for the Aging Population. Washington, D.C., FHWA-SA-14-015, 2014. http://safety.fhwa.dot.gov/older_users/handbook/aging_driver_handbook_2014_final%20.pdf.
6. Migletz, J., and J. Grahm. NCHRP Synthesis 306: Long-Term Pavement Marking Practices. Washington, D.C., 2002. http://www.trb.org/Main/Blurbs/152126.aspx.
7. Hawkins, H. G., A. H. Parham, and K. N. Womack. NCHRP Report 484: Feasibility Study for an All-White Pavement Marking System. Texas Transportation Institute, Washington, D.C., ISBN 0-309-06772-3, 2002. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_484.pdf.
8. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Washington, D.C., 2009.
9. Carlson, P. J. Synthesis of Pavement Marking Research. Texas A&M Transportation Insititute, College Station, Texas, FHWA-SA-15-063, 2015. https://safety.fhwa.dot.gov/roadway_dept/night_visib/pavement_marking/pvmnt_mrkg_synth.pdf.
10. Zwahlen, T. H., and T. Schnell. Driver Eye-Scanning Behavior as Function of Pavement Marking Configuration. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1605, 1997, pp. 62-72. http://trrjournalonline.trb.org/doi/abs/10.3141/1605-08. DOI: http://dx.doi.org/10.3141/1605-08

Design Standards & Guidelines Chapter 3

Chapter 3 contains design standards and guidelines for the Oregon State Highway System related to pavement markings and other traffic control devices in Part 3 of the MUTCD.

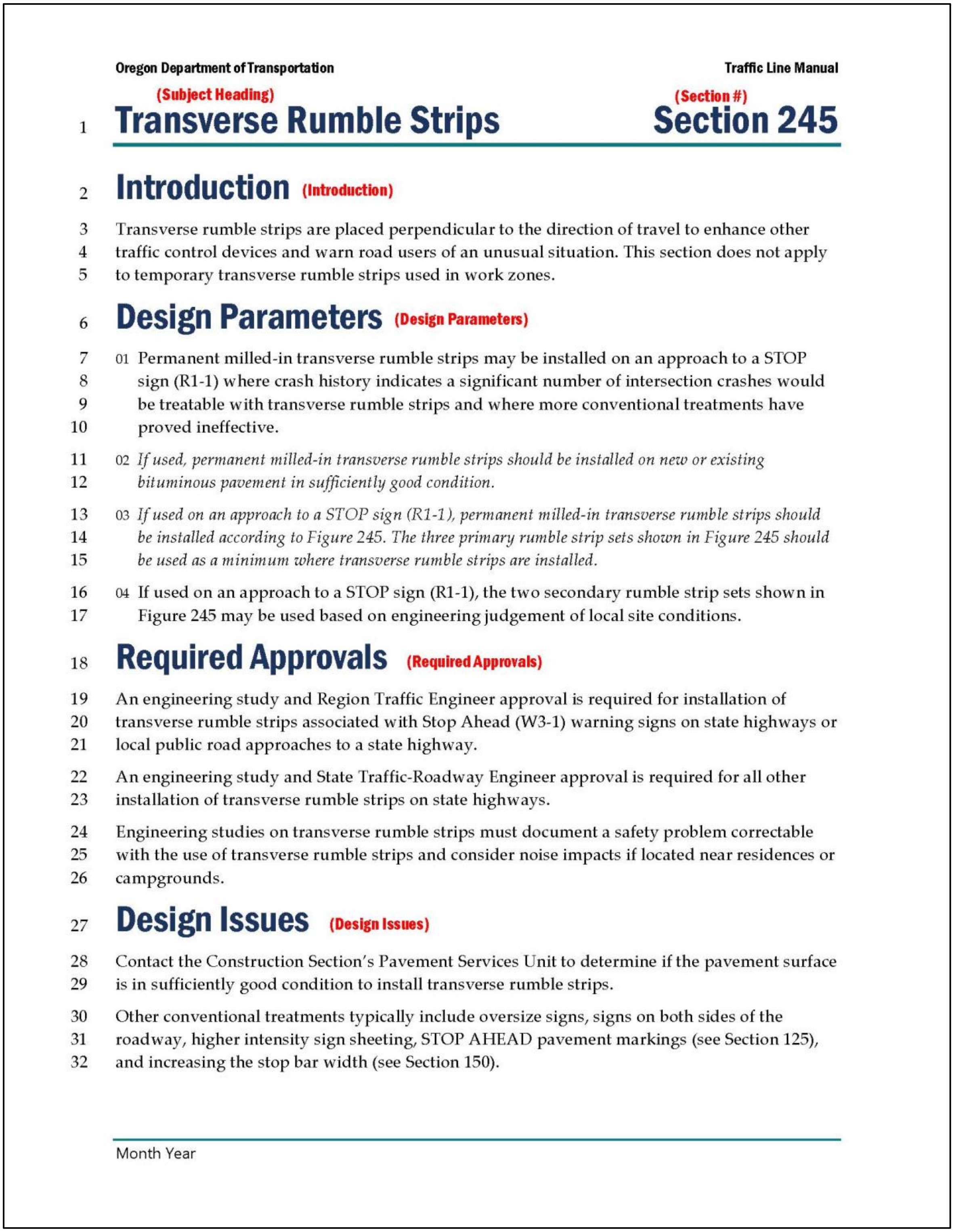
The chapter is organized in the following categories:

Section	Category
100s	Foundational Elements
200s	Roadway Segments
300s	Intersections
400s	Biking & Walking Facilities
500s	Rail & Transit Facilities
600s	Miscellaneous Standards

Individual sections use a format that is adapted from NCHRP Report 600. This layout is intended to provide a consistent display of design information in a concise manner. Some sections build on the information contained in other sections in order to keep information focused and brief for the benefit of the reader and reduce redundancy. A cross reference section is included in each section listing other topics that the current section built on or is related to.

A sample section is shown in Figures 1-4; detailed description of each subsection is provided after the figures.

Figure 1: Example Subject Heading, Section #, Introduction, Design Parameters, Required Approvals, and Design Issues



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(Subject Heading) (Section #)

Transverse Rumble Strips Section 245

Introduction (Introduction)

Transverse rumble strips are placed perpendicular to the direction of travel to enhance other traffic control devices and warn road users of an unusual situation. This section does not apply to temporary transverse rumble strips used in work zones.

Design Parameters (Design Parameters)

01 Permanent milled-in transverse rumble strips may be installed on an approach to a STOP sign (R1-1) where crash history indicates a significant number of intersection crashes would be treatable with transverse rumble strips and where more conventional treatments have proved ineffective.

02 *If used, permanent milled-in transverse rumble strips should be installed on new or existing bituminous pavement in sufficiently good condition.*

03 *If used on an approach to a STOP sign (R1-1), permanent milled-in transverse rumble strips should be installed according to Figure 245. The three primary rumble strip sets shown in Figure 245 should be used as a minimum where transverse rumble strips are installed.*

04 If used on an approach to a STOP sign (R1-1), the two secondary rumble strip sets shown in Figure 245 may be used based on engineering judgement of local site conditions.

Required Approvals (Required Approvals)

An engineering study and Region Traffic Engineer approval is required for installation of transverse rumble strips associated with Stop Ahead (W3-1) warning signs on state highways or local public road approaches to a state highway.

An engineering study and State Traffic-Roadway Engineer approval is required for all other installation of transverse rumble strips on state highways.

Engineering studies on transverse rumble strips must document a safety problem correctable with the use of transverse rumble strips and consider noise impacts if located near residences or campgrounds.

Design Issues (Design Issues)

Contact the Construction Section's Pavement Services Unit to determine if the pavement surface is in sufficiently good condition to install transverse rumble strips.

Other conventional treatments typically include oversize signs, signs on both sides of the roadway, higher intensity sign sheeting, STOP AHEAD pavement markings (see Section 125), and increasing the stop bar width (see Section 150).

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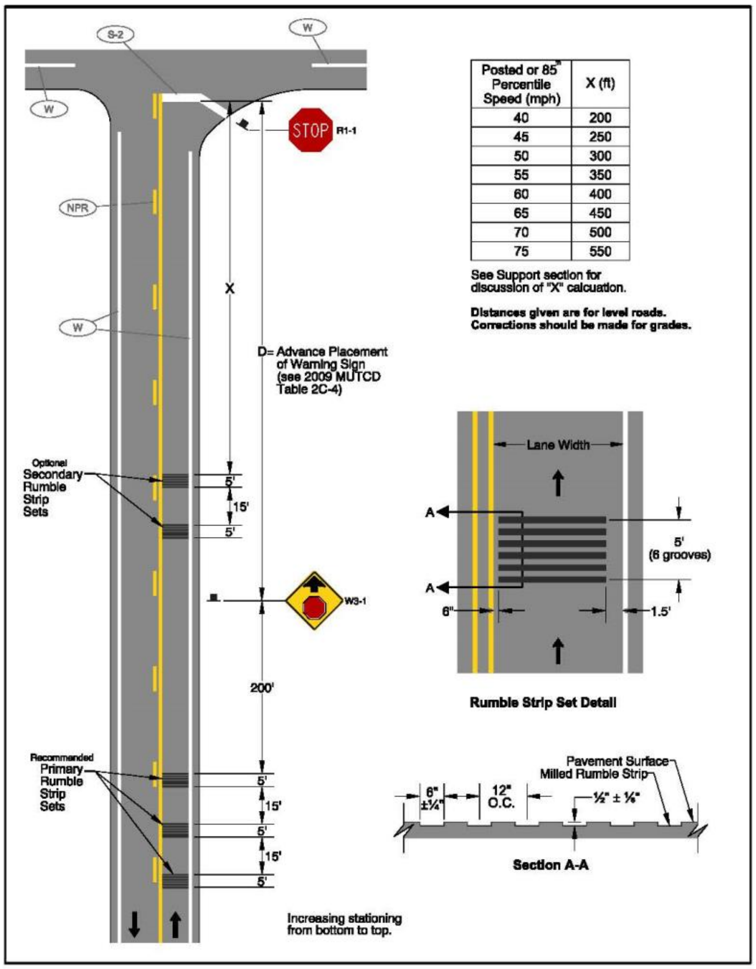
Figure 2: Example Figures & Tables

Figures & Tables (Figures & Tables)

Figure 245: Typical Transverse Rumble Strip Installation on an Approach to a STOP Sign



Posted or 85th Percentile Speed (mph)	X (ft)
40	200
45	250
50	300
55	350
60	400
65	450
70	500
75	550

Figure 3: Example Support

Support (Support)

Transverse rumble strips provide a warning to drivers of an approaching condition, but the rumble strips themselves do not communicate what action needs to be taken in response to that condition (*2*).

Many different configurations of transverse rumble strips have been tested across a variety of studies, including milled-in and preformed thermoplastics of various widths, thickness/depth, and patterns. The design shown in Figure 245 is based on a design used by Minnesota DOT. This design was one of two contributing designs studied for development of crash modification factors by Srinivasan, Baek, and Council (*3*). Srinivasan, Baek, and Council found the milled-in transverse rumble strips they studied can be effective at reducing fatal and serious injury crashes at minor road stop-controlled intersections. They also found these rumble strips might increase property-damage-only crashes, though the reason for this increase could not be determined at the time. One theory from other sources (*2*) (*4*)is the rumble strips increase speed variability which might increase rear-end crashes.

Transverse rumble strips generally do not have a practical effect on reducing vehicle speed at approaches to stop-controlled intersections (≤1-2 mph) (*2*) (*5*) (*6*) and in speed transition zones (*7*).

Transverse rumble strips need to be positioned to provide enough advance warning time for drivers to respond and take an appropriate action (*2*). The design in Figure 245-A sets the distance of the first grouping of rumble strip sets 200 feet in advance of the Stop Ahead sign (W3-1). This alerts the driver before the sign legibility distance used by the 2009 MUTCD (*8*) for this warning condition (180 feet). This also positions the rumble strip sets approximately at Stopping Sight Distance given in the AASHTO Green Book (*9*).

The last two rumble strip sets crossed by an approaching driver are positioned to give a final warning with a sufficient distance to make a hard stop. This distance assumes the driver is alert from the previous rumble strip sets and has a brake reaction time of 1.0 second. This also assumes that if the driver hasn't started to decelerate at this point, he or she will decelerate more aggressively than the deceleration rates used to calculate advance warning sign placement and stopping sight distance (11.2 ft/s2). The discussion of braking distance in the AASHTO Green Book says the literature shows most drivers decelerate at a rate greater than 14.8 ft/s2 when confronted with the need to stop for an unexpected object in the roadway. This was the deceleration rate used to calculate braking distance in this case.

The design assumptions discussed above places these rumble strip sets in a location consistent with Iowa DOT's design for a 50-55 mph approach speed. The groove depth, width, and spacing matches Iowa DOT's design as well to create the same level of vibration and noise associated with crash modification factors developed from the design (*3*).

Figure 4: Example Cross References and Key References

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Transverse Rumble Strips Section 245

A 15-foot gap between rumble strip sets provides a minimal pause in the noise generated from the rumble strips for passenger cars (85th percentile vehicle length in the U.S. fleet is about 17 feet (*10*)).

A 1.5-foot clear space between the rumble strip and the edge line shown in Figure 245 gives people on bikes a minimal gap to avoid the transverse rumble strips to the right.

Cross References (Cross References)

Transverse Markings.. Section 125
Stop Bars .... Section 150

Key References (Key References)

1. Miles, J. D., M. P. Pratt, and P. J. Carlson. Evaluation of Erratic Maneuvers Associated with Installation of Rumble Strips. *Transportation Research Record: Journal of the Transportation Research Board Online*, Vol. 1973, 2006, pp. 73-79. http://trrjournalonline.trb.org/doi/abs/10.3141/1973-11. DOI: https://doi.org/10.3141/1973-11
2. Brian, R., W. Kittleson, J. Knudsen, B. Nevers, P. Ryus, K. Sylvester, I. Potts, D. Harwood, D. Gilmore, D. Torbic, F. Hanscom, J. McGill, and D. Stewart. *NCHRP Report 613: Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections*. Transportation Research Board of the National Academies, Washington, D.C., 2008. http://www.trb.org/Publications/Blurbs/160046.aspx.
3. Srinivasan, R., J. Baek, and F. Council. Safety Evaluation of Transverse Rumble Strips on Approaches to Stop-Controlled Intersections in Rural Areas. in *2010 Annual Meeting of the Transportation Research Board*, Washington, D.C., September 2010.
4. Isebrands, H., S. Hallmark, and N. Hawkins. Effects of Approach Speed at Rural High-Speed Intersections: Roundabouts Versus Two-Way-Stop Control. *Transportation Research Record: Journal of the Transportation Research Board Online*, Vol. 2402, 2014, pp. 67-77. http://trrjournalonline.trb.org/doi/abs/10.3141/2402-08. DOI: https://doi.org/10.3141/2402-08
5. Thompson, T. D., M. W. Burris, and P. J. Carlson. Speed Changes Due to Transverse Rumble Strips on Approaches to High-Speed Stop-Controlled Intersections. *Transportation Research Record: Journal of the Transportation Research Board Online*, Vol. 1973, 2006, pp. 1-9. http://trrjournalonline.trb.org/doi/abs/10.3141/1973-03. DOI: 10.3141/1973-03
6. Yang, L., H. Zhou, L. Zhu, and H. Qu. Operation Effects of Transverse Rumble Strips on Approaches to High-Speed Intersections. *Transportation Research Record: Journal of the Transportation Research Record Online*, Vol. 2602, 2016, pp. 78-87. http://trrjournalonline.trb.org/doi/abs/10.3141/2602-10. DOI: 10.3141/2602-10
7. Torbic, D. J., D. K. Gilmore, K. M. Bauer, C. D. Bokenkroger, D. W. Harwood, L. M. Lucas, R. J. Frazier, C. S. Kinzel, D. L. Petree, and M. D. Forsberg. *NCHRP Report 737: Design Guidance for High-Speed to Low-Speed Transition Zones for Rural Highways*. Transportation Research Board of the National Academies, Washington, D.C., 2012. http://www.trb.org/Publications/Blurbs/168309.aspx.
8. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
9. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*, 6th ed. Washington, D.C., 2011.
10. Institute of Transportation Engineers. *Traffic Engineering Handbook*, 6th ed. Institute of Transportation Engineers, Washington, D.C., 2010.

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3.1 Section Elements

Subject Heading

The main design element being discussed is centered and bolded at the top of each page. See Figure 1 for example "Subject Heading."

Introduction

Briefly introduces the subject. For example, definitions fundamental to the subject might be given in this subsection. This subsection is for information only and does not convey any degree of mandate, recommendation, authorization, prohibition, or enforceable condition. See Figure 1 for example "Introduction."

Design Parameters

This subsection gives the design parameters for the subject. Design parameters are the design standards, guidance, and options for the subject using the verbs "shall," "should," and "may." The design parameters are immediately after the "Introduction" for a section. Each paragraph in the Design Parameters section is numbered for reference. See Figure 1 for example "Design Parameters."

Required Approvals

This subsection lists any needed approvals to install or remove a feature. This includes any state traffic-roadway engineer approvals or region traffic engineer/manager approvals. Required approvals are always presented prominently directly below the "Design Parameters" section. See Figure 1 for example "Required Approvals."

Design Issues

This subsection presents special design considerations associated with a particular subject, if needed. These special considerations may include design goals from the perspective of other disciplines (e.g.: signal, signing, roadway, etc.), interactions with other subjects, special difficulties associated with the subject's conceptualization or measurement, or special performance implications associated with the subject. The design issues subsection is for information only and does not convey any degree of mandate, recommendation, authorization, prohibition, or enforceable condition. See Figure 1 for example "Design Issues."

Figures and Tables

This subsection provides a figure or table to augment the design parameters. This figure or table provides information considered particularly important to the conceptualization and use of the design parameters. It provides a visual representation of the design parameters (or some aspect of the design parameters themselves), which are text based.

Design elements addressed in that section's design parameters have bubble call-outs that are not grey-scaled and include a "required," "recommended," or "optional" header. Design elements addressed in other sections or are included for context only have grey-scaled bubble call-outs. See Figure 2 for example "Figures & Tables."

Support

This subsection briefly summarizes the rationale behind the design parameters. In particular, the support subsection explains the logic, premises, assumptions, and related literature associated with development of the design parameters. The focus is on information deemed relevant to the subject. The support subsection can take many forms, including a brief review of applicable literature, references to traditional design practice, or an analysis of relevant information. See Figure 3 for example "Support."

The support subsection is presented primarily to help readers understand, explain, and justify the design parameters. Also, because these design parameters are expected to be revised as national standards are revised and as additional research results become available, this subsection will be useful in future revisions of the Traffic Line Manual. In particular, the support subsection helps future developers determine how new information on pavement marking design can or should be integrated into the existing design parameters.

The support subsection is for information only and does not convey any degree of mandate, recommendation, authorization, prohibition, or enforceable condition.

Cross References

This subsection lists the subject titles and section numbers of other sections within the Traffic Line Manual that are relevant to the subject. See Figure 4 for example "Cross References."

Key References

This subsection lists the references cited in the "Support" subsection. Each of these references will have an assigned reference number that was used to note it within the "Support" subsection. A complete reference section of all references used in the Traffic Line Manual is provided in the appendix. See Figure 4 for example "Key References."

3.2 Definitions

Terms used in this chapter are defined in MUTCD Section 1A.13 as modified by Section 1A.13 in the Oregon Supplement to the MUTCD, with the exception of the following:

Standard – a statement of required, mandatory, or specifically prohibitive practice regarding a traffic control device. All standard statements appear in bold type in design parameters sections. The verb “shall” is typically used. The adjective “required” is typically used in figures to illustrate standard statements. The verbs “should” and “may” are not used in standard statements. The adjectives “recommended” and “optional” are only used in standard statements to describe recommended or optional design features as they relate to required design features. Standard statements are sometimes modified by options.

Guidance – a statement of recommended, but not mandatory, practice in typical situations. All guidance statements appear in italicized type in design parameters sections. The verb “should” is typically used. The adjective “recommended” is typically used in figures to illustrate guidance statements. The verbs “shall” and “may” are not used in guidance statements. The adjectives “required” and “optional” are only used in guidance statements to describe required or optional design features as they relate to recommended design features. Guidance statements are sometimes modified by options.

Option – a statement of practice that is a permissive condition and carries no requirement or recommendation. Option statements sometimes contain allowable modifications to a standard or guidance statement. All option statements appear in plain non-bold, non-italicized type in design parameters sections. The verb “may” is typically used. The adjective “optional” is typically used in figures to illustrate option statements. The verbs “shall” and “should” are not used in option statements. The adjectives “required” and “recommended” are only used in option statements to describe required or recommended design features as they relate to optional design features.

Support – an informational statement that does not convey any degree of mandate, recommendation, authorization, prohibition, or enforceable condition. Support statements are labeled and the text appears in plain non-bold, non-italicized type. The words “shall,” “required,” “should,” “recommended,” “may,” and “optional” are not used in support statements.

3.3 Markings Used for Asset Management

Culvert locations are identified with pavement markings and ID markers to support maintenance of these facilities. These markings and/or markers are not traffic control devices and are beyond the scope of this manual; see the ODOT Hydraulics Manual for culvert field marking requirements.

Pavement Marking Plans Section 101

Introduction

Developing pavement marking plans is an opportunity to make sure layouts meet the standards outlined in this manual and document how markings need to be installed or re-installed.

Design Parameters

01 **Pavement marking plans sealed by a registered professional engineer shall be developed where existing pavement markings will be modified.**

02 *Pavement marking plans sealed by a registered professional engineer should be developed where existing pavement markings will be replaced in-kind.*

03 *If pavement marking plans are not developed, a registered professional engineer should verify that existing pavement markings conform to current standards and document existing pavement markings to allow replacement-in-kind.*

Support

Developing pavement marking plans is an opportunity to make sure pavement markings conform to current standards (e.g.: verify and correct no-passing zones, legends, etc.), aids field crews during construction, reduces the chance of installation errors, helps develop a more accurate cost estimate, and documents the decisions of the engineer of record. Preservation projects are the perfect time to consider changes to the existing pavement markings to address safety and efficiency issues (e.g.: changing a 4-lane section to 2-lanes with bike lanes and a two-way left turn lane).

See the ODOT Pavement Marking Design Guidelines (*1*) for information on developing pavement marking plans and information on pavement marking materials.

Pavement marking plans (including drawings, details, sketches, etc.) need a registered professional engineer's seal according to ODOT policy, ODOT directives, and Oregon law (ORS 672.020).

Key References

1. Oregon Department of Transportation. *ODOT Pavement Marking Design Guidelines*, 2nd ed. Oregon Department of Transportation, Salem, Oregon, 2011. http://www.oregon.gov/ODOT/Engineering/Documents_TrafficStandards/Pavement-Marking-Design-Guide.pdf.

Design Flexibility Section 102

Introduction

Pavement markings communicate critical information to road users for safety and operations of the road. Consistent and uniform use of markings is meant to provide a clear and effective way to communicate this information to road users. Given the sheer number of road users that must correctly receive and act on this information in a short amount of time, uniformity helps improve understanding of these important messages.

However, just as language changes over time, it is important to provide a process to deviate from design parameters to allow continuing advances in design techniques following research, to allow the best design solution to a unique problem, and to accommodate evolution of transportation technology.

Design Parameters

01 A deviation from a guidance ("should") statement may be made if engineering judgement or an engineering study indicates the deviation is appropriate.

02 *Deviations from guidance ("should") statements should be documented in a design narrative or similar format and filed with the Region Traffic office.*

Required Approvals

Deviations from standard ("shall") statements require state traffic-roadway engineer approval. In some cases, these deviations might also require an experimental approval from FHWA following the experimentation process in MUTCD Section 1A.10.

The level of approval needed for a deviation from a guidance ("should") statement needs to be based on a risk assessment of the deviation in consultation with the region traffic engineer/manager.

Support

To a large extent, the traveling public relies heavily on pavement markings for guidance, vehicle positioning, and information. Road users could be confused and uncertain of the purpose of a marking unless the same marking always conveys the same meaning. The experimental process helps ensure new devices are introduced in a controlled and well documented way so engineers can learn what works and what doesn't, what effect new devices have on road users, and how the device should be implemented in the future, if at all. The experimentation process is outlined in MUTCD (*1*) Section 1A.10.

Key References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.

Colors Section 110

Introduction

Pavement marking colors convey specific messages to road users.

Design Parameters

01 **The color for markings shall conform to the standard highway colors specified in the "Color Specifications for Retroreflective Sign and Pavement Marking Materials" (appendix to subpart F of Part 655 of Title 23 of the Code of Federal Regulations).**

02 **Pavement markings shall be yellow, white, red, blue, or green in color. Unless otherwise specified in this manual, the colors for pavement markings shall conform to standard highway colors and the following basic concepts:**

- **When used, yellow lines separate opposing flows of traffic; the left edge of the roadways of divided and one-way highways and ramps; and the separation of two-way left turn lanes and reversible lanes from other lanes.**
- **When used, white lines separate lanes of traffic flowing in the same general direction or mark the right edge of travel lanes. Transverse markings (crosswalks, words, symbols, etc.) shall be white unless otherwise specified in this manual.**
- **When used, red raised pavement markers delineate one-way roadways, ramps, or travel lanes that shall not be entered or used in the direction from which the markers are visible (i.e. wrong way treatments), and truck escape ramps.**
- **When used, blue markings supplement white markings for parking spaces for persons with disabilities.**
- **When used, green colored pavement supplements bicycle lane markings to enhance the conspicuity of a bicycle lane or extension of a bicycle lane.**
- **When used, red colored pavement enhances the conspicuity of travel lanes and locations reserved for the exclusive use of transit vehicles.**

03 Black may be used as a border color of the five colors above where a light-colored pavement does not provide sufficient contrast with the markings.

04 Colored truck aprons may be used on the state highway system.

Required Approvals

State traffic-roadway engineer approval is required for use of colored truck aprons on the state highway system. See the Traffic Manual Section 310.7 for more details.

See cross referenced sections for more details on other markings that may require approvals.

Support

Standard color specifications are set in Federal Regulations under 23 CFR 655 and are available on the MUTCD website (*1*) and in ASTM D6628 (*2*).

The color of longitudinal lines are generally effective at conveying one- or two-way directionality of a roadway, though road users tend to use signs and other traffic as primary cues to determine directionality (*3*).

Green colored markings have been approved for use on all public roads in Oregon under an FHWA Statewide Interim Approval letter (*4*). See Section 413 for more information on green colored markings.

Red colored markings have been approved for use on all public roads in Oregon under an FWWA Statewide Interim Approval letter (*5*). See Section 531 for more information on red colored markings.

The use of red-backed RPMs is covered in Section 361 Interchange Ramps: Ramp Terminals. See Section 361 for use and approvals required for red-backed RPMs.

Cross References

Design Flexibility .... Section 102
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Transverse Markings .... Section 125
Raised Pavement Markers .... Section 130
RPMs Used for Supplementation .... Section 131
RPMs Used for Positioning Guides .... Section 132
Typical Layouts for RPMs .... Section 133
Surface Mounted Tubular Markers .... Section 140
Stop Bars .... Section 150
Yield Lines .... Section 151
Lane Use Arrows .... Section 160
Center Lines .... Section 210
No-Passing Zone Markings .... Section 211
Lane Lines .... Section 220
Edge Lines .... Section 230
Lane Reduction Transitions .... Section 250
Traversable Medians .... Section 260
Two-Way Left Turn Lanes .... Section 261
Channelizing Lines and Traversable Channelizing Islands .... Section 270
Approach to a Fixed Obstruction .... Section 280
Non-Traversable Medians & Channelizing Islands .... Section 281
Left Turn Lanes .... Section 310
Added Right Turn Lanes .... Section 320
Channelized Right-Turn Lanes .... Section 321
Dropped Lanes and Auxiliary Lanes on Conventional Roads .... Section 330

Key References

1. Federal Highway Administration. MUTCD Color Specifications. *Manual on Uniform Traffic Control Devices*, October 20, 2015. http://mutcd.fhwa.dot.gov/kno-colorspec.htm. Accessed November 24, 2015.
2. ASTM International. (2016) ASTM D6628: Standard Specification for Color of Pavement Marking Materials. [Online]. https://www.astm.org/cgi-bin/resolver.cgi?D6628. DOI: https://doi.org/10.1520/D6628-16
3. Parham, A. H., K. N. Womack, and H. G. Hawkins Jr. Driver Understanding of Pavement Marking Colors and Patterns. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1844, 2003, pp. 35-44. http://trrjournalonline.trb.org/doi/abs/10.3141/1844-05. DOI: http://dx.doi.org/10.3141/1844-05
4. Kehrli, M. R. MUTCD - Interim Approval for Optional Use of Green Colored Pavement for Bike Lanes (IA-14). June 29, 2011.
5. Knopp, M. C. MUTCD - Interim Approval for Optional Use of Red-Colored Pavement for Transit Lanes (IA-22). December 4, 2019. https://mutcd.fhwa.dot.gov/resources/interim_approval/ia22/ia22.pdf. Accessed April 17, 2020.

Functions, Widths, and Patterns of Longitudinal Lines Section 120

Introduction

The width and pattern of longitudinal lines communicate different meanings to road users and define how the road will be used.

Design Parameters

01 **The general functions of longitudinal lines shall be:**

- **A solid line discourages or prohibits crossing.**
- **A double line indicates maximum or special restrictions.**
- **A broken line indicates a permissive condition.**
- **A dotted line provides guidance or warning of a downstream change in lane function.**

02 **The widths and patterns of longitudinal lines shall be as follows:**

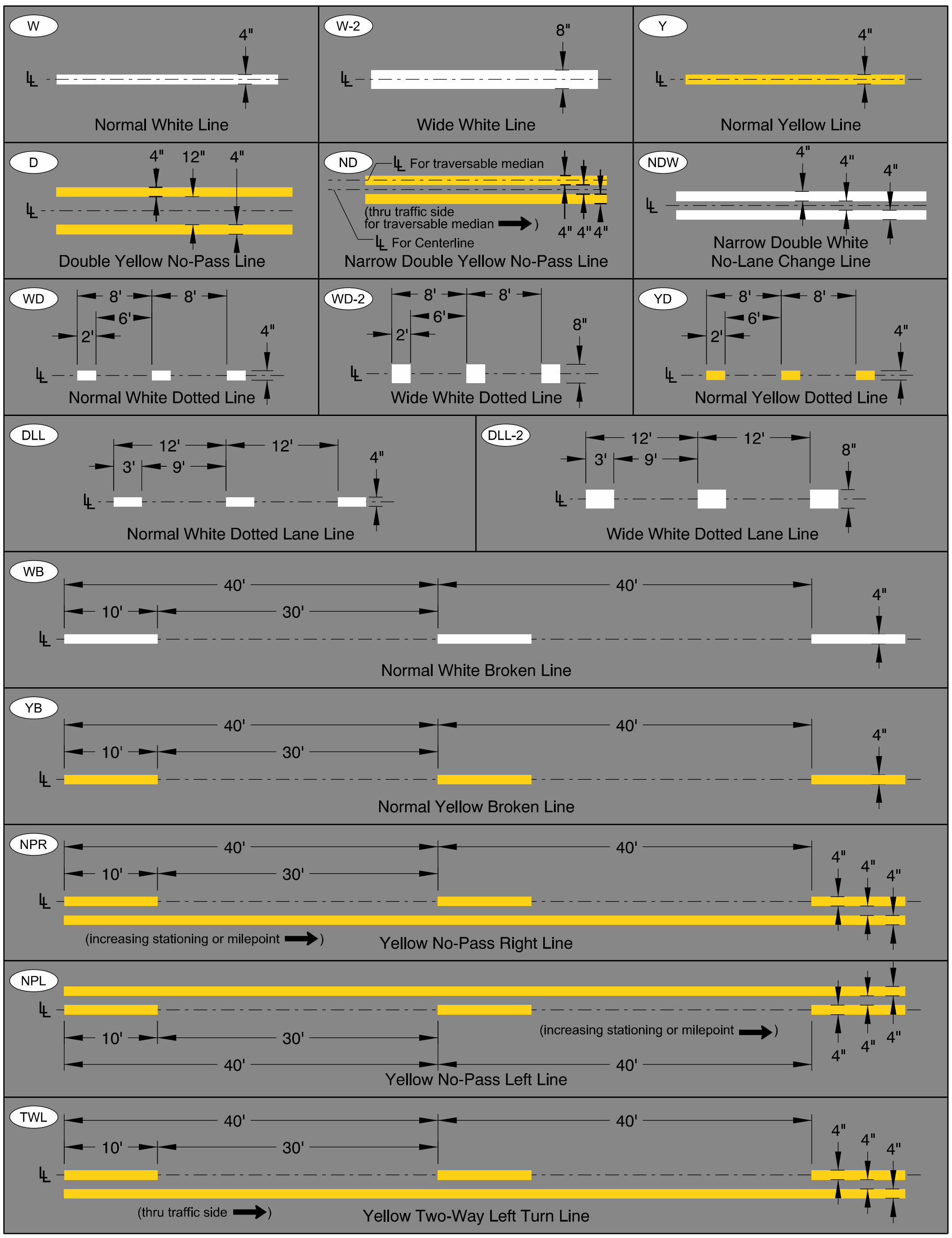
- **Normal line – 4 inches wide.**
- **Wide line – 8 inches wide.**
- **Double line – two normal-width parallel lines separated by 12 inches for a standard double line or 4 inches for a narrow double line.**
- **Broken line – 10-foot segments of normal width line separated by 30-foot gaps.**
- **Dotted line –2-foot line segments separated by shorter gaps than used for a broken line. The width of a dotted line extension shall be at least the same as the width of the line it extends.**
- *A dotted line for line extensions within an intersection or taper area should have 2- to 6-foot gaps.*
- **Dotted lane line – 3-foot line segments separated by 9-foot gaps.**
- **One-direction no-passing line or a two-way left turn line – a normal width solid line parallel to a broken line separated by a 4-inch space.**

Design Issues

Solid double white lines are not defined in statute as prohibiting lane changes; these restrictions are communicated through signing. Signing associated with lane line crossing prohibitions, such as "NO LANE CHANGES NEXT XXXX FT" (OR22-16) and/or "NO LANE CHANGES NEXT ½ MILE" (OR22-17) signs, can be found in the Sign Policy and Guidelines.

Figures & Tables

Figure 120: Longitudinal Line Types



Support

Line patterns and widths come from Section 3A.06 of the 2009 MUTCD (*1*).

The MUTCD only requires parallel double lines be separated by a “discernable” gap. ODOT’s standard gap of 12 inches for standard double lines and 4 inches for narrow double lines has been used since at least 1976. There is no documentation why 12 inches was chosen for standard double lines, but there are several possible reasons it has remained standard practice, including:

1) Keeps the location of centerlines constant as the pattern transitions between YB, NPR, NPL, and D lines by using a 3-gun equipment setup.
2) Striping equipment capabilities.
3) Aesthetically pleasing.
4) Provides slightly more separation between opposing traffic (12 inches vs. 4 inches).

Possible reasons for the 4-inch gap for narrow double lines includes consistency with the width of normal lines and easier re-trace compared to narrower gaps (the 1966 Traffic Line Manual used a gap as small as 2.5 inches). Even though a wider gap results in a visually wider target, increasing the gap width does not appear to significantly affect the distance at which road users can first detect the line (*2*).

Much like bold typeface, the wide lines communicate greater emphasis (*1*). For example, wide lines are used at gore points to provide greater visual guidance that a ramp splits away from the mainline road at that point. Similarly, a wide dotted lane line is used prior to a dropped lane as an added emphasis that the lane will be taking the road user somewhere else soon (like an exit only lane or right turn only lane).

Longitudinal line patterns have remained uniform at 1:3 for many decades; however, past editions of the MUTCD used a 3:5 ratio (as late as the 1970s). This was based on long-standing practice by states for rural highways using a 15-foot long line with a 25-foot gap for a total cycle length of 40 feet (*3*).

The energy crisis in the mid-1970s caused the cost of traffic paint to double or triple and suppliers were unable to furnish enough paint to sustain basic pavement marking operations. Several states experimented with alternative skip-gap pattern lengths to reduce paint consumption while still conveying the same meaning as the 3:5 ratio. That experimentation resulted in the 1:3 ratio used today, which provides logistical and financial benefits with no discernible negative effects on safety compared to the 3:5 ratio. Most states adopted the 1:3 ratio or switched to that ratio to achieve financial savings, and the National Committee on Uniform Traffic Control Devices adopted the ratio in 1974 resulting in a change to the 1978 MUTCD (*3*).

Dotted lines first appeared in the 1971 MUTCD to extend a line through an intersection or interchange area. Today, these are used to extend lines through breaks for intersections and other conflict areas. Dotted lines are 2 feet long with a 6-foot gap; ODOT plans use the WD bubble note for white dotted lines and YD for yellow dotted lines.

Dotted lane lines first appeared in the 2003 MUTCD following research in the mid-1990s (*4*) (*5*) on ways to improve road user understanding of an impending change in the function of a lane (e.g.: dropped lane). These are used as a different pattern on a lane line to communicate a change in the function of a lane. Dotted lane lines are 3 feet long with a 9-foot gap; ODOT plans use the DLL bubble note for white dotted lane lines and DLL-2 for wide white dotted lane lines.

Cross References

Key References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
2. Zwahlen, H. T., T. Schnell, and T. Hagiwara. Effects of Lateral Separation Between Double Center-Stripe Pavement Markings on Visibility Under Nighttime Driving Conditions. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1495, 1995, pp. 87-98. http://onlinepubs.trb.org/Onlinepubs/trr/1995/1495/1495-011.pdf.
3. Federal Highway Administration. Frequently Asked Questions - Part 3 - Markings. *Manual on Uniform Traffic Control Devices*, October 20, 2015. http://mutcd.fhwa.dot.gov/knowledge/faqs/faq_part3.htm. Accessed July 6, 2016.
4. Fitzpatrick, K., M. Ogden, and T. Lienau. Motorists' Comprehension of Exit Lane Drop Signs and Markings. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1464, 1994, pp. 51-59. http://onlinepubs.trb.org/Onlinepubs/trr/1994/1464/1464-007.pdf.
5. Fitzpatrick, K., M. Lance, and T. Lienau. Effects of Pavement Markings on Driver Behavior at Freeway Lane Drop Exits. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1495, 1995, pp. 17-27. http://onlinepubs.trb.org/Onlinepubs/trr/1995/1495/1495-003.pdf.

Transverse Markings Section 125

Introduction

Transverse markings include shoulder markings, word and symbol markings, arrows, stop bars, yield lines, crosswalk bars, speed hump markings, and parking space markings, among others. They are used for the purpose of regulating, warning, and guiding traffic.

Design Parameters

01 **All letters, numerals, symbols, and arrows shall be white in color, except as provided in Section 3B.20 of the 2009 MUTCD, and in conformance with the design details in the Pavement Markings chapter of FHWA's "Standard Highway Signs and Markings" book, 2004 Edition.**

02 *Word and symbol markings should be centered within the lane to which they apply.*

03 *If a pavement marking word message consists of more than one line of information, it should read in the direction of travel. The first word of the message should be nearest to the road user.*

04 Except for the word message "BIKE LANE," pavement marking word messages meant for bicyclists may read against the direction of travel (the first word of the message may be farthest from the bicyclist).

05 *Except for the two opposing arrows of a two-way left turn lane marking, the longitudinal space between word or symbol message markings, including arrow markings, should be at least four times the height of the characters for low-speed roads, but no more than ten times the height of the characters under any conditions.*

06 *Except for the SCHOOL word marking (see Section 610), pavement word, symbol, and arrow markings should be no more than one lane in width.*

07 **Except at the end of aisles in parking lots, the word STOP shall not be used on the pavement unless accompanied by a stop line and STOP sign. At the ends of aisles in parking lots, the word STOP shall not be used on the pavement unless accompanied by a stop line.**

08 **The word STOP shall not be placed on the pavement in advance of a stop line, unless every vehicle is required to stop at all times.**

Design Issues

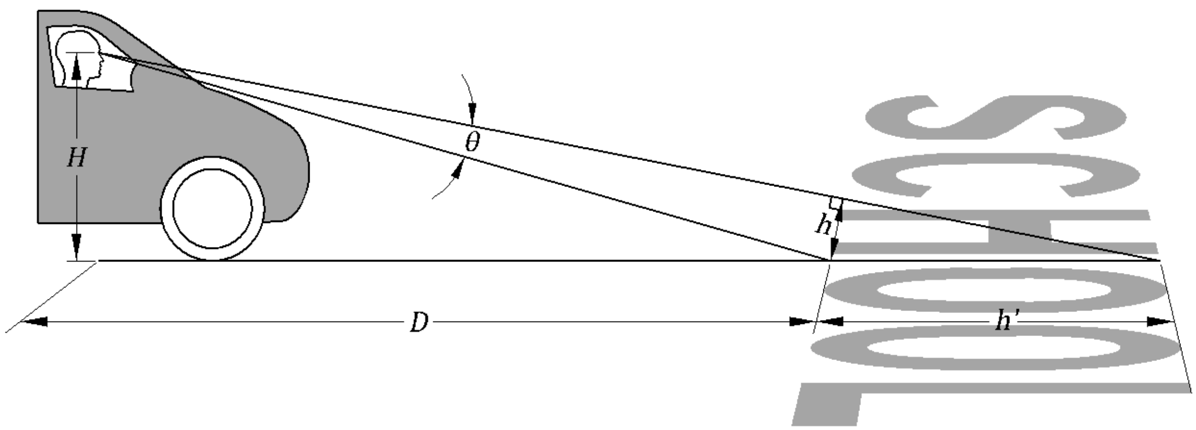
Design parameters related to specific transverse markings are provided throughout the Traffic Line Manual. See the cross references of this section.

Warning message word legends like SCHOOL XING and STOP AHEAD are typically placed at the same location as the warning signs they supplement.

Green colored pavement is a type of transverse marking treatment. See Section 413 for design parameters and more information.

Figures & Tables

Figure 125: Viewing Angle of Transverse Pavement Marking



$$\theta = \tan^{-1}\left(\frac{D+h'}{H}\right) - \tan^{-1}\left(\frac{D}{H}\right)$$

Where:

$\theta=$ viewing angle
$D=$ viewing distance
$H=$ driver eye height (3.5' typ. for passenger vehicle)
$h=$ apparent letter height
$h'=$ letter height (8' and 10' typical)

Support

Approximately 90 percent of the driving task is related to obtaining visual information from the road to maneuver the vehicle safely. Drivers' visual fixations are predominantly within their own lane – approximately 80 percent of driver fixations are within the central 15 degrees of visual field (*1*). Additionally, when drivers experience a high-stress situation or are presented with too much information, drivers tend to focus on more important tasks and focus on the road ahead and less on side or overhead-mounted signing (*1*). Transverse markings have the unique ability to place regulation, warning, and guidance messages centered within the drivers' visual field, even in complex driving situations.

One illustration of this benefit is a STOP AHEAD legend. At stop-controlled intersections with a high frequency of right-angle and rear-end crashes, particularly where driver awareness might be an issue, adding a STOP AHEAD legend on approaches controlled by a STOP sign can significantly reduce total and injury crashes (2).

Transverse markings are elongated along the direction of approaching traffic because of the low approach angles at which pavement markings are viewed. As a road user approaches a transverse marking, the transverse marking appears to get taller (apparent height is a tangent function of the distance the marking is being viewed at, shown in Figure 125). Elongating transverse markings along the direction of approaching traffic increases the distance road users can see, recognize, and act upon a transverse marking's message (*3*) (*4*) (*5*), though there is a practical limit to how much a transverse marking can be elongated before it becomes distorted (*5*).

If used, word markings typically supplement standard signs because word markings will provide less reading time of the message compared to standard signs (*6*). For example, the minimum MUTCD recommendation for letter height on signs is 1 inch of letter height per 30 feet of legibility distance (*7*) (angle of about 9.5 minutes of visual arc), which accommodates drivers with compromised vision (human factors research has suggested a person with 20/20 vision can correctly identify objects that encompass about 0.5 minutes of visual arc (*6*)). Using a passenger vehicle driver eye height of 3.5 feet, a standard 8-foot tall word legend will achieve the minimum MUTCD sign letter viewing angle at approximately 95 feet from the legend; a 10-foot tall legend will achieve this at approximately 105 feet. Even at lower speeds, this only accommodates 2-3 seconds of reading time before the driver passes over the marking.

Pavement marking arrows also provide a shorter viewing distance than lane use arrows on signs (*3*). This is one reason multiple arrows are used at turn lanes, or if just one arrow is used, it is used at the beginning of the turn lane. Providing early guidance in the turn lane gives road users time to choose the appropriate lane before reaching the intersection.

Diagonal crosshatch markings are transverse markings. The color depends on the direction of traffic relative to the chevron and diagonal crosshatch marking. See Sections 260 and 270 for more information.

Cross References

Colors .... Section 110
Stop Bars .... Section 150
Yield Lines .... Section 151
Lane Use Arrows .... Section 160
Lane Reduction Transitions .... Section 250
Lane Addition Transition & No-Passing Zones in 3-Lane Sections .... Section 251
Traversable Medians .... Section 260
Two-Way Left Turn Lanes .... Section 261
Approach to a Fixed Obstruction .... Section 280
Left Turn Lanes .... Section 310
Added Right Turn Lanes .... Section 320
Channelized Right-Turn Lanes .... Section 321
Dropped Lanes and Auxiliary Lanes on Conventional Roads .... Section 330
Roundabouts .... Section 350
Interchange Ramps: Ramp Terminals .... Section 361

Bicycle Lanes .... Section 410
Bicycle Lane Buffers .... Section 412
Colored Pavement in Bicycle Lanes .... Section 413
Intersection Bicycle Box .... Section 414
Bicycle Detector Markings .... Section 416
Shared Lane Markings .... Section 420
Marked Crosswalks .... Section 430
Railroad Crossing Markings .... Section 510
Bus Pullouts .... Section 520
Preferential Lane Markings .... Section 530
School Markings .... Section 610
Ramp Meters .... Section 620
Parking Space Markings .... Section 630
Cattle Guard Markings .... Section 650

Key References

1. Campbell, J. L., M. G. Lichty, J. L. Brown, C. M. Richard, J. S. Graving, J. Graham, M. O'Laughlin, D. Torbic, and D. Harwood. NCHRP Report 600: Human Factors Guidelines for Road Systems. 2012. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_600Second.pdf. Accessed October 23, 2012.
2. Gross, F., R. Jagannathan, C. Lyon, and K. Eccles. Safety Effectiveness of "Stop Ahead" Pavement Markings. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2056, 2008, pp. 25-33. http://trrjournalonline.trb.org/doi/abs/10.3141/2056-04. DOI: http://dx.doi.org/10.3141/2056-04
3. Zwahlen, H. T., T. Schnell, and S. Miescher. Recognition Distances of Different Pavement Arrow Designs During Daytime and Nighttime. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1692, 1999, pp. 119-128. http://trrjournalonline.trb.org/doi/pdf/10.3141/1692-13. DOI: http://dx.doi.org/10.3141/1692-13
4. Ullman, B. R., M. D. Finley, S. T. Chrysler, N. D. Trout, A. A. Nelson, and S. Young. Guidelines for the Use of Pavement Marking Symbols at Freeway Interchanges. Texas Transportation Institute, College Station, TX, FHWA/TX-10/0-5890-1, 2010. http://tti.tamu.edu/documents/0-5890-1.pdf.
5. Chitturi, M. V., I. Alsghan, K. R. Santiago, and D. A. Noyce. Field Evaluation of Elongated Pavement Marking Signs. *Transportation Research Record: Journal of the Transportation Research Board Online*, Vol. 2624, 2017, pp. 28-37. http://trrjournalonline.trb.org/doi/abs/10.3141/2624-04. DOI: https://doi.org/10.3141/2624-04
6. Chrysler, S. T., and S. D. Schrock. Field Evaluations and Driver Comprehension Studies of Horizontal Signing. Texas Transportation Institute, College Station, Texas, FHWA/TX-05/0-4471-2, 2005. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-4471-2.pdf.
7. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.

Raised Pavement Markers Section 130

Introduction

Raised pavement markers (RPMs) are raised delineation devices installed on a roadway surface or in a groove to enhance the centerline, lane line(s), and other areas requiring additional emphasis (such as gore areas). RPMs provide better visibility over painted or durable lines during wet-weather conditions, especially at night. They also provide a tactile and auditory warning when vehicle tires cross over them.

Design Parameters

01 **The color of raised pavement markers under both daylight and nighttime conditions shall conform to the color of the marking for which they serve as a positioning guide, or for which they supplement or substitute. Non-retroreflective RPMs shall not substitute for other types of pavement markings unless accompanied by retroreflective markers.**

02 *On freeways with an average annual daily traffic (AADT) of 20,000 vehicles per day or greater, RPMs should be used to supplement lane lines and wide white channelizing lines at exit gore areas.*

03 *On non-freeways, RPMs should be used in accordance with the Region RPM Plan. The Region RPM Plan should consider using RPMs in locations with a history of wet weather nighttime crashes.*

04 *RPMs should be installed such that directional configurations of reflective and non-reflective surfaces minimize visibility of information to road users that does not apply to them.*

05 *RPMs should not be used within bicycle lanes and should not be used to substitute a line separating bicycle lanes from adjacent travel lanes. At locations where a bicycle lane is adjacent to a line supplemented with RPMs or where RPMs are used as positioning guides, the RPMs should be positioned outside the bicycle lane and the spacing should be long enough to allow safe passage if a bicyclist leaves the bicycle lane.*

06 *If used, RPMs should be recessed in snow zones and on roadways that are frequently plowed (see Figures 130-A and 130-B).*

07 Where used, RPMs may function as:

- A supplement for longitudinal pavement markings,
- Vehicle positioning guides,
- A location marker for fire hydrants, and
- Advance warning for freeway median crossovers.

08 Blue RPMs may be used to help emergency personnel locate fire hydrants.

09 RPMs may be used to supplement other markings such as channelizing islands, gore areas, or approaches to obstructions.

10 RPMs may be used in the roadway immediately adjacent to curbed approach ends of raised medians and curbs of islands, or on top of such curbs.

Design Issues

Replacement of RPMs depends mostly on exposure to traffic and is generally within 2-4 years (*1*).

Surface-installed RPMs provide better guidance to road users than recessed RPMs in dry and wet weather conditions, but RPMs are susceptible to damage and removal from traffic and plowing. This damage can be reduced by recessing the RPM below the roadway surface (*1*).

Recessed RPMs do not perform as well as raised RPMs under dry and wet weather conditions. Grooves tend to seasonally collect rain, snow, ice, or debris that obscures part of the RPM. Moving traffic helps clean the top of the groove so recessed markers remain visible (*1*). However, a recessed RPM that collects debris but remains in service through a winter is better than a surface mounted RPM that will be removed by the first plow blade of the season. The groove is designed to reflect part of the RPM's reflective surface from 200 feet with a headlight 2.0 feet above the pavement surface. At highway speeds on level roadways, this provides the minimum preview distance for lane keeping (2.0-2.5 seconds).

Contact Construction Section's Pavement Services Unit early in the project planning process for all installations of recessed RPMs due to pavement type and condition being considerations in using recessed RPMs.

Recessed RPMs are not allowed on concrete bridge decks, see Section 1.9 of the Bridge Design Manual for more information.

Edge line RPMs can be mistaken for lane lines if not very close together and can be difficult to ride over on a bicycle. There are areas where it can be beneficial: lane reduction transitions, pinch points of reduced lane width (e.g.: narrow structures), and freeway exit gore areas.

Figures & Tables

Figure 130-A: Bi-Directional Recessed Pavement Marker Detail

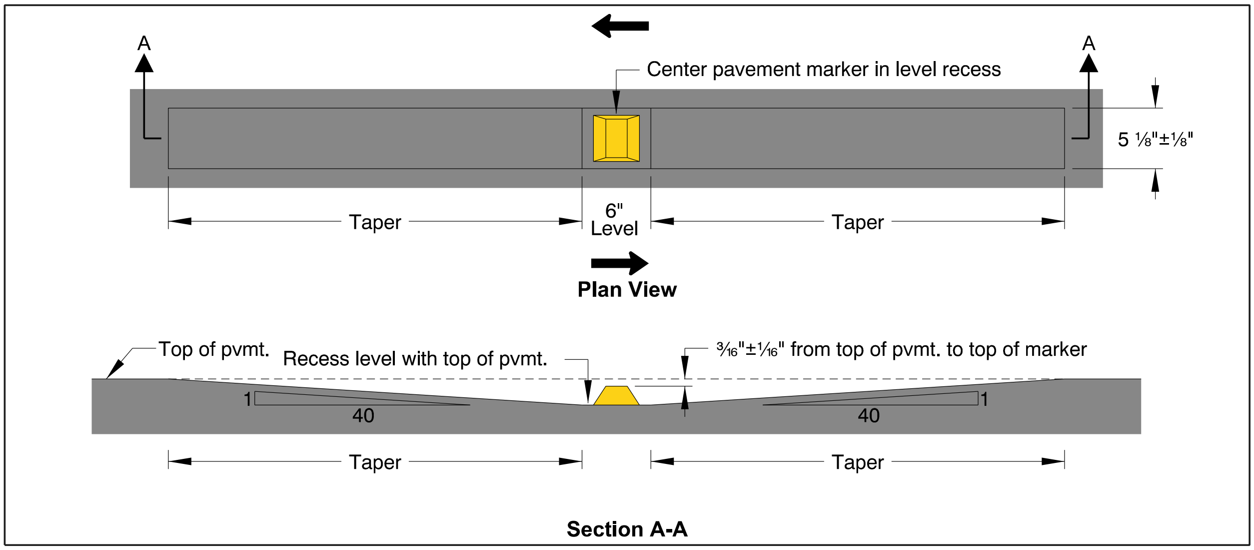
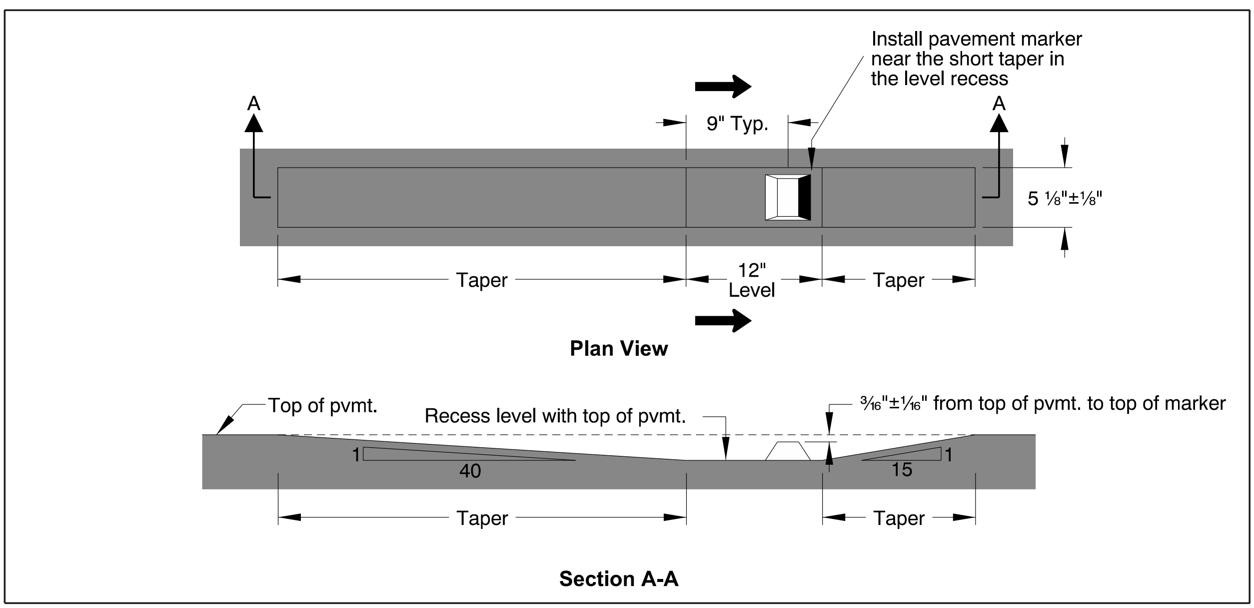


Figure 130-B: Mono-Directional Recessed Pavement Marker Detail



Support

At higher speeds, road users need to see the roadway farther ahead. Human factors studies estimate this distance is 2-3 seconds to maintain lane position; 3-5 seconds to feel comfortable with changes in the roadway path. Raised pavement markers (RPMs) increase preview distance and guidance for road users, especially in inclement weather and low-light conditions, and provides a tactile and auditory warning to smaller vehicles when tires hit the RPMs (*1*).

Improved delineation from RPMs affects lane control and speed control – two types of driver behavior that affects safety at night and in poor visibility (*1*). RPMs provide longer wet-night detection distance than any pavement marking material - even marking materials designed for wet weather performance (*2*), and visibility of RPMs can be better than visibility of paint under all weather conditions even after the RPMs have been in service for multiple years (*1*).

Well-maintained RPMs can also reduce the need for high levels of pavement marking retroreflectivity. RPMs can provide enough preview information to nighttime drivers that the pavement markings are mainly needed for short-distance visual information required for lateral placement control of the vehicle. Many marking materials can provide sufficient retroreflectivity to accommodate most drivers at 55 mph and lower when the marking is new, but cannot maintain that needed level of retroreflectivity over the life of the material. Adding RPMs makes it possible to accommodate most drivers' preview distance needs, even at high speeds (*3*).

The use of red-backed RPMs is covered in Section 361 Interchange Ramps: Ramp Terminals. See Section 361 for use and approvals required for red-backed RPMs.

NCHRP project 05-21 is underway to develop a more robust guide on use and placement of RPMs; design parameters in this section will be updated following publication from this NCHRP project (*4*).

2-Lane Roadways

Blanket, non-selective implementation of RPMs on 2-lane roadways does not significantly change frequency of total or nighttime crashes. Locations selected on the basis of wet weather nighttime crash history show positive safety effects for total and nighttime crashes (*1*).

Drivers tend to move away from delineation measures like RPMs. When used with a centerline, this can reduce head-on crashes but could increase run-off-the-road crashes, especially on roadways with narrow or no shoulders (*1*).

Improved delineation decreases driver workload and drivers could compensate by increasing speed. This is most important where drivers already operate close to the side friction margin of safety, such as on sharp curves. RPMs on curves with a degree of curvature greater than 3.5 (radius <1600 ft.) could cause an increase in nighttime non-intersection crash frequency on two-lane roads. Conversely, run-off-the-road and head-on crashes during wet nights could be reduced from RPMs on gentle curves where demanded side friction remains well below side friction capacity (*1*).

On sharper curves (radius <1600 ft.) other delineation measures such as delineators and especially chevrons are effective devices to guide road users and reduce road departure crashes (*5*) (*6*) (*7*).

Freeway-Type Facilities

Lane line RPMs on freeway-type facilities decrease nighttime crashes with increasing benefits as traffic volume increases. Most benefits come from a decrease in guidance-related crashes (sideswipe/lane keeping) and decreases in wet-weather-related crashes. RPMs are most effective in reducing nighttime crashes when the AADT exceeds 20,000 vehicles per day. Speed could increase with improved delineation on freeway-type facilities, but these are built to higher standards so it is unlikely that small speed increases will cause drivers to operate at or close to the side friction margin of safety, though increased speed does increase stopping and weaving distances. RPMs in gore areas also reduce the frequency of encroachment in the gore (*1*).

Cross References

Colors .... Section 110
RPMs Used for Supplementation Section131
RPMs Used for Positioning Guides .... Section 132
Non-Traversable Medians & Channelizing Islands .... Section 281
Freeway Median Crossovers .... Section 640

Key References

1. Bahar, G., C. Mollett, B. Persaud, C. Lyon, A. Smiley, T. Smahel, and H. McGee. NCHRP Report 518: Safety Evaluation of Permanent Raised Pavement Markers. Transportation Research Board, Washington, D.C., ISBN 0-309-08790-2, 2004. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_518.pdf.
2. Carlson, P. J., J. D. Miles, A. M. Pike, and E. S. Park. Evaluation of Wet-Weather and Constrast Pavement Marking Applications: Final Report. Texas Transportation Institute, Texas A&M University System, College Station, TX, FHWA/TX-07/0-5008-2, 2007. http://tti.tamu.edu/documents/0-5008-2.pdf.
3. Migletz, J., and J. Grahm. NCHRP Synthesis 306: Long-Term Pavement Marking Practices. Washington, D.C., 2002. http://www.trb.org/Main/Blurbs/152126.aspx.
4. Transportation Research Board. NCHRP 05-21: Safety and Performance Criteria for Retroreflective Pavement Markers. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3859. Accessed May 4, 2017.
5. Fitzpatrick, K., K. Balke, D. W. Harwood, and I. B. Anderson. NCHRP Report 440: Accident Mitigation Guide for Congested Rural Two-Lane Highways. Transportation Research Board of the National Academies, Washington, D.C., ISBN 0-309-06627-7, 2000.
6. Torbic, D. J., D. W. Harwood, D. K. Gilmore, R. Pfefer, T. R. Neuman, K. L. Slack, and K. K. Hardy. NCHRP Report 500 Volume 7: A Guide for Reducing Collisions on Horizontal Curves. Transportation Research Board of the National Academies, Washington, D.C., ISBN 0-309-08760-0, 2004. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_500v7.pdf.
7. Campbell, J. L., M. G. Lichty, J. L. Brown, C. M. Richard, J. S. Graving, J. Graham, M. O'Laughlin, D. Torbic, and D. Harwood. NCHRP Report 600: Human Factors Guidelines for Road Systems. 2012. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_600Second.pdf. Accessed October 23, 2012.

RPMs Used for Supplementation Section 131

Introduction

Raised pavement markers supplementing longitudinal lines convey information about where lines are located and information about passing and lane-use restrictions.

Design Parameters

01 Raised pavement markers may be used to supplement longitudinal lines as shown in Figure 131.

02 *When supplementing wide line markings, pairs of raised pavement markers placed laterally adjacent to each other and outside the through travel lane should be used.*

03 *When supplementing solid line markings, raised pavement markers should be spaced no greater than 40 feet apart, except when supplementing channelizing lines, a spacing no greater than 20 feet should be used, and when supplementing edge lines, a spacing no greater than 10 feet should be used.*

04 *When supplementing broken line markings, a spacing no greater than 40 feet should be used.*

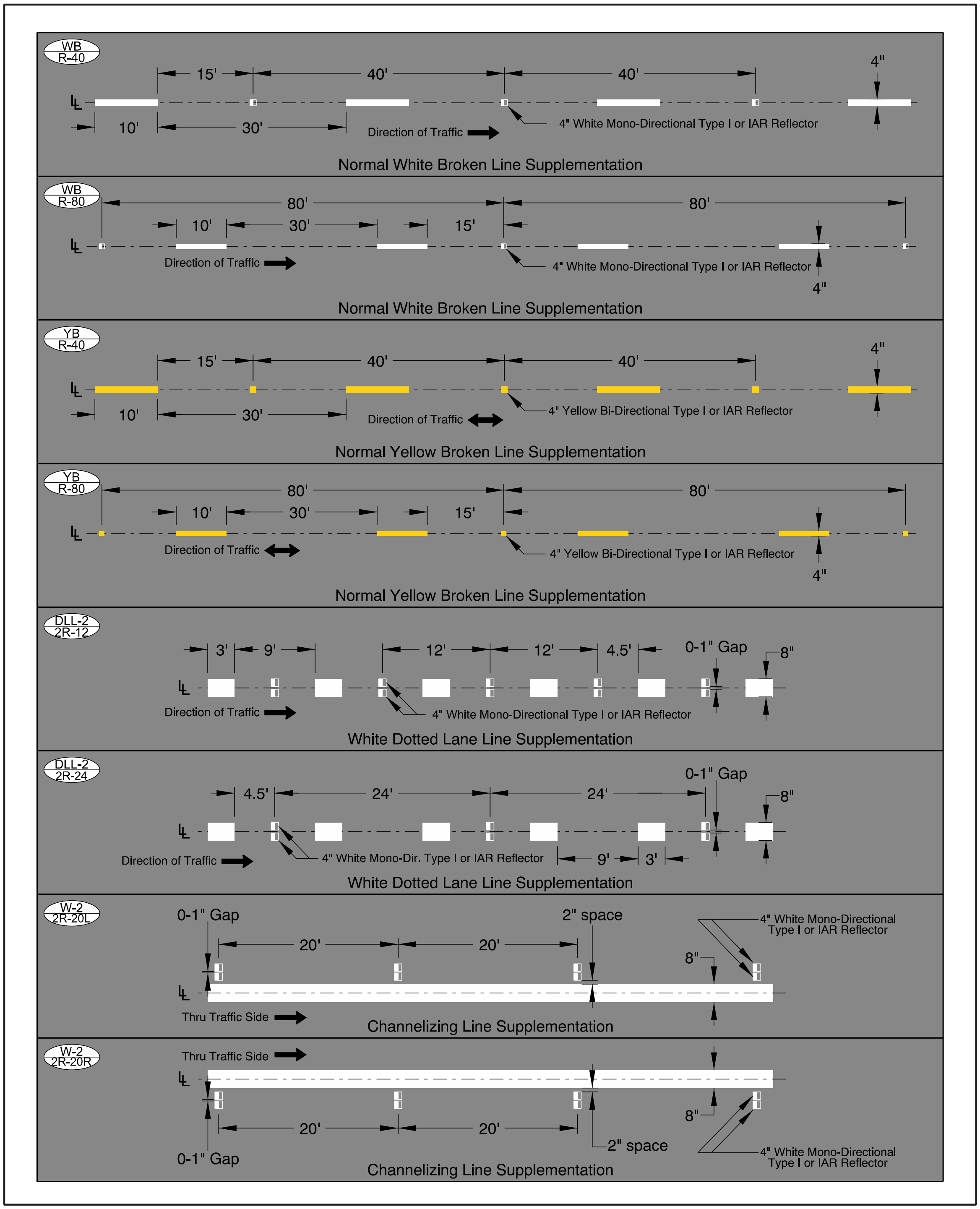
05 When supplementing broken line markings on tangent sections, a spacing no greater than 80 feet may be used based on engineering judgement.

06 *When supplementing dotted lane line markings, a spacing no greater than 24 feet should be used. Where engineering judgement determines a need for greater emphasis, a spacing no greater than 12 feet should be used.*

07 *Raised pavement markers should not supplement right-hand edge lines unless an engineering study or engineering judgement indicates the benefits of enhanced delineation of a curve or other location would outweigh possible impacts on bicycles using the shoulder, and the spacing of raised pavement markers on the right-hand edge is close enough to avoid misinterpretation as a broken line during wet night conditions.*

Figures & Tables

Figure 131: Longitudinal Line RPM Supplementation Details



Support

RPMs supplementing longitudinal lines convey information about where lines are located and information about passing or lane-use restrictions (*1*). For example, supplementation of a wide solid white line uses two RPMs placed next to the painted lines instead of a single RPM, communicating that the solid line is wide and therefore has greater emphasis.

Supplementation layouts are primarily based on guidance in the MUTCD (*1*) and the ITE Traffic Control Devices Handbook (*2*) (referenced by the MUTCD for RPM spacing). Broken and dotted lane lines have two standard spacings – RPMs placed every cycle or every other cycle (40 or 80 feet for broken lines; 12 or 24 feet for dotted lane lines). The ITE Traffic Control Devices Handbook recommends the shorter spacing through horizontal curves to provide enhanced delineation in high driver workload areas and to minimize loss of delineation because of generally higher rates of damage and loss at horizontal curves.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Raised Pavement Markers Section130
Typical Layouts for RPMs .... Section 133

Key References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
2. Institute of Transportation Engineers. *Traffic Control Devices Handbook*. Institute of Transportation Engineers, Washington, D.C., 2001.

RPMs Used for Positioning Guides Section 132

Introduction

Raised pavement markers used as positioning guides convey information about where lines are located, but not necessarily information about passing or lane-use restrictions.

Design Parameters

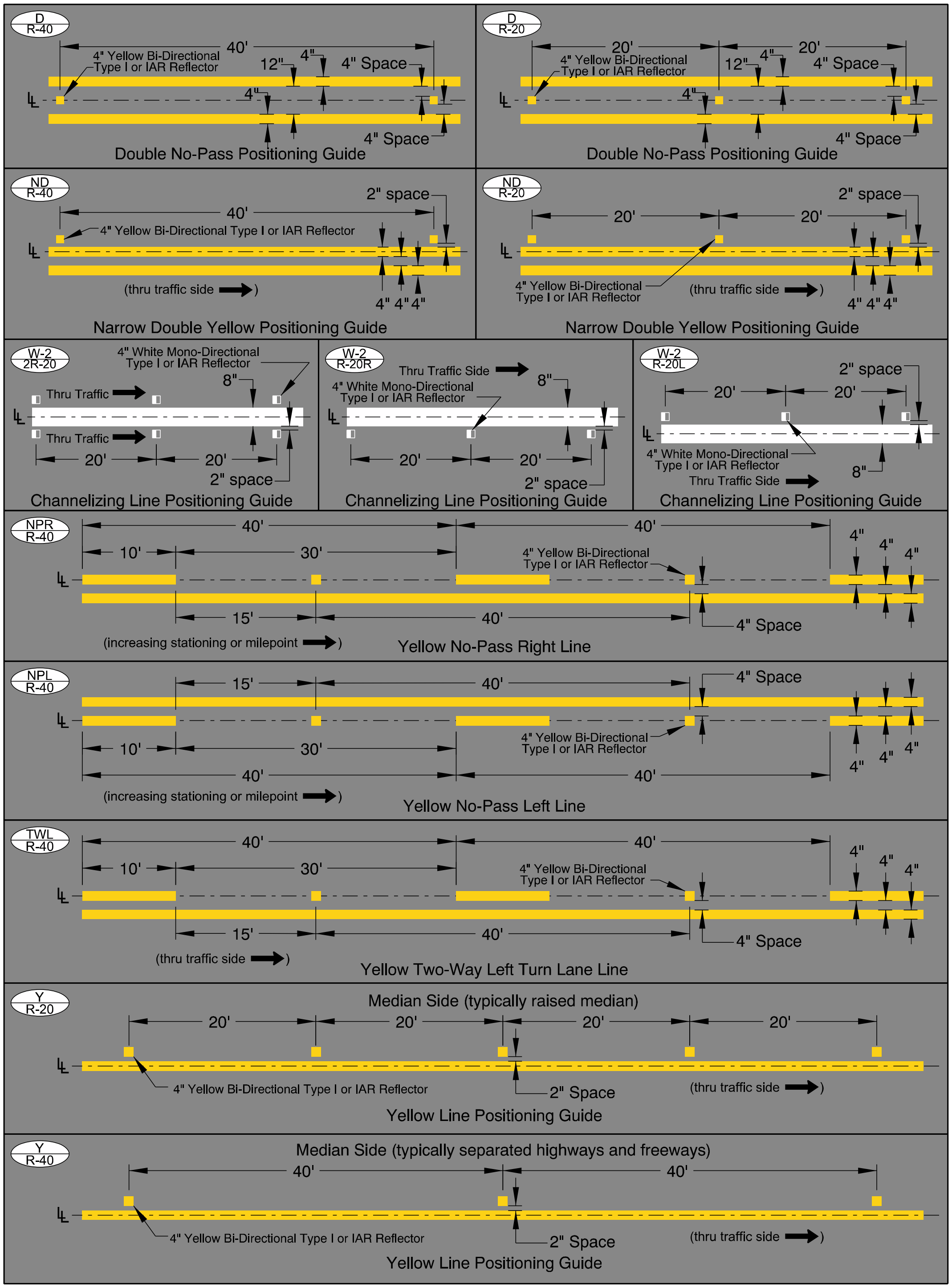
01 Raised pavement markers may be used as positioning guides with longitudinal line markings as shown in Figure 132.

Design Issues

The groove for recessed RPMs tend to seasonally collect rain, snow, ice, or debris that obscures part of the RPM (*1*). Wind created by moving traffic tends to clean out part of these grooves. Side-street approaches to intersections might not have enough moving traffic to generate sufficient wind to clean recessed RPM grooves (e.g.: left or right turn lane positioning guides), especially if the side street is stop controlled.

Figures & Tables

Figure 132: Longitudinal Line RPM Positioning Guide Details



Support

RPMs used as positioning guides convey information about where lines are located but not necessarily information about passing or lane-use restrictions (*2*). For example, supplementation of a double yellow no-passing line uses pairs of RPMs placed immediately outside the painted lines instead of a single RPM placed between the painted lines, communicating that there are two solid lines (this is commonly seen in California). A single RPM is used as positioning guide for all center line patterns, communicating where the center line is but not the pattern.

Positioning guide layouts are primarily based on guidance in the MUTCD (*2*) and the ITE Traffic Control Devices Handbook (*3*) (referenced by the MUTCD for RPM spacing). Double lines have two standard spacings – 40 feet (corresponding to a standard broken line cycle) and 20 feet (corresponding to half a standard broken line cycle). The ITE Traffic Control Devices Handbook recommends 20-foot spacing for solid lines on horizontal curves to provide enhanced delineation in high driver workload areas and to minimize loss of delineation because of generally higher rates of damage and loss at horizontal curves.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Raised Pavement Markers Section130
RPMs Used for Supplementation Section131
Typical Layouts for RPMs .... Section 133

Key References

1. Bahar, G., C. Mollett, B. Persaud, C. Lyon, A. Smiley, T. Smahel, and H. McGee. NCHRP Report 518: Safety Evaluation of Permanent Raised Pavement Markers. Transportation Research Board, Washington, D.C., ISBN 0-309-08790-2, 2004. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_518.pdf.
2. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
3. Institute of Transportation Engineers. *Traffic Control Devices Handbook*. Institute of Transportation Engineers, Washington, D.C., 2001.

Typical Layouts for RPMs Section 133

Introduction

RPM layouts in this section are typical for the features shown.

Design Parameters

01 *Where raised pavement markers are used at:*

- *Left turn lanes, they should be installed according to Figure 133-A and 133-B.*
- *Island noses, they should be installed according to Figure 133-C.*
- *Tapered freeway exit ramps, they should be installed according to Figure 133-D.*
- *Single lane drop freeway exit ramps, they should be installed according to Figure 133-E.*
- *Two-lane freeway exit with single lane drop, they should be installed according to Figure 133-F.*
- *Multi-lane freeway exit with two or more dropped lanes, they should be installed according to Figure 133-G.*

02 RPM spacing shown in Figures 133-A, 133-B, and 133-C may be shortened by half, based on engineering judgement. RPM supplementation may be used for white longitudinal lines where RPMs are shown as positioning guides for white longitudinal lines in Figures 133-A and 133-B.

Figures & Tables

Figure 133-A: Typical Narrow Median Left Turn Lane Layout with RPMs

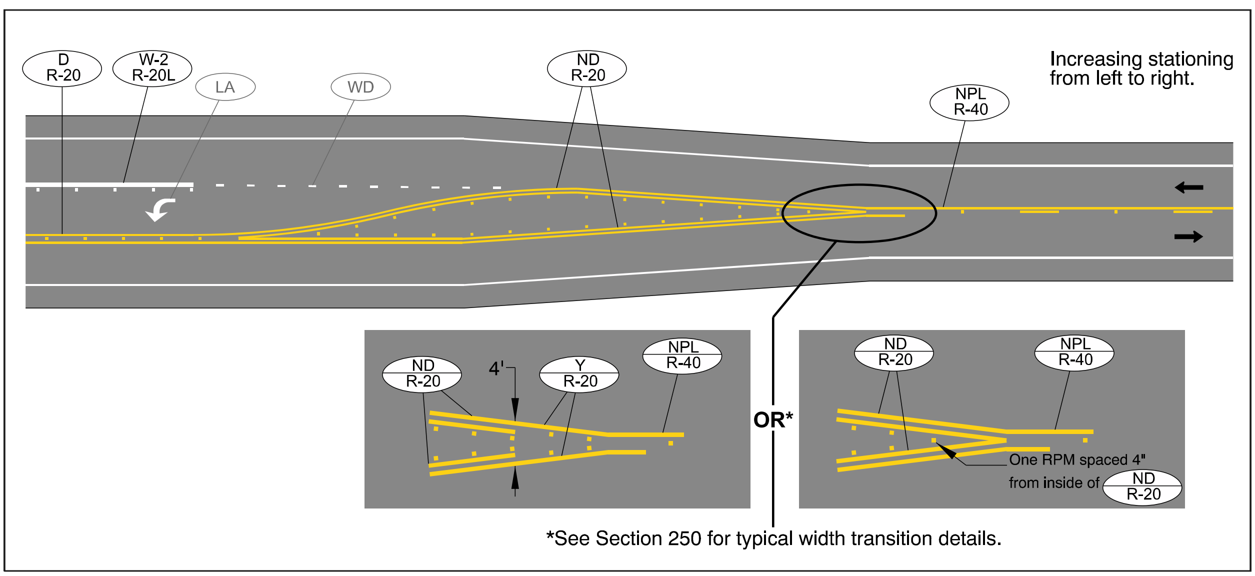


Figure 133-B: Typical Wide Median Left Turn Lane Layout with RPMs

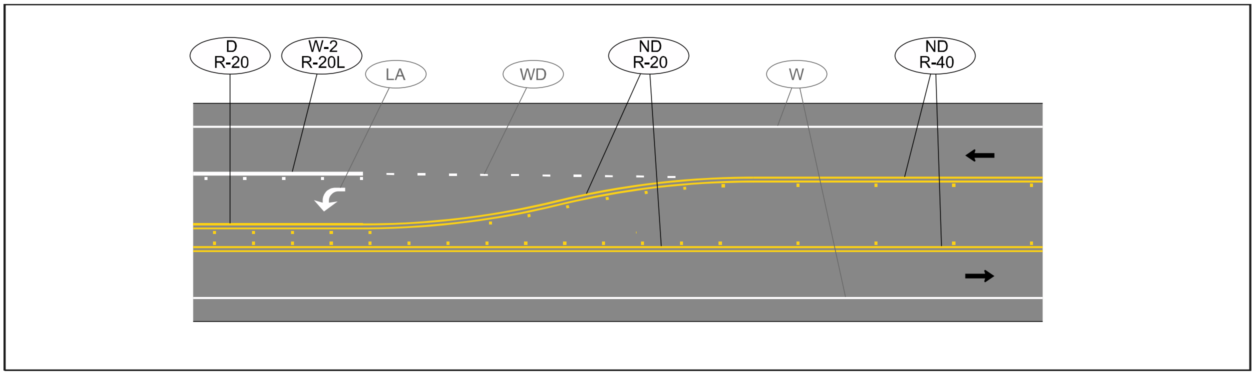


Figure 133-C: Typical RPM Layout at Raised Medians and Channelizing Islands

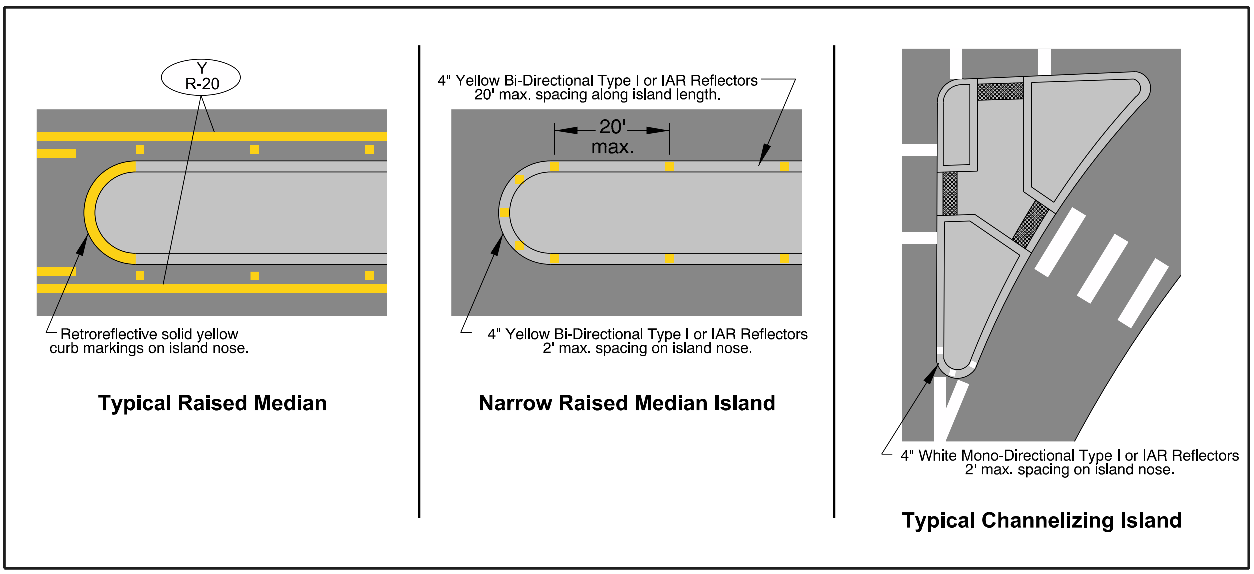


Figure 133-D: Typical Freeway Exit Ramp RPM Layout (Tapered Deceleration Lane)

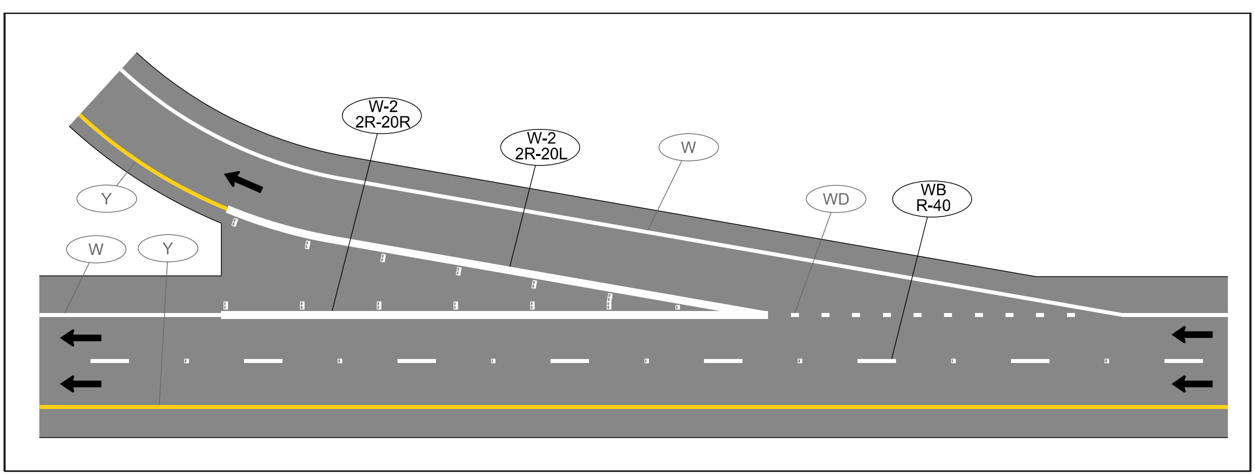


Figure 133-E: Typical Freeway Exit Ramp RPM Layout (Single Lane Drop)

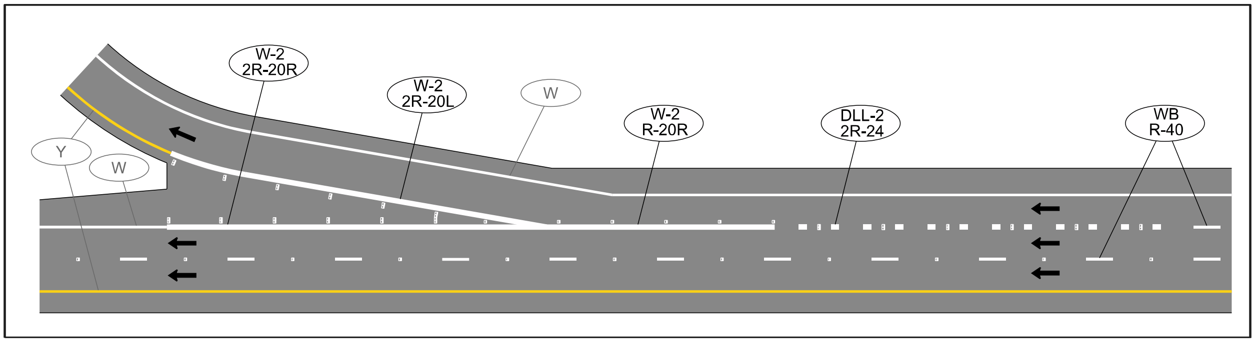


Figure 133-F: Typical Freeway Exit Ramp RPM Layout (Two-Lane Exit with Single Lane Drop)

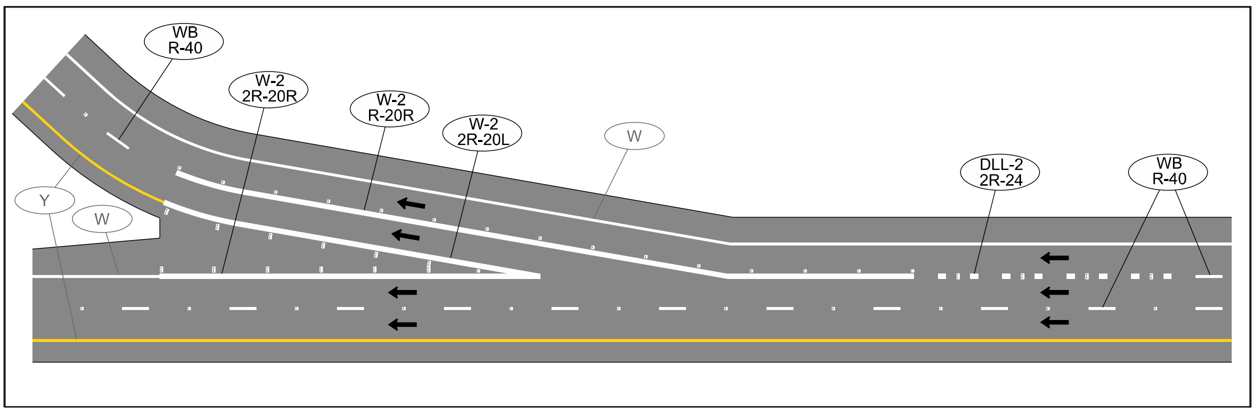
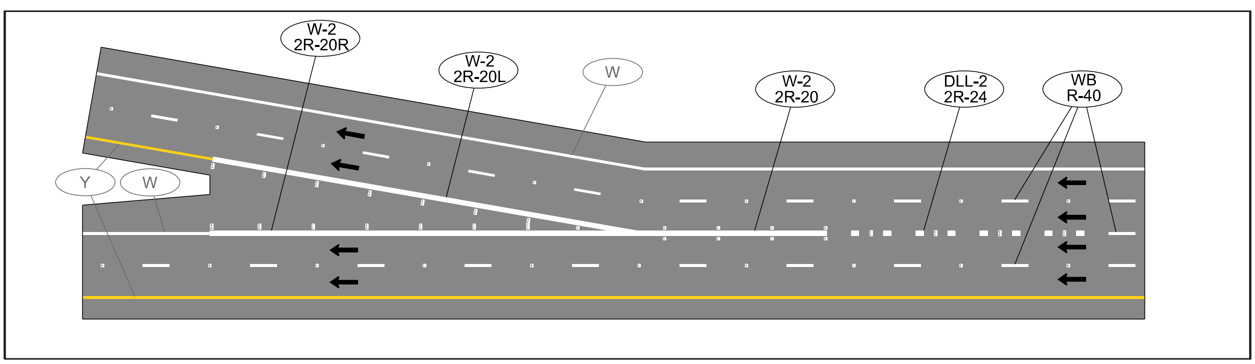


Figure 133-G: Typical Freeway Exit Ramp RPM Layout (Multi-Lane Exit with Two or More Dropped Lanes)



Support

The layouts shown in Figures 133-A through 133-G are based on standard supplementation and positioning guide layouts for individual line types (see Sections 131 and 132), past layouts in Oregon, and engineering judgement.

The channelizing lines in the freeway gore areas use RPM supplementation instead of positioning guide because of the greater emphasis needed at these high speed diverges, especially at dropped exit lanes.

At dropped exit lanes, RPMs are positioned on the exiting lane side of the wide white channelizing line before the painted gore point. This is consistent with how RPMs are used as positioning guides for turn lanes on non-freeways. At multi-lane exits with two or more dropped lanes, RPMs are positioned on both sides of the wide white channeling line prior to the painted gore because these splits are often located at major interstate-interstate interchanges with relatively balanced volumes. This is a standard layout for solid lines at these types of exits in other states such as California (*1*), and Arizona (*2*).

Cross References

Raised Pavement Markers Section130
RPMs Used for Supplementation Section131
RPMs Used for Positioning Guides .... Section 132
Center Lines .... Section 210
Lane Lines .... Section 220
Non-Traversable Medians & Channelizing Islands .... Section 281
Channelized Right-Turn Lanes .... Section 321
Interchange Ramps: Exit & Entrance Ramps .... Section 360

Key References

1. California Department of Transportation. *California Manual on Uniform Traffic Control Devices*. California Department of Transporation, Sacramento, California, 2014. http://www.dot.ca.gov/hq/traffops/engineering/mutcd/ca_mutcd2014.htm.
2. Arizona Department of Transportation. *ADOT Traffic Engineering Policies, Guidelines, and Procedures*. Arizona Department of Transportation, 2000. http://www.azdot.gov/business/engineering-and-construction/traffic/policies-guidelines-and-procedures-(pgp).

Surface Mounted Tubular Markers Section 140

Introduction

Surface mounted tubular markers, also known as flexposts or plastic wands, are vertical channelizing devices attached to the roadway surface, median islands, or channelizing islands. They are used to delineate travel lanes, discourage turns and lane changes, or warn of vertical obstructions in the road (like a raised island).

Design Parameters

01 Surface mounted tubular markers may be used for general traffic control purposes, such as adding emphasis to channelizing lines or islands. Surface mounted tubular markers may also be used along a center line to preclude turns or along lane lines to preclude lane changing, as determined by engineering judgement.

02 **If used, surface mounted tubular markers shall be the same color as the pavement marking that they supplement, or for which they are substituted, and shall not be less than 28 inches high and 3 inches wide facing road users.**

03 Surface mounted tubular markers may be a minimum of 18 inches high, when used for pedestrian detection and to discourage travel across marked area for ADA purposes.

04 *When surface mounted tubular markers are used to enhance a buffer space between a general travel lane and a bicycle lane, the surface mounted tubular markers should be 28 inches high.*

05 **If used, surface mounted tubular markers shall have two flexible retroreflective bands at least three inches wide placed according to Figure 140-A. The color of the retroreflective band shall match the color of the surface mounted tubular marker.**

06 *Except as provided in paragraphs 07 and 08, surface mounted tubular markers should be spaced according to engineering judgement.*

07 *When surface mounted tubular markers are used to:*

- *Supplement or substitute for channelizing lines, a spacing no greater than 20 feet should be used.*
- *Preclude turns, a spacing no greater than 10 feet should be used.*
- *Enhance a buffer space between a general travel lane and a bicycle lane, a spacing no greater than 20 feet should be used.*

08 When surface mounted tubular markers are used along a non-traversable median or raised channelizing island, a spacing of no greater than 80 feet may be used, based on engineering judgement.

09 Surface mounted tubular markers may be placed on the top of approach ends to non-traversable medians and channelizing islands according to Figure 140-B and 140-C.

10 *Surface mounted tubular markers should be kept clean and bright to maximize target value.*

Required Approvals

An engineering study and senior ADA standards engineer approval is required for use of tubular markers for pedestrian guidance.

Send request to the senior ADA standards engineer and cc the state traffic investigations engineer. The request will come from the region roadway manager. Concurrence from the district maintenance manager is recommended.

On form 734-5175 the region roadway manager signature will replace the region traffic engineer signature line.

Design Issues

All permanent surface mounted tubular markers on ODOT's Qualified Products List are capable of being bolted and epoxied to the pavement. Some products rely on the tubular marker material itself to return to a vertical position after being hit; others are designed with internal mechanical systems (like a spring) to return to vertical. Some markers have bases that make removal and replacement relatively easy; others might require the entire base be removed before replacement.

High-impact areas like the leading edge of a run of tubular markers might need more durable markers to minimize lifecycle costs and maintenance crew exposure to traffic. Depending on how often they are hit by motor vehicle traffic, surface mounted tubular markers might need to be replaced frequently to maintain the device's color, retroreflectivity, and respectability. Some areas might also require periodic removal and replacement of the marker, such as for sweeping or plowing operations.

Contact the region pavement marking manager for maintenance's preferences in each location.

Figures & Tables

Figure 140-A: Typical Surface Mounted Tubular Marker Types

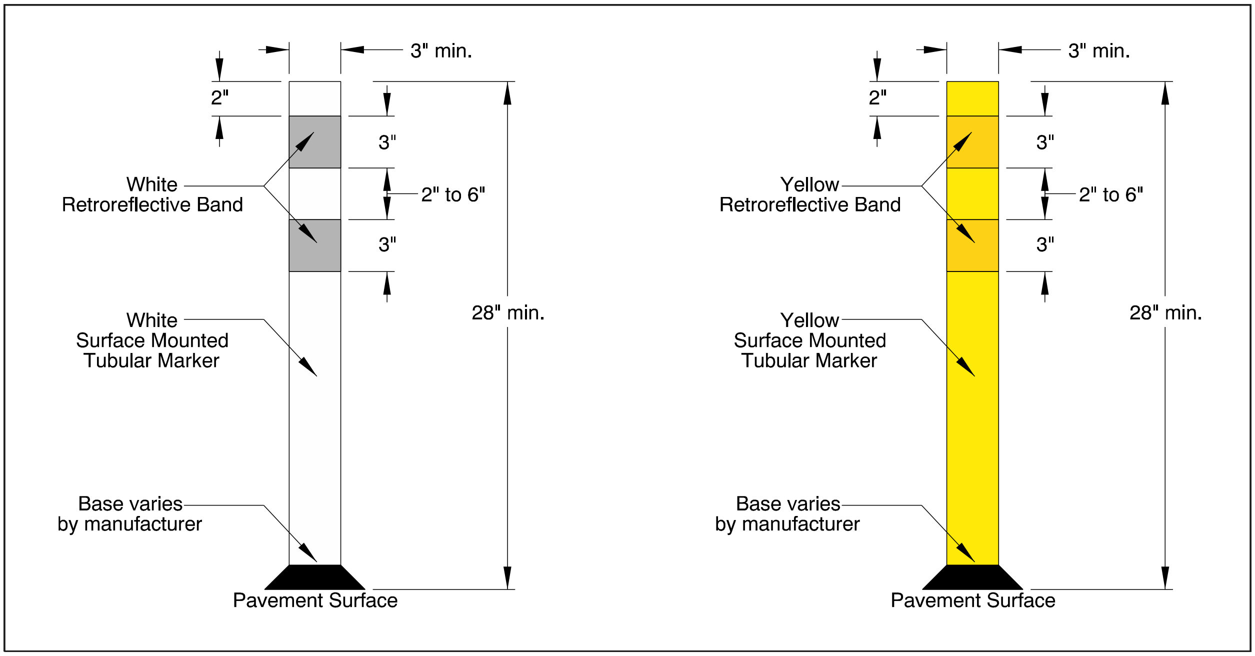


Figure 2140-B: Typical Tubular Marker Placement at Raised Median Island

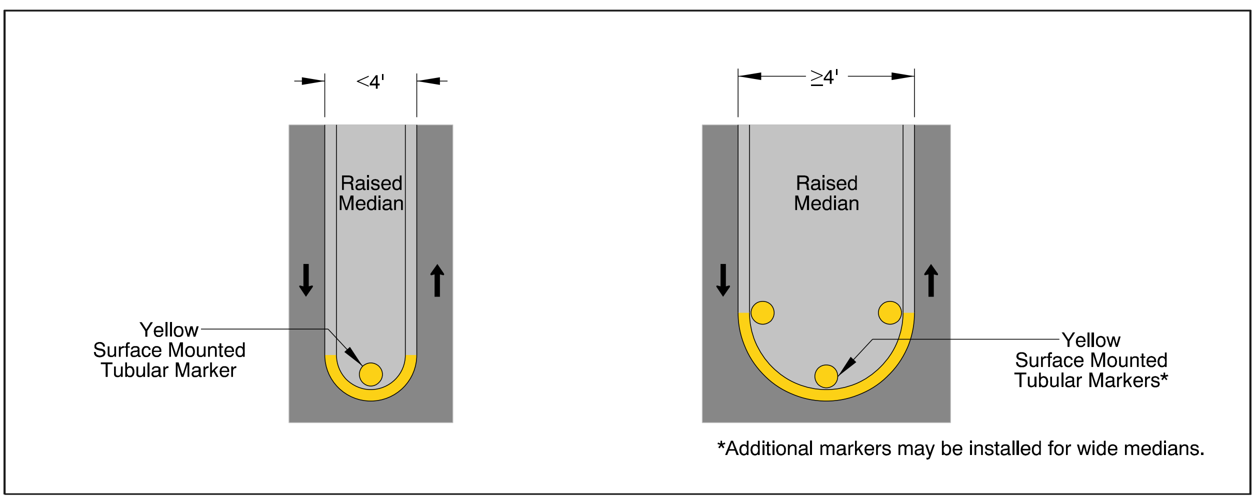
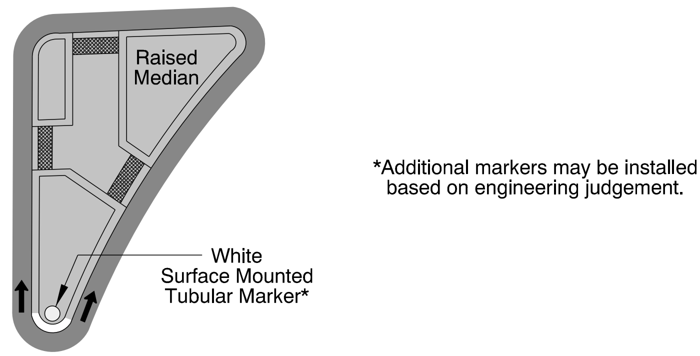


Figure 3140-C: Typical Tubular Marker Placement at Channelizing Island Nose



Support

Except for spacing guidance, the design parameters for surface mounted tubular markers come from Chapter 3H in the 2009 MUTCD (*1*). The minimum height of 28 inches is an MUTCD minimum height for tubular markers used at night. The 28 inch recommended height for tubular markers used in bicycle lane buffers is intended to reduce conflicts with handlebars, which are 36-44 inches above the road surface for a typical adult bicycle (*2*).

The MUTCD does not give guidance for spacing of permanent surface mounted tubular markers. The spacing recommendations in the design parameters are based on MUTCD spacing for temporary traffic control, spacing of raised pavement markers, past practice, and engineering judgement. Maximum spacing for bicycle lane buffers is based on recommendations in FHWA's Separated Bike Lane Planning and Design Guide (*3*).

Surface mounted tubular markers can be used to supplement, but not a replacement for, markings or raised pavement marker treatments at median and channelizing island noses according to the MUTCD. Compared to painted curb and raised pavement markers, tubular markers have good target value and place retroreflective material more in-line with drivers' view. However, surface mounted tubular markers are more prone to damage and removal that could leave the nose unmarked.

Using surface mounted tubular markers has become an option as a detectable warning device for people with limited or no vision. Some intersections with geometric constraints can benefit from having a surface mounted tubular marker installed to help guide people with limited or no vision. The lower height is allowed in this circumstance, because drivers do not need to be able to see it. Having it a lower height also draws less attention to the device and blocks less view of pedestrians on the sidewalk. The tubular marker reduces property damage to errant vehicles in comparison to a solid concrete bollard or other fixed objects in the clear zone.

Cross References

Colors .... Section 110
Traversable Medians .... Section 260
Non-Traversable Medians & Channelizing Islands .... Section 281
Channelized Right-Turn Lanes .... Section 321
Bicycle Lane Buffers .... Section 412
Slow Moving Vehicle Turnouts .... Section 660

Key References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
2. American Association of State Highway and Transportation Officials. *Guide for the Development of Bicycle Facilities*, 4th ed. Washington, D.C., 2012.
3. Federal Highway Administration. *Separated Bike Lane Planning and Design Guide*. U.S. Department of Transportation, Washington, D.C., 2015. https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/separated_bikelane_pdg/separatedbikelane_pdg.pdf.

Delineators Section 145

Introduction

Delineators are retroreflective devices mounted on or near the roadway surface in a series to indicate the alignment of the roadway, especially at night or in adverse weather. They are guidance devices that may be used on long continuous sections of highway or through short stretches where there are changes in horizontal alignment.

Design Parameters

See Chapter 3F Delineators in the Manual on Uniform Traffic Control Devices (*1*) for guidance on delineator use.

Key References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.

Stop Bars Section 150

Introduction

A stop bar (also known as a stop line) is a solid white pavement marking bar extending across approach lanes to indicate the point where a stop is intended or required to be made. To avoid confusion with longitudinal lines, transverse lines are referred to as bars in this Manual.

Design Parameters

01 **A stop bar shall consist of a solid white line extending across approach lanes to indicate the point at which a stop is intended or required to be made (Figure 150-A).**

02 **A stop bar shall be used to indicate the point behind which vehicles are required to stop in compliance with a traffic control signal, unless the near-side bar of a marked crosswalk is used to indicate this point instead. The stop bar shall be placed at least 40 feet in advance of overhead signal indication(s).**

03 Stop bars may be placed closer than 40 feet in advance of overhead signal indications at rail grade crossings according to Section 510.

04 *Stop bars should be used to indicate the point behind which vehicles are required to stop:*

- *In compliance with a "STOP" (R1-1) sign or "Stop Here for Pedestrians" (R1-5b or R1-5c) sign, unless the near-side bar of a marked crosswalk is used to indicate this point instead.*
- *In advance of marked crosswalks, except at approaches and departures from roundabouts, with uncontrolled, multi-lane approaches (e.g. a thru lane and a dedicated turn lane or two thru lanes) (Figure 150-D).*
- *In advance of staggered continental-type marked crosswalks at signalized intersections.*

05 **If used, stop bars shall extend across the traveled way of vehicles to be stopped.**

06 *If used, stop bars should be placed:*

- *As near as possible to the traveled way of the intersected roadway, but should not be closer than 4 feet nor farther than 30 feet from the nearest edge of the intersecting traveled way or nearest crosswalk bar. In sections with sidewalk, the stop bar should be placed 2 to 3 feet back from the throat of the ADA ramp (see Figure 150-B).*
- *20 to 50 feet (typically 30 feet) from the nearside edge of marked crosswalks across uncontrolled multi-lane approaches. A wide stop bar (S-2) should be used at these locations. A stop bar may be omitted where the marked crosswalk is on the far side of the intersection and the stop bar would be placed more than 50 feet from the crosswalk to avoid putting the stop bar in the intersection (Figure 150-D).*
- *So vehicles at the stop bar will not be in the design vehicle's left turning path.*
- *Perpendicular to the path of approaching vehicles.*

07 If used, stop bars may be staggered longitudinally on a lane-by-lane basis (Figure 150-C) in order to improve the driver's view of pedestrians, to provide better sight distance for turning vehicles, to accommodate a bicycle box (Section 414), and to increase the turning radius for left-turning vehicles.

08 *If stop bars are staggered longitudinally on an approach, a maximum of two separate stop bar locations per approach and a maximum offset distance of 20 feet should be used.*

Required Approvals

An engineering study and region traffic engineer approval is required for use of advance stop bars where it is desirable to provide a separate point for vehicles to stop (e.g.: to improve sight distance or to allow adequate turning radii), except in advance of a crosswalk across an uncontrolled multi-lane approach.

Design Issues

At signalized intersections, placement of signal detection is based on distance from the stop bar and partially based on signal head height – if road users stop too close to a signal head it could be obscured (*1*). See 2009 Oregon Supplement to the MUTCD (*2*) Section 3B.16 and 2009 MUTCD (*3*) Figure 4D-5 for additional design parameters.

Figures & Tables

Figure 150-A: Stop Bar Types

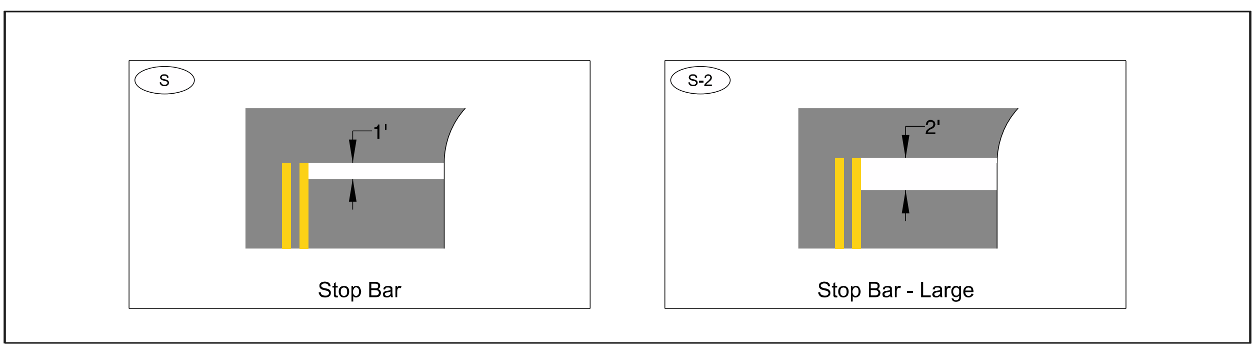


Figure 150-B: Typical Stop Bar Layouts

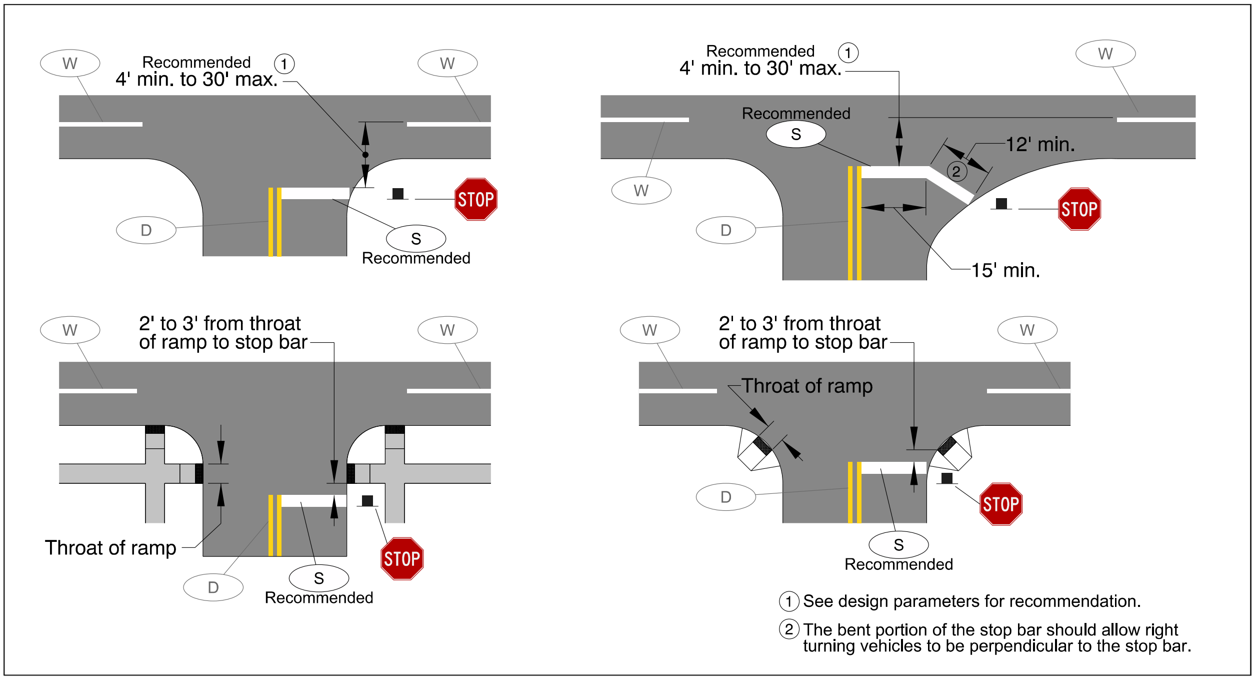


Figure 150-C: Typical Stop Bar Layout for Multiple Lanes

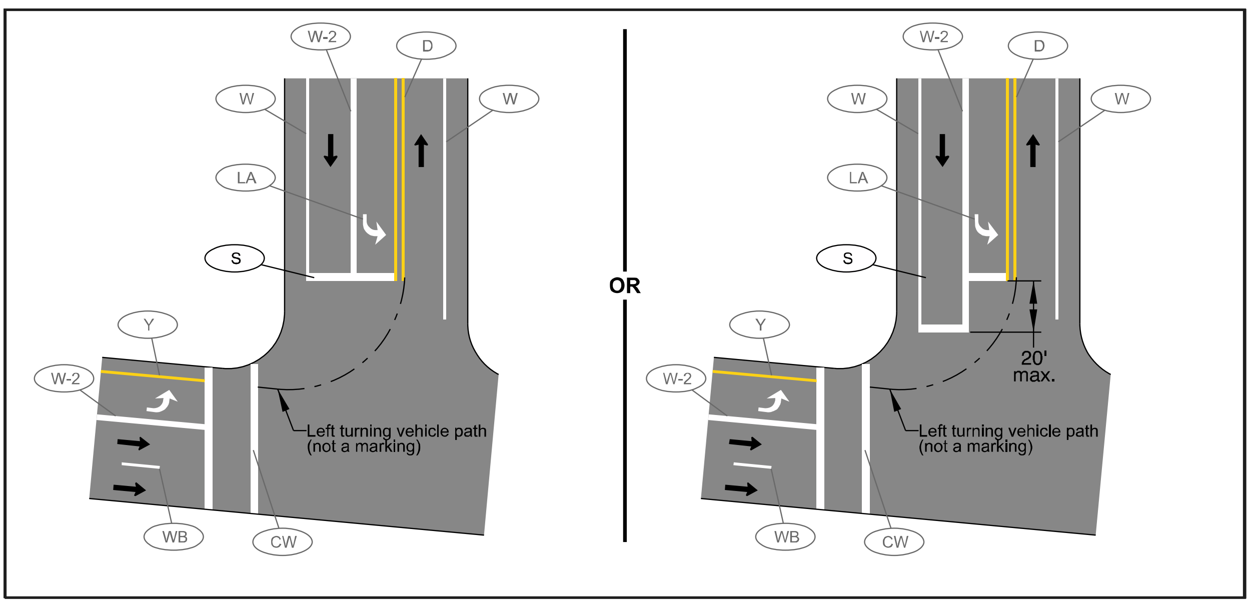
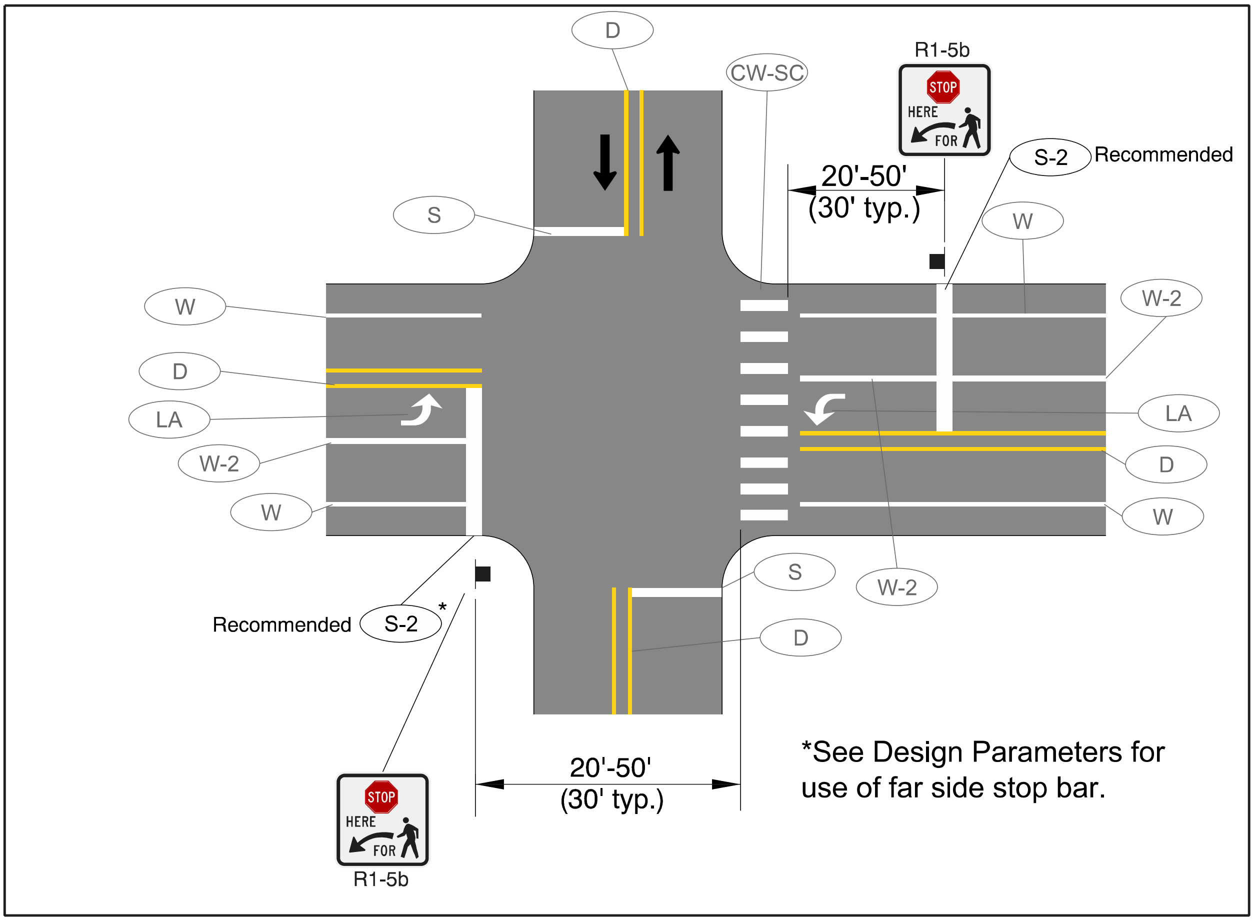


Figure 150-D: Typical Stop Bar Layout for Multi-Lane Approach to Uncontrolled Marked Crosswalk



Support

Stop bars are a fundamental transverse pavement marking that help road users know where they need to stop in response to another traffic control device (signal, stop sign, crosswalk, ramp meter, etc.) and improves the safety, operations, and efficiency of an intersection.

Standard widths of 12 inches for a standard stop bar and 24 inches for a wide stop bar come from 2009 MUTCD (*3*) Section 3B.16.

The MUTCD uses the term “stop line” while ODOT’s standard convention is the term “stop bar.” This terminology is used at ODOT to avoid confusion between longitudinal and transverse markings during design and construction since longitudinal lines are paid on the length basis and transverse bars are paid on the area basis.

If an approach to a signal or stop sign is marked with standard transverse crosswalk bars, the nearside bar of the crosswalk functions as a stop bar. This practice is not common in other states (*4*). The minimum MUTCD width of a marked crosswalk is 6 feet with an advance stop bar 4 feet from the nearside crosswalk bar. Because Oregon's standard crosswalk width is already 10 feet, the nearside crosswalk bar adequately performs the same function as the stop line with minimal practical vehicular encroachment into the crosswalk and without being confusing to the road user (*2*). This also reduces installation and maintenance costs associated with transverse crosswalk bars.

No more than two stop bars offset up to one passenger vehicle length (20 feet) are recommended in the design parameters to avoid confusion and increase compliance at the stop bars. Past installations of stop bars offset more than one vehicle length resulted in poor stopping compliance at the stop bar, which can affect signal detection and potentially affect left turning paths of large vehicles.

A wide stop bar (S-2) increases the detection distance of the stop bar (see Section 125) and is typically used on high speed approaches and approaches where extra emphasis is needed, like rail grade crossings and mid-block crosswalks.

Special consideration is needed at advance stop bars for a far-side multi-lane, uncontrolled approach to a marked crosswalk at an intersection (i.e.: not signal- or stop-controlled). If the purpose of the stop bar is not obvious that it is for the crosswalk and it is placed too far in advance of the crosswalk (generally farther than 50 feet), drivers might ignore the stop bar or think their approach to the intersection is stop controlled (*5*). Drivers are also not allowed to stop within an intersection per ORS 811.550. See the Marked Crosswalk Section 430 for more information on advance stop bars at marked crosswalks.

See the Ramp Meter Section 620 for more information on stop bars at ramp meters.

Cross References

Colors .... Section 110
Transverse Markings .... Section 125
Interchange Ramps: Ramp Terminals .... Section 361
Intersection Bicycle Box .... Section 414
Marked Crosswalks .... Section 430
Railroad Crossing Markings .... Section 510
Ramp Meters .... Section 620

Key References

1. Oregon Department of Transportation. *Traffic Signal Design Manual*, 2016 ed. Oregon Department of Transportation, Salem, OR, 2016. http://www.oregon.gov/ODOT/Engineering/Pages/Signal-Design-Manual.aspx.
2. Oregon Department of Transportation. *Oregon Supplement to the 2009 MUTCD*, 2009 ed. Oregon Department of Transportation, Salem, Oregon, 2011. http://www.oregon.gov/ODOT/Engineering/Documents_TrafficStandards/MUTCD-OR-Supplement.pdf.
3. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
4. Friedman, B. E. NCHRP Synthesis 356: Pavement Markings - Design and Typical Layout Details. Washington, D.C., ISBN 0-309-09763-0, 2006. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_356.pdf.

5. Zegeer, C. V., C. Seiderman, P. Lagerwey, M. Cynecki, M. Ronkin, and R. Schneider. Pedestrian Facilities Users Guide - Providing Safety and Mobility. Highway Safety Research Center, University of North Carolina, Chapel Hill, NC, FHWA-RD-01-102, 2002. https://www.fhwa.dot.gov/publications/research/safety/01102/01102.pdf.

Yield Lines Section 151

Introduction

A yield line is a row of white triangles pointing toward approaching vehicles extending across approach lanes to indicate the point at which the yield is intended or required to be made.

Design Parameters

01 A yield line may be used to indicate the point behind which vehicles are required to yield in compliance with a "YIELD" (R1-2) sign.

02 **A yield line shall consist of a row of solid white isosceles triangles pointing toward approaching vehicles extending across approach lanes to indicate the point at which the yield is intended or required to be made (Figure 151).**

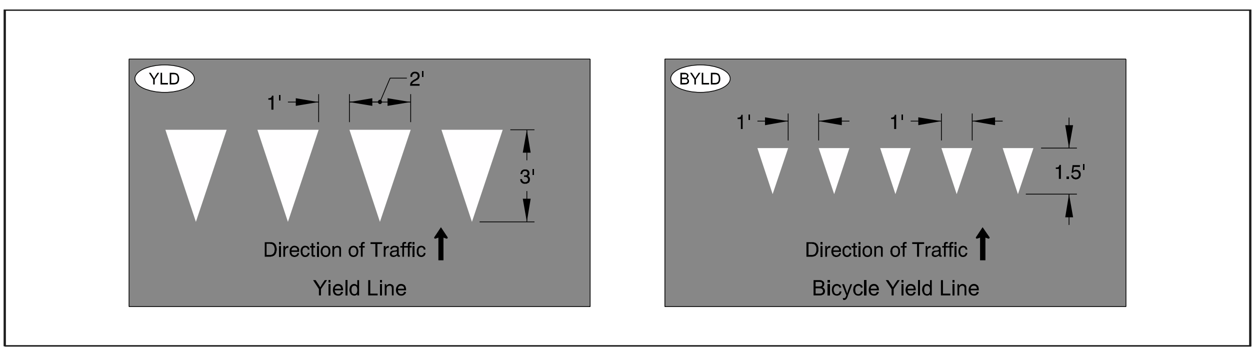
03 **Yield lines shall not be used in advance of a marked crosswalk.**

Design Issues

Yield lines point in the direction of approaching traffic.

Figures & Tables

Figure 151: Yield Line Types



Support

Similar to stop lines, yield lines help reinforce where road users need to yield. Yield lines first appeared in the 2000 edition of the MUTCD. The 2009 MUTCD (*1*) gives a range for the size of triangles used in the yield line, with a minimum base of 12 inches and maximum base of 24 inches, and a height of 1.5 times the base. Initially, the large triangles were only used in rural or high speed areas and the smaller triangles were used in lower-speed urban areas. However, based on field observations and region feedback, the smaller triangles were too small when viewed from the motorists' perspective. Reportedly, the triangle shape looked more like a blob or odd-shaped dot. The large triangles were then set as the standard for motor vehicle yield lines. The smaller triangles are better suited and have had good success for yield lines across bicycle paths and bicycle lanes.

Yield lines are not used in advance of crosswalks because Oregon law (ORS 811.028) requires that drivers stop for pedestrians crossing a roadway within a marked or unmarked crosswalk.

Cross References

Colors .... Section 110
Channelized Right-Turn Lanes .... Section 321
Roundabouts .... Section 350
Shared-Use Path Markings .... Section 440

Key References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.

+Lane Use Arrows Section 160

Introduction

Lane use arrows are used to indicate mandatory or permissible movements in certain lanes and in two-way left turn lanes.

Design Parameters

01 **All lane use arrows shall be white in color and in conformance with the design details in the Pavement Markings chapter of FHWA's "Standard Highway Signs and Markings" book, 2004 Edition.**

02 *Lane use arrows should be used in lanes designated for the exclusive use of a turning movement. Lane use arrows should also be used in lanes from which movements are allowed that are contrary to the normal rules of the road, or that have unexpected or non-standard lane use.*

03 *Where an alley entrance intersects with a turn lane for a downstream intersection, lane use arrows should be placed beyond the alley entrance toward the intersection.*

04 **At intersection approaches with an advance stop bar or advance yield line, lane use arrows shall not be positioned downstream from the advance stop bar or advance yield line.**

05 Where the wide white line (W-2) separating a turn lane from adjacent lane(s) is less than 40 feet, the second (downstream) arrow may be omitted.

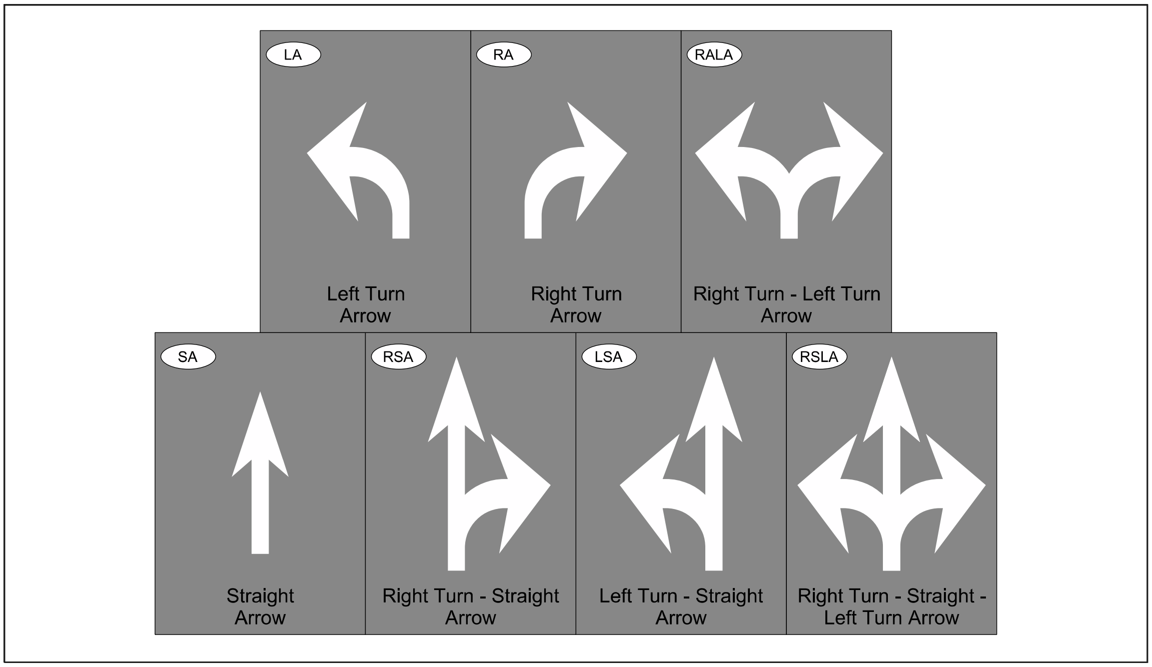
Design Issues

Use elongated lane use arrows (Figures 160-C and 160-D) for ODOT projects unless otherwise directed by the region traffic engineer. If used, fish-hook style arrows are used on approaches to roundabouts (Figures 160-E and 160-F; see Section 350).

Lane use arrows are required in some cases. See the turn lane (Sections 310-330), ramp terminal (Section 361), and Roundabout (Section 350) sections for more information.

Figures & Tables

Figure 160-A: Arrow Types



Lane Use Arrows Section 160

Figure 160-B: Arrow Dimensions

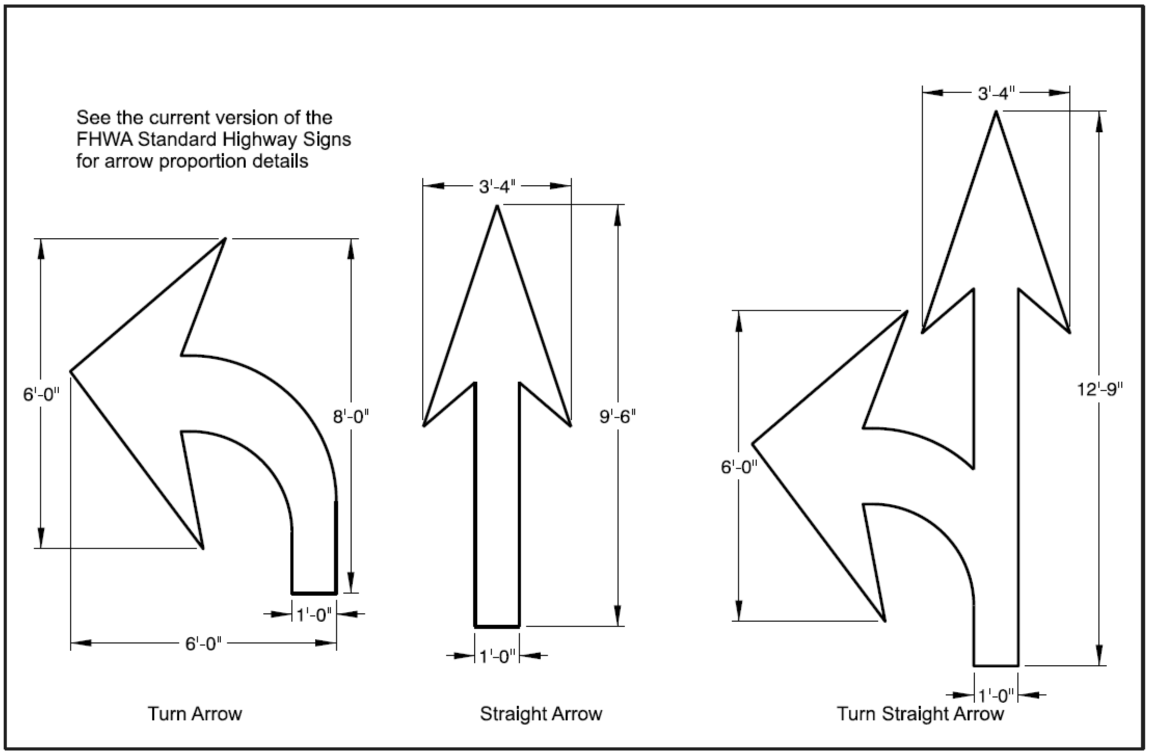


Figure 160-C: Elongated Arrow Types

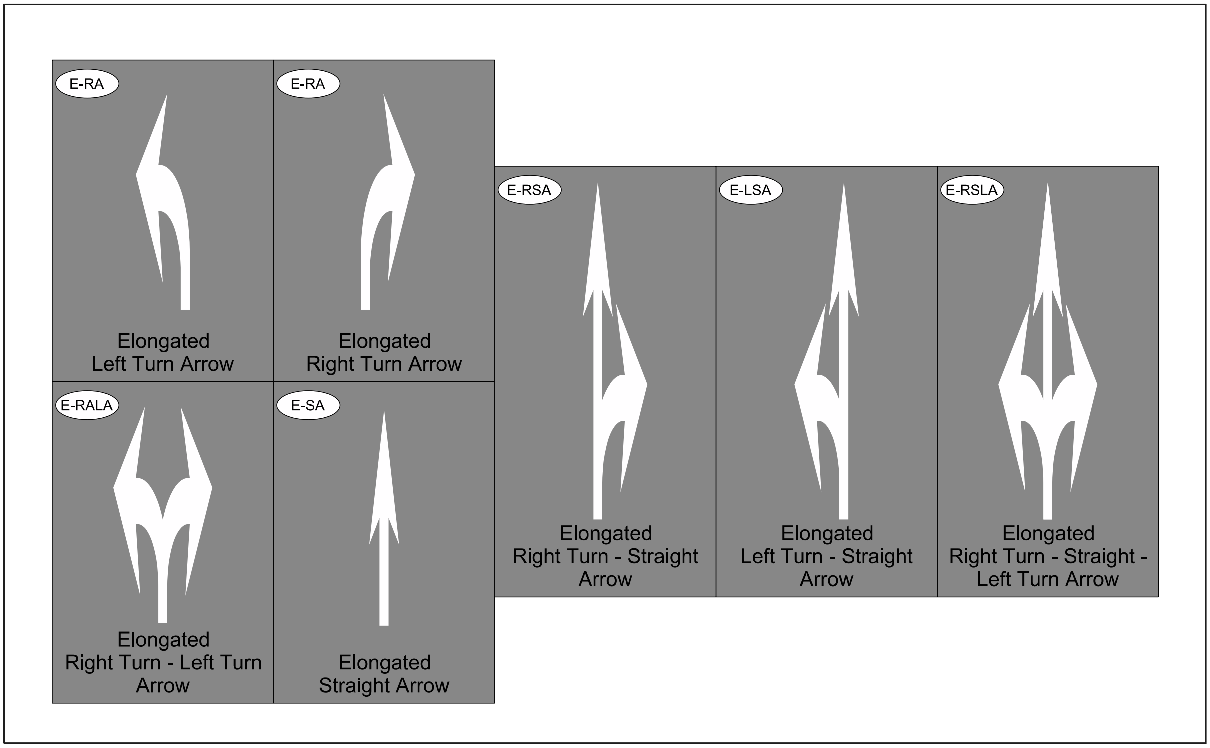


Figure 160-D: Elongated Arrow Dimensions

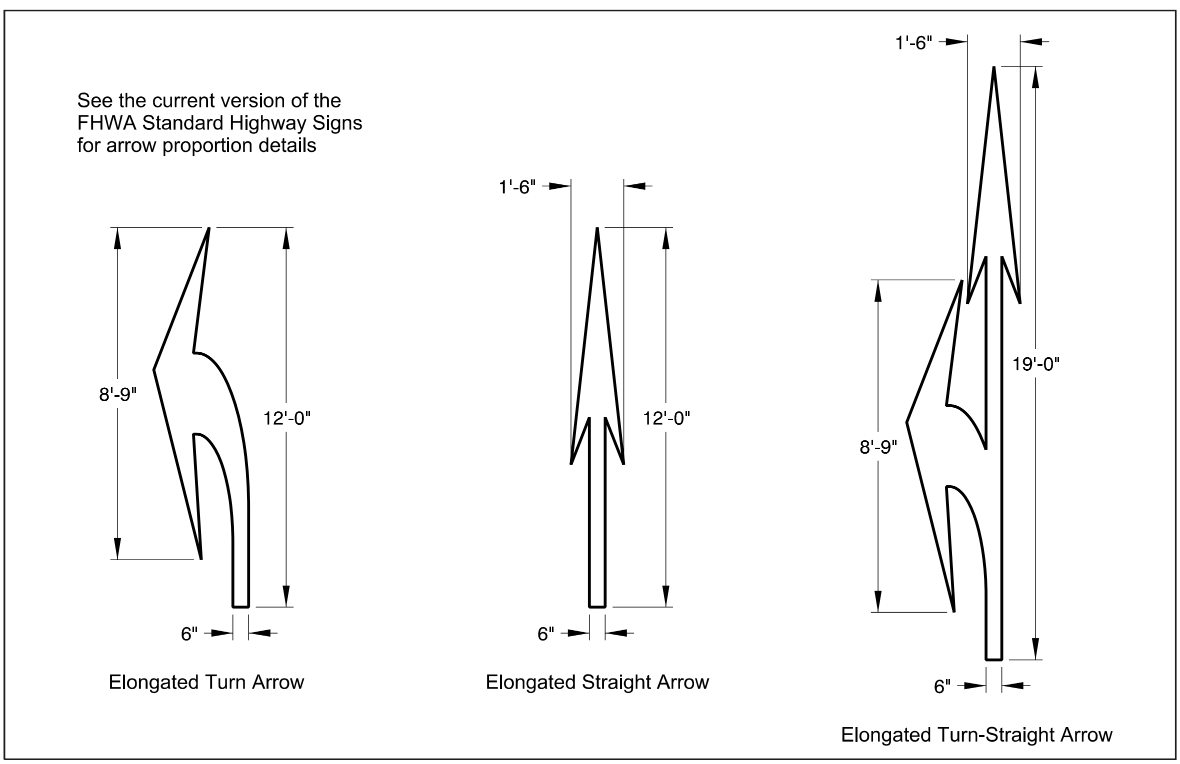


Figure 160-E: Fish-hook Arrow Types

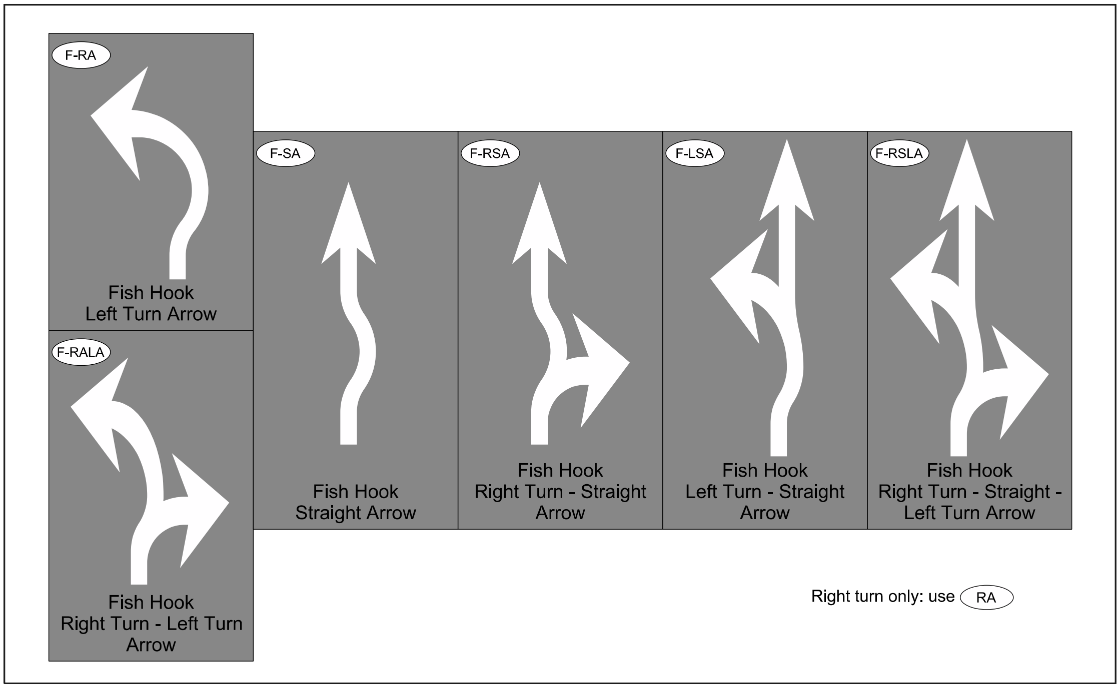


Figure 160-F: Fish-hook Arrow Dimension (1 of 2)

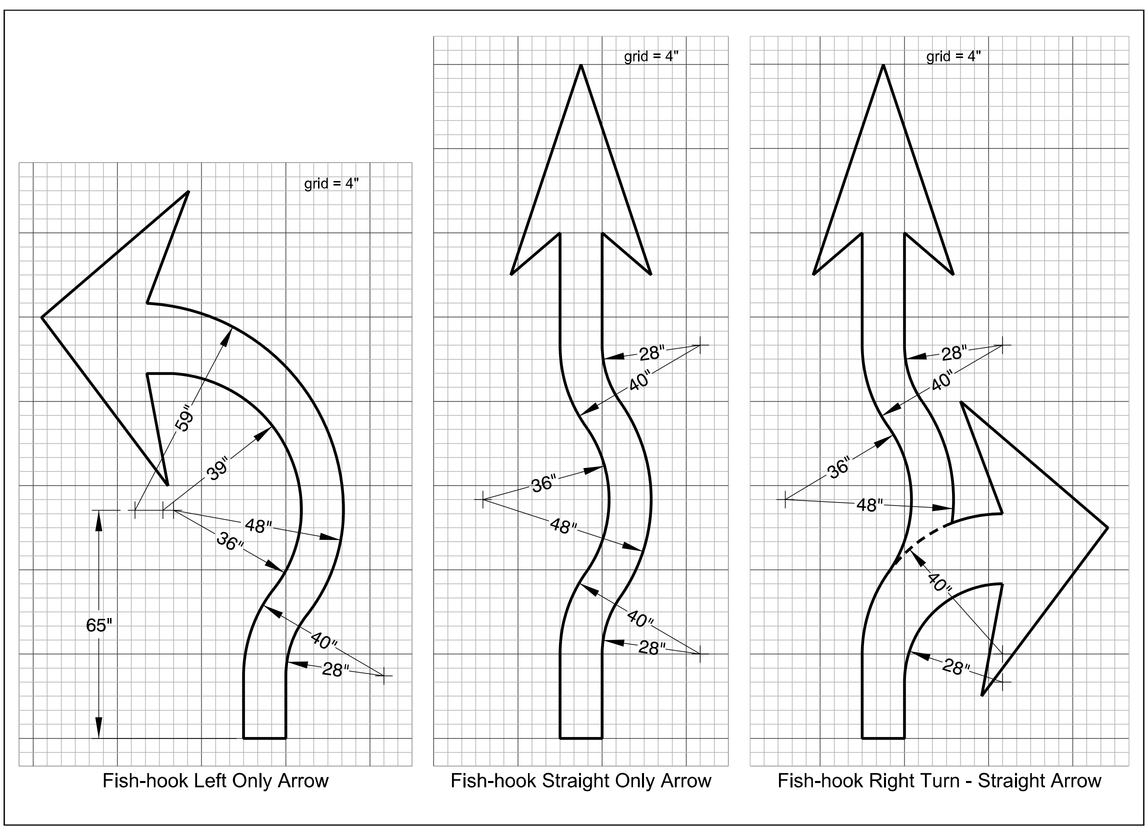
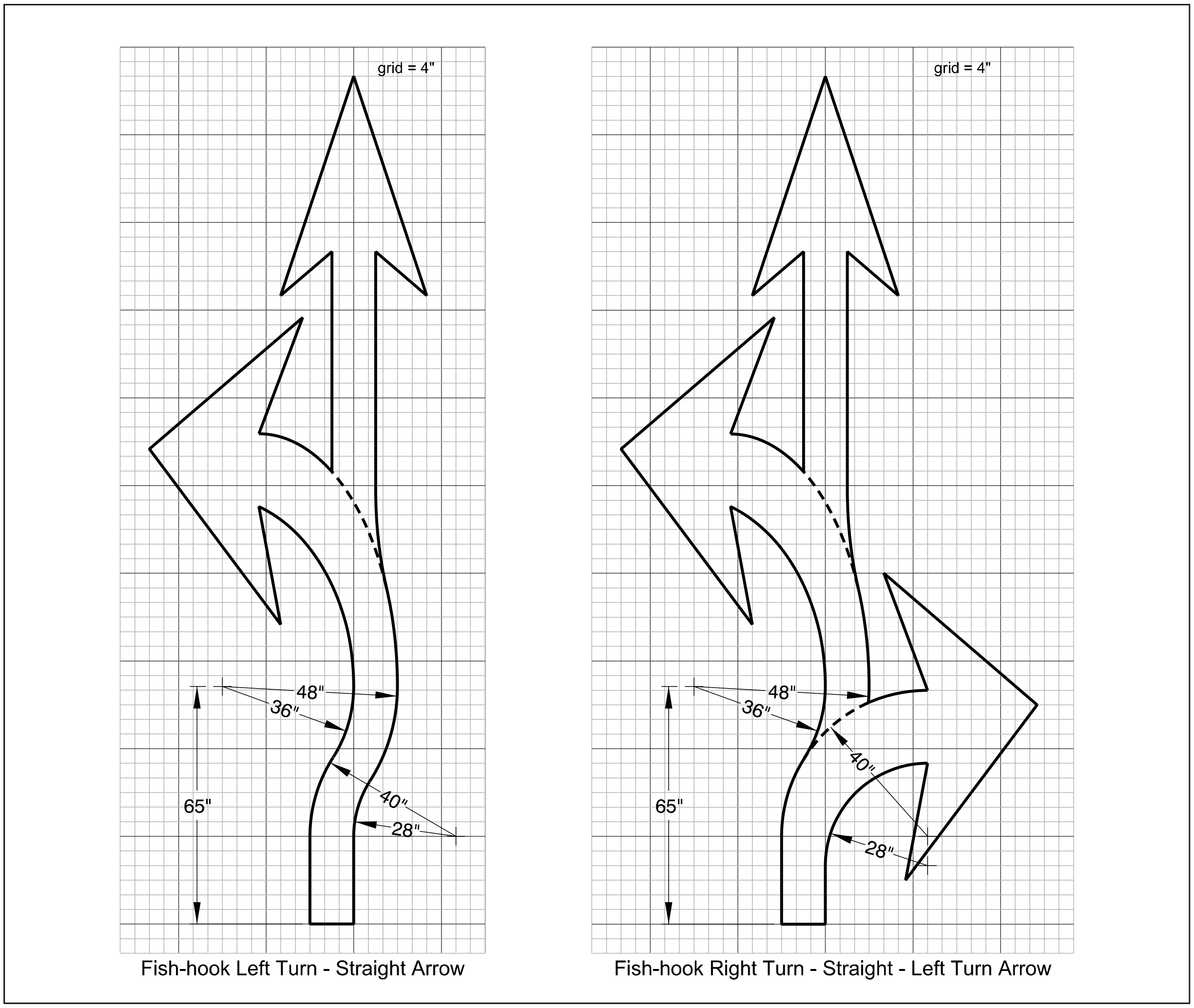


Figure 160-G: Fish-hook Arrow Dimensions (2 of 2)



Support

Lane use arrow shapes and dimensions derive from FHWA's Standard Highway Signs and Markings (SHS) publication (*1*).

Fish-hook style lane use arrows are allowed in the 2009 MUTCD (*2*), but are not available in the current SHS publication. Fish-hook style shapes and dimensions are based on arrows in the latest draft update of the SHS provided to ODOT upon request from FHWA in October 2016. At that time FHWA did not have a timeline for a SHS update. The fish-hook style arrows provided in this section are a stop-gap for ODOT facilities until they are included in the SHS.

Pavement marking arrows provide a shorter legible viewing distance than lane use arrows on signs because of the more severe viewing angle to the pavement (*3*). This is one reason multiple arrows are used at turn lanes, or if just one arrow is used, it is used at the beginning of the turn lane. More information on the benefits and limitations of transverse markings are available in Section 125.

Where alley entrances intersect with a turn lane meant for a downstream intersection, placing the lane use arrow beyond the alley entrance avoids road user confusion about the function of the turn lane.

ODOT region striping crews have seen a benefit of using the elongated arrow option. With these arrows being narrower when placed they are typically in-between the wheel path and do not wear down as soon. With less wear elongated arrows can keep their presence in lane better as well as save on maintenance costs.

Cross References

Colors .... Section 110
Left Turn Lanes .... Section 310
Added Right Turn Lanes .... Section 320
Channelized Right-Turn Lanes .... Section 321
Dropped Lanes and Auxiliary Lanes on Conventional Roads .... Section 330
Roundabouts .... Section 350
Interchange Ramps: Ramp Terminals .... Section 361

Key References

1. Federal Highway Administration. *Standard Highway Signs*, 2004 ed. Federal Highway Administration, Washington, D.C., 2004.
2. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
3. Zwahlen, H. T., T. Schnell, and S. Miescher. Recognition Distances of Different Pavement Arrow Designs During Daytime and Nighttime. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1692, 1999, pp. 119-128. http://trrjournalonline.trb.org/doi/pdf/10.3141/1692-13. DOI: http://dx.doi.org/10.3141/1692-13

Center Lines Section 210

Introduction

A center line separates traffic traveling in opposite directions. It does not need to be at the geometric center of the pavement.

Design Parameters

01 **Center line markings on two-lane, two-way roadways shall be one of the following:**

- **Two-direction passing zone markings consisting of a normal broken yellow line (YB) where crossing the center line markings for passing with care is permitted for traffic traveling in either direction.**
- **One-direction no-passing zone markings consisting of a double yellow line, one of which is a normal broken yellow line and the other is a normal solid yellow line (NPR or NPL), where crossing the center line markings for passing with care is permitted for the traffic traveling adjacent to the broken line, but is prohibited for traffic traveling adjacent to the solid line.**
- **Two-direction no-passing zone markings consisting of two normal solid yellow lines (D or ND) where crossing the center line markings for passing is prohibited for traffic traveling in either direction.**

02 **Center line markings on undivided two-way roadways with four or more lanes for moving motor vehicle traffic shall be the two-direction no-passing zone markings consisting of a solid double yellow line (D or ND).**

03 **Center line markings on undivided 3-lane, 2-way roadways shall be one- or two-direction no-passing zone markings according to Sections 211 and 240.**

04 **Center line markings shall be placed on:**

- **All paved roadways with a traveled way of 18 feet or more in width and an average daily traffic (ADT) of 3,000 vehicles per day or greater.**
- **All paved two-way roadways with three or more lanes for moving motor vehicle traffic.**

05 *Center lines should be provided on other paved traveled ways where an engineering study indicates a need (e.g.: route continuity at intersecting routes, etc.).*

06 Center lines may be provided on other paved two-way traveled ways that are 16 feet or greater in width.

07 **When used, center line markings shall not continue across intersections and major driveways, including private driveways with substantial approach volumes (Figure 210-C).**

08 *When used, center line markings should continue across minor driveways (public or private) and alleys (Figure 210-C).*

Design Issues

Equipment for installation and maintenance are important considerations on very narrow roadways and next to non-traversable medians. Check with the striping maintenance manager to make sure he or she has the right equipment for these areas. Yellow lines are typically offset approximately 12 inches when next to non-traversable medians. For more design parameters see Section 3B.01 in the 2009 MUTCD (*1*).

Figures & Tables

Figure 210-A: Typical 2-Lane, 2-Way Center Line Markings with No-Passing Zones

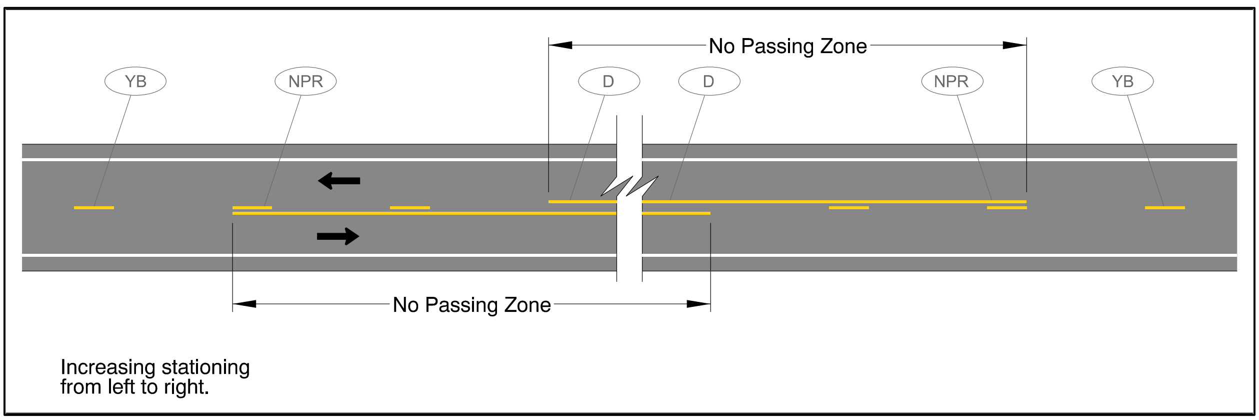


Figure 210-B: Typical 4-Lane, 2-Way Center Line Markings

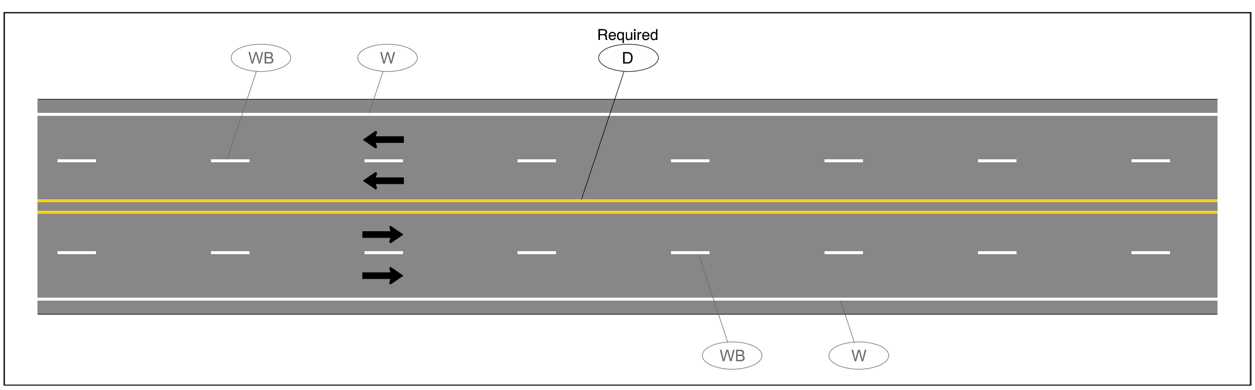
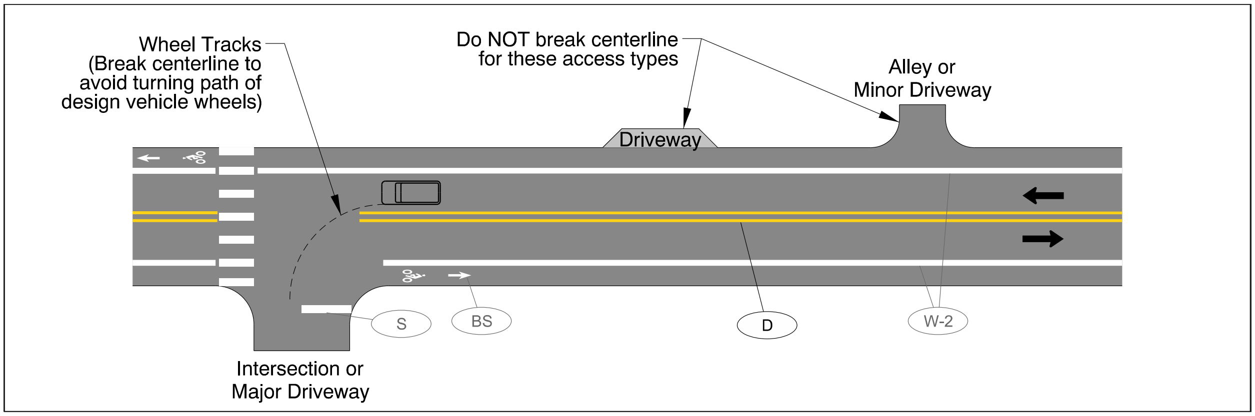


Figure 210-C: Typical Centerline Striping at Intersections, Driveways, and Alleys



Support

A center line provides fundamental, continuous information to road users about the roadway path. It also communicates passing allowances, directionality of traffic, and is a proven tool to reduce crashes (2). Center line treatments generally cause road users to shift their lateral position away from the center line (3).

A marked centerline, particularly no-passing zone centerlines, can affect how drivers overtake a bicyclist on rural roadways (4). In some locations with very low motor vehicle volumes and significant use by people walking and biking, such as at narrow bridges, omitting the centerline or operating the location as one-way for motor vehicles might be one strategy to meet local needs.

Breaking longitudinal striping at major access points (such as intersections and major driveways) is an important visual and wayfinding cue for motorists. This helps them identify where an access point is located, especially in inclement weather. Center line breaks are not applied to minor access points like driveways (public or private) and alleys because too many center line breaks would make the treatment less effective at major access points and making the center line less effective overall. The breaking of the line is typically based on turning wheel paths (Figure 210-C). At uncontrolled intersection approaches there is no requirement to break the line in advance of unmarked crosswalks.

Some access points are easy to define and mark accordingly (e.g. signalized intersections and major route intersections); some are not. Consider the following when determining whether or not to break longitudinal lines for access points that are less easily defined.

Intersection Indicators:

- The area of a roadway created when two or more public ways join together at any angle. The junction of an alley or driveway with a public way is not considered an intersection (see MUTCD Section 1A.13 and ORS 801.320).
- Curb returns and/or significant radii.

- A street name sign on the intersecting roadway or the intersecting roadway is identified on a city/county map. The intersecting roadway could be gravel.
- A stop sign on the intersecting roadway.
- Turn lanes on the major roadway at the intersecting roadway.

Major Driveway Indicators (public or private):

- Curb returns and/or significant radii (not a dustpan design or curb cut).
- A stop sign at the driveway.
- Multiple approach lanes on the driveway.
- Turn lanes present on the major roadway at the driveway.
- Substantial volumes entering and leaving the driveway.

Minor driveway or alley indicators:

- Dustpan design, curb cut, or small radii.
- Narrow width of intersecting roadway.
- Minor volumes entering and leaving driveway (e.g.: single home or small business).

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Raised Pavement Markers .... Section 130
RPMs Used for Supplementation .... Section 131
RPMs Used for Positioning Guides .... Section 132
Typical Layouts for RPMs .... Section 133
No-Passing Zone Markings .... Section 211
Lane Reduction Transitions .... Section 250
Lane Addition Transition & No-Passing Zones in 3-Lane Sections .... Section 251
Traversable Medians .... Section 260
Two-Way Left Turn Lanes .... Section 261
Approach to a Fixed Obstruction .... Section 280
Non-Traversable Medians & Channelizing Islands .... Section 281
Left Turn Lanes .... Section 310
Line Extensions Through Intersections .... Section 340
Roundabouts .... Section 350
Interchange Ramps: Exit & Entrance Ramps .... Section 360
Interchange Ramps: Ramp Terminals .... Section 361
Bicycle Lanes .... Section 410
Marked Crosswalks .... Section 430
Shared-Use Path Markings .... Section 440
Railroad Crossing Markings .... Section 510

Key References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
2. Carlson, P. J., E. S. Park, and C. K. Anderson. Benefits of Pavement Markings: A Renewed Perspective Based on Recent and Ongoing Research. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2107, 2009, pp. 59-68. http://trrjournalonline.trb.org/doi/pdf/10.3141/2107-06. DOI: 10.3141/2107-06
3. Campbell, J. L., M. G. Lichty, J. L. Brown, C. M. Richard, J. S. Graving, J. Graham, M. O'Laughlin, D. Torbic, and D. Harwood. NCHRP Report 600: Human Factors Guidelines for Road Systems. 2012. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_600Second.pdf. Accessed October 23, 2012.
4. Chapman, J., and D. Noyce. Observations of Driver Behavior During Overtaking of Bicycles on Rural Roads. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2321, 2012, pp. 38-45. http://trrjournalonline.trb.org/doi/abs/10.3141/2321-06. DOI: 10.3141/2321-06

No-Passing Zone Markings Section 211

Introduction

No-passing zone markings legally establish the limits where vehicles are prohibited from crossing the centerline, except to turn left onto or from an intersection, alley, private roadway, or driveway.

Design Parameters

01 **On roadways with centerline markings, no-passing zone markings shall be used at:**

- **Undivided highways of 4 or more lanes. A two-direction no-passing centerline (D or ND) is required in these locations.**
- **Vertical curves, horizontal curves, and elsewhere on 2- and 3-lane highways where passing sight distance is less than the minimum shown in Table 211-1.**
- **Lane reduction transitions (Section 250).**
- **Lane addition transitions and the 2-lane direction of undivided 3-lane highways (Section 251).**
- **Approaches to a "STOP" sign, signal indications, marked crosswalks, and school zones (see Table 211-2).**
- **Approaches to obstructions that must be passed on the right (Sections 280 and 281).**
- **Approaches to highway-rail grade crossings (Section 510).**
- **Approaches to a traversable median (Section 260), non-traversable median (Section 281), or left turn lane (Section 310) where traffic is required to keep to the right (see Table 211-2).**

02 Approaches to non-signalized intersections without a median or left turn lane may be marked with no-passing zone markings beginning a minimum distance shown in in Table 211-2 from the intersection.

03 *Where no-passing zone markings are established:*

- *They should be 500 feet or longer. Where necessary, the no-passing zone marking should be extended at the beginning of the no-passing zone to obtain this minimum.*
- *The distance between successive no-passing zones for one direction of travel should not be less than 800 feet. If the distance is less than 800 feet, no-passing zone markings should connect the successive no-passing zones.*

04 **Where no-passing zones are established on horizontal or vertical curves, no-passing markings shall begin and continue as long as passing sight distance is less than the minimum shown in Table 211-1.**

05 **Passing sight distance on horizontal curves shall be determined using one of the following methods:**

- **Standard Method – Passing sight distance is the distance measured along the centerline between two points 3.5 feet above the pavement on a line tangent to the edge of pavement (Figure 211-A).**
- **Alternative Method –Passing sight distance is the distance measured along the centerline between two points 3.5 feet above the pavement on a line tangent to an obstruction that cuts off the view on the inside of the curve (Figure 211-B).**

06 *Use of the alternative method should be based on engineering judgement.*

07 **Passing sight distance on a vertical curve shall be the distance at which an object 3.5 feet above the pavement surface can be seen from a point 3.5 feet above the pavement surface (Fig. 211-C).**

Required Approvals

An engineering study and region traffic engineer approval is required for no-passing zone markings for any locations not listed in the design parameters of this section.

Design Issues

Based on the geometry of a crest vertical curve, no-passing zones may or may not overlap at the crest of the curve. Additional design parameters are available in 2009 MUTCD (*1*) Section 3B.02.

Figures & Tables

Table 211-1: Minimum Required Passing Sight Distances

Posted or 85th Percentile Speed (mph)	20	25	30	35	40	45	50	55	60	65	70	75
Minimum Passing Sight Distance (ft)	400	450	500	550	600	700	800	900	1000	1100	1200	1300

Table 211-2: Min. Recommended No-Passing Zone Length for Approaches to Locations Where Traffic Must Keep Right

Posted or 85th Percentile Speed (mph)	20	25	30	35	40	45	50	55	60	65	70	75
Minimum Passing Sight Distance (ft)	500	500	500	550	600	700	800	900	1000	1100	1200	1300

Figure 211-A: Standard Method: Minimum Passing Sight Distance for Horizontal Curves (Based on Edge of Pavement)

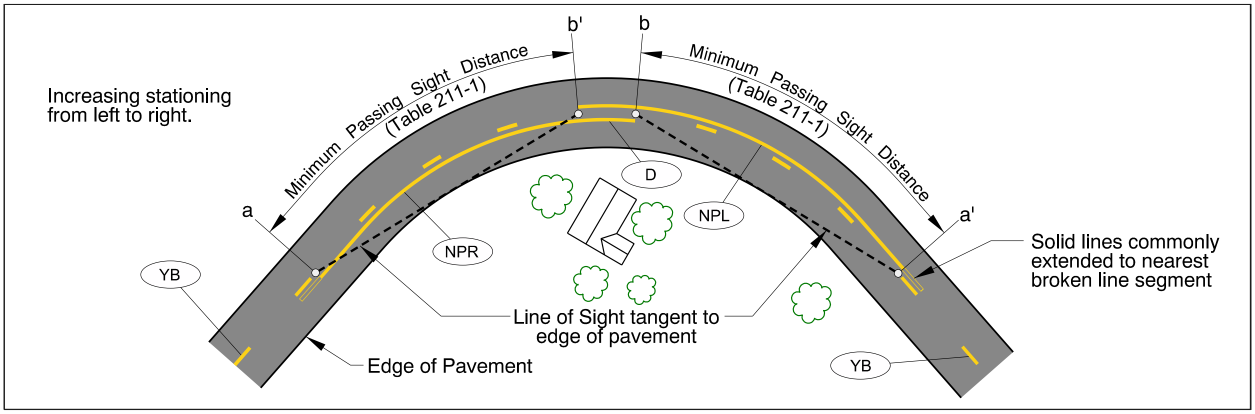


Figure 211-B: Alternative Method: Passing Sight Distance for Horizontal Curves (Based on Obstruction)

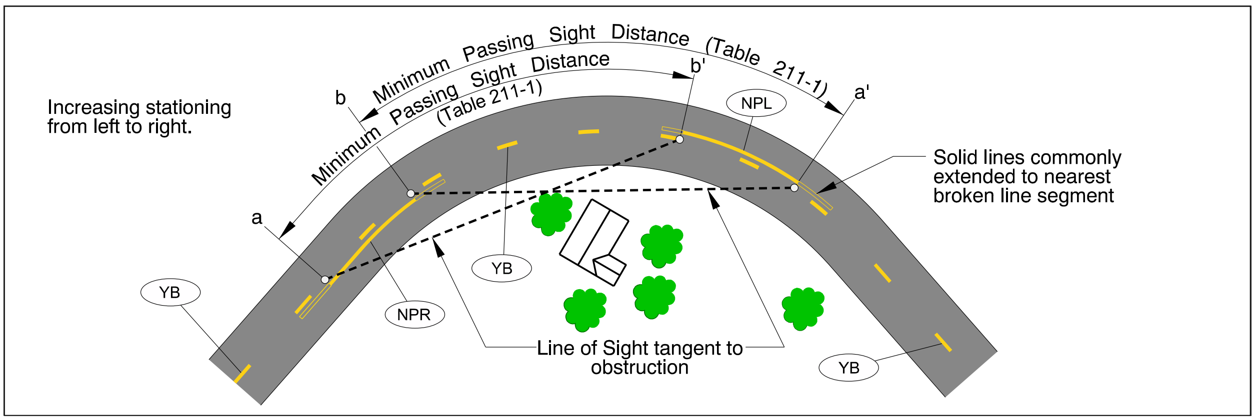
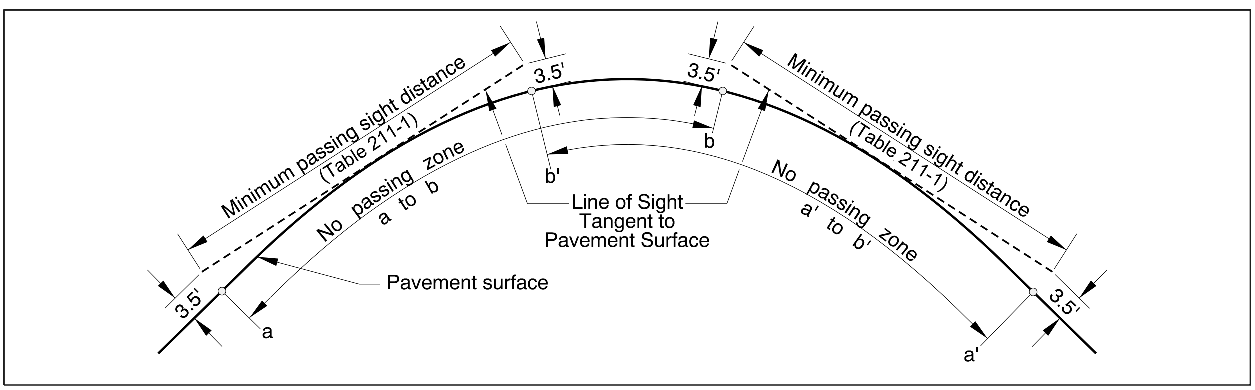


Figure 211-C: Passing Sight Distance for Vertical Curves



Support

The safety of passing operations ultimately depends on the judgement of drivers in response to the view of the roadway ahead provided by passing sight distance and the no-passing zone markings (*2*).

Frequent passing opportunities are important to operational efficiencies of rural two-lane roadways. Passing on rural two-lane roadways is also one of the most complex maneuvers drivers make. The passing driver ultimately determines if he or she can safely complete a passing maneuver (*2*).

Actual driver behavior during passing maneuvers varies widely. There have been several different models developed to try and explain the passing process, each with their own assumptions and parameters to cover a high percentage of driver behavior. The models that most closely represent the needs of passing drivers and recommend passing sight distances very close to MUTCD minimums, developed by Glennon (*3*) and Hassan et al. (*4*), recognize that passing drivers will abort a pass up to a critical position beyond which he or she is committed to completing the passing maneuver. Field data show this occurs when the two vehicles are approximately abreast – after approximately 40 percent of the total left-lane distance has been traveled by the passing vehicle. No-passing zones established with MUTCD methods are generally consistent with field observations of passing maneuvers and have a good safety record (*2*).

Short passing zones (400 feet to 800 feet long) contribute very little to the operational efficiency of two-lane roadways. Field studies show less than 2% of drivers with headways <3 seconds take advantage of short zones and the vast majority of passing maneuvers in short passing zones (92%) end beyond the start of the solid line (*2*). In NCHRP Report 605, 800 feet was a proposed minimum length for high-speed roads. In very constrained corridors, shorter passing zones (as short as 400’) can still be used per MUTCD.

The minimum length of no-passing zone (500 feet) ensures no-passing zones are long enough to be respected by road users. This value appears to be a legacy minimum from past editions of the MUTCD; this minimum has generally been proven as good practice over decades of use by ODOT.

Locations where traffic needs to keep to the right (such as left turn lanes) are transition areas where passing would not allow for safe operations. Extending a no-passing zone upstream provides a buffer for passing maneuvers to complete before reaching the transition area. See the ODOT Traffic Manual (*5*) for information on marking no-passing zones at unchannelized intersections.

The horizontal curve alternative method allows for more passing opportunities than the standard method. However, the original line of sight using the alternative method could be compromised over time or at certain times. Field conditions (such as growing vegetation, future buildings, railroads parallel to the highway, etc.) need to be monitored on a regular basis to ensure no-passing zones are still appropriate. The standard method accounts for changing field conditions by being more conservative; this results in longer and more frequent no-passing zones.

To evaluate passing sight distance, the eye height of the driver and object height of opposing vehicle are set at 3.50 feet above the pavement surface, shown in Figure 211-C. This object height assumes a vehicle height of 4.35 feet (the 15th percentile of vehicle heights in the current passenger car fleet) minus an allowance of 0.85 feet. The allowance represents a near-maximum amount of the vehicle height that needs to be visible for another driver to recognize the object as an approaching vehicle. These design values are adequate for night conditions because the headlight beams of an opposing vehicle can generally be seen a greater distance than the vehicle can be recognized during the day (*6*).

The beginning of a no-passing zone (in Figure 211-C, point "a" for the left-to-right direction and point a' for the right-to-left direction) is the point where passing sight distance first becomes less than the minimum specified in Table 211-1. The end of the no-passing zone (in Figure 211-C, point "b" for the left-to-right direction and point b' for the right-to-left direction) is the point where passing sight distance becomes greater than the minimum specified in Table 211-1.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Center Lines .... Section 210
Lane Reduction Transitions .... Section 250
Traversable Medians .... Section 260
Approach to a Fixed Obstruction .... Section 280
Non-Traversable Medians & Channelizing Islands .... Section 281
Left Turn Lanes .... Section 310
Interchange Ramps: Ramp Terminals .... Section 361
Marked Crosswalks .... Section 430
Railroad Crossing Markings .... Section 510

Key References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
2. Harwood, D. W., D. K. Gilmore, K. R. Richard, J. M. Dunn, and C. Sun. NCHRP Report 605: Passing Sight Distance Criteria. Transportation Research Board of the National Academies, Washington, D.C., ISBN: 978-0-309-09927-1, 2008. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_605.pdf.
3. Glennon, J. C. New and Improved Model of Passing Sight Distance on Two-Lane Highways. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1195, 1998, pp. 132-137. http://trid.trb.org/view.aspx?id=302154.
4. Hassan, Y., S. M. Easa, and A. O. Abd El Halim. Passing Sight Distance on Two-Lane Highways: Review and Revision. *Transportation Research Part A*, Vol. 30, no. 6, November 1996, pp. 453-467. http://www.sciencedirect.com/science/article/pii/0965856495000321. DOI: 10.1016/0965-8564(95)00032-1

5. Oregon Department of Transportation. Traffic Manual, 2016 Edition. January 2016. http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Traffic-Manual-v2016.pdf. Accessed July 3, 2017.

6. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*, 6th ed. Washington, D.C., 2011.

Lane Lines Section 220

Introduction

Lane lines separate lanes of traffic traveling in the same direction.

Design Parameters

01 **Lane lines shall be used on all roadways that are intended to operate with two or more adjacent lanes traveling in the same direction.**

02 **When used, lane lines shall:**

- **Be white.**
- **Not continue across intersections and major driveways, including private drive approaches with substantial approach volumes (Figure 220-A), except as provided in Section 340.**

03 *When used, lane lines should continue across minor driveways (public or private), and alleys (Figure 220-A).*

04 **A normal width white broken line (WB) shall be used where crossing the lane line markings with care is permitted, except locations where a dotted lane line (DLL or DLL-2) is specified in this manual.**

05 **Where crossing the lane line markings is discouraged, the lane line markings shall consist of a wide solid white line (W-2) (Figure 220-B).**

06 **Where crossing the lane line markings is prohibited, the lane line markings shall consist of a solid double white line (NDW) (Figure 220-C).**

07 **A wide dotted lane line (DLL-2) shall be used at dropped lanes according to Sections 330 and 360.**

08 **A dotted lane line (DLL) shall be used at parallel acceleration lanes according to Sections 322 and 360.**

Design Issues

Lane widths can directly affect safety and operations of a roadway; needed width depends on the need of the lane and roadway segment. See the ODOT Highway Design Manual (*1*) for design parameters, considerations, and exceptions related to lane widths.

Solid double white lines are not defined in statute as prohibiting lane changes; these restrictions are communicated through signing. Signing associated with lane line crossing prohibitions, such as “NO LANE CHANGES NEXT XXXX FT” (OR22-16) and/or “NO LANE CHANGES NEXT ½ MILE” (OR22-17), can be found in the Sign Policy and Guidelines.

Figures & Tables

Figure 220-A: Typical Lane Line Striping at Unsignalized Intersections

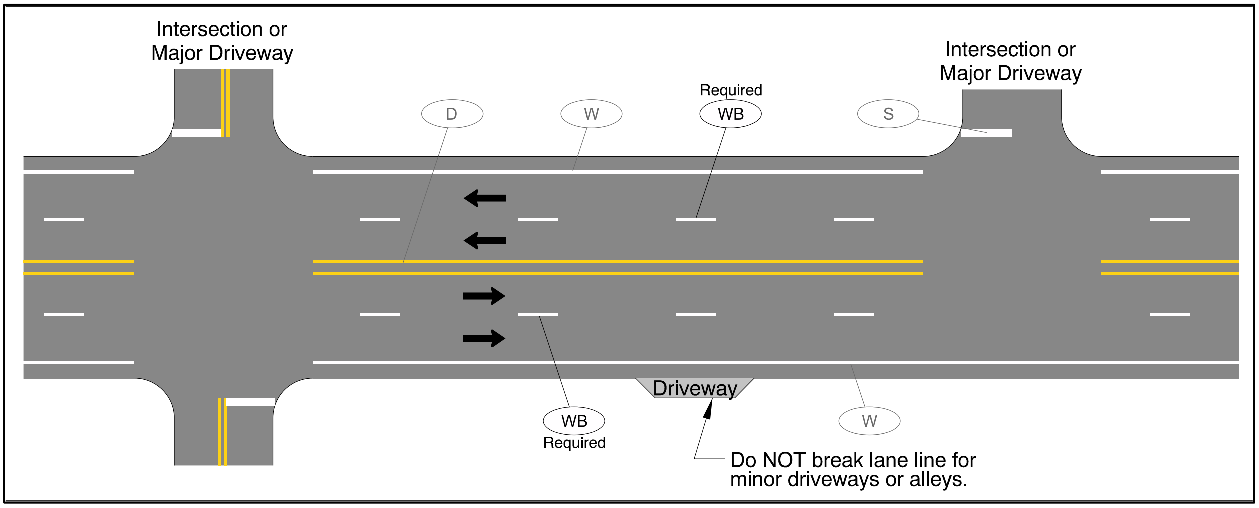


Figure 220-B: Typical Lane Line Striping where Crossing is Discouraged

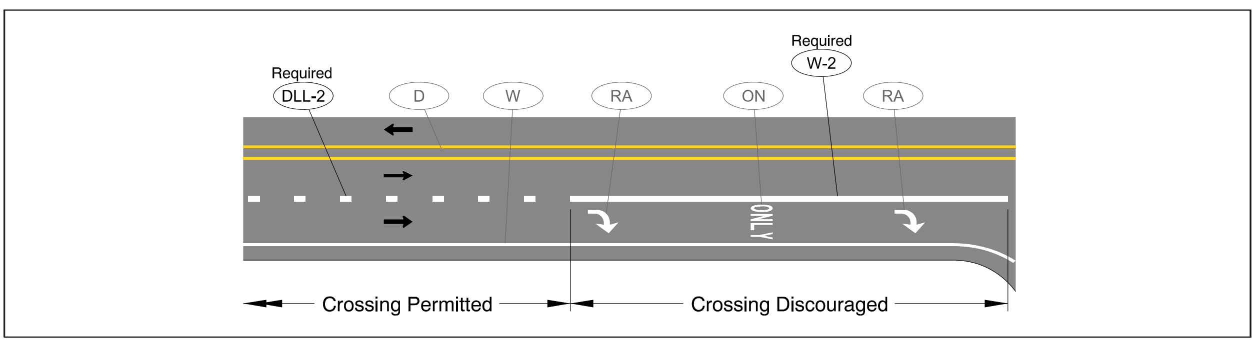
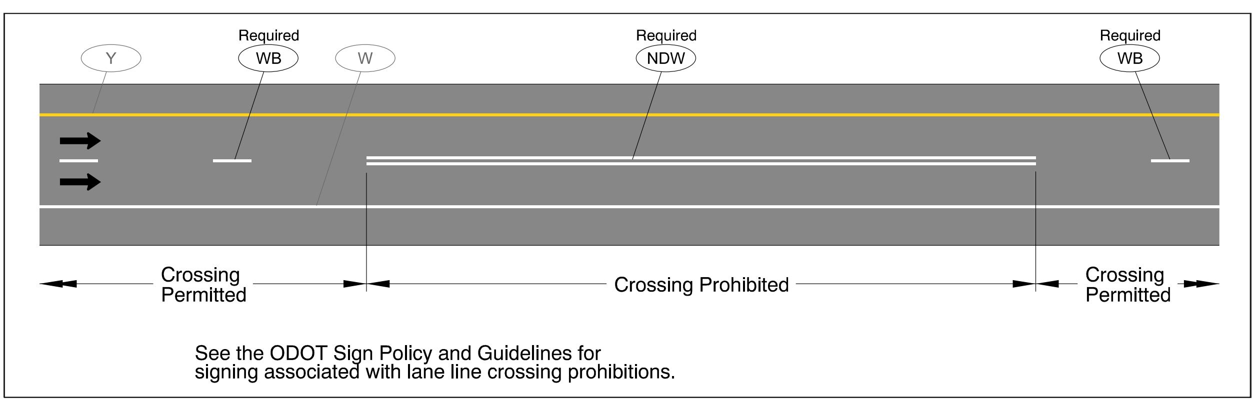


Figure 220-C: Typical Lane Line where Crossing is Prohibited



Support

Design parameters related to lane lines come from Section 3B.04 of the 2009 MUTCD (*2*).

Typical locations where crossing a lane line is discouraged include:

- Separating thru lanes from left and right turn lanes.
- Bike lane lines.
- In tunnels or on bridges with narrow lane widths.
- Interchange areas, where lane changing can disrupt safe operations.

Locations where crossing is prohibited need to be selected carefully. Often, discouraging lane changes with a single wide white line is sufficient to minimize lane changes without introducing a legal requirement to not cross the line. Locations where crossing is prohibited are often safety related. Sufficient signing is often needed to reinforce the crossing prohibition and make sure road users know which lane they need to be in prior to the crossing prohibition (e.g.: advance guide signing before an interchange or intersection).

Breaking longitudinal striping at major access points (such as intersections and major driveways) is an important visual and wayfinding cue for motorists. This helps them identify where an access point is located, especially in inclement weather. Lane line breaks are not applied to minor access points like driveways (public or private) and alleys because too many lane line breaks would make the treatment less effective at major access points and making the lane lines less effective overall. Characteristics of locations where lane lines are broken are available in the Center Lines Section 210.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Raised Pavement Markers .... Section 130
RPMs Used for Supplementation .... Section 131
RPMs Used for Positioning Guides .... Section 132
Lane Reduction Transitions .... Section 250
Approach to a Fixed Obstruction .... Section 280
Left Turn Lanes .... Section 310
Added Right Turn Lanes .... Section 320
Channelized Right-Turn Lanes .... Section 321
Dropped Lanes and Auxiliary Lanes on Conventional Roads .... Section 330
Line Extensions Through Intersections .... Section 340
Roundabouts .... Section 350
Interchange Ramps: Exit & Entrance Ramps .... Section 360
Interchange Ramps: Ramp Terminals .... Section 361
Bicycle Lanes .... Section 410
Bicycle Lane End Transitions .... Section 411
Bicycle Lane Buffers .... Section 412

Key References

1. Oregon Department of Transportation. *Highway Design Manual*. Oregon Department of Transportation, Salem, Oregon, 2012.
2. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.

Edge Lines Section 230

Introduction

Edge lines delineate the right or left edge of a roadway.

Design Parameters

01 **Edge lines shall be provided on interstates, freeways, expressways, rural multi-lane divided roadways, and rural roadways with a traveled way of 20 feet or more in width and an ADT of 3,000 vehicles per day or greater.**

02 *Edge lines should be provided:*

- *Where engineering judgment determines a need.*
- *Where lateral positioning of vehicles may be difficult without an edge line as guidance (e.g.: lane reduction transitions from beginning of the advance warning sign to beyond the beginning of the narrower roadway).*
- *On rural roadways with an ADT of 3,000 vehicles per day or greater.*
- *On roadways with shoulders that have lesser structural pavement strength than the traveled way (to minimize unnecessary driving on shoulders or refuge areas).*
- *Any new paved 2-lane, 2-way roadways having a width of 24 feet or more, with adequate surfaced shoulder.*

03 **The edge lines of two-way undivided roadways and right edge line of divided roadways shall be a normal width white solid line. The left edge line of divided highways and one-way roadways, including ramps, shall be a normal width yellow solid line (See Figure 230-A).**

04 Wide solid edge line markings may be used for greater emphasis.

05 **When used, edge lines shall not continue across intersections and major driveways, including private drive approaches with substantial approach volumes, except as provided in Paragraph 06.**

06 **When used, the edge line on the far side of a T-intersection shall not be broken (Figure 230-B).**

07 *When used, edge lines should continue across minor driveways (public or private) and alleys (Figure 230-B).*

08 Edge lines may be:

- Provided on roadways with a nominal paved with of 20 feet (two 10 foot lanes) if sufficient existing shoulder width allows for operation of striping installation and maintenance equipment.
- Omitted where the traveled way is delineated by curbs, parking, bicycle lane, or other markings.
- Omitted at narrow bridges if additional delineation measures are used along the narrow bridge based on engineering judgement (e.g.: barrier mounted delineators, curb mounted RPMs, etc.) (Figure 230-C).
- Placed on roadways with or without centerline markings.
- Extended using a dotted line across wide, complex intersections or intersections located on a horizontal curve (see Section 340).

Design Issues

Installation and maintenance are important considerations on very narrow roadways and next to vertical roadside obstacles (guardrail, barrier, etc.). Check with the striping maintenance manager to make sure he or she has the right equipment for these areas. See Sections 3B.06-3B.08 in the MUTCD (*1*).

Figures & Tables

Figure 230-A: Edge Line Striping on Different Facility Types

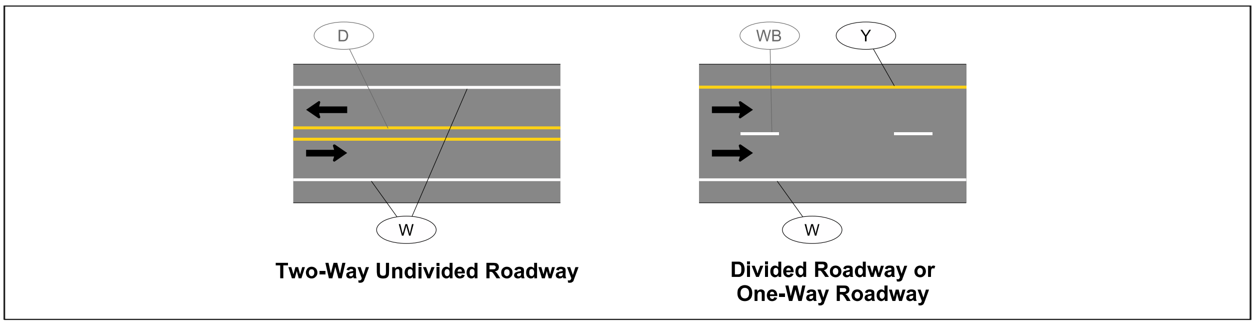


Figure 230-B: Typical Edge Line Striping at Intersections

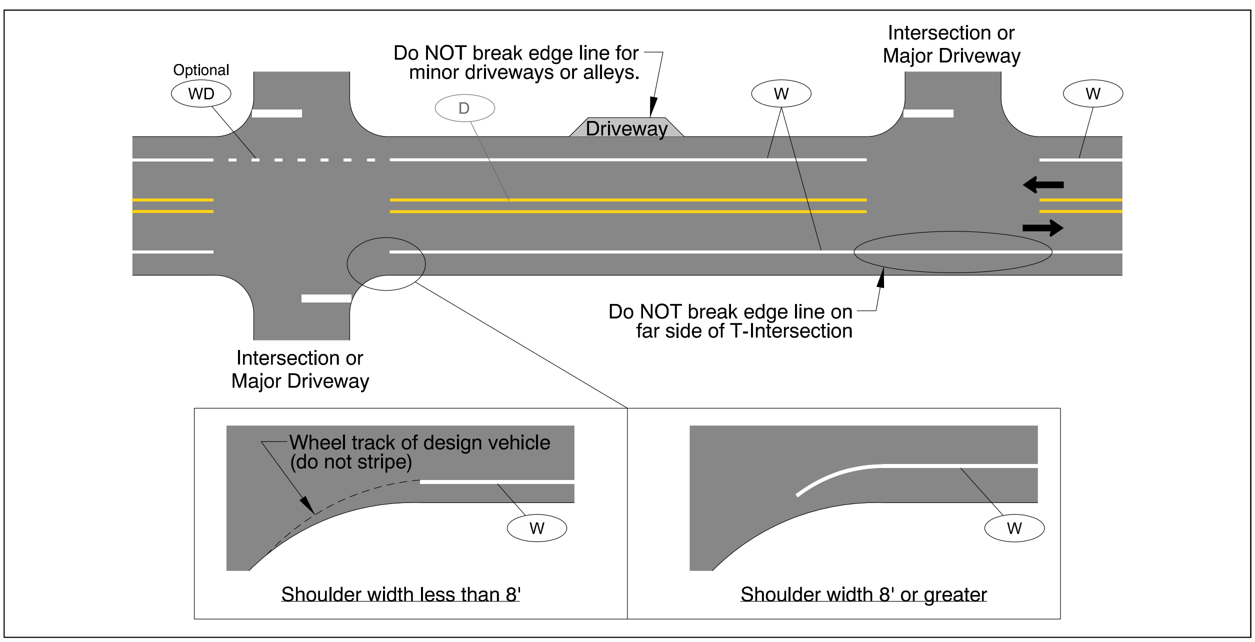
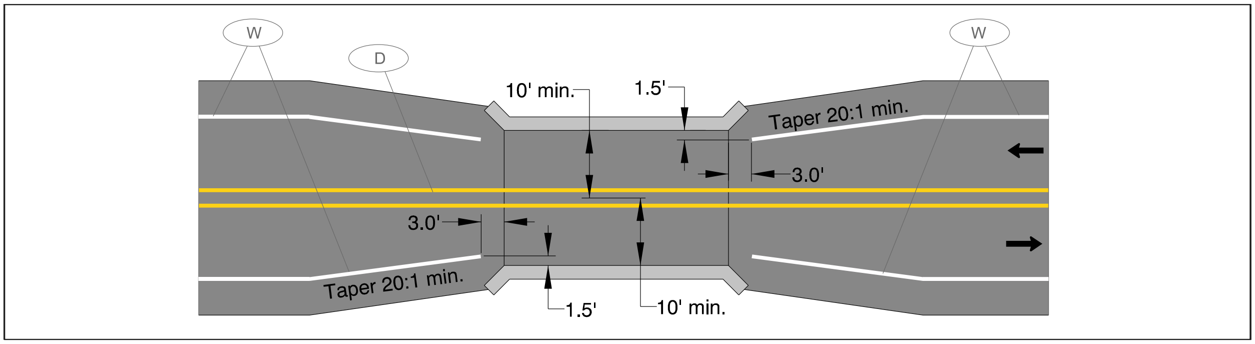


Figure 230-C: Typical Pavement Edge Line Striping at Narrow Bridge



Support

Edge lines provide fundamental, continuous information to road users about the roadway path and their lane-position stability. In general, edge lines give road users the greatest benefit in areas with sharp or frequent curves, on narrow roadways, and in the vicinity of crossing roadways or major driveways (*2*). Edge lines significantly improve safety in rural and urban settings, in all terrain types, for various lane widths, and in various visibility conditions. Adding edge lines have little to no impacts on vehicle speed and lateral position. Edge lines could also decrease driver workload at night on narrow two-lane roadways (*3*).

Recent research (*4*) (*5*) is beginning to show wider edge lines (>4” wide) reduce all crash types on rural two-lane roadways with narrow shoulders, such as where installing shoulder rumble strips is not practical. Of those crash types affected, run-off-the-road crashes are affected the most. It is not clear why wider edge lines reduce crashes. Findings on vehicle speed and lateral lane position in the presence of wider edge lines are inconsistent and inconclusive; detection distances are not significantly different either. Because drivers are more reliant on peripheral vision than foveal vision for short range driving tasks like lane positioning, one theory is that a stronger signal to the driver’s peripheral vision, such as wide lines, could improve driver comfort and short-range driving performance (*2*). Still, other devices and strategies like rumble strips can require less maintenance and, in the case of rumble strips, have been proven as a run-off-the-road countermeasure.

Breaking longitudinal striping at major access points (such as intersections and major driveways) is an important visual and wayfinding cue for motorists. This helps them identify where an access point or intersection is located, especially in inclement weather. Edge line breaks are not applied to minor access points like driveways (public or private) and alleys because too many lane line breaks would make the treatment less effective at major access points and making the edge lines less effective overall. The breaking of the line is typically based on turning wheel paths (Figure 230-B). At uncontrolled intersection approaches there is no requirement to break the line in advance of unmarked crosswalks. Characteristics of locations where edge lines are broken are available in the Centerlines section (Section 210).

Edge lines are not broken on the far side of T-intersections to give an important visual cue that the intersection does not have a receiving leg on that side, especially at night and during inclement weather.

Cross References

Key References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Washington, D.C., 2009.
2. Campbell, J. L., M. G. Lichty, J. L. Brown, C. M. Richard, J. S. Graving, J. Graham, M. O'Laughlin, D. Torbic, and D. Harwood. NCHRP Report 600: Human Factors Guidelines for Road Systems. 2012. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_600Second.pdf. Accessed October 23, 2012.
3. Carlson, P. J., E. S. Park, and C. K. Anderson. Benefits of Pavement Markings: A Renewed Perspective Based on Recent and Ongoing Research. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2107, 2009, pp. 59-68. http://trrjournalonline.trb.org/doi/pdf/10.3141/2107-06. DOI: 10.3141/2107-06
4. Park, E. S., P. J. Carlson, R. J. Porter, and C. K. Anderson. Safety Effects of Wider Edge Lines on Rural, Two-Lane Highways. *Accident Analysis and Prevention*, Vol. 48, September 2012, pp. 317-325. http://dx.doi.org/10.1016/j.aap.2012.01.028.
5. Carlson, P., E.-S. Park, A. Pike, R.J. Porter, J. Miles, B. Boulanger, O. Smadi, N. Hawkins, S. Chalmers, F. Darmiento, A. Burde, B. Kuhn, and W. Ealding. Pavement Marking Demonstration Projects: State of Alaska and State of Tennessee. Texas Transportation Institute, The Texas A&M University, McLean, VA, FHWA-HRT-12-048, 2013. http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/12048/12048.pdf.

Longitudinal Rumble Strips: General Section 240

Introduction

Longitudinal rumble strips are grooved patterns in the pavement that make a rumbling sound and physical vibration that immediately warns inattentive drivers that they are leaving their driving lane.

Sections 240, 241, 242, and 243 apply to installation of longitudinal rumble strips on state highways by State Transportation Improvement Program (STIP) projects.

A centerline rumble strip is a milled rumble strip placed under the centerline markings or within a median, either along the edge or inside the median.

A shoulder rumble strip is a milled rumble strip placed in the shoulder offset from the outside of the left or right edge line.

An edge line rumble strip is a milled rumble strip placed under the edge line marking.

Clear shoulder width is the shoulder width that is rideable on a bicycle from the shoulder side of the rumble strip to the edge of pavement, or face of guardrail, concrete barrier, or other obstacle if present, as shown in Figures 240-B and 240-C.

The division between “urban” and “rural” is undefined in Sections 240, 241, 242, and 243 and should be gauged by the nature of the roadside environment. Heavily developed sections of rural highway are looked at from an urban perspective and relatively undeveloped sections of urban highway are looked at from a rural perspective.

A bicycle/bike gap pattern is a gap in the edge line or shoulder rumble strip that lets people on bikes cross the rumble strip (see Sections 241 and 242).

A rectangular rumble strip is a rectangular groove that is ground into the pavement in regular intervals.

A sinusoidal rumble strip is like rectangular rumble strips, but the sinusoidal rumble strips is ground into a wave pattern. The wave pattern is meant to reduce the external noise caused by the rumble strips.

Design Parameters

01 *When installing new or modifying existing rumble strips, public outreach should be completed explaining the purpose of the rumble strip installation.*

02 **Construction Section’s Pavement Services Unit shall be contacted early in the project planning process for all rumble strip installations to evaluate impacts to pavements. Construction Section’s Pavement Services Unit will develop pavement-related recommendations on the installation of rumble strips in collaboration with the district manager and the region traffic engineer.**

03 *Pavement-related recommendations should consider road user safety as the top priority. Additional considerations include: pavement condition, potential impacts on pavement condition and/or increased risk of pavement failure by installing rumble strips.*

04 **A bicycle gap pattern shall be used for all right edge line and right shoulder rumble strips.**

05 *A bicycle gap pattern should consist of a 48-foot long rumble strip and a 12-foot gap for a 60-foot cycle length.*

06 **Right edge line and right shoulder rumble strips shall not be installed where the clear shoulder width would be less than the minimums in Figure 240-A.**

07 **If longitudinal rumble strips are removed, they shall be replaced according to Sections 240, 241, 242, and 243 of this manual if:**

- **The removal results in a gap in rumble strip of 0.50 miles or more, and**
- **The total amount of rumble strips that would be installed is 0.50 miles or more.**

08 If longitudinal rumble strips are removed, they may be replaced according to Sections 240, 241, 242, and 243 of this manual if the removal results in a gap in rumble strips less than 0.50 miles.

Required Approvals

Region traffic engineer approval is required for certain exceptions in Figure 240-A. State traffic engineer approval is required for exceptions not listed in Figure 240-A. Requests must be submitted by the region traffic engineer.

See Sections 241, 242, and 243 for other approvals related to longitudinal rumble strips.

Figures & Tables

Figure 240-A: Minimum Clear Shoulder Widths after Installation

Rumble Strip Type and Location	Adjacent to Guardrail or Concrete Barrier?	Minimum Clear Shoulder Width After Installation
All right shoulder and edge line rumble strips	Yes	5 feet-0 inches ①
	No	4 feet-0 inches ①
Left shoulder rumble strips on rural freeways and divided highways	Yes	3 feet-0 inches ②
	No	1 foot-0 inches

① May be reduced to 1 foot-0 inches if approved by the Region Traffic Engineer where
1. AADT is 1500 vehicles per day or less, and
2. where passing sight distance is greater than the minimum in Section 211.

② May be reduced to 1 foot-0 inches if approved by the Region Traffic Engineer. Installation and maintenance of rumble strips is difficult in restricted width areas.

Figure 240-B: Clear Shoulder Width Example Right Shoulder Rectangular Rumble Strip No Guardrail or Concrete Barrier Present

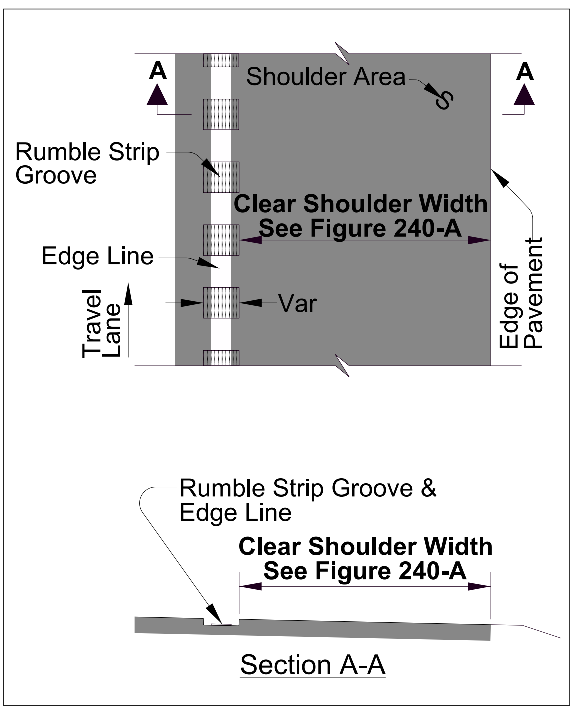
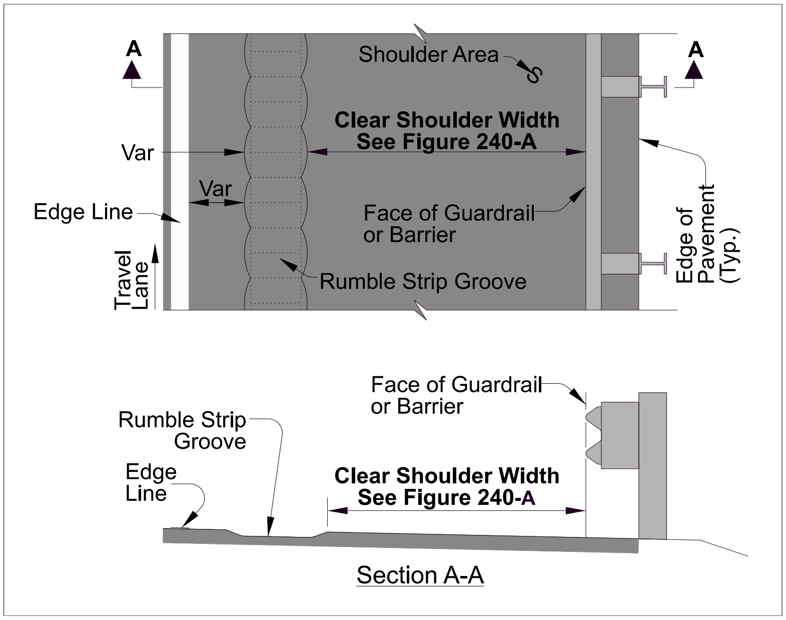


Figure 240-C: Clear Shoulder Width Example Right Shoulder Sinusoidal Rumble Strip Guardrail or Concrete Barrier Present



Support

A roadway departure crash occurs after a vehicle crosses an edge line or a center line or otherwise leaves the traveled way.

Roadway departure crashes are the most common type of fatal and serious injury crash on Oregon's rural highways. Between 2009 and 2013 approximately 53 percent of all fatal and serious injury crashes in Oregon included a roadway departure, contributing to 1,188 fatalities and 3,745 serious injuries. About 73 percent of these crashes were in a rural environment (*1*).

Rumble strips are a highly effective and cost efficient method of reducing roadway departure crashes. NCHRP Report 641 (*2*) reports the following estimates of safety effectiveness for rumble strips based on roadway functional classification:

Table 240-1: Estimated Safety Effectiveness of Rectangular Rumble Strips

Facility Type	Rumble Strip Location	Estimated Crash Reduction: All Roadway Departure	Estimated Crash Reduction: Fatal & Injury Roadway Departure
Rural Freeway	Shoulder	11% (SE=6)	16% (SE=8)
Rural Multi-Lane Divided Highway	Shoulder	22% (SE not reported)	51% (SE not reported)

Longitudinal Rumble Strips: General — Section 240

Facility Type	Rumble Strip Location	Estimated Crash Reduction: All Roadway Departure	Estimated Crash Reduction: Fatal & Injury Roadway Departure
Rural 2-Lane Highway	Shoulder	15% (SE=7)	29 (SE=9)
Rural 2-Lane Highway	Centerline	30% (SE=5)	44% (SE=6)
Urban 2-Lane Highway	Centerline	40% (SE=17)	64% (SE=27)

Edge line and shoulder rumble strips can be difficult for people on bicycles to traverse, and a clear, ridable shoulder next to rumble strips is needed for safe and predictable shoulder riding. The AASHTO Guide for the Development of Bicycle Facilities (*3*) does not recommend rumble strips on shoulders used by people on bikes unless there is a minimum clear path of 4 feet from the rumble strip to the edge of pavement, or 5 feet to an adjacent guardrail or other obstacle. The AASHTO Guide (*3*) also recommends gaps in the rumble strip pattern of at least 12 feet every 40 to 60 feet to allow people on bicycles to move across the rumble strip to avoid debris and other obstacles in the shoulder, pass other cyclists, make left turns, etc. Longer gaps might be needed on steep downgrades because of higher bicycle speeds.

To maximize the locations where shoulder and edge line rumble strips can be used, this policy allows right shoulder and edge line rumble strips where clear shoulder widths are less than the minimums in Figure 240-A on low volume highways (AADT is 1500 vehicles per day or less) where there is passing sight distance available. This volume is the upper threshold recommended in the ODOT Bicycle and Pedestrian Design Guide (*4*) where a shared lane condition is tolerable. Omitting shoulder or edge line rumble strips in areas with limited passing sight distance allows cyclists to stay as far to the right as possible in areas where approaching drivers have limited sight distance and allows for simplified installation as these areas already need to have no-passing zone markings.

There are added safety benefits where rumble strips are installed next to guardrail or concrete barrier. These include reduced damage to vehicles and less frequent maintenance or replacement of guardrail or barrier because rumble strips reduce the frequency and severity of crashes.

Rumble strips are a systemic treatment that work best when applied on a corridor-basis. When a project needs to remove a short section of rumble strips, the safety benefits of reinstalling rumble strips may not outweigh the cost to do so. The cost-per-mile to install rumble strips increases exponentially as quantity decreases, especially for quantities less than 0.5 miles. Consider the following when replacing rumble strips gap that is less than 0.5 miles long:

- Total gap in rumble strip
- Roadway departure crash history

- AADT
- 85th percentile speed

A rumble strip only works to alert an errant driver if the rumble strip is present. As the number of drivers increases (AADT), so does the potential for an errant driver, and higher vehicle speed means less time for a driver to react if they leave the road.

Cross References

Longitudinal Rumble Strips: Rural Freeways and Divided Highways .... Section 241
Longitudinal Rumble Strips: Rural Non-Freeways and Undivided Highways .... Section 242
Longitudinal Rumble Strips: Urban Highways .... Section 243

Key References

1. Oregon Department of Transportation. *2016 Oregon Transportation Safety Action Plan*. Oregon Department of Transportation, Salem, Oregon, 2016. http://www.oregon.gov/ODOT/Safety/Documents/TSAP_2016.pdf.
2. Torbic, D. J., J. M. Hutton, C. D. Bokenkroger, K. M. Bauer, D. W. Harwood, D. K. Gilmore, J. M. Dunn, J. Ronchetto, E. T. Donnell, H. J. Sommer Ill, P. M. Garvey, B. Persaud, and C. Lyon. NCHRP Report 641: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips. Transportation Research Board of the National Academies, Washington, D.C., ISSN 0077-5614, 2009. http://www.trb.org/Publications/Blurbs/162610.aspx.
3. American Association of State Highway and Transportation Officials. *Guide for the Development of Bicycle Facilities*, 5th ed. Washington, D.C., 2024.
4. Oregon Department of Transportation. *Bicycle and Pedestrian Design Guide*, 3rd ed. Oregon Department of Transportation, Salem, Oregon, 2011. http://www.oregon.gov/ODOT/Engineering/Documents_RoadwayEng/HDM_L-Bike-Ped-Guide.pdf.

Longitudinal Rumble Strips: Rural Freeways and Divided Highways Section 241

Introduction

Rural freeways and divided highways are typically highways with two lanes in each direction and a median width of 4 feet or more constructed in a way to preclude its use by moving vehicles. There might be use of these non-traversable medians for emergencies or for authorized emergency or maintenance U-turns. Examples are rural freeways with full access control or divided sections of multilane rural highways with partial access control, such as expressways or parkways sharing many of the functional characteristics of rural freeways. See Section 240 for more rumble strip definitions.

Design Parameters

01 **Right shoulder rectangular rumble strips shall be installed where the clear shoulder width is greater than or equal to the minimums in Figure 240-A.**

02 **Rumble strips on right shoulders shall be installed in a bike gap pattern.**

03 **Left shoulder rectangular rumble strips shall be installed where the clear shoulder width is greater than or equal to the minimums in Figure 240-A.**

04 **Rumble strips on left shoulders shall be installed in a continuous pattern.**

05 *Shoulder rumble strips should be placed according to Figures 241-A through 241-L.*

06 **Rumble strips shall not extend across crosswalks, marked or unmarked, including the far side of a T-intersection**.

Exceptions

07 **Exceptions approved under this section shall be documented in a design narrative or similar format and filed with the region traffic office.**

08 *In locations where rumble strips are being evaluated for omission, consideration should be given to installing rumble strips if the location has a history of roadway departure crashes.*

09 Right shoulder rumble strips may be offset up to 4 feet from the outside edge of the right edge line where clear shoulder widths are greater than or equal to the minimums in Figure 240-A and any one of the following locations:

- Where maintenance work zones could be adversely affected by driver behavior during lane shifts onto the shoulder.

- Uphill sections where trucks or oversize loads use the shoulder to allow truck drivers to position their left wheels fully out of the lane without running on the rumble strip.
- Sections where the rumble strip must be offset due to a longitudinal pavement joint (such as PCC lanes and HMAC shoulders) or locations adjacent to these sections to maintain consistent application of rumble strips through a corridor.
- Where the region traffic engineer, in collaboration with the district manager and pavement services engineer, determine pavement condition and risk of pavement failure require offsetting the rumble strip.
- Where sections have an approved bus shoulder lane for the right shoulder of the roadway.

10 Shoulder rumble strips may be omitted where the region traffic engineer, in collaboration with the district manager and pavement services engineer, determine pavement condition and risk of pavement failure outweigh the safety benefit of rumble strips.

11 Right shoulder rumble strips may be omitted on uphill sections where trucks or oversize loads drive on the shoulder.

12 Right shoulder rumble strips may be omitted next to guardrail or concrete barrier where the clear shoulder width is greater than the minimums shown in Figure 240-A. The benefits of rumble strips should be considered in these locations.

13 Right shoulder rumble strips may be omitted where the right shoulder of the roadway is a bus shoulder lane.

14 Rumble strips may be omitted where rumble strips were not previously installed and the total amount of rumble strips that would be installed is 0.5 miles or less.

15 Sinusoidal rumble strips may be used instead of rectangular rumble strips based on an engineering study (see Section 242 for sinusoidal rumble strip pattern details and supporting information).

16 Right shoulder and edge line rumble strips may be omitted within T-intersections.

Required Approvals

Region traffic engineer approval is required for exceptions in this section. Exceptions not in this section require state traffic engineer approval. Requests must be submitted by the region traffic engineer.

Figures & Tables

Figure 241-A: Shoulder Rectangular Rumble Strip Details for Rural Freeway or Divided Highway

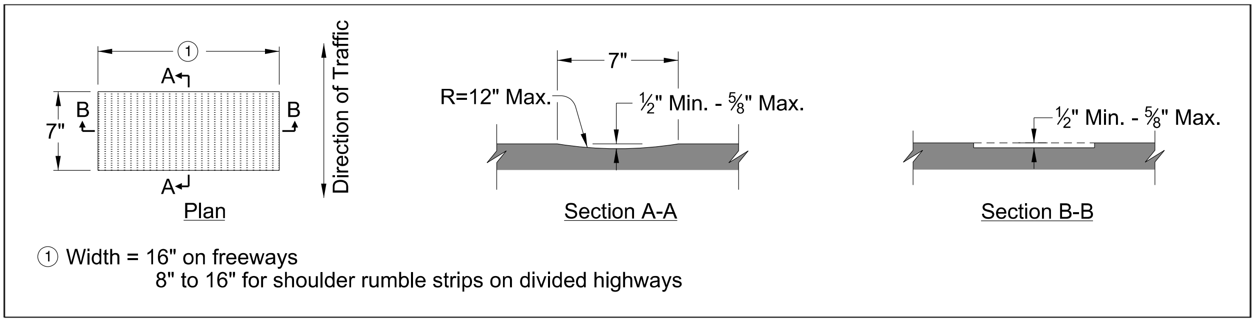
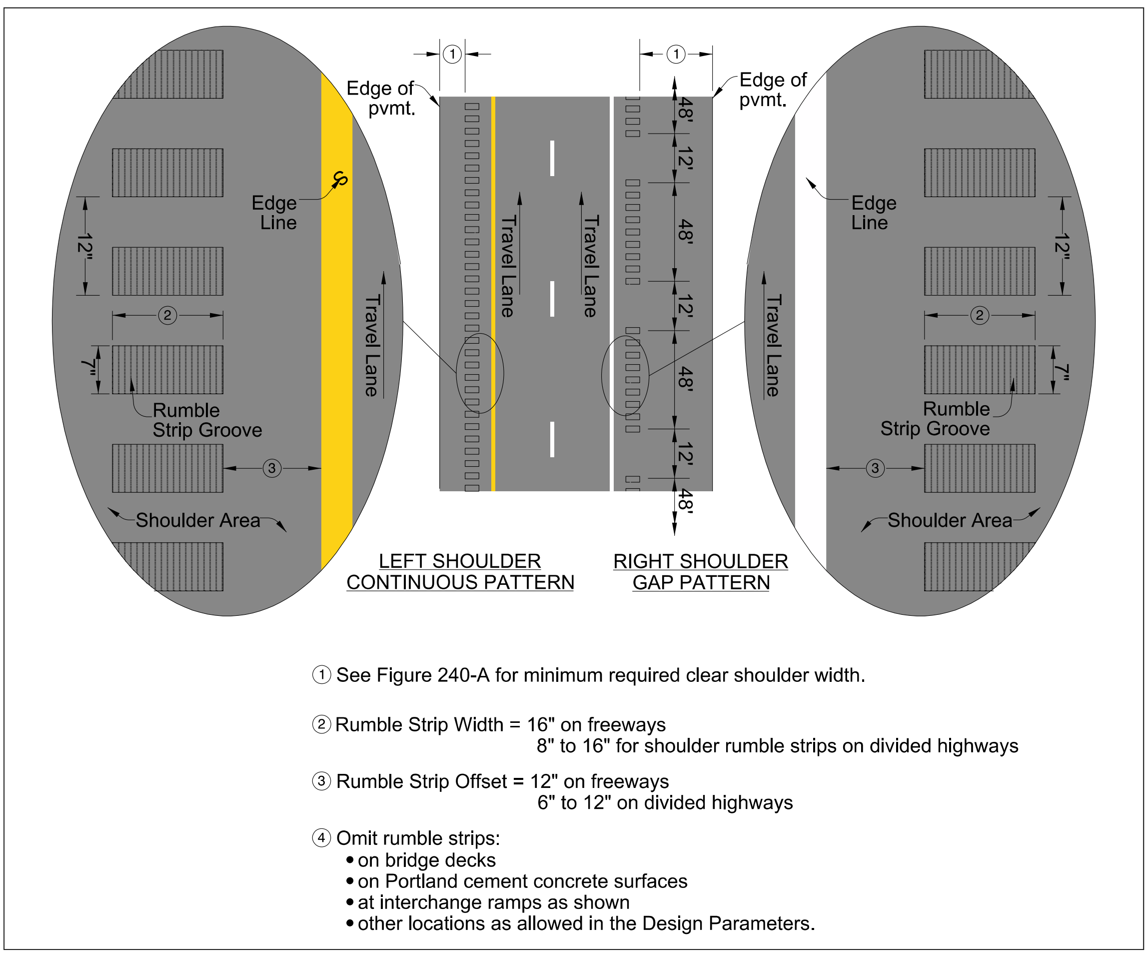
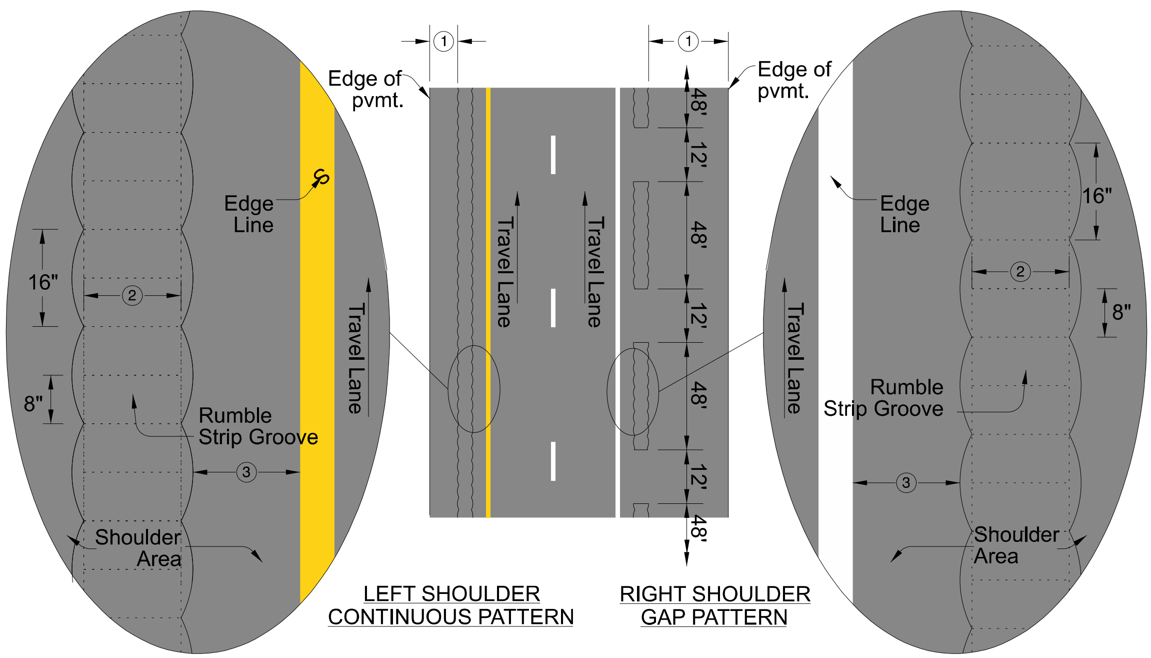


Figure 241-B: Typical Shoulder Rectangular Rumble Strip Placement on Rural Freeway or Divided Highway



Longitudinal Rumble Strips: Rural Freeways and Divided Highways

Figure 241-C: Typical Shoulder Sinusoidal Rumble Strip Placement on Rural Freeway or Divided Highway



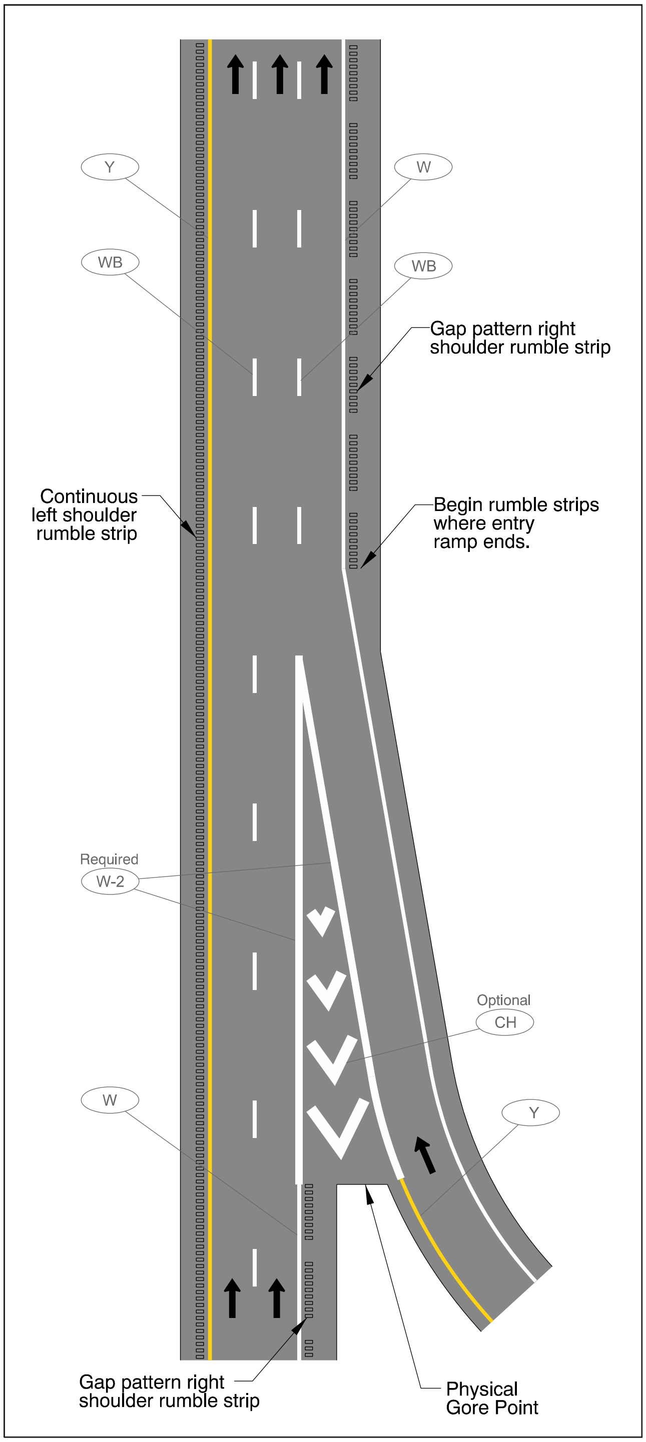
① See Figure 240-A for minimum required clear shoulder width.

② Rumble Strip Width = 8", 12", or 16"
Determined by space constraints and Region Traffic Engineer

③ Rumble Strip Offset = 12" on freeways
6" to 12" on divided highways

④ Omit rumble strips:
- on bridge decks
- on Portland cement concrete surfaces
- at interchange ramps as shown
- other locations as allowed in the Design Parameters.

Figure 241-D: Typical Shoulder Rectangular Rumble Strip Placement at Entrance Ramp with Added Lane



Longitudinal Rumble Strips: Rural Freeways and Divided Highways

Figure 241-E: Typical Shoulder Rectangular Rumble Strip Placement at Entrance Ramp with Parallel Acceleration Lane

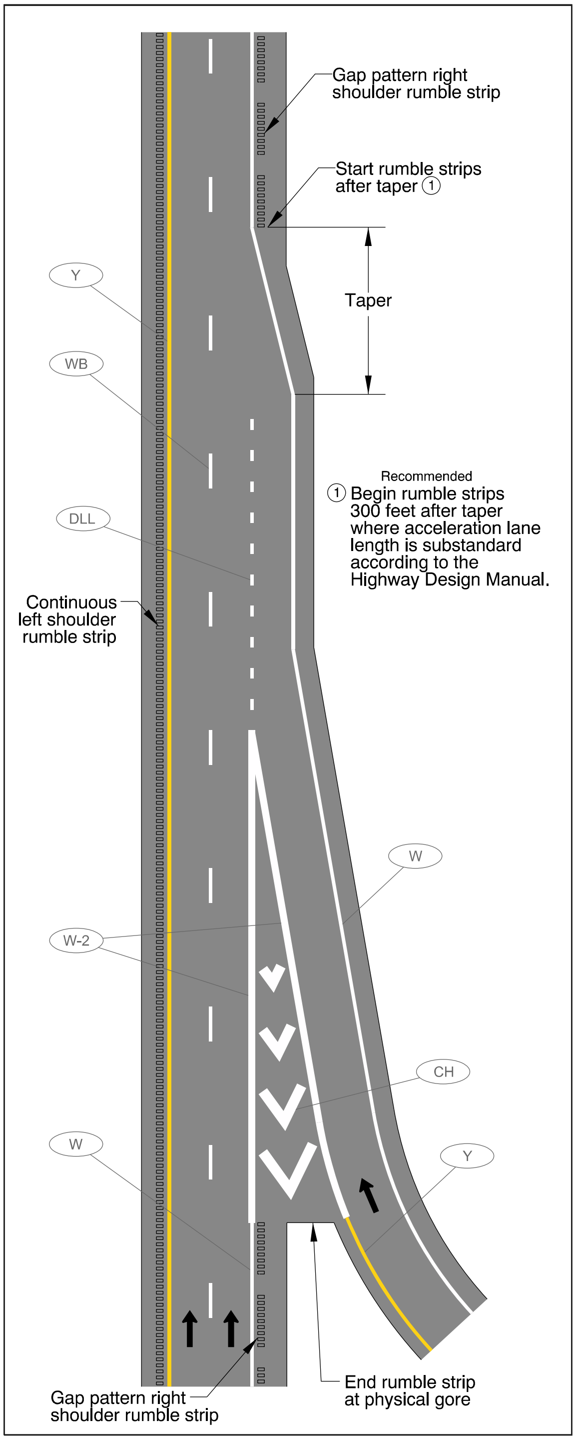


Figure 241-F: Typical Shoulder Rectangular Rumble Strip Placement at Tapered Deceleration Lane

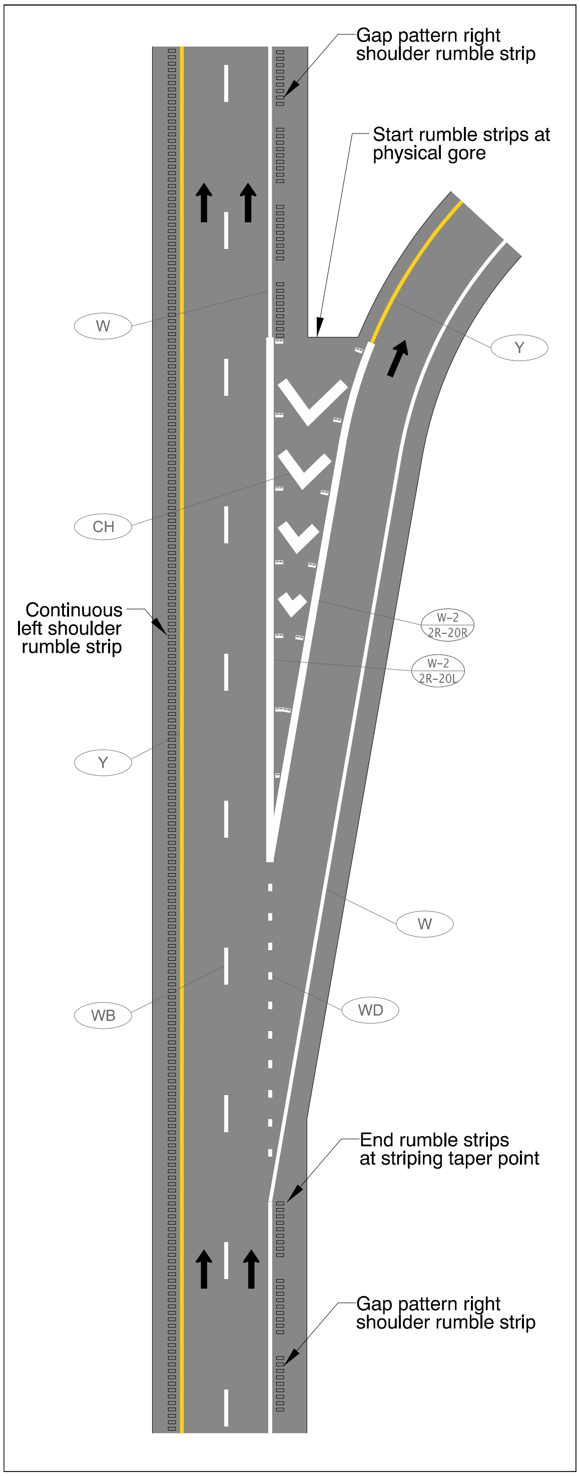


Figure 241-G: Typical Shoulder Rectangular Rumble Strip Placement at Rural Divided Highway T-Intersections

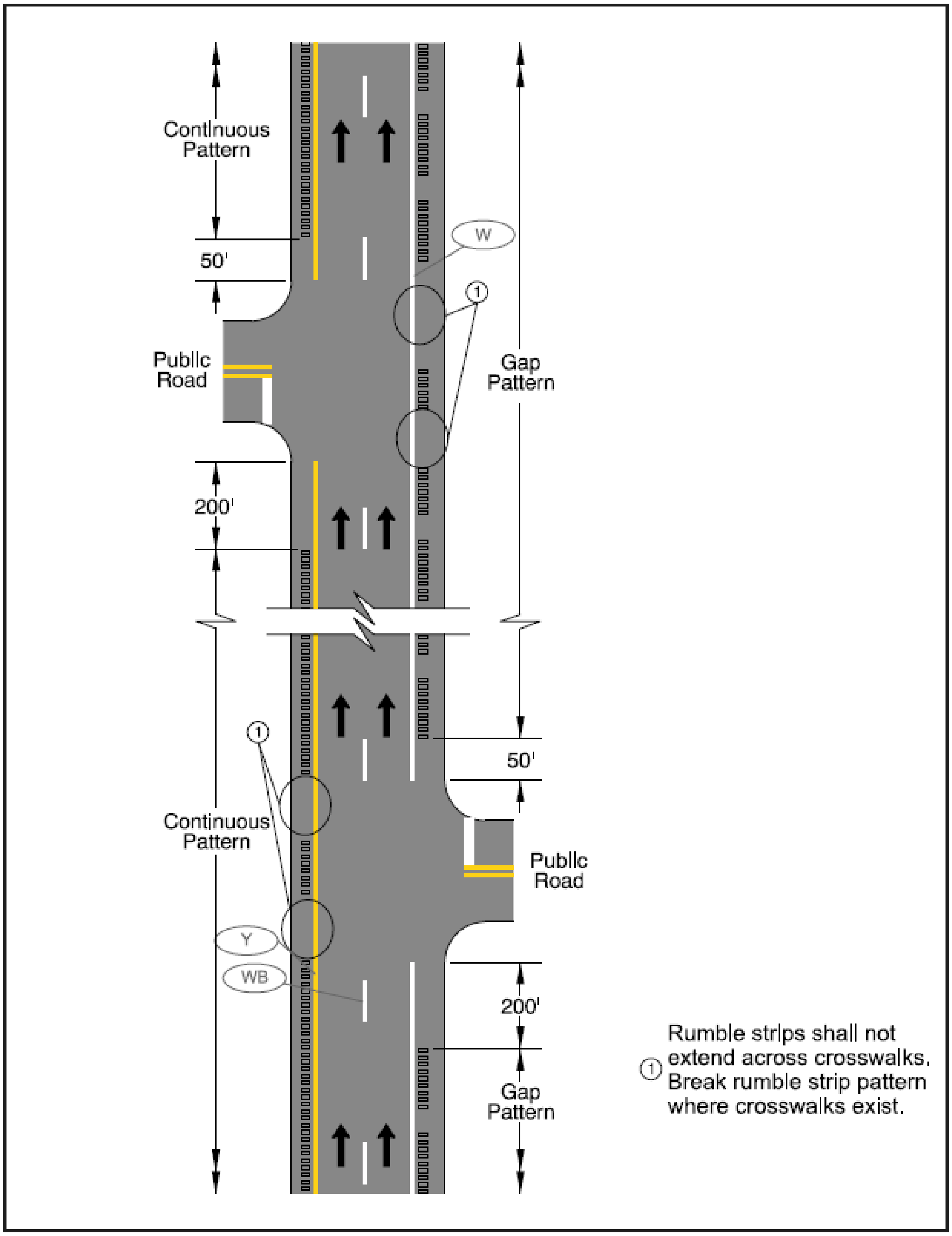


Figure 241-H: Typical Shoulder Rectangular Rumble Strip Placement at Rural Divided Highway Intersection

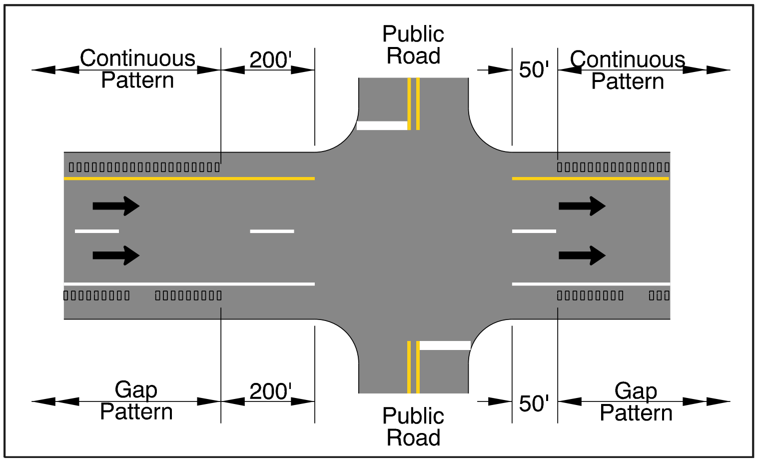
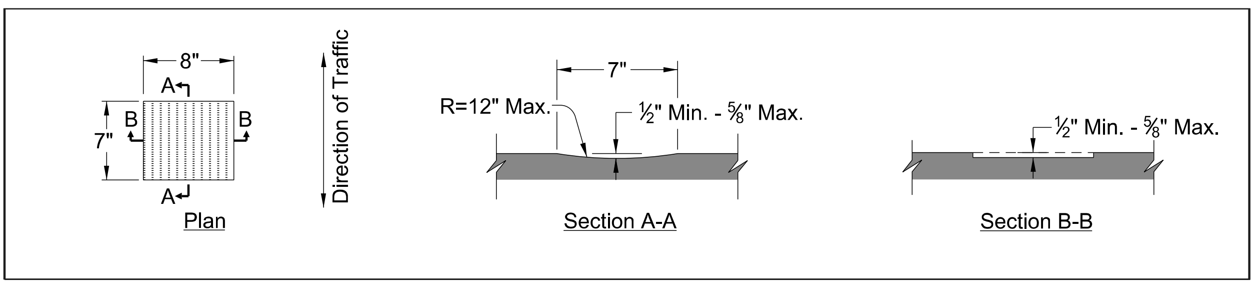


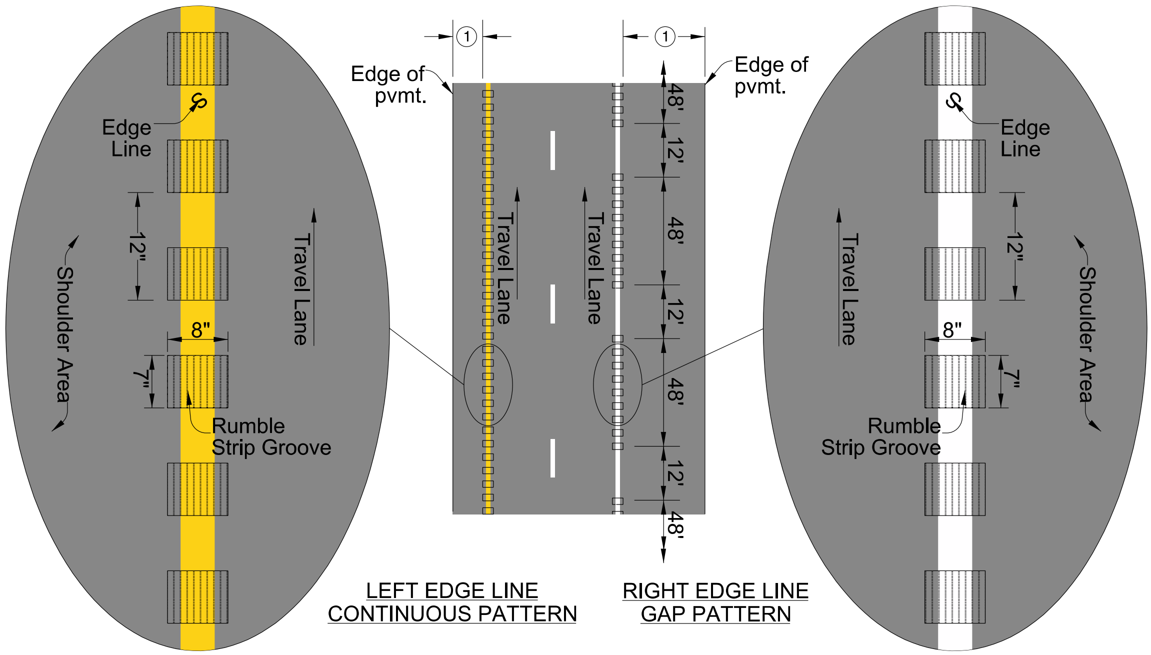
Figure 241-I: Edge Line Rectangular Rumble Strip Details for Rural Divided Highway



Longitudinal Rumble Strips: Rural Freeways and Divided Highways

Section 241

Figure 241-J: Typical Edge Line Rectangular Rumble Strip Placement on Rural Divided Highway



① See Figure 240-A for minimum required clear shoulder width.

② Center edge line rumble strips on edge line stripe.

③ Omit rumble strips:
- on bridge decks
- on Portland cement concrete surfaces
- at interchange ramps as shown
- other locations as allowed in the Design Parameters.

Figure 241-K: Typical Edge Line Rectangular Rumble Strip Placement at Rural Divided Highway T-Intersections

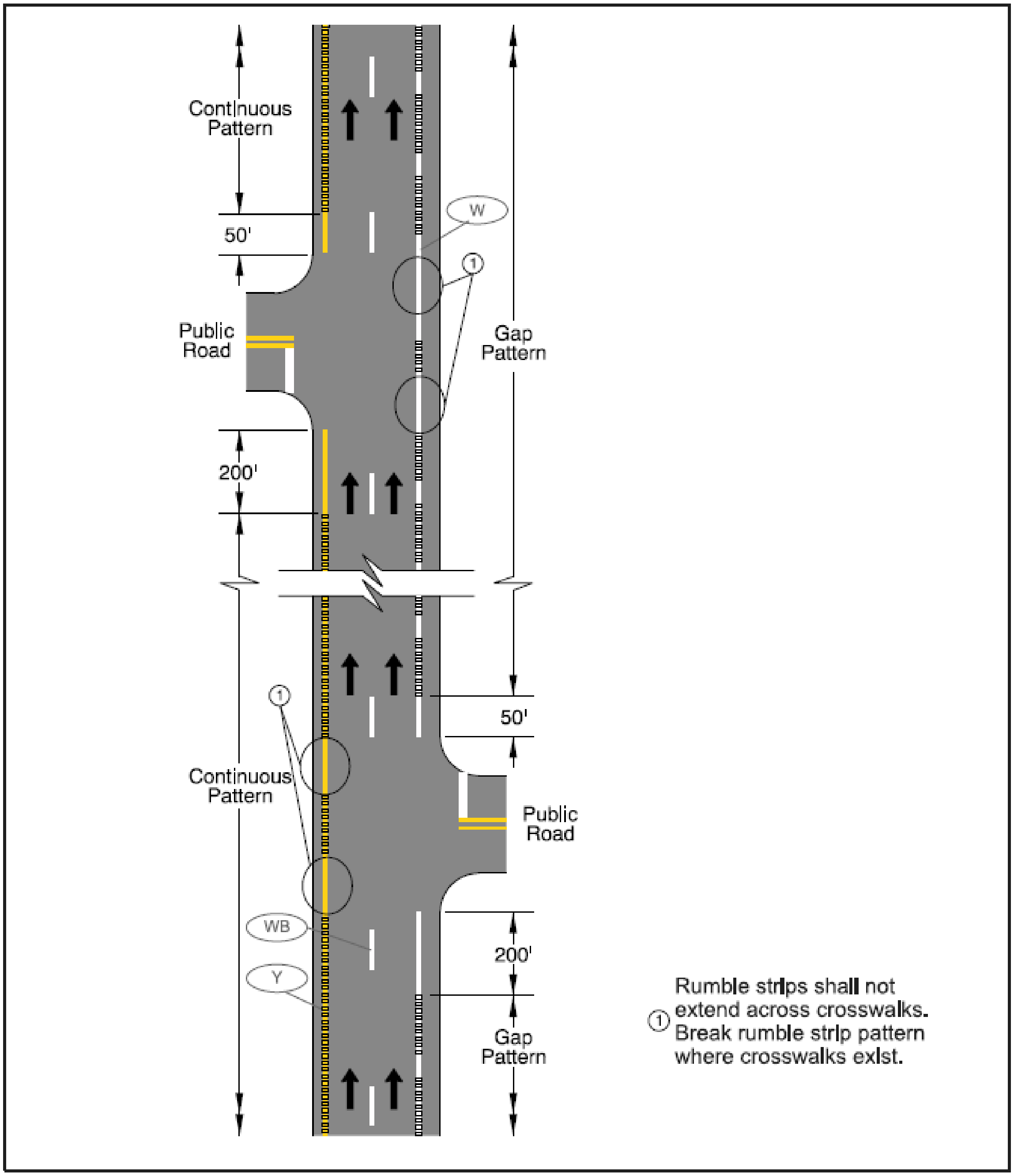
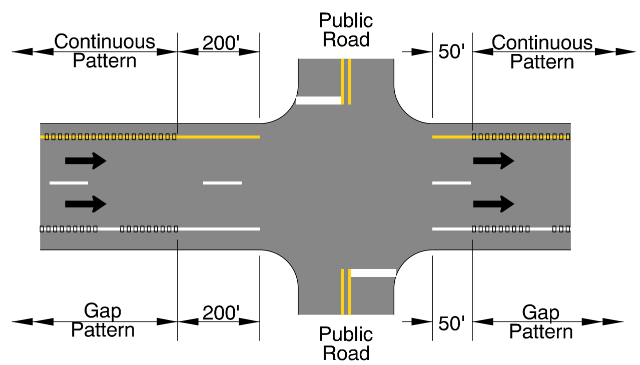


Figure 241-L: Typical Edge Line Rectangular Rumble Strip Placement at Rural Divided Highway Intersection



Support

A roadway departure crash occurs after a vehicle crosses an edge line or a center line or otherwise leaves the traveled way.

Roadway departure crashes are the most common type of fatal and serious injury crash on Oregon’s rural highways. Between 2014 and 2018 approximately 41% of all fatal and serious injury crashes in Oregon included a roadway departure, contributing to 1,330 fatalities and 3,336 serious injuries. About 68% of these crashes were in a rural environment (*1*).

Rumble strips are a highly effective and cost efficient method of reducing roadway departure crashes. NCHRP Report 641 (*2*) reports shoulder rumble strips on rural freeways can be expected to reduce fatal and injury roadway departure crashes by 16% (SE=8); shoulder rumble strips on rural multilane divided highways can be expected to reduce fatal and injury roadway departure crashes by 51% (SE not reported).

Short duration temporary traffic control measures on rural freeways and divided highways that shift road users onto the shoulder can experience poor driver compliance if rumble strips are present. Drivers tend to straddle rumble strips if there is not enough clear driving space on one side of the rumble strip. This can create unsafe conditions for workers and road users if this positions vehicles too close to the work area. In these cases, the option to offset rumble strips up to 4-foot on rural freeways and divided highways can address some maintenance concerns while still providing a safety benefit from the rumble strips. These areas need to be chosen carefully; there is conclusive evidence that rural freeway rumble strips placed closer to the edge line are more effective at reducing fatal and injury roadway departure crashes compared to rumble strips placed farther from the edge line (*2*).

Bicyclists can legally ride on interstate freeway shoulders, except for specific areas in the Portland area and Medford, according to OAR 734-020-0045. Edge line and shoulder rumble strips can be difficult for people on bicycles to traverse, and a clear, ridable shoulder next to rumble strips is needed for safe and predictable shoulder riding. The AASHTO Guide for the Development of Bicycle Facilities (*3*) does not recommend rumble strips on shoulders used by people on bikes unless there is a minimum clear path of 4 feet from the rumble strip to the edge of pavement, or 5 feet to an adjacent guardrail or other obstacle. The AASHTO Guide (*3*) also recommends gaps in the rumble strip pattern of at least 12 feet every 40 to 60 feet to allow people on bicycles to move across the rumble strip to avoid debris and other obstacles in the shoulder, pass other cyclists, make left turns, etc. Longer gaps might be needed on steep downgrades because of higher bicycle speeds.

There are added safety benefits where rumble strips are installed next to guardrail or concrete barrier. These include reduced damage to vehicles and less frequent maintenance or replacement of guardrail or barrier because rumble strips reduce the frequency and severity of crashes.

The rumble strip design dimensions shown in Figure 241-A and Figure 241-B are the most common dimensions of milled shoulder rumble strips in the United States. These generate sufficient noise in the upper range of recommended noise design thresholds to alert inattentive, distracted, drowsy, or fatigued drivers, including drivers of heavy vehicles (*2*).

Longitudinal rumble strips are a systemic safety countermeasure that provides the most benefit when applied to long sections of highway. The per-mile cost to install rumble strips increases as total quantity decreases, largely due to costs for contractors to mobilize equipment and workers. Because of this, there is an exception for very small quantities where rumble strips were not previously installed.

When breaking rumble strip patterns for crosswalks at T-intersections, it may be easier to break the rumble strip pattern for the entirety of the intersection. Doing so may help avoid confusion in the rumble strip pattern, as well as make constructing the rumble strip pattern easier by limiting stopping and restarting of the equipment through the intersection.

Cross References

This subsection lists the subject titles and page numbers of other sections within the Traffic Manual that are relevant to the subject.

Key References

1. Oregon Department of Transportation. *2021 Oregon Transportation Safety Action Plan*. Oregon Department of Transportation, Salem, Oregon, 2021. https://www.oregon.gov/odot/Safety/Documents/2021_Oregon_TSAP.pdf.

2. Torbic, D. J., J. M. Hutton, C. D. Bokenkroger, K. M. Bauer, D. W. Harwood, D. K. Gilmore, J. M. Dunn, J. Ronchetto, E. T. Donnell, H. J. Sommer Ill, P. M. Garvey, B. Persaud, and C. Lyon. NCHRP Report 641: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips. Transportation Research Board of the National Academies, Washington, D.C., ISSN 0077-5614, 2009. http://www.trb.org/Publications/Blurbs/162610.aspx.

3. American Association of State Highway and Transportation Officials. *Guide for the Development of Bicycle Facilities*, 5th ed. Washington, D.C., 2024.

Longitudinal Rumble Strips: Rural Non-Freeways and Undivided Highways Section 242

Introduction

Rural non-freeways and undivided highways are typically rural two-lane, two-way highways and sections of rural multilane highways without a median barrier or unpaved median to separated opposing directions of traffic. There might be a two-way left turn lane separating directions of traffic. See Section 240 for more rumble strip definitions.

Design Parameters

01 **Centerline rectangular rumble strips shall be installed wherever:**

- **Adjacent lanes are 12 feet wide or wider (measured from lane line to lane line; see Section 120); or**
- **There is 26 feet or more of roadway width from edge of pavement to edge of pavement.**

02 **Centerline rectangular rumble strips shall be installed in a continuous pattern.**

03 **Edge line or shoulder rectangular rumble strips shall be installed where the clear shoulder width is greater than or equal to the minimums in Figure 240-A for at least ½ mile, treating breaks for driveways or approaches as continuous shoulder.**

04 **Edge line and shoulder rectangular rumble strips shall be installed in a bike gap pattern.**

05 **Centerline, edge line, and shoulder rectangular rumble strips shall not continue across intersections and major driveways where centerline and edge line pavement markings are not continued across intersections and major driveways (see Sections 210 and 230).**

06 *Shoulder rectangular rumble strips should be placed according to Figures 242-A, -C, -D, -G, and -H. Edge line rumble strips should be placed according to Figures 242-E, -F, -I, and -J. Centerline rumble strips should be placed according to Figures 242-K, -L, -M, -N, -O, -P, -Q, -R, -S, -T, , -U, -W, and –W. Centerline rumble strips with recessed RPMs should be placed according to Figure 242-X. Sinusoidal rumble strips should be placed following the same figures, but use the details of Figure 242-B to replace the rectangular rumbles strips with sinusoidal rumble strips (for example see Figure 242-D).*

07 **Rumble strips shall not extend across crosswalks, marked or unmarked, including the far side of a T-intersection**.

Exceptions

08 **Exceptions approved under this section shall be documented in a design narrative or similar format and filed with the region traffic office.**

09 *In locations where rumble strips are being evaluated for omission, consideration should be given to installing rumble strips if the location has a history of roadway departure crashes.*

10 Centerline, edge line, and shoulder rumble strips may be omitted within 600 feet of a residence or campground (distance to residence, not driveway) due to roadside noise. For shoulder rumble strips, this distance may be reduced to 200 feet if public outreach is completed explaining why rumble strips are proposed to within 200 feet.

11 Where existing shoulder rumble strips have been in place with no history of noise complaints and provide clear shoulder widths greater than or equal to the minimums in Figure 240-A, bike gap shoulder rumble strips may be re-installed in the existing location.

12 Centerline rumble strips may be omitted due to roadside noise where frequent passing occurs, particularly after a long section with few practical passing opportunities.

13 Centerline, edge line, and shoulder rumble strips may be omitted at horizontal curves with frequent vehicle off-tracking (e.g.: because of a small curve radius) and at approaches to intersecting roads and driveways with vehicles frequently turning off the highway.

14 Centerline rumble strips may be omitted from sections of a two-way left turn lane (TWLTL).

15 Centerline, shoulder, and edge line rumble strips may be omitted in locations with a history of frequent maintenance issues, such as sunken grades requiring regular overlays.

16 Centerline, shoulder, and edge line rumble strips may be omitted where the region traffic engineer, in collaboration with the district manager and pavement services engineer, determine pavement condition and risk of pavement failure outweigh the safety benefit of rumble strips.

17 Centerline rumble strips may be installed where adjacent lanes are less than 12 feet wide or where there is less than 26 feet of roadway width from edge of pavement to edge of pavement.

18 Rumble strips may be omitted where rumble strips were not previously installed and the total amount of rumble strips that would be installed is 0.5 miles or less.

19 Right shoulder rumble strips may be omitted or offset up to 4 feet from the outside edge of the edge line where the right shoulder of the roadway is a bus shoulder lane.

20 Sinusoidal rumble strips may be used instead of rectangular rumble strips based on an engineering study.

21 Right shoulder and edge line rumble strips may be omitted within T-intersections.

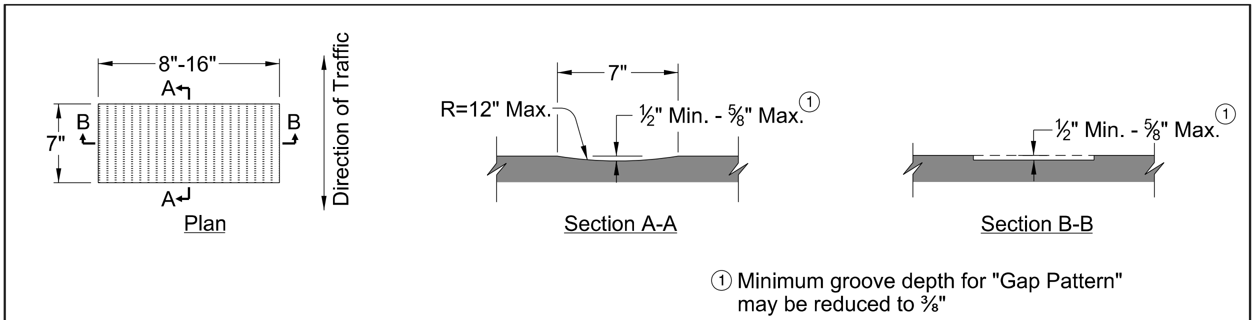
22

Required Approvals

Region traffic engineer approval is required for exceptions in this section. Exceptions not in this section require state traffic-roadway engineer approval. Requests must be submitted by the region traffic engineer.

Figures & Tables

Figure 242-A: Shoulder Rectangular Rumble Strip Details for Rural Non-Freeway & Undivided Highway



Longitudinal Rumble Strips: Rural Non-Freeways and Undivided Highways

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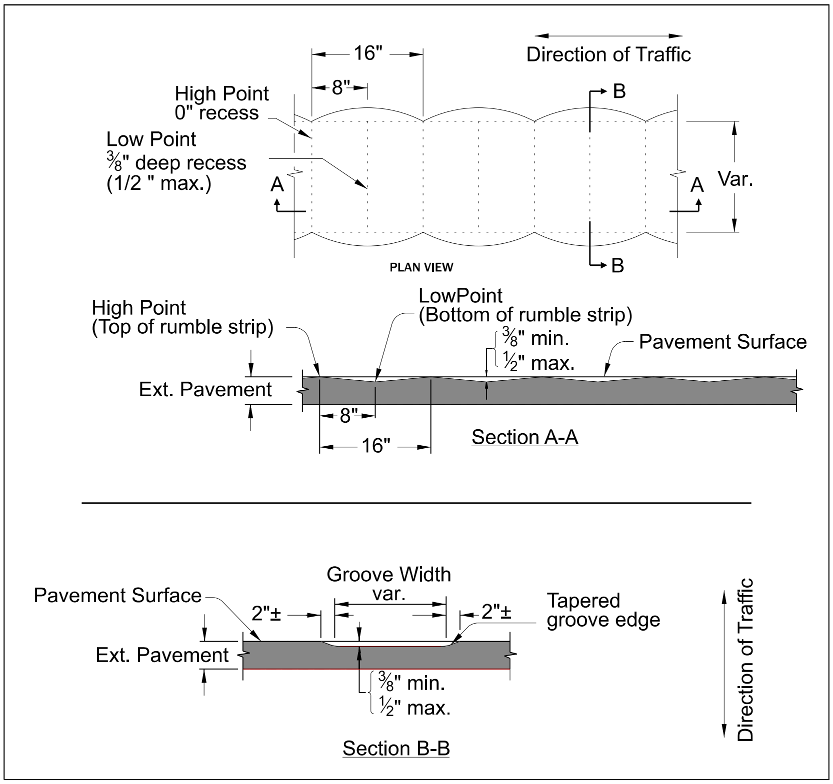
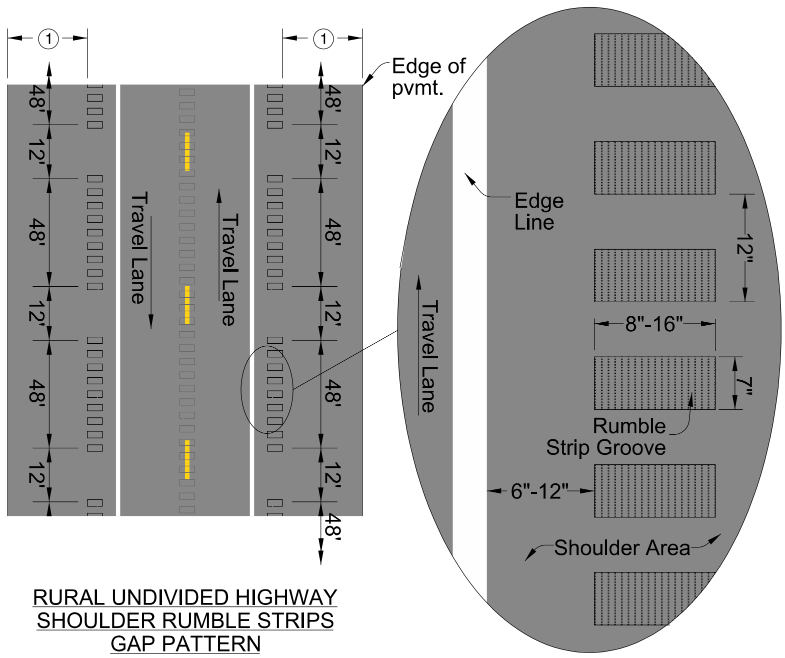
Figure 242-B: Sinusoidal Rumble Strip Details for Rural Non-Freeway & Undivided Highway



Longitudinal Rumble Strips: Rural Non-Freeways and Undivided Highways

Section 242

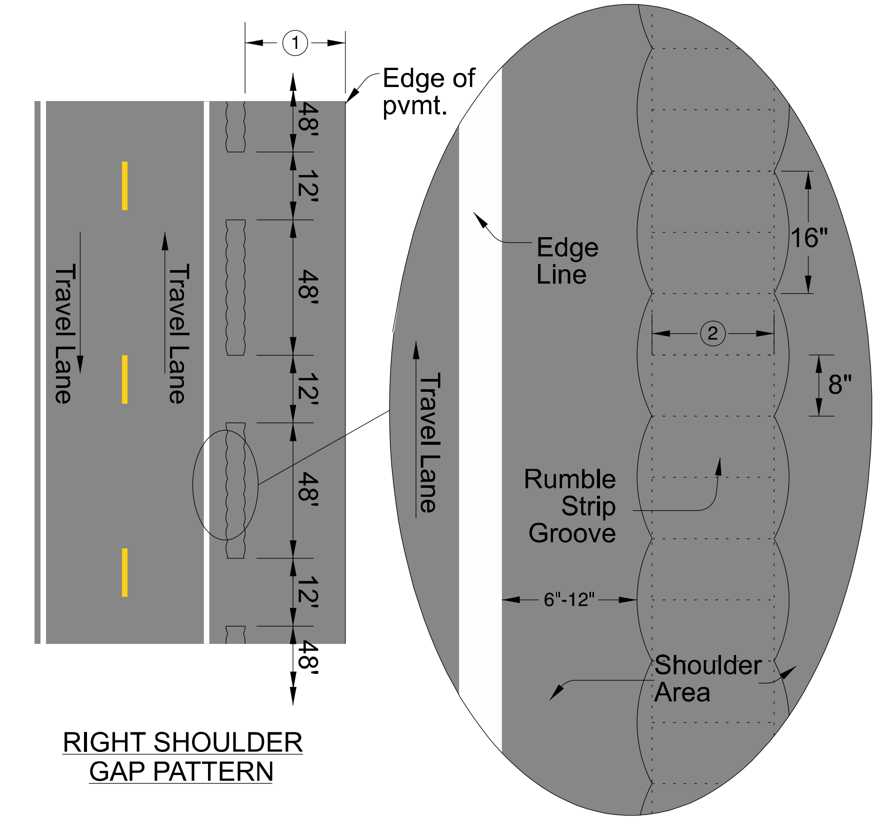
Figure 242-C: Typical Shoulder Rectangular Rumble Strip Placement on Rural Non-Freeway & Undivided Highways



① See Figure 240-A for minimum required clear shoulder width.

② Omit rumble strips:
- on bridge decks
- on Portland cement concrete surfaces
- at interchange ramps as shown
- other locations as allowed in the Design Parameters.

Figure 242-D: Typical Shoulder Sinusoidal Rumble Strip Placement on Rural Non-Freeway & Undivided Highways



① See Figure 240-A for minimum required clear shoulder width.

② Rumble Strip Width = 8", 12", or 16"
Determined by space constraints and Region Traffic Engineer

④ Omit rumble strips:
- on bridge decks
- on Portland cement concrete surfaces
- at interchange ramps as shown
- other locations as allowed in the Design Parameters.

Longitudinal Rumble Strips: Rural Non-Freeways and Undivided Highways

Section 242

Figure 242-E: Edge Line Rectangular Rumble Strip Details for Rural Non-Freeway & Undivided Highway

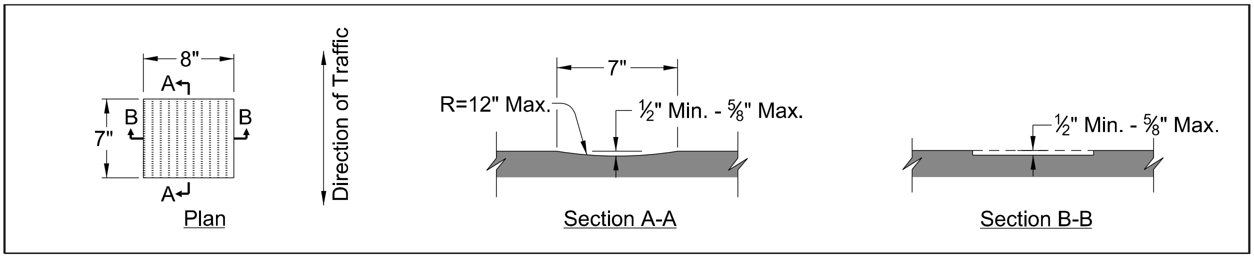


Figure 242-F: Typical Edge Line Rectangular Rumble Strip Placement on Rural Non-Freeway & Undivided Highways

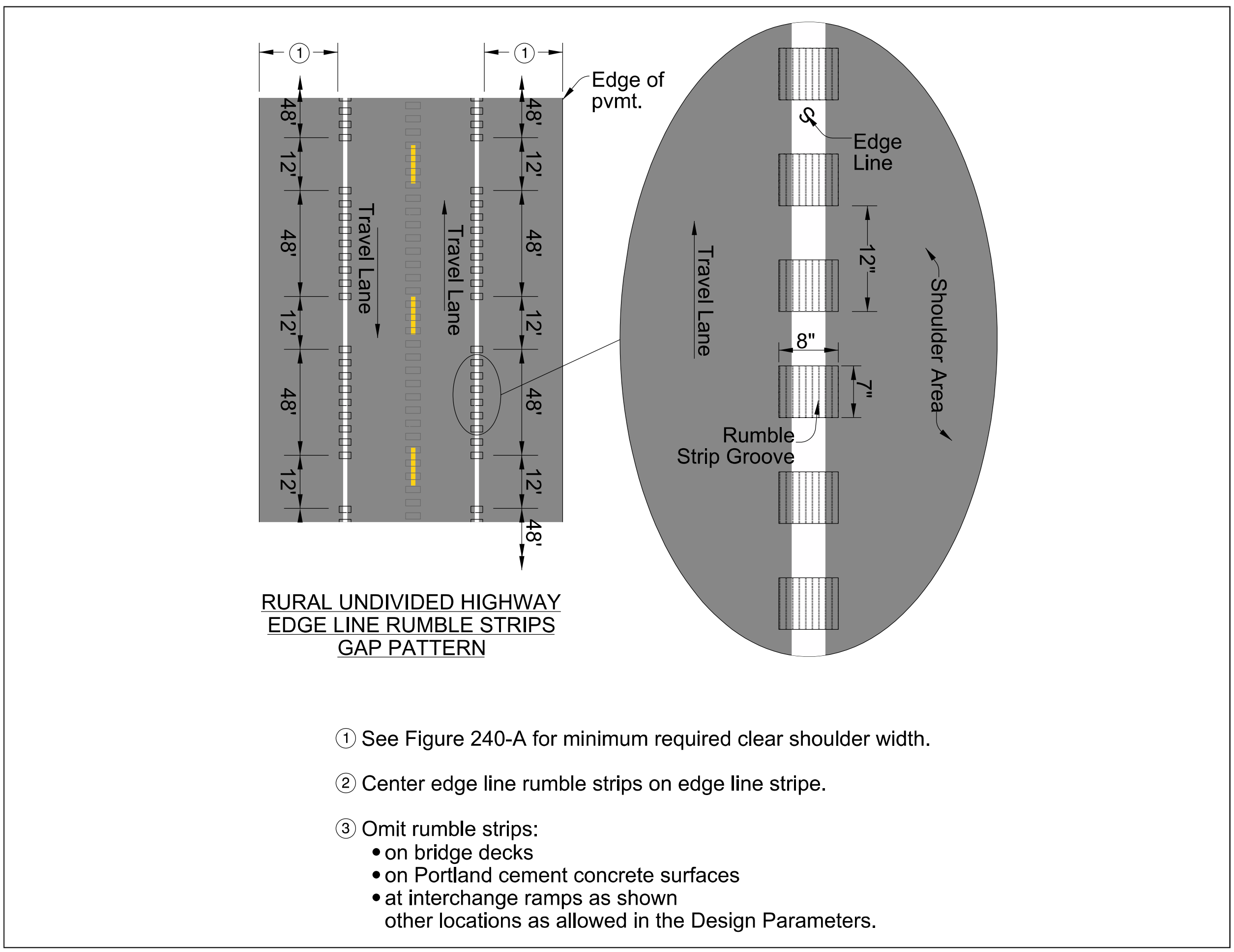


Figure 242-G: Typical Shoulder Rectangular Rumble Strip Placement at Rural Undivided Highway T-Intersections

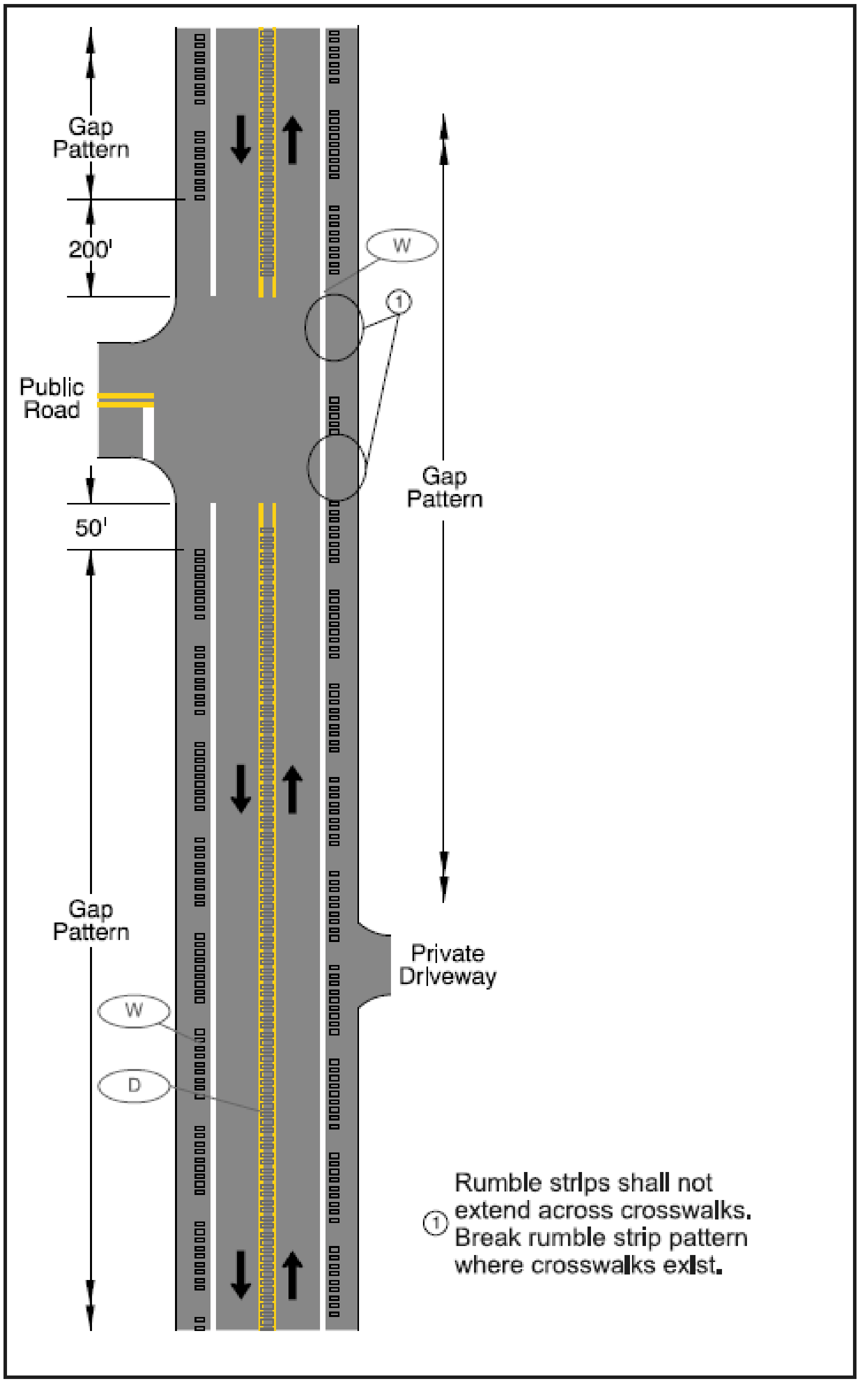


Figure 242-H: Typical Shoulder Rumble Strip Placement at Rural Undivided Highway Intersection

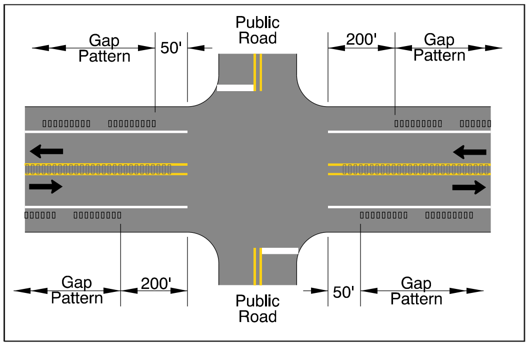


Figure 242-I: Typical Edge Line Rectangular Rumble Strip Placement at Rural Undivided Highway T-Intersections

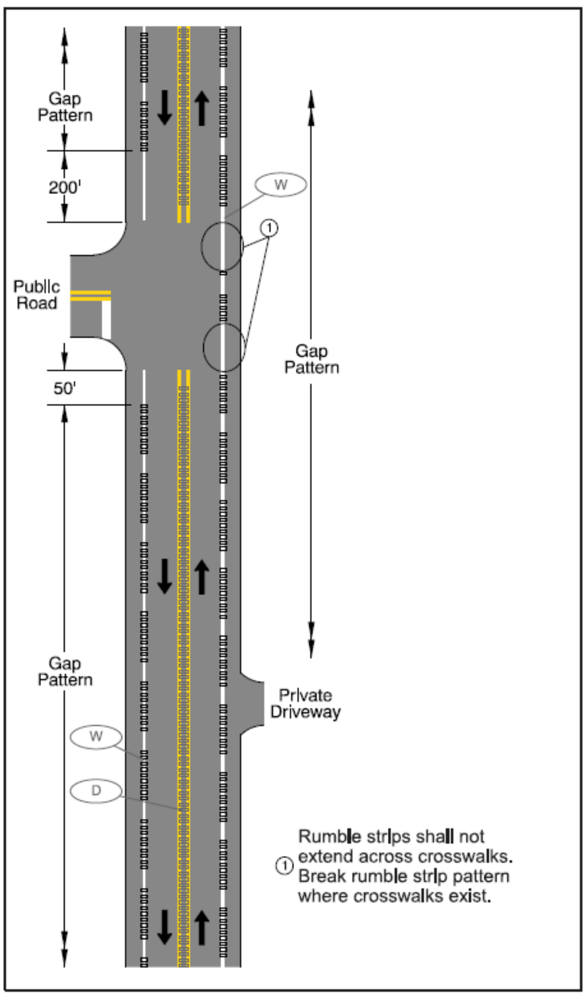


Figure 242-J: Typical Edge Line Rectangular Rumble Strip Placement at Rural Undivided Highway Intersection

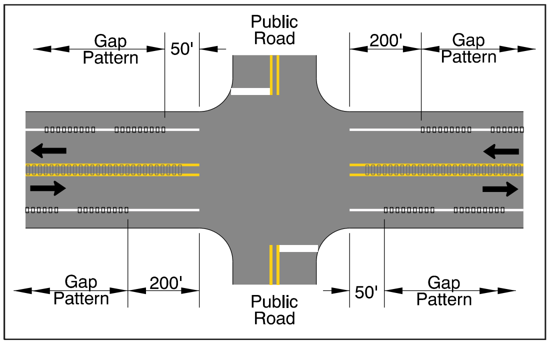
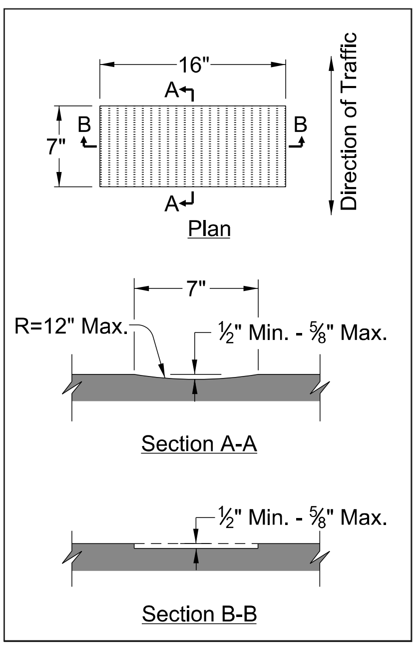


Figure 242-K: Centerline Rectangualr Rumble Strip Details



Longitudinal Rumble Strips: Rural Non-Freeways and Undivided Highways — Section 242

Figure 242-L: Continuous Pattern Rectangular Rumble Strip Centerline Installation

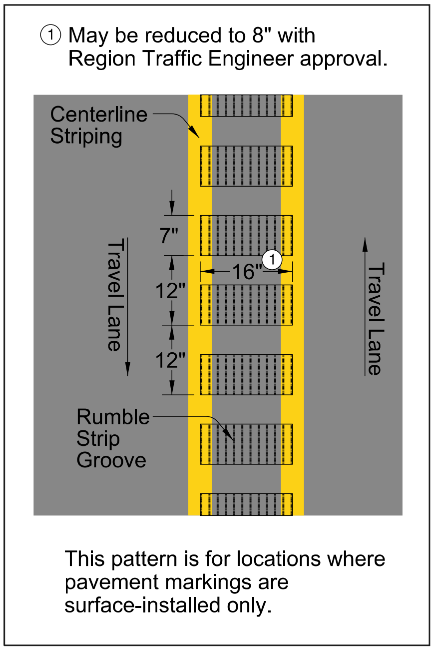
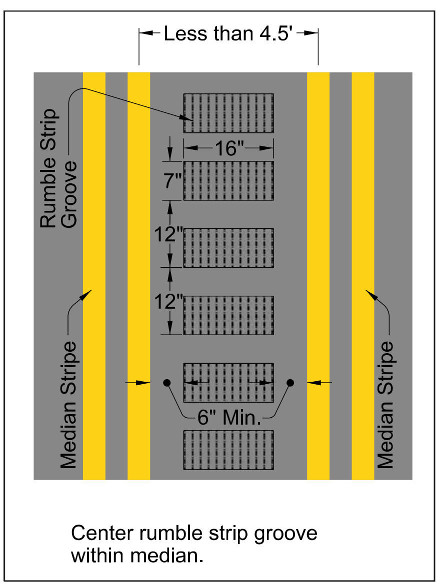


Figure 242-M: Continuous Pattern Rectangular Rumble Strip Narrow Median Installation



Longitudinal Rumble Strips: Rural Non-Freeways and Undivided Highways

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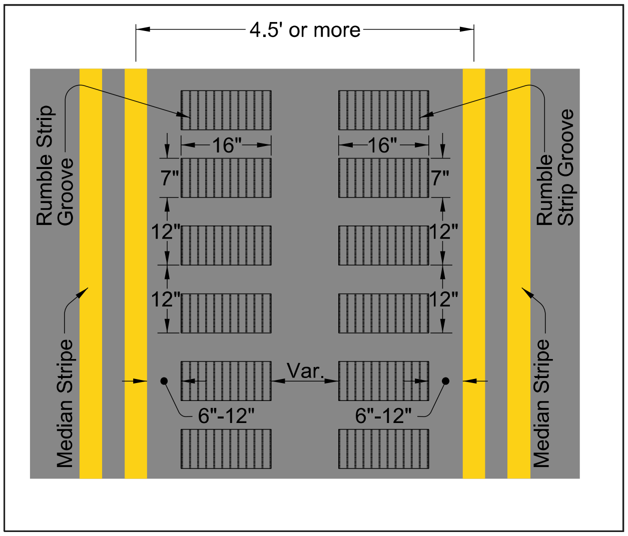
Figure 242-N: Continuous Pattern Rectangular Rumble Strip Wide Median Installation



Longitudinal Rumble Strips: Rural Non-Freeways and Undivided Highways

Figure 242-O: Centerline Rectangular Rumble Strip Typical Intersection Installation on Multilane Highway

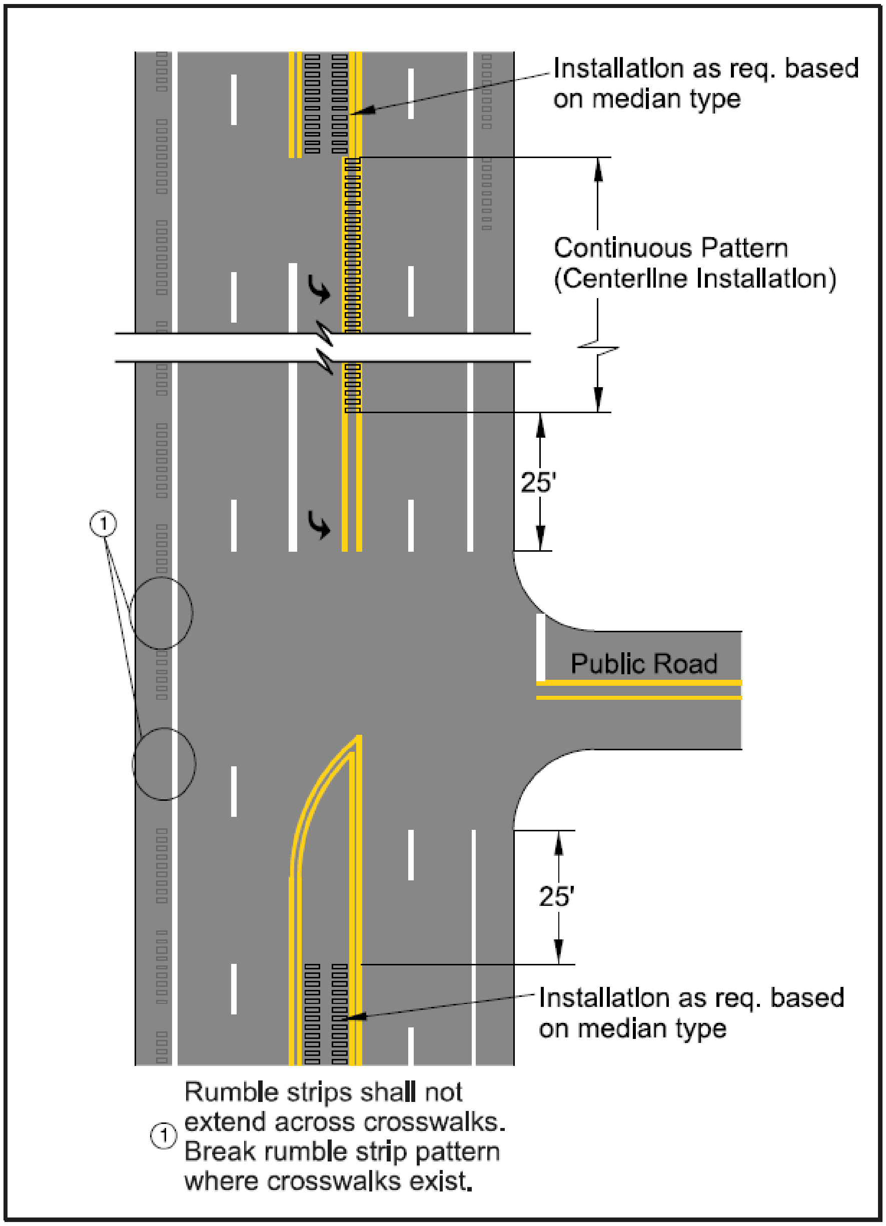


Figure 242-P: Centerline Rectangular Rumble Strip Typical Intersection Installation on 2-Lane Highway

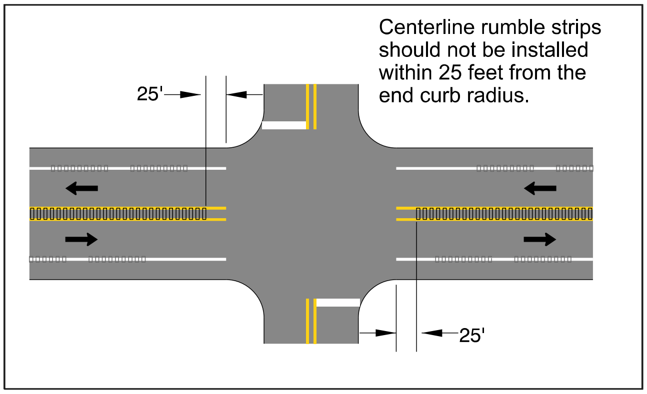


Figure 242-Q: Typical Centerline Rectangular Rumble Strip Transition No Median to Wide Median

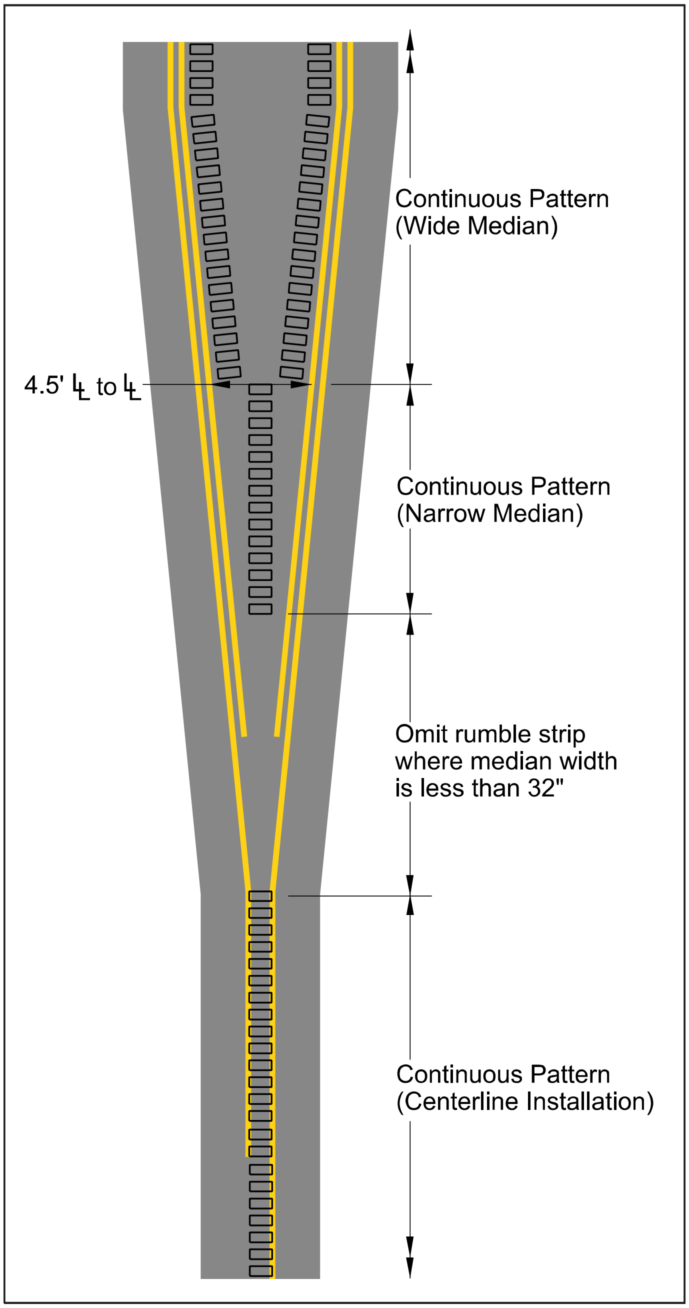
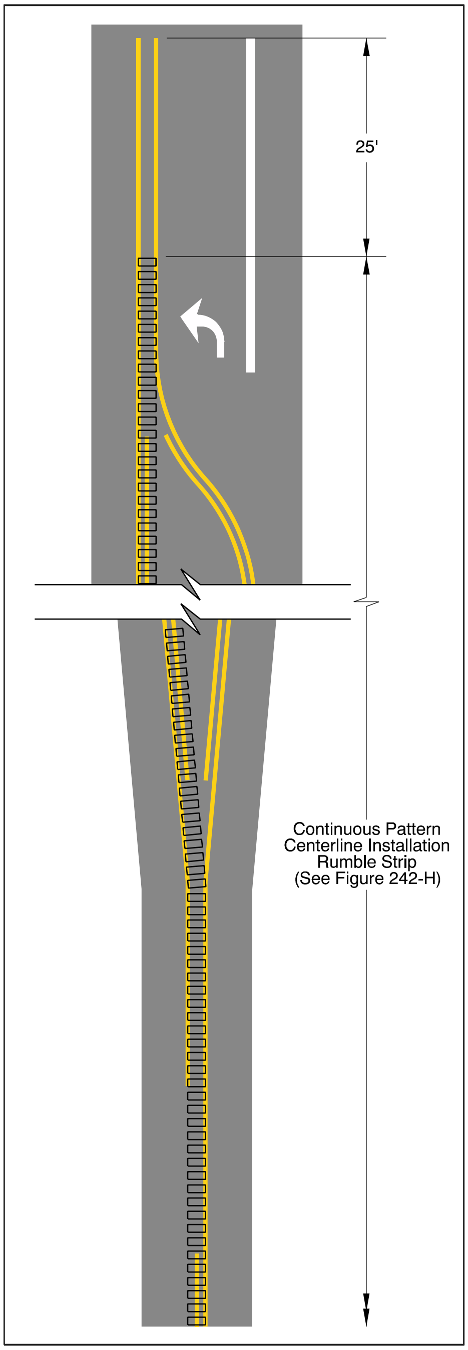


Figure 242-R: Typical Centerline Rectangular Rumble Strip Transition at Left Turn Lane



Longitudinal Rumble Strips: Rural Non-Freeways and Undivided Highways

Figure 242-S: Pattern "C" and "D" Centerline Rectangular Rumble Strip Details

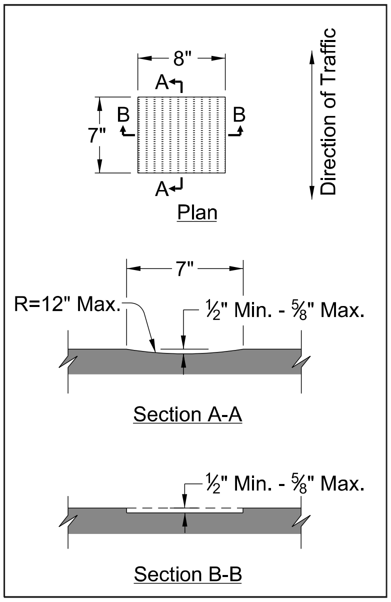
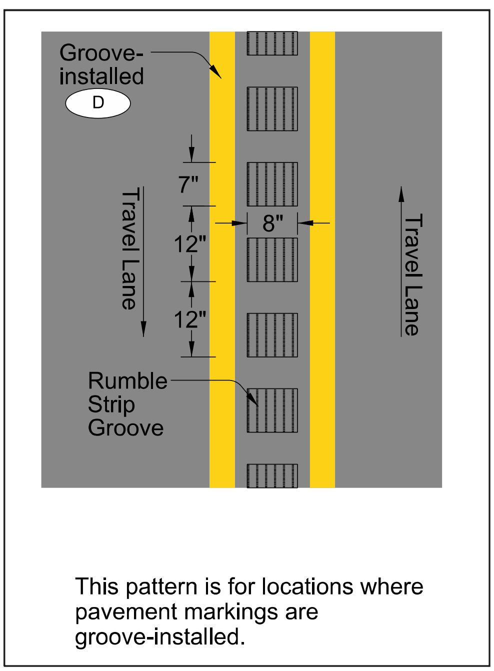
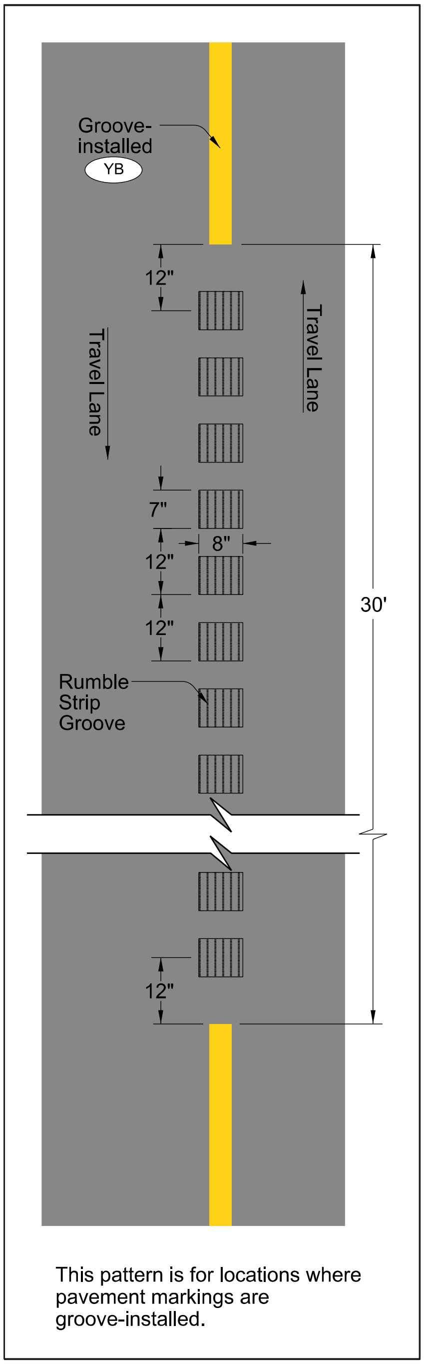


Figure 242-T: Continuous Patter "C" Rectangular Rumble Strip Centerline Installation Double No-Pass Lines



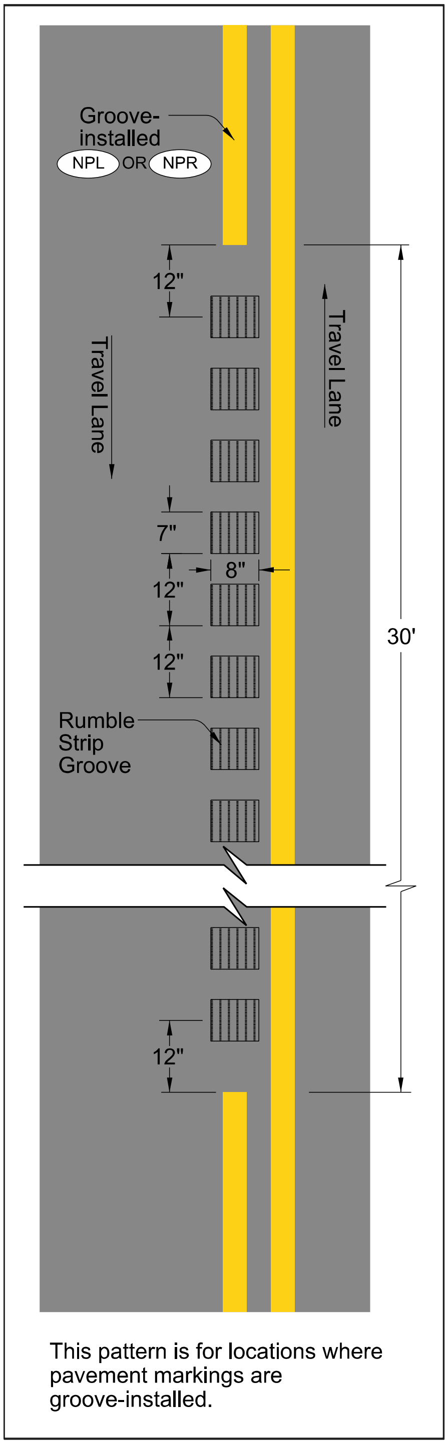
Longitudinal Rumble Strips: Rural Non-Freeways and Undivided Highways

Figure 242-U: Continuous Pattern "D" Rectangular Rumble Strip Centerline Installation Yellow Broken Lines



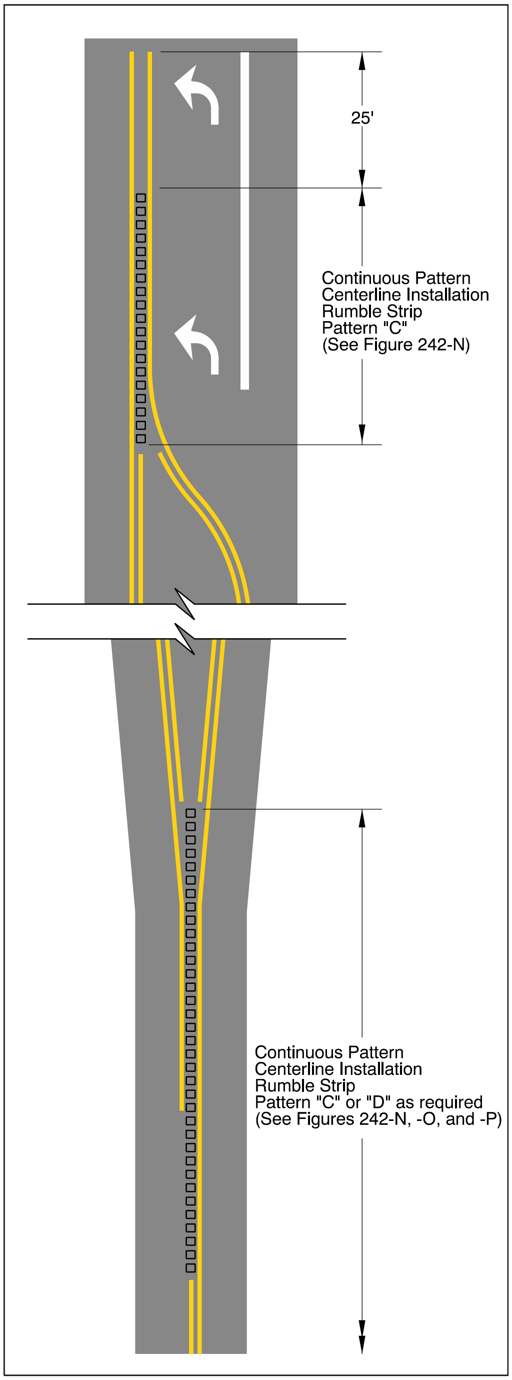
Longitudinal Rumble Strips: Rural Non-Freeways and Undivided Highways

Figure 242-V: Continuous Pattern "D" Rectangular Rumble Strip Centerline Installation No-Pass Left/Right Lines



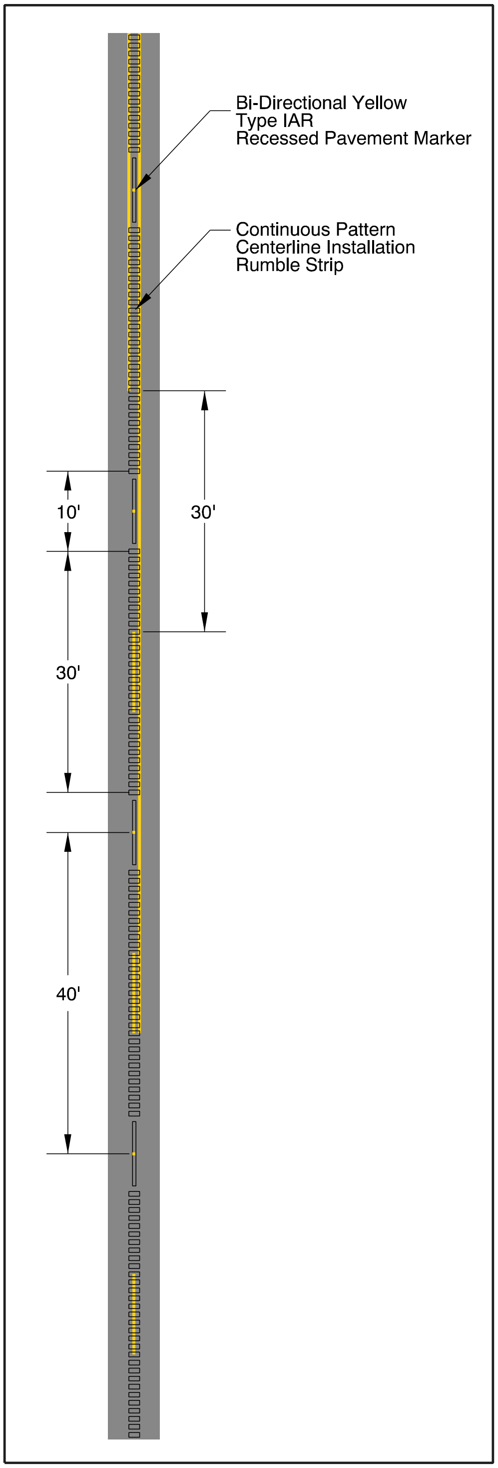
Longitudinal Rumble Strips: Rural Non-Freeways and Undivided Highways

Figure 242-W: Typical Centerline Rectangular Rumble Strip Transition at Left Turn Lane with Groove-Installed Markings



Longitudinal Rumble Strips: Rural Non-Freeways and Undivided Highways

Figure 242-X: Typical Centerline Rectangular Rumble Strip with recessed RPMs



Support

Roadway departure crashes are the most common type of fatal and serious injury crash on Oregon's rural highways. Between 2009 and 2013 approximately 53% of all fatal and serious injury crashes in Oregon included a roadway departure, contributing to 1,188 fatalities and 3,745 serious injuries. About 73% of these crashes were in a rural environment (*1*).

Rumble strips are a highly effective and cost efficient method of reducing roadway departure crashes. NCHRP Report 641 (*2*) reports shoulder rumble strips on rural two-lane roads can be expected to reduce fatal and injury roadway departure crashes by 29% (SE=9); centerline rumble strips on rural two-lane roads can be expected to reduce fatal and injury roadway departure crashes by 44% (SE=6).

Noise generated by rumble strips affects people in nearby residences and camp grounds. Distances used for noise exceptions considered several sources including NCHRP Report 641 (*2*) and a recent Minnesota DOT rumble strip noise study (*3*). There have been several local and national research projects that have examined ways to reduce noise impacts of rumble strips, including modeling how sound travels and alternative patterns that reduce roadside noise while maintaining sufficient internal noise and shaking to alert drivers. Multiple reports have shown or predicted that a sinusoidal rumble strip pattern has a lower exterior noise than a rectangular rumble strip pattern while still meeting the minimum levels from FHWA (*4*) for interior noise. These reports include research by ODOT (*5*), Caltrans (*6*), and WashDOT (*7*). The research done by ODOT (*5*) showed that sinusoidal rumble strips produce a 5.8 dBa for a passenger car, a 4.6 dBA for a van, and a 6 dBA for heavy trucks over baseline conditions. For the passenger car and van this value is roughly half of the dBa interior noise change from rectangular rumble strips. The values for sinusoidal rumble strips exceed the 3 dBA change minimum of FHWA (*4*) and is near the of the recommended level of a 6 dBa noise change. The research done by ODOT (*5*) also compares the estimated distance of external noise between rectangular rumble strips and sinusoidal rumble strips. The estimated distance for the sound of the rumble strip strike to fall back down to the baseline level of the highway for passenger cars is 69′ for sinusoidal rumble strips and 170′ for rectangular rumble strips. For vans the estimated value is 39′ for sinusoidal rumble strips and 120′ for cans.

From the recent research on sinusoidal rumble strips, it is shown that sinusoidal rumble strips provide an adequate noise to drivers driving the strike the rumble strips, while causing less exterior noise. Sinusoidal rumble strips may be ideal for use where previous projects have omitted rumble strips due to proximity of residences. Other locations region traffic may want to utilize sinusoidal rumble strips are locations rumble strips are not required that have not been considered before due to noise concerns. An engineering study is necessary to determine if sinusoidal rumble strips are the correct choice for projects. The study may include and consider the following, in addition to other elements:

- Average daily traffic.
- Roadway type.
- Ambient noise of the highway.
- Highway proximity to residences.
- Heavy truck traffic.
- Highway speed.

Edge line and shoulder rumble strips can be difficult for people on bicycles to traverse, and a clear, ridable shoulder next to rumble strips is needed for safe and predictable shoulder riding. The AASHTO Guide for the Development of Bicycle Facilities (*8*) does not recommend rumble strips on shoulders used by people on bikes unless there is a minimum clear path of 4 feet from the rumble strip to the edge of pavement, or 5 feet to an adjacent guardrail or other obstacle. The AASHTO Guide (*8*) also recommends gaps in the rumble strip pattern of at least 12 feet every 40 to 60 feet to allow people on bicycles to move across the rumble strip to avoid debris and other obstacles in the shoulder, pass other cyclists, make left turns, etc. Longer gaps might be needed on steep downgrades because of higher bicycle speeds.

To maximize the locations where shoulder and edge line rumble strips can be used, this policy allows shoulder and edge line rumble strips where clear shoulder widths are less than the minimums in Figure 240-A on low volume highways (AADT is 1500 vehicles per day or less), where there is passing sight distance available. This volume is the upper threshold recommended in the ODOT Bicycle and Pedestrian Design Guide (*9*) where a shared lane condition is tolerable. Omitting shoulder or edge line rumble strips in areas with limited passing sight distance allows cyclists to stay as far to the right as possible in areas where approaching drivers have limited sight distance and allows for simplified installation as these areas already need to have no-passing zone markings.

The presence of centerline rumble strips in a passing zone generally has little to no influence on passing behavior in the passing zone (*2*). This means in areas that are used frequently for passing maneuvers, it can be reasonable to assume there will be noise issues for nearby residents.

The rumble strip design dimensions shown in this section's figures are based on the most common dimensions of milled shoulder and centerline rumble strips in the United States. These generate sufficient noise in the upper range of recommended noise design thresholds to alert inattentive, distracted, drowsy, or fatigued drivers, including drivers of heavy vehicles. Wider rumble strips generate more noise than narrower rumble strips; however, for design flexibility, widths as narrow as 8 inches can still generate sufficient noise to stay within the 6-12 dBA recommended noise increase range (*2*).

Centerline rumble strips are omitted in Figure 242-O where the median is less than 32 inches for striping installation and maintenance. If rumble strips were in this section, the striping truck wheels would be on the rumble strip as it transitions to/from the taper, causing issues with installation/retrace and possible damage to the truck's sensitive equipment.

Longitudinal rumble strips are a systemic safety countermeasure that provides the most benefit when applied to long sections of highway. The per-mile cost to install rumble strips increases as total quantity decreases, largely due to costs for contractors to mobilize equipment and workers. Because of this, there is an exception for very small quantities where rumble strips were not previously installed.

When breaking rumble strip patterns for crosswalks at T-intersections, it may be easier to break the rumble strip pattern for the entirety of the intersection. Doing so may help avoid confusion in the rumble strip pattern, as well as make constructing the rumble strip pattern easier by limiting stopping and restarting of the equipment through the intersection.

Cross References

Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Center Lines .... Section 210
Edge Lines .... Section 230
Longitudinal Rumble Strips: General .... Section 240
Longitudinal Rumble Strips: Rural Freeways and Divided Highways .... Section 241
Longitudinal Rumble Strips: Urban Highways .... Section 243

Key References

1. Oregon Department of Transportation. *2016 Oregon Transportation Safety Action Plan*. Oregon Department of Transportation, Salem, Oregon, 2016. http://www.oregon.gov/ODOT/Safety/Documents/TSAP_2016.pdf.
2. Torbic, D. J., J. M. Hutton, C. D. Bokenkroger, K. M. Bauer, D. W. Harwood, D. K. Gilmore, J. M. Dunn, J. Ronchetto, E. T. Donnell, H. J. Sommer Ill, P. M. Garvey, B. Persaud, and C. Lyon. NCHRP Report 641: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips. Transportation Research Board of the National Academies, Washington, D.C., ISSN 0077-5614, 2009. http://www.trb.org/Publications/Blurbs/162610.aspx.
3. Terhaar, E., and D. Braslau. Rumble Strip Noise Evaluation. St. Paul, Minnesota, MN/RC 2015-07, 2015. http://www.dot.state.mn.us/research/TS/2015/201507.pdf.
4. Federal Highway Administration. Rumble Strip Implementation Guide: Addressing Noise Issues on Two-Lane Roads. FHWA, Final Technical Report FHWA-SA-15-033, 2015.
5. Hurwitz, D., M. Christopher, D. Ross, S. Kothuri, and H. Jashami. Quantifying the Performance of Low-Noise Rumble Strips. Oregon State University and Portland State University, Salem, Oregon, Final Technical Report FHWA-OR-RD-19-06, 2019.
6. Donavan, P., and D. Buehler. Design and Acoustic Evaluation of Optimal Sinusoidal Mumble Strips versus Conventional Ground-In Rumble Strips. Californial Department of Transportation, Sacramento, California, Final Technical Report CTHWANP-RT-18-365.01.2, 2018.

7. Laughlin, J., and J. Donahue. Evaluation of New Rumble Strip Designs to Reduce Roadside Noise and Promote Safety. Washington State Department of Transportation, Olympia, Washington, Final Technical Report WA-RD 881.1, 2018.

8. American Association of State Highway and Transportation Officials. *Guide for the Development of Bicycle Facilities*, 4th ed. Washington, D.C., 2012.

9. Oregon Department of Transportation. *Bicycle and Pedestrian Design Guide*, 3rd ed. Oregon Department of Transportation, Salem, Oregon, 2011. http://www.oregon.gov/ODOT/Engineering/Documents_RoadwayEng/HDM_L-Bike-Ped-Guide.pdf.

Longitudinal Rumble Strips: Urban Highways Section 243

Introduction

Historically, rumble strips have not been used often on urban highways. However, there are sections of urban highway that could benefit from the application of rumble strips.

Design Parameters

01 Longitudinal rectangular rumble strips may be installed on urban highways according to Sections 240, 241, and 242.

02 Sinusoidal rumble strips may be used instead of rectangular rumble strips based on an engineering study (see Section 242 for sinusoidal rumble strip pattern details and supporting information).

Required Approvals

Region traffic engineer approval is required for installation of rumble strips on urban highways.

Design Issues

Rumble strips are typically not installed on urban highways because of problems with noise. Some urban areas that could benefit from rumble strips include:

- Shoulder rumble strips installed on urban sections of freeway; or
- Centerline rumble strips on higher speed roadways within city limits.

Typically, this would apply to highways experiencing lane departure crashes that would benefit from rumble strips. Locations within urban areas isolated from close nearby residences are more likely candidates due to noise concerns.

Support

Rumble strips are a highly effective and cost efficient method of reducing roadway departure crashes. NCHRP Report 641 (*1*) reports centerline rumble strips on urban two-lane roads can be expected to reduce total roadway departure crashes by 40% (SE=17); fatal and injury roadway departure crashes by 64% (SE=27).

Noise generated by rumble strips affects people in nearby residences. There are several local and national research projects underway examining ways to reduce noise impacts of rumble strips, including tools to model how sound travels in a given area next to the highway and alternative patterns that reduce roadside noise while maintaining sufficient internal noise and shaking to alert drivers.

Edge line and shoulder rumble strips can be difficult for people on bicycles to traverse, and a clear, ridable shoulder next to rumble strips is needed for safe and predictable shoulder riding. The AASHTO Guide for the Development of Bicycle Facilities (2) does not recommend rumble strips on shoulders used by people on bikes unless there is a minimum clear path of 4 feet from the rumble strip to the edge of pavement, or 5 feet to an adjacent guardrail or other obstacle. The AASHTO Guide (2) also recommends gaps in the rumble strip pattern of at least 12 feet every 40 to 60 feet to allow people on bicycles to move across the rumble strip to avoid debris and other obstacles in the shoulder, pass other cyclists, make left turns, etc. Longer gaps might be needed on steep downgrades because of higher bicycle speeds.

See Section 242 for supporting information on sinusoidal rumble strips.

Cross References

Longitudinal Rumble Strips: General .... Section 240
Longitudinal Rumble Strips: Rural Freeways and Divided Highways .... Section 241
Longitudinal Rumble Strips: Rural Non-Freeways and Undivided Highways .... Section 242

Key References

1. Torbic, D. J., J. M. Hutton, C. D. Bokenkroger, K. M. Bauer, D. W. Harwood, D. K. Gilmore, J. M. Dunn, J. Ronchetto, E. T. Donnell, H. J. Sommer Ill, P. M. Garvey, B. Persaud, and C. Lyon. NCHRP Report 641: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips. Transportation Research Board of the National Academies, Washington, D.C., ISSN 0077-5614, 2009. http://www.trb.org/Publications/Blurbs/162610.aspx.

2. American Association of State Highway and Transportation Officials. *Guide for the Development of Bicycle Facilities*, 4th ed. Washington, D.C., 2012.

Transverse Rumble Strips Section 245

Introduction

Transverse rumble strips are placed perpendicular to the direction of travel to enhance other traffic control devices and warn road users of an unusual situation. This section does not apply to temporary transverse rumble strips used in work zones.

Design Parameters

01 Permanent milled-in transverse rumble strips may be installed on an approach to a "STOP" sign (R1-1) where crash history indicates a significant number of intersection crashes would be treatable with transverse rumble strips and where more conventional treatments have proved ineffective.

02 *If used, permanent milled-in transverse rumble strips should be installed on new or existing bituminous pavement in sufficiently good condition.*

03 *If used on an approach to a "STOP" sign (R1-1), permanent milled-in transverse rumble strips should be installed according to Figure 245. The three primary rumble strip sets shown in Figure 245 should be used as a minimum where transverse rumble strips are installed.*

04 If used on an approach to a "STOP" sign (R1-1), the two secondary rumble strip sets shown in Figure 245 may be used based on engineering judgement of local site conditions.

Required Approvals

An engineering study and region traffic engineer approval is required for installation of transverse rumble strips associated with "Stop Ahead" (W3-1) warning signs on state highways or local public road approaches to a state highway.

An engineering study and state traffic-roadway engineer approval is required for all other installation of transverse rumble strips on state highways.

Engineering studies on transverse rumble strips must document a safety problem correctable with the use of transverse rumble strips and consider noise impacts if located near residences or campgrounds.

Design Issues

Contact the Construction Section's Pavement Services Unit to determine if the pavement surface is in sufficiently good condition to install transverse rumble strips.

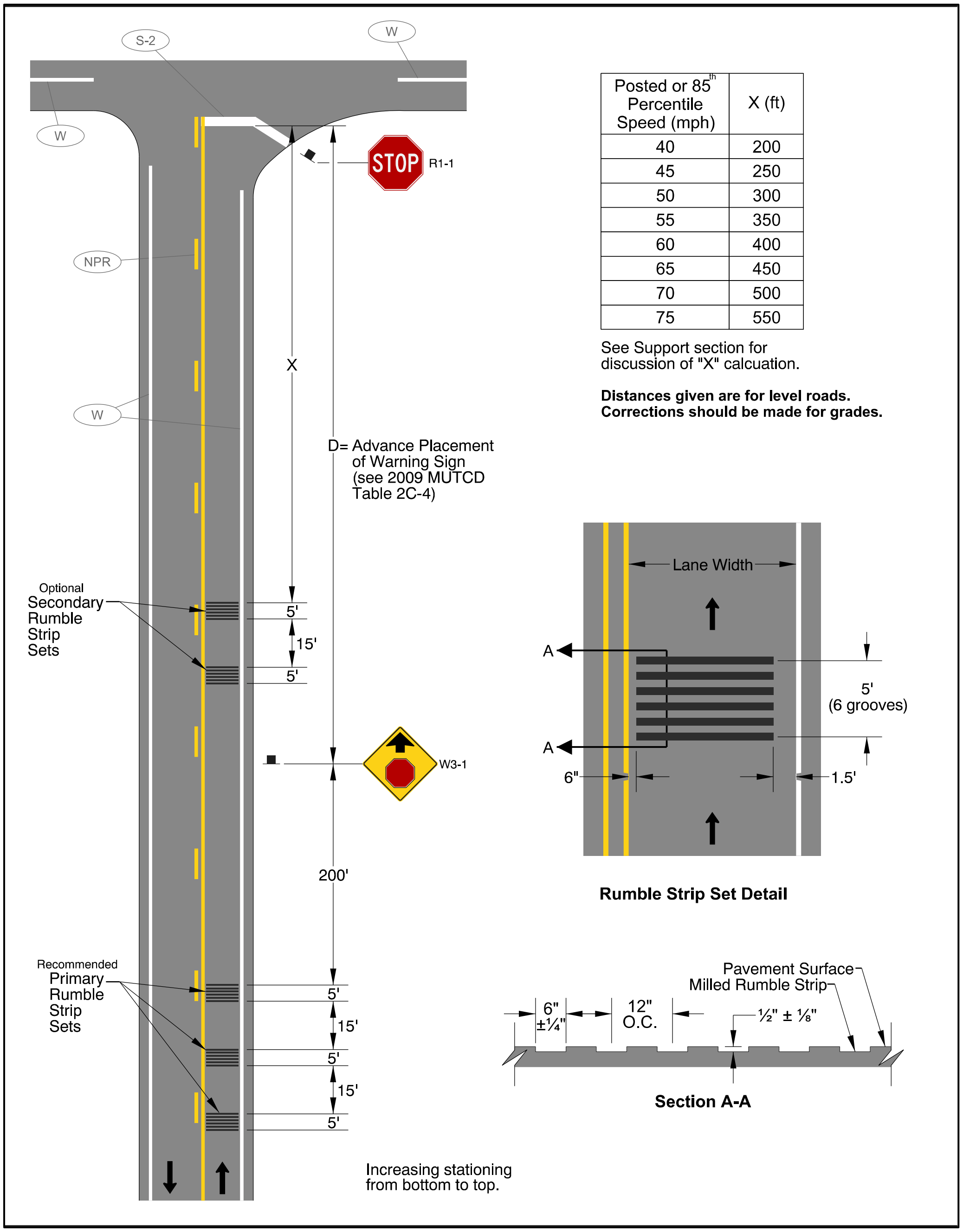
Other conventional treatments typically include oversize signs, signs on both sides of the roadway, higher intensity sign sheeting, STOP AHEAD pavement markings (see Section 125), and increasing the stop bar width (see Section 150).

Transverse rumble strips installed on local public road approaches to state highways typically need an intergovernmental agreement (IGA) between ODOT and the local road authority detailing who will pay for installation and maintenance of traffic control devices approaching the state highway, including the transverse rumble strips.

Potential adverse effects of transverse rumble strips include noise generated by vehicles continuously traversing them, effects on plowing operations, maintenance concerns with durability, and concerns by motorcyclists and bicyclists. There is a possibility that drivers might go around them by driving in the opposing lane, though there is some evidence this is not common for short rumble strip sets (*1*).

Figures & Tables

Figure 245: Typical Transverse Rumble Strip Installation on an Approach to a STOP Sign



Posted or 85th Percentile Speed (mph)	X (ft)
40	200
45	250
50	300
55	350
60	400
65	450
70	500
75	550

Support

Transverse rumble strips provide a warning to drivers of an approaching condition, but the rumble strips themselves do not communicate what action needs to be taken in response to that condition (*2*).

Many different configurations of transverse rumble strips have been tested across a variety of studies, including milled-in and preformed thermoplastics of various widths, thickness/depth, and patterns. The design shown in Figure 245 is based on a design used by Minnesota DOT. This design was one of two contributing designs studied for development of crash modification factors by Srinivasan, Baek, and Council (*3*). Srinivasan, Baek, and Council found the milled-in transverse rumble strips they studied can be effective at reducing fatal and serious injury crashes at minor road stop-controlled intersections. They also found these rumble strips might increase property-damage-only crashes, though the reason for this increase could not be determined at the time. One theory from other sources (*2*) (*4*)is the rumble strips increase speed variability which might increase rear-end crashes.

Transverse rumble strips generally do not have a practical effect on reducing vehicle speed at approaches to stop-controlled intersections (≤1-2 mph) (*2*) (*5*) (*6*) and in speed transition zones (*7*).

Transverse rumble strips need to be positioned to provide enough advance warning time for drivers to respond and take an appropriate action (*2*). The design in Figure 245-A sets the distance of the first grouping of rumble strip sets 200 feet in advance of the Stop Ahead sign (W3-1). This alerts the driver before the sign legibility distance used by the 2009 MUTCD (*8*) for this warning condition (180 feet). This also positions the rumble strip sets approximately at stopping sight distance given in the AASHTO Green Book (*9*).

The last two rumble strip sets crossed by an approaching driver are positioned to give a final warning with a sufficient distance to make a hard stop. This distance assumes the driver is alert from the previous rumble strip sets and has a brake reaction time of 1.0 second. This also assumes that if the driver hasn’t started to decelerate at this point, he or she will decelerate more aggressively than the deceleration rates used to calculate advance warning sign placement and stopping sight distance (11.2 ft/s2). The discussion of braking distance in the AASHTO Green Book says the literature shows most drivers decelerate at a rate greater than 14.8 ft/s2 when confronted with the need to stop for an unexpected object in the roadway. This was the deceleration rate used to calculate braking distance in this case.

The design assumptions discussed above places these rumble strip sets in a location consistent with Iowa DOT’s design for a 50-55 mph approach speed. The groove depth, width, and spacing matches Iowa DOT’s design as well to create the same level of vibration and noise associated with crash modification factors developed from the design (*3*).

A 15-foot gap between rumble strip sets provides a minimal pause in the noise generated from the rumble strips for passenger cars (85th percentile vehicle length in the U.S. fleet is about 17 feet (*10*)).

A 1.5-foot clear space between the rumble strip and the edge line shown in Figure 245 gives people on bikes a minimal gap to avoid the transverse rumble strips to the right.

In 2021, IOWA DOT completed a synthesis of transverse rumble strips at rural stop-controlled intersections (*11*). This synthesis is a good source of information on how other states use transverse rumble strips.

Cross References

Transverse Markings.......... Section 125
Stop Bars .... Section 150

Key References

1. Miles, J. D., M. P. Pratt, and P. J. Carlson. Evaluation of Erratic Maneuvers Associated with Installation of Rumble Strips. *Transportation Research Record: Journal of the Transportation Research Board Online*, Vol. 1973, 2006, pp. 73-79. http://trrjournalonline.trb.org/doi/abs/10.3141/1973-11. DOI: https://doi.org/10.3141/1973-11
2. Brian, R., W. Kittleson, J. Knudsen, B. Nevers, P. Ryus, K. Sylvester, I. Potts, D. Harwood, D. Gilmore, D. Torbic, F. Hanscom, J. McGill, and D. Stewart. *NCHRP Report 613: Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections*. Transportation Research Board of the National Academies, Washington, D.C., 2008. http://www.trb.org/Publications/Blurbs/160046.aspx.
3. Srinivasan, R., J. Baek, and F. Council. Safety Evaluation of Transverse Rumble Strips on Approaches to Stop-Controlled Intersections in Rural Areas. in *2010 Annual Meeting of the Transportation Research Board*, Washington, D.C., September 2010.
4. Isebrands, H., S. Hallmark, and N. Hawkins. Effects of Approach Speed at Rural High-Speed Intersections: Roundabouts Versus Two-Way-Stop Control. *Transportation Research Record: Journal of the Transportation Research Board Online*, Vol. 2402, 2014, pp. 67-77. http://trrjournalonline.trb.org/doi/abs/10.3141/2402-08. DOI: https://doi.org/10.3141/2402-08
5. Thompson, T. D., M. W. Burris, and P. J. Carlson. Speed Changes Due to Transverse Rumble Strips on Approaches to High-Speed Stop-Controlled Intersections. *Transportation Research Record: Journal of the Transportation Research Board Online*, Vol. 1973, 2006, pp. 1-9. http://trrjournalonline.trb.org/doi/abs/10.3141/1973-03. DOI: 10.3141/1973-03
6. Yang, L., H. Zhou, L. Zhu, and H. Qu. Operation Effects of Transverse Rumble Strips on Approaches to High-Speed Intersections. *Transportation Research Record: Journal of the Transportation Research Record Online*, Vol. 2602, 2016, pp. 78-87. http://trrjournalonline.trb.org/doi/abs/10.3141/2602-10. DOI: 10.3141/2602-10
7. Torbic, D. J., D. K. Gilmore, K. M. Bauer, C. D. Bokenkroger, D. W. Harwood, L. M. Lucas, R. J. Frazier, C. S. Kinzel, D. L. Petree, and M. D. Forsberg. *NCHRP Report 737: Design Guidance for High-Speed to Low-Speed Transition Zones for Rural Highways*. Transportation Research Board of the National Academies, Washington, D.C., 2012. http://www.trb.org/Publications/Blurbs/168309.aspx.
8. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
9. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*, 6th ed. Washington, D.C., 2011.

10. Institute of Transportation Engineers. *Traffic Engineering Handbook*, 6th ed. Institute of Transportation Engineers, Washington, D.C., 2010.

11. Oneyear, N., S. Hallmark, and H. Naraghi. *Iowa State University Institute for Transportation*, December 2021. https://intrans.iastate.edu/app/uploads/2022/01/transverse_rumble_strips_at_rural_stop_controlled_intersections_synthesis_w_cvr.pdf. Accessed October 2022.

Lane Reduction Transitions Section 250

Introduction

Lane reduction transitions are used where the number of through lanes is reduced because the roadway narrows or because of a section of on-street parking in what would otherwise be a through lane. Lane reduction transition markings are not used for lane drops.

Design Parameters

01 **Where pavement markings are used, lane-reduction transition markings shall be used according to this section to guide traffic through transition areas where the number of through lanes is reduced.**

02 **Lane reduction transitions shall include an edge line in the direction of the lane reduction transition. On 2-way roadways, lane reduction transitions shall include:**

- **No-passing zone markings in the direction of the lane reduction to the end of the taper.**
- **No-passing zone markings for opposing traffic from the "Lane Ends" sign (W4-2) to a minimum length "A" following the taper (Figure 250).**

03 On low-speed urban roadways where curbs clearly define the roadway edge in the lane-reduction transition, or where a through lane becomes a parking lane, the edge line required in paragraph 02 may be omitted as determined by engineering judgement.

04 *Except as provided in paragraph 03, the edge line markings required in paragraph 02 should be installed from the location of the "Lane Ends" warning sign (W4-2) to beyond the beginning of the narrower roadway.*

05 *For roadways having a posted or statutory speed limit of 45 mph or greater, the transition taper length for a lane-reduction transition should be computed by the formula L=WS. For roadways where the posted or statutory speed limit is less than 45 mph, the formula L=WS2/60 should be used to compute the taper length (see Figure 250). Where observed speeds exceed posted or statutory speed limits, longer tapers should be used.*

06 *For roadways having a posted or statutory speed limit of 45 mph or greater, two lane reduction arrows should be used in the lane reduction area according to Figure 250.*

07 An additional lane reduction arrow may be used between the two recommended lane reduction arrows based on engineering judgement.

08 *Lane line markings (WB) should be discontinued at lane reduction transitions ¼ of the distance between the Lane Ends sign (W4-2) and the point where the transition taper begins (Figure 250).*

09 A different "d" distance may be used based on an engineering study if the "d" distance in Figure 250 is not practical.

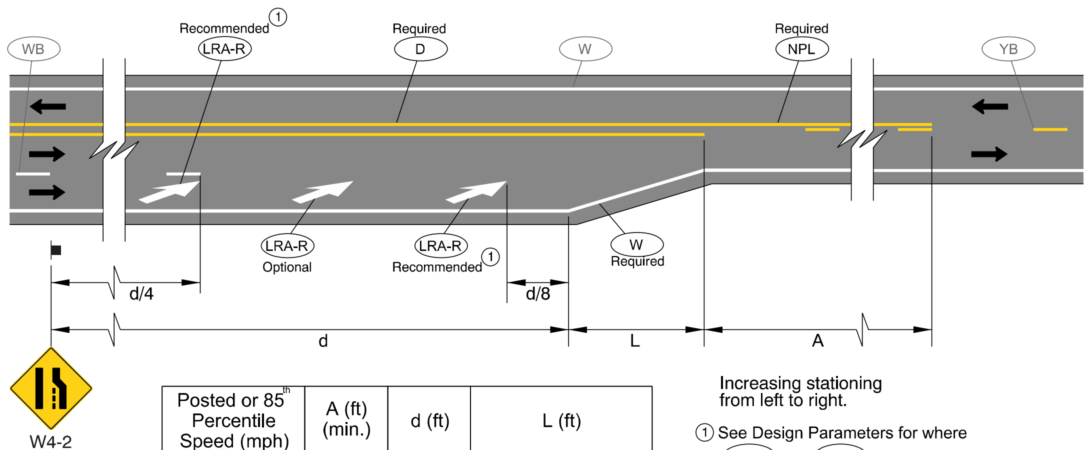
Design Issues

Many lane reduction transitions for climbing lanes occur near the crest of vertical curves. Depending on roadway geometry and where the lane reduction taper begins, sight distance to the lane reduction arrows and, more importantly, lane reduction taper can be reduced in these cases. Adding the middle arrow can add more guidance and emphasis that the lane is ending before drivers reach the lane reduction taper.

The “d” distance shown in Figure 250 might not be available at all lane reduction transitions; “d” is typically set based on where the lane reduction sign (W4-2) can be placed in these cases. See the support section for more discussion. For on-ramps with ramp meters, see Section 620.

Figures & Tables

Figure 250: Typical Lane Reduction Transition



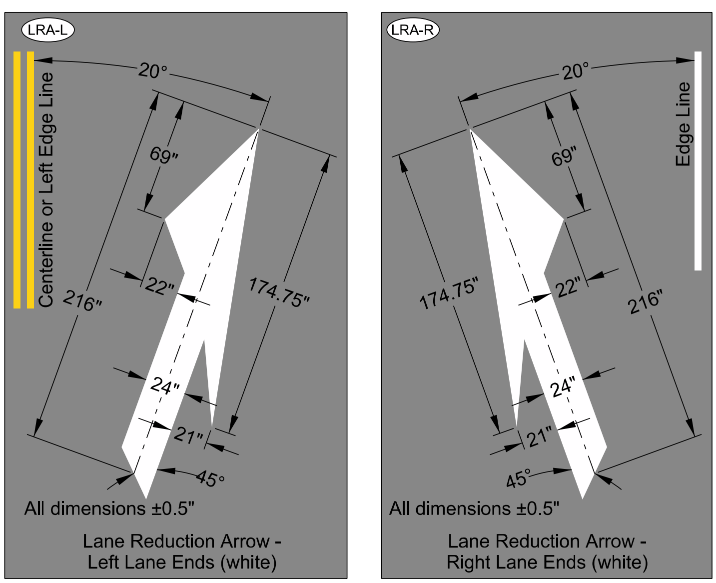
Posted or 85th Percentile Speed (mph)	A (ft) (min.)	d (ft)	L (ft)
25	500	325	$L = \frac{WS^2}{60}$
30	500	460	
35	550	565	
40	600	670	
45	700	775	L=WS
50	800	885	
55	900	990	
60	1000	1100	
65	1100	1200	
70	1200	1250	
75	1300	1350	

Increasing stationing from left to right.

① See Design Parameters for where LRA-R and LRA-L are recommended.

Where:
- L= taper length (feet)
- W = width of lane being reduced (feet)
- S = posted or 85th percentile speed, whichever is higher (mph)
- d = advance warning distance (ft)

Distances given are for level roads. Corrections should be made for grades.



Support

Lane reduction layouts are required to match the layout shown in Figure 3B-14 of the 2009 MUTCD by a standard statement in Section 3B.09. ODOT has added some guidance where the MUTCD is silent on placement of the last arrow and allowance to add a middle lane reduction arrow; however, the overall layout is set by the MUTCD with very little flexibility. There have been recent efforts examining changes to the layout (*1*), but more study will be needed before significant changes are proposed.

A lane reduction transition is a complex driving situation, especially in heavy traffic (*2*). Beyond the signing and lane reduction arrows, a major visual cue for navigating lane reduction transitions is the taper. If the full 2-lane pavement width continues beyond the lane reduction transition, shoulder bars or other visual cues are ways to show that the lane does not continue beyond the end of the taper (*2*). There is also evidence that drivers judge where a lane change needs to occur based on where the lane line ends (i.e.: ending the lane line further upstream gives more time to perceive a need to merge) (*1*).

The “L” formulas come from MUTCD Section 3B.09. L=WS first appeared in the 1971 MUTCD.

L=(WS2)/60 first appeared in the 1978 MUTCD, based on Graham and Sharp’s 1977 report (*3*) on shorter taper lengths at lower speeds in four long-term construction zones. At the time, there was a desire to examine shorter taper lengths at lower speeds to accommodate site constraints typically associated with lower speeds (driveway/intersection density, more traffic control devices, etc.). At the speeds studied (15 to 45 mph), the shorter taper length did not produce more erratic maneuvers, slow-moving vehicle conflicts, or encroachments on the adjacent lane than the standard L=WS taper, so the sections for permanent and temporary lane reduction tapers were updated in the MUTCD (*4*).

The “d” distance given in Figure 250 is the advance placement of a warning sign for a speed reduction and lane change in heavy traffic according to MUTCD Table 2C-4. This distance provides drivers with a perception-reaction time of 14.0 to 14.5 seconds for the maneuver, minus a legibility distance of 180 feet for the warning sign (*4*). This length of perception-reaction time is the decision sight distance from the AASHTO Green Book (*5*) for Avoidance Maneuver E: speed/path/direction change on urban road. Perception-reaction times for other avoidance maneuvers are 10.2 to 11.2 seconds for speed/path/direction changes on rural roads, and 12.1 to 12.9 seconds for speed/path/direction changes on suburban roads.

Before the 2011 Traffic Line Manual, ODOT used an alternate lane reduction transition layout based on a 1988 Transportation Research Record paper by Harwood, Hoben, and Warren (*6*). At the time, the MUTCD “d” distance was significantly shorter than today’s “d” distance. Harwood, Hoben, and Warren argued that drivers needed more advance warning for a lane reduction than the MUTCD “d” distance and that the first lane reduction sign needed to be placed at 1000 feet from the beginning of the taper.

The MUTCD "d" distance was lengthened in the 2003 Edition and again in the 2009 Edition. ODOT switched to the lane reduction transition layout in the 2009 MUTCD when it adopted the 2009 MUTCD to 1) better meet driver expectations by being more uniform with nationwide layouts, 2) because the 2009 "d" distance was more in-line with Harwood, Hoben, and Warren's recommendations (*2*), and 3) because the MUTCD layout shown in Figure 3B-14 is required under Section 3B.09.

Cross References

Colors .... Section 110
Center Lines .... Section 210
No-Passing Zone Markings .... Section 211
Lane Lines .... Section 220
Edge Lines .... Section 230
Ramp Meters .... Section 620

Key References

1. Balk, S. A., and S. Jackson. Lane Line Markings in Advance of Lane-Reduction Transitions. Traffic Control Devices Pooled Fund Study, Washington, D.C., 2016. http://pooledfund.org/Document/Download/6265.
2. Campbell, J. L., M. G. Lichty, J. L. Brown, C. M. Richard, J. S. Graving, J. Graham, M. O'Laughlin, D. Torbic, and D. Harwood. NCHRP Report 600: Human Factors Guidelines for Road Systems. 2012. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_600Second.pdf. Accessed October 23, 2012.
3. Graham, J. L., and M. C. Sharp. Effects of Taper Length on Traffic Operations in Construction Zones. Midwest Research Institute, Washington, D.C., FHWA-RD-77-162, 1977.
4. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
5. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*, 6th ed. Washington, D.C., 2011.
6. Harwood, D. W., C. J. Hoban, and D. L. Warren. Effective Use of Passing Lanes on Two-Lane Highways. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, no. 1195, 1988, pp. 79-91. http://trid.trb.org/view.aspx?id=302149.
7. Graham, J. L., D. W. Harwood, and M. C. Sharp. Effects of Taper Length on Traffic Operations in Construction Zones. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, no. 703, 1979, pp. 19-24. https://trid.trb.org/View/145597.

Lane Addition Transition & No-Passing Zones in 3-Lane Sections Section 251

Introduction

Lane additions are transitions where a motor vehicle lane is added to a segment of roadway.

Design Parameters

01 **Lane addition transitions shall include a white broken line (WB) as soon as full lane width is developed. On 2-way roadways, no-passing zone markings shall precede the start of the lane addition taper a minimum length "A" shown in 251 and through the lane addition taper.**

02 **No-passing zone markings shall be used in the 2-lane direction of a 3-lane, 2-way roadway.**

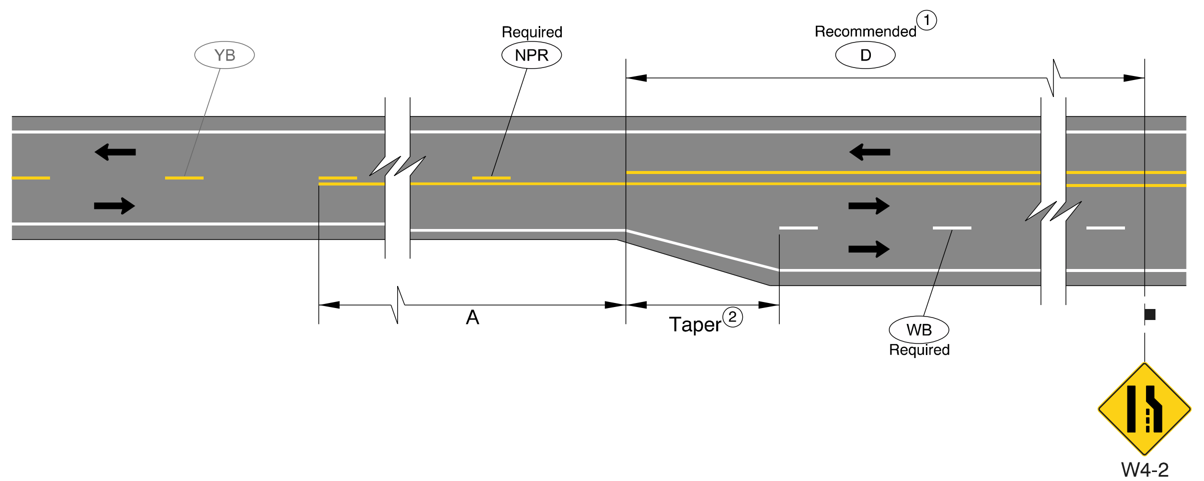
03 No-passing zone markings should be used in the single-lane direction of a 3-lane, 2-way roadway.

04 Passing may be allowed in the single-lane direction if:

- There is sufficient passing sight distance available according to Section 211,
- The ADT of the highway segment is less than 3000 vehicles per day,
- The passing permitted section would be longer than 800 feet, and
- A passing lane is not provided in the single lane direction within 2 miles of both ends of the passing permitted section.

Figures & Tables

Figure 251: Typical Lane Addition Transition & 3-Lane 2-Way Passing Allowances



Increasing stationing from left to right.

① No-passing zone markings required for 2-lane direction. See design parameters for optional use of NPR.
② Match pavement taper. Lane addition taper length is typically L/2 to 2L/3, where L is calculated in Section 250.

Posted or 85th Percentile Speed (mph)	25	30	35	40	45	50	55	60	65	70	75
A (ft) (min)	500	500	550	600	700	800	900	1000	1100	1200	1300

Support

Lane Addition Transitions

The typical taper length of L/2 to 2L/3 comes from the recommended lane addition taper length in the ODOT Highway Design Manual (*1*).

No-Passing Zones in 3-Lane Sections

Passing on rural two-lane roadways is one of the most complex maneuvers drivers make (*2*). There are several differences in the passing environment of a 3-lane section compared to a 2-lane section. A driver traveling in the single-lane direction desiring to pass does not just need to determine if there is oncoming traffic like he or she would normally do for a 2-lane section; he or she also needs to determine if there is oncoming traffic that could use the center lane. That oncoming traffic could be hidden behind the lead vehicle in the queue (commonly large heavy vehicles). Average speeds in passing lanes are generally greater than the surrounding 2-lane segments (*3*) and drivers have difficulty judging the speed of oncoming vehicles (*4*), so determining whether an acceptable gap exists to pass is made even more difficult. There also could be better passing opportunities nearby, like a passing lane, allowing for safer and more comfortable passing.

The effect of a passing lane section on operations extends for some distance downstream, reducing the need to allow passing immediately after a lane reduction in the downhill direction of a climbing lane section. One study (*5*) estimated this halo distance could be as long as 1.5 miles and another (*6*) up to several miles, depending on volumes and length of passing lane section.

As traffic volume increases, passing opportunities become more infrequent and passing demand increases as larger platoons form (*2*) (*5*) (*6*) and drivers generally become more willing to accept smaller gaps in opposing traffic to pass (*7*). At a certain volume threshold, passing opportunities become impractical unless a passing lane is added.

In some cases a 3-lane section could be the best opportunity to pass in the single-lane direction if passing is restricted too much in the surrounding corridor. There is a limit to how long drivers are willing to follow a slow-moving vehicle before attempting to make a passing maneuver (legal or not) (*4*) (*5*) (*6*). As distance from a passing lane increases, platooning and passing demand increases (*5*). Drivers become less patient as following distance increases and speed decreases, tempting drivers to pass in a no-passing zone (*4*) (*8*) (*9*). Passing permitted in the single-lane direction of a 3-lane section with sufficient passing sight distance can give drivers a safer location to pass than picking a spot in a no-passing zone that does not have sufficient passing sight distance.

Cross References

Colors .... Section 110
Center Lines .... Section 210
No-Passing Zone Markings .... Section 211
Lane Lines .... Section 220
Edge Lines .... Section 230
Lane Reduction Transitions .... Section 250

Key References

1. Oregon Department of Transportation. *Highway Design Manual*. Oregon Department of Transportation, Salem, Oregon, 2012.
2. Polus, A., M. Livneh, and B. Frischer. Evaluation of the Passing Process on Two-Lane Rural Highways. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1701, 2000, pp. 53-60. http://trrjournalonline.trb.org/doi/abs/10.3141/1701-07. DOI: 10.3141/1701-07
3. Engerg, A., and M. Pursula. Traffic Flow Characteristics on a Three-Lane Rural Highway in Finland: Results from Empirical Studies and Simulations. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1572, 1997, pp. 33-42. http://trrjournalonline.trb.org/doi/abs/10.3141/1572-05. DOI: 10.3141/1572-05

4. Harwood, D. W., D. K. Gilmore, K. R. Richard, J. M. Dunn, and C. Sun. NCHRP Report 605: Passing Sight Distance Criteria. Transportation Research Board of the National Academies, Washington, D.C., ISBN: 978-0-309-09927-1, 2008. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_605.pdf.

5. Al-Kaisy, A., and Z. Freedman. Empirical Examination of Passing Lane Operational Benefits on Rural Two-Lane Highways. *Procedia - Social and Behavioral Sciences*, Vol. 16, 2011, pp. 340-351. http://www.sciencedirect.com/science/article/pii/S1877042811010019. DOI: 10.1016/j.sbspro.2011.04.455

6. Harwood, D. W., C. J. Hoban, and D. L. Warren. Effective Use of Passing Lanes on Two-Lane Highways. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, no. 1195, 1988, pp. 79-91. http://trid.trb.org/view.aspx?id=302149.

7. Farah, H., and T. Toledo. Passing Behavior on Two-Lane Highways. *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 13, no. 6, November 2010, pp. 355-364. http://www.sciencedirect.com/science/article/pii/S1369847810000653. DOI: 10.1016/j.trf.2010.07.003

8. Pollatschek, M. A., and A. Polus. Modeling Impatience of Drivers in Passing Maneuvers. in *Transportation and Traffic Theory: Flow, Dynamics and Human Interaction: Proceedings of the 16th International Symposium on Transportation and Traffic Theory*, College Park, Maryland, 2005, pp. 267-279.

9. Farah, H. Age and Gender Differences in Overtaking Maneuvers on Two-Lane Rural Highways. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2248, 2011, pp. 30-36. http://trrjournalonline.trb.org/doi/abs/10.3141/2248-04. DOI: http://dx.doi.org/10.3141/2248-04

Traversable Medians Section 260

Introduction

Traversable medians separate opposing flows of traffic. Traversable medians are delineated only by pavement markings and do not physically prevent vehicles from crossing or entering the median.

Design Parameters

01 **A traversable median separating travel in opposite directions shall consist of solid double yellow lines as shown in Figure 260-A. Other markings in the median shall also be yellow, except crosswalk markings which shall be white.**

02 *Traversable medians should consist of:*

- *Two narrow double yellow lines (ND) where the median width is 2.5 feet or greater (Figure 260-A).*
- *A wide double yellow line (D) where the median width is less than 2.5 feet (Figure 260-A).*

03 **Where a traversable median is 6 feet wide or wider at an intersection, the yellow traversable median lines shall be joined using a curve (Figure 260-D) (this is commonly referred to as a "bull nose").**

04 **A minimum length of no-passing zone markings "A" shall precede the start of the taper of a wide traversable median (Figure 260-C).**

05 A traversable median may be supplemented with yellow transverse median bars based on engineering judgement placed at 20-foot intervals if the median width is 4.5 feet or greater (see Figure 260-B). Where the distance between accesses exceeds 200 feet, the spacing may be increased to 40 feet.

Design Issues

A bull nose is typically 100 feet long. This length is enough to provide an aesthetically pleasing curve that misses the wheel path of vehicles turning left from the side street and can be installed and maintained with most striping equipment.

Under access management laws in Oregon, it is illegal to cross a traversable median with yellow transverse median bars (referred in statute as "crosshatching") according to ORS 811.430. Contact the region access management engineer when considering transverse median bars in the vicinity of accesses.

Figures & Tables

Figure 260-A: Traversable Median Markings- Turning Movements Across Allowed

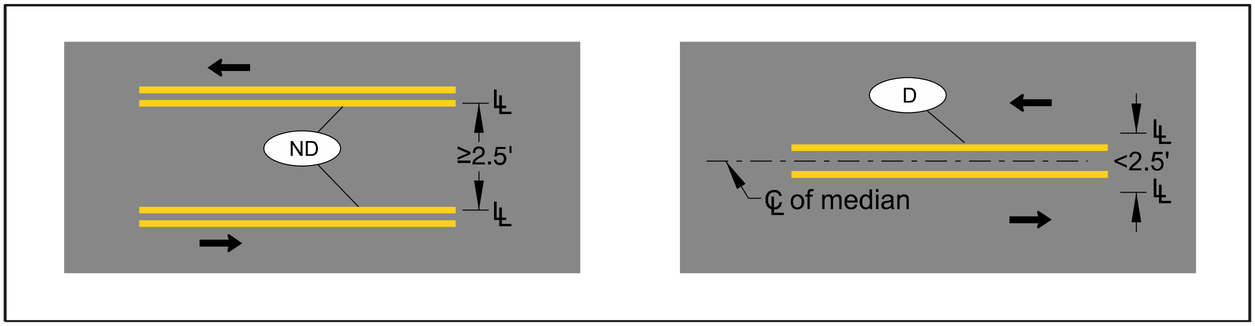


Figure 260-B: Supplemental Transverse Median Bars – Turning Movements Across Prohibited

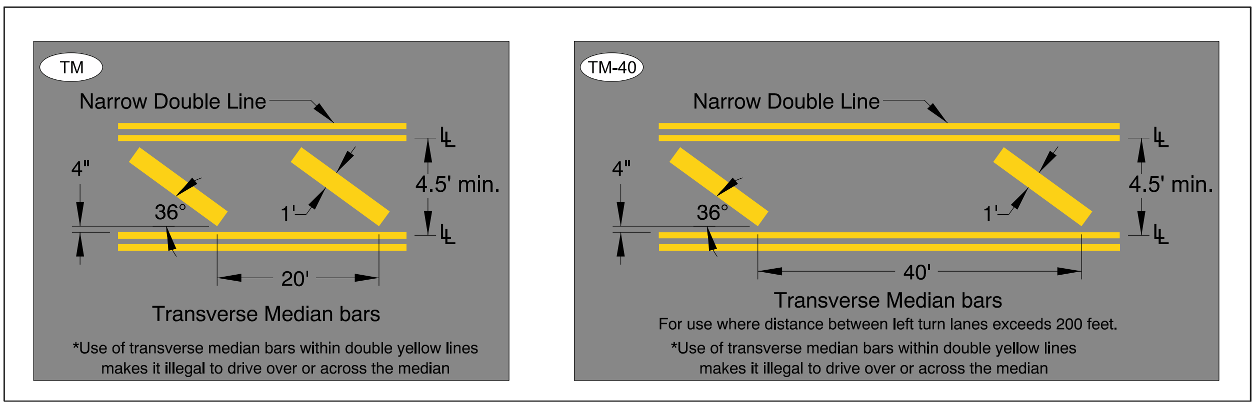
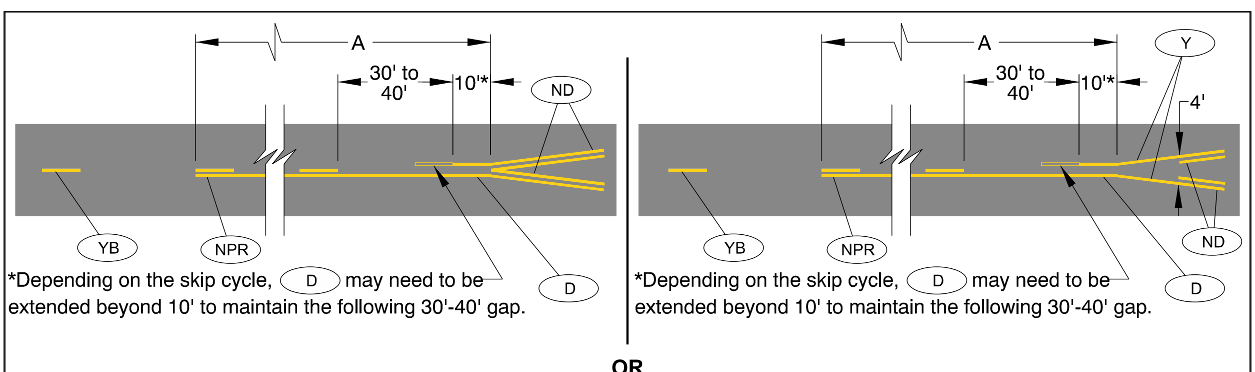


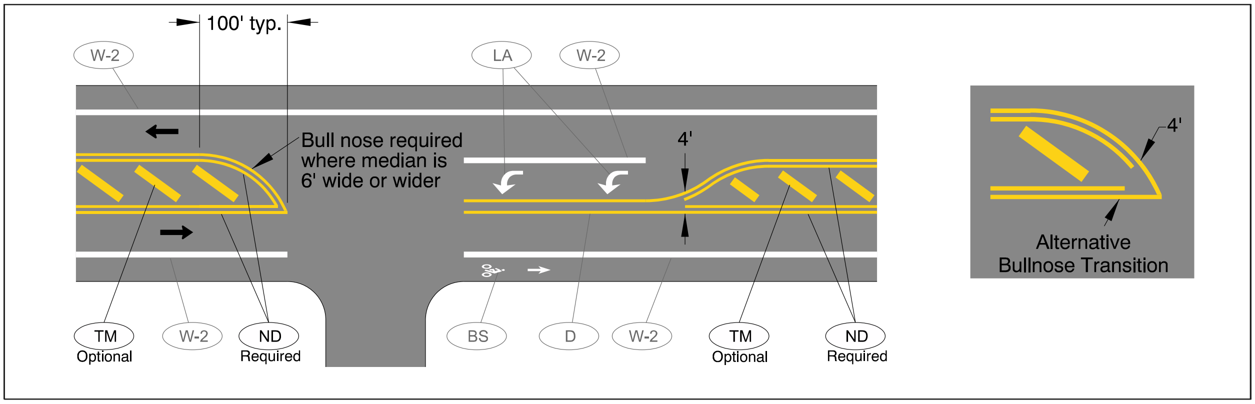
Figure 260-C: Typical Traversable Median Width Transitions



Posted or 85th Percentile Speed (mph)	25	30	35	40	45	50	55	60	65	70	75
A (min.) (ft.)	500	500	550	600	700	800	900	1000	1100	1200	1300

Increasing stationing from left to right.

Figure 260-D: Typical Traversable Median Layout



Support

There is a practical limit to how narrow a traversable median can be before the two sets of double yellow lines no longer look like two distinct lines. Similarly, there is a practical limit to the size of the space in a double yellow line before it begins to look like two distinct single yellow lines. There is no guidance in the MUTCD (*1*) or in human factors studies on these thresholds. Based on past experience in Oregon, a space between two sets of narrow double yellow lines that is approximately double the out-to-out width of a narrow double yellow line provides sufficient separation for the lines to appear as two distinct lines. To avoid the appearance of using two distinct single lines to mark the traversable median, and for consistency with maintenance equipment, traversable medians narrower than this threshold use a single standard double yellow line.

A bull nose treatment (typically 100 feet long) is required for wide (6 feet or more) traversable medians at intersections to guide turning traffic into the appropriate travel lane. A traversable median is not meant for use by vehicles; this discourages the traversable median's use as a two-way left turn lane. Traversable medians less than 6 feet wide are too narrow for use as a refuge, so a bull nose treatment for narrow traversable medians is not required.

Traversable medians create space between opposing directions of travel often for roadway elements such as left turn lanes or in advance of a raised curb. Completing a passing maneuver within or to the left of a traversable median has clear safety consequences. The required no-passing zone in advance of the traversable median taper allows passing maneuvers started in the passing-permitted section to complete prior to reaching the taper.

The transverse median bar layout in Figure 260-B has been used since the 1976 edition of the Traffic Line Manual with good success. The 20-foot standard spacing is half a standard broken line cycle length and provides excellent visibility of the restricted nature of the median. The 36 degree angle has been used since the 1966 edition of the Traffic Line Manual. There is no documentation from that time why 36 degrees was originally chosen; the fact that a 3-4-5 triangle makes this angle might be a reason it was chosen so field layout and verification could be simplified. This angle has since become the standard for all other angled transverse markings used by ODOT.

The median width transition layouts in Figure 260-C have been used since the 1990 edition of the Traffic Line Manual. The left detail in Figure 260-C joins the two inner lines of the traversable median to "finish" the median; this layout visually complies with MUTCD Figures 3B-2 and 3B-4. However, installing and re-tracing the inner lines so they are physically joined at the end of the taper can be difficult in the field. The right detail in Figure 260-C was first introduced in the 1996 edition of the Traffic Line Manual as an option for an acceptable tolerance for where the inner lines could end prior to the end of the taper. Both options have been used successfully in the field.

The 10-foot length of wide double yellow line just before the taper begins and ends has been used since the 1976 edition of the Traffic Line Manual. The 10-foot length provides a uniform and aesthetically pleasing way to transition from the taper to the one-direction no-pass line that typically follows the end of the taper.

The 30- to 40-foot gap between the wide double yellow line and the next broken line segment allows the striping operator to start or end the one-direction no-pass line at the taper point regardless of the direction the striping truck is traveling (to keep broken line cycles consistent). This also gives the striping operator time to switch guns and allows a clean transition that allows the road user to clearly see the start of the one-direction no-pass pattern.

See the ODOT Highway Design Manual (*2*) and ODOT Traffic Manual (*3*) for more information on traversable medians.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Transverse Markings .... Section 125
Raised Pavement Markers .... Section 130
RPMs Used for Supplementation .... Section 131
Typical Layouts for RPMs .... Section 133
Center Lines .... Section 210
No-Passing Zone Markings .... Section 211
Two-Way Left Turn Lanes .... Section 261
Approach to a Fixed Obstruction .... Section 280
Non-Traversable Medians & Channelizing Islands .... Section 281
Left Turn Lanes .... Section 310
Bicycle Lane Buffers .... Section 412

Key References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.

2. Oregon Department of Transportation. *Highway Design Manual*. Oregon Department of Transportation, Salem, Oregon, 2012.

3. Oregon Department of Transportation. Traffic Manual, 2016 Edition. January 2016. http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Traffic-Manual-v2016.pdf. Accessed July 3, 2017.

Two-Way Left Turn Lanes Section 261

Introduction

Two-way left turn lanes (also known as TWLTL, special turn lane, continuous two-way left turn lane, CTWLTL) are used to provide left turn access to and from adjacent properties and roadways, while minimizing impacts of left turning vehicles on through traffic.

Design Parameters

01 **The lane line pavement markings on each side of a two-way left turn lane shall consist of a normal broken yellow line and a normal solid yellow line to delineate the edges of a lane that can be used by traffic in either direction as part of a left-turn maneuver. These markings shall be placed with the broken line toward the two-way left turn lane and the solid line toward the adjacent traffic lane as shown in Figure 261-A.**

02 **A two-way left turn lane shall be followed by a single-direction left turn lane(s) or a traversable median or non-traversable median on the approach to a signalized intersection.**

03 *A two-way left turn lane should be followed by a single-direction left turn lane(s) or a traversable median or non-traversable median on the approach to a major unsignalized intersection. Two-way left turn lanes should be marked up to the intersection on the approach to a minor intersection (Figure 261-C).*

04 **Two-way left turn lanes shall not continue across intersections and major driveways, including private driveways with substantial approach volumes (Figure 261-C).**

05 *Two-way left turn lanes should continue across minor driveways (public or private) and alleys (Figure 261-C).*

06 **A single-direction lane use arrow shall not be used in a two-way left turn lane.**

07 *Two-way left turn lanes should include opposing left turn arrows at or just downstream from the beginning of a two-way left turn lane (Figure 261-B). Opposing left turn arrows should be spaced 8 to 16 feet apart (Figure 261-A).*

08 Additional sets of opposing left turn arrows may be placed at even intervals within the two-way left turn lane, proportioned within the block and spaced apart (in feet) approximately 10 times the posted speed in mph.

09 A striped bullnose may be used in a two-way left turn lane at a minor T-intersection (Figure 261-C).

Required Approvals

Region traffic engineer approval is required for use of a striped bull nose in a two-way left turn lane at a minor T-intersection.

Design Issues

Past design practice allowed single left turn arrows in two-way left turn lanes at intersections. This practice is no longer allowed by the MUTCD. Arrows in two-way left turn lanes need to come in sets of two opposing left turn arrows.

A bull nose is typically 100 feet long. This length is enough to provide an aesthetically pleasing curve that misses the wheel path of vehicles turning left from the side street and can be installed and maintained with most striping equipment.

Consider conflicting movements, turning volumes, and location of accesses when determining whether a left turn lane needs to be provided at a minor unsignalized intersection instead of a two-way left turn lane.

Figures & Tables

Figure 261-A: Two-Way Left Turn Lane Details

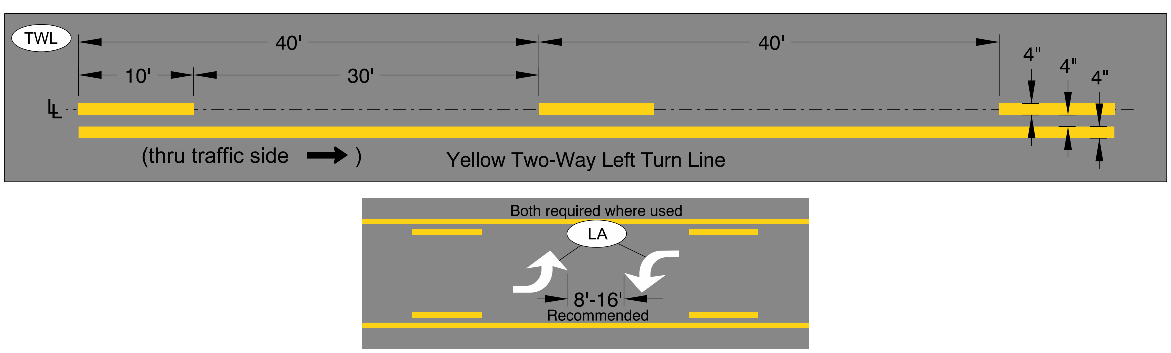
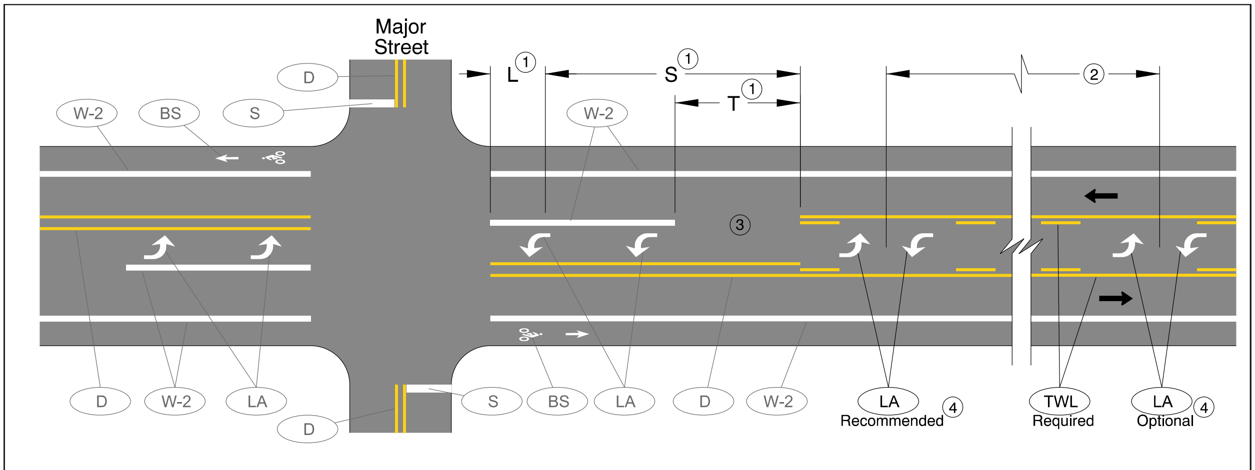
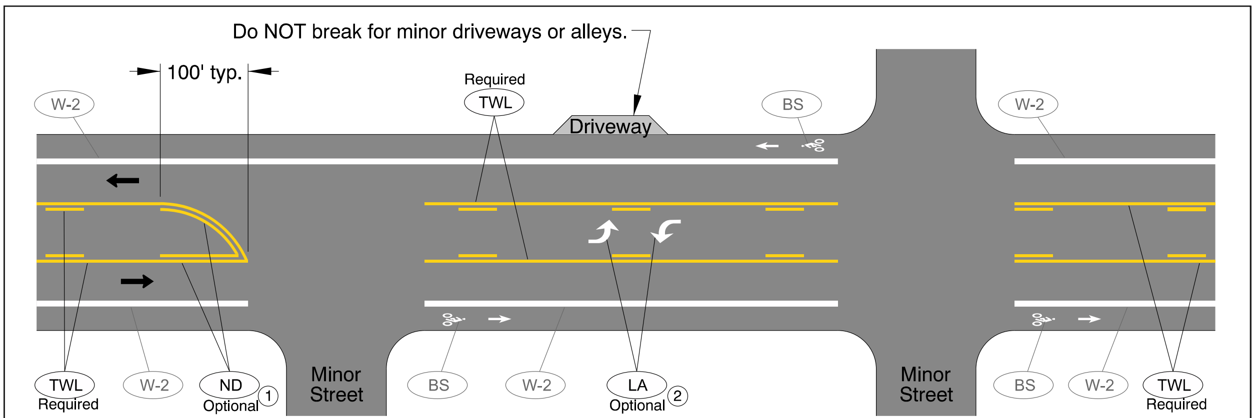


Figure 261-B: Typical Two-Way Left Turn Lane at Major Unsignalized Intersection



① See Left Turn Lane section for dimensions.
② Approximate spacing between opposing arrow sets = 10 x (posted speed in mph), 250' minimum.
③ See Left Turn Lane section for design parameters related to entry taper treatments.
④ Both arrows are required where used (see Figure 261-A).

Figure 261-C: Typical Two-Way Left Turn Lane at Minor Intersection



① See design parameters for optional use of bullnose end treatments.
② Both arrows are required where used (see Figure 261-A).

Support

Two opposing lane use arrows (instead of one) are needed in two-way left turn lanes because the set of two arrows communicates the two-direction function of the lane. A single arrow sends a conflicting message and has been prohibited by the MUTCD.

The distance between two sets of arrows (10 x posted speed) is based on past ODOT practice and is shared by at least two other states. The minimum of 250 feet shown in Figure 261-B is also based on past ODOT practice and is similar to marking practice in other states (*1*).

Similar to centerlines and edge lines, two-way left turn lanes are broken at intersections and major driveways to help identify where an intersecting road is located. See the centerline section for indicators of intersections and major driveways where two-way left turn lane striping needs to be broken.

Left turn lanes are provided at signalized intersections instead of two-way left turn lanes for safe signal operations. During typical protected left turn signal operations, the left-turn phase can start and/or end at different times than the adjacent through movements. This requires an exclusive left-turn lane (*2*). Detection of left turning vehicles is also needed at signalized intersections with protected left turn phasing. A left-turning vehicle traveling away from the intersection could cause the signal to bring up an unnecessary left turn phase if the two-way left turn lane is provided up to the intersection.

Major unsignalized intersections where a one-way left turn lane is recommended at the intersection instead of a two-way left turn lane can be characterized by one or more of the following:

- A significant product of conflicting left turns (both from the highway and the intersecting road) that creates a safety concern for drivers attempting to complete a two-stage left turn using the TWLTL.
- The intersecting road has multiple approach lanes.
- The intersecting road has a marked center line.

It may be desirable at uncontrolled intersections with a marked crosswalk to provide a left turn lane instead of a TWLTL. This change can help with identifying advance stop bar locations for the crosswalk, as well as limiting the use of the lane near the crosswalk to one direction.

At some T-intersections with access and safety concerns, a bull nose end treatment can help guide left turning drivers from the side street into the travel lane (instead of into the two-way left turn lane in a two-stage left maneuver).

While two-way left turn lanes are a tool to improve safety (*3*), there are limitations to their capabilities. See the ODOT Traffic Manual (*4*) and ODOT Highway Design Manual (*5*) for more information on two-way left turn lanes.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Lane Use Arrows .... Section 160
Traversable Medians .... Section 260
Non-Traversable Medians & Channelizing Islands .... Section 281
Left Turn Lanes .... Section 310

Key References

1. Friedman, B. E. NCHRP Synthesis 356: Pavement Markings - Design and Typical Layout Details. Washington, D.C., ISBN 0-309-09763-0, 2006. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_356.pdf.
2. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
3. Lyon, C., B. Persaud, N. Lefler, D. Carter, and K. A. Eccles. Safety Evaluation of Installing Center Two-Way Left-Turn Lanes on Two-Lane Roads. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2075, December 2008, pp. 34-41. http://trrjournalonline.trb.org/doi/pdf/10.3141/2075-05. DOI: http://dx.doi.org/10.3141/2075-05
4. Oregon Department of Transportation. Traffic Manual, 2016 Edition. January 2016. http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Traffic-Manual-v2016.pdf. Accessed July 3, 2017.
5. Oregon Department of Transportation. *Highway Design Manual*. Oregon Department of Transportation, Salem, Oregon, 2012.

Channelizing Lines and Traversable Channelizing Islands Section 270

Introduction

Channelizing lines are used to discourage or prohibit sideway movements of traffic proceeding in the same general direction. Traversable channelizing islands are formed by channelizing lines and help direct road users through an intersection, around obstructions, or laterally separate same-direction traffic.

Design Parameters

01 **A channelizing line shall be a wide (W-2) or double solid white line (NDW).**

02 **Traversable channelizing islands shall be formed by two channelizing lines. If used, other pavement markings in the channelizing island area shall be white.**

03 Where the traversable channelizing island is 4.5 feet wide or wider, white chevron bars (CH) may be used within the neutral area to discourage travel in the neutral area.

04 **Where crosshatch markings are used in paved areas that separate traffic flows in the same general direction, they shall be white and they shall be shaped as chevron markings, with the point of each chevron facing toward approaching traffic, as shown in Figure 270-A.**

05 *Chevrons bars (CH) should be at least 12 inches wide. The longitudinal spacing of the chevron bars should be 20 feet. The chevrons should form an angle of 36 degrees with the longitudinal lines that they intersect (see Figure 270-A).*

Required Approvals

Some types of traversable channelizing islands require state traffic-roadway engineer approval (e.g.: channelized right-turn lanes).

Figures & Tables

Figure 270-A: Chevron Bar Details

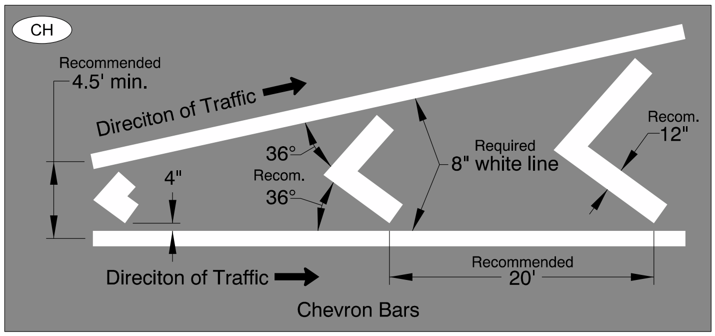
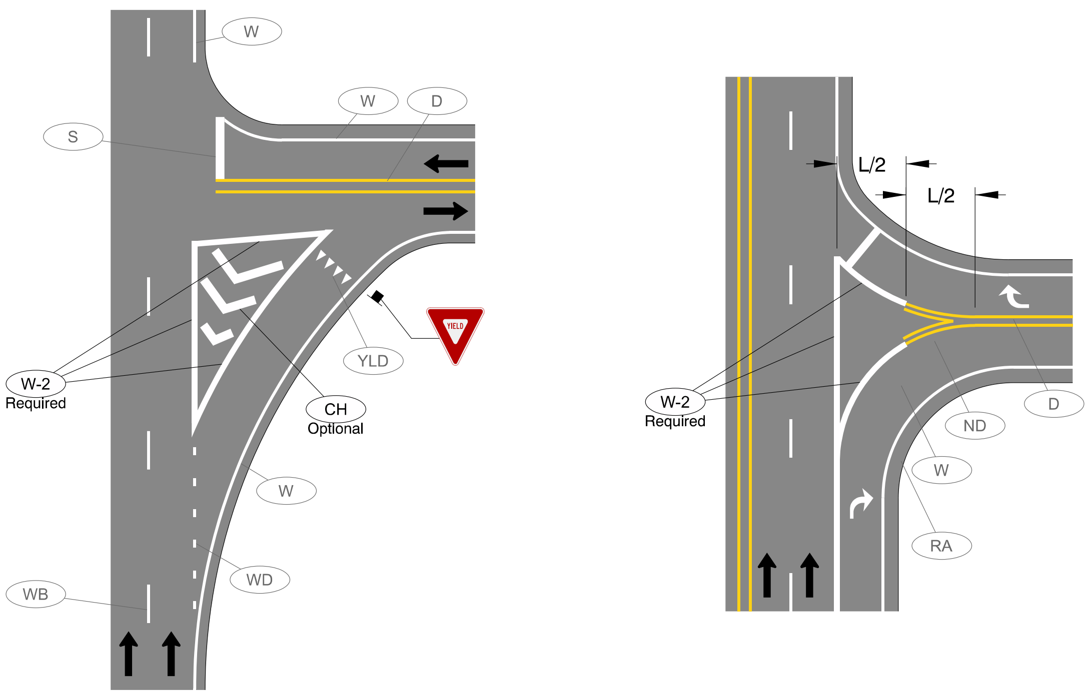


Figure 270-B: Typical Traversable Channelizing Island Applications



Typical Traversable Channelized Right Turn Lane

Typical Right-In-Right-Out with Traversable Channelizing Island

Support

Traversable channelizing islands can be preferable to non-traversable islands where access management is not needed, where approach speeds are relatively high, where there is little to no pedestrian traffic, where illumination is not provided, or where significant snow removal is needed (*1*).

Like bold typeface, wide lines communicate greater emphasis for channelizing. White lines and chevrons are used to create and fill channelizing islands because channelizing islands separate traffic traveling in the same general direction (*2*).

Marked crosswalks are typically not provided to or from traversable channelizing islands. Markings alone do not provide the same pedestrian refuge or the same information for visually impaired pedestrians about the direction of the crosswalk as a non-traversable island. They also do not provide the same protection for elements like signs and signal hardware as a non-traversable island.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Approach to a Fixed Obstruction .... Section 280
Non-Traversable Medians & Channelizing Islands .... Section 281
Channelized Right-Turn Lanes .... Section 321
Interchange Ramps: Exit & Entrance Ramps .... Section 360
Bicycle Lane Buffers .... Section 412

Key References

1. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*, 6th ed. Washington, D.C., 2011.
2. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.

Approach to a Fixed Obstruction Section 280

Introduction

Fixed obstructions in the roadway can include bridge supports, sign supports, or raised barriers. Markings for non-traversable medians and channelizing islands are discussed in Section 281.

Design Parameters

01 **Pavement markings shall be used to guide traffic away from fixed obstructions within a paved roadway. Approach markings for fixed obstructions in the roadway shall consist of a tapered line or lines extending from the center line or the lane line to a point 1 to 2 feet to the right-hand side, or to both sides, of the approach end of the obstruction (see Figure 280).**

02 *For roadways having a posted or statutory speed limit of 45 mph or greater, the taper length of the tapered line markings should be computed by the formula L=WS. For roadways where the posted or statutory speed limit is less than 45 mph, the formula L=WS2/60 should be used to compute the taper length.*

03 *The minimum taper length should be 100 feet in urban areas and 200 feet in rural areas.*

04 **If traffic is required to pass only to the right of the obstruction, the markings shall consist of a two-direction no-passing marking (D or ND) at least twice the length "L" as determined by the appropriate taper formula (see Figure 280 Detail A).**

05 If traffic is required to pass only to the right of the obstruction, transverse median bars (TM) may be placed in the flush median area between the narrow two-direction no-passing lines (ND). Other markings, such as yellow delineators, yellow surface mounted tubular markers, yellow raised pavement markers, and white crosswalk pavement markings, may also be placed in the flush median area.

06 **If traffic can pass either to the right or left of the obstruction, the markings shall consist of two wide white (W-2) channelizing lines diverging from the lane line, one to each side of the obstruction. In advance of the point of divergence, a wide white (W-2) channelizing line or narrow double white line (NDW) shall be extended in place of the broken lane line for a distance equal to the length of the diverging lines (Figure 280 Detail C)**

07 If traffic can pass either to the right or left of the obstruction, white chevrons bars (CH) may be placed in the flush neutral area between the wide white lines. Other markings, such as white delineators, white channelizing devices, white raised pavement markers, and white crosswalk markings may also be placed in the flush neutral area.

08 Pavement markings used to delineate non-traversable medians and channelizing islands may be installed according to Section 281.

Required Approvals

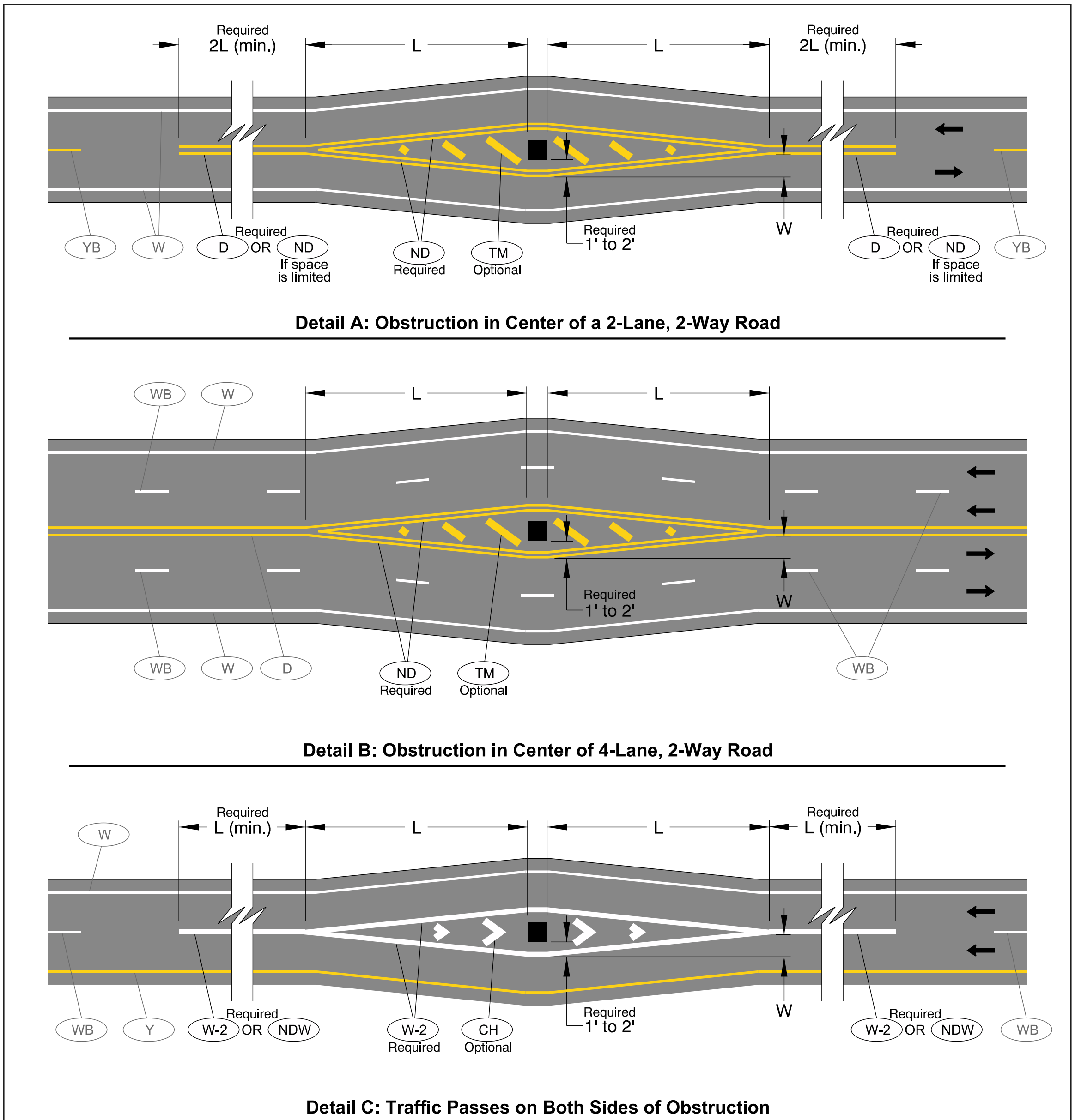
Lane width reductions on the approach to a fixed obstruction require a roadway design exception.

Design Issues

Due to striping equipment limitations, a line typically cannot be placed closer than 1.5 feet from the face of a physical barrier. Some equipment might allow the line to be placed closer; some might require farther placement. Check with the region striping manager to confirm equipment limitations when designing a line within 3 feet of a physical barrier to ensure the line can be maintained after installation.

Figures & Tables

Figure 280: Markings on Approaches to Fixed Obstructions



For speeds 40 mph or less: $L(ft) = \frac{WS^2}{60}$

For speeds 45 mph or greater: L(ft) = WS

Where:
- L= taper length (feet)
- W = Offset distance (feet)
- S = posted, statutory, or 85th percentile speed, whichever is higher (mph)

L = 100' minimum in urban areas
L = 200' minimum in rural areas

Length "L" should be extended as required by sight distance conditions.

■ = obstruction, including attenuators, if used.

Support

Fixed obstructions within a roadway like bridge supports, sign supports, and raised barriers present clear safety consequences. In some cases, like legacy bridge supports, the obstruction is pre-existing and must be delineated to guide road users around the obstruction. The design parameters, dimensions, and layout of markings on the approach to a fixed obstruction come from Section 3B.10 in the 2009 MUTCD (*1*).

Under the taper length formula, L is the taper length in feet, W is the width of the offset distance in feet, and S is the 85th percentile speed or the posted or statutory speed limit, whichever is higher.

Where traffic can pass either to the right or left of the obstruction, a wide white line or narrow double white line is required in the design parameters before and after the taper. This is usually marked with a wide white line, but can be marked with a narrow double white line where crossing the line needs to be prohibited. Section 120 gives more information on line types and meanings.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Transverse Markings .... Section 125
Center Lines .... Section 210
No-Passing Zone Markings .... Section 211
Lane Lines .... Section 220
Non-Traversable Medians & Channelizing Islands .... Section 281

Key References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.

Non-Traversable Medians & Channelizing Islands Section 281

Introduction

Non-traversable medians like raised medians and traffic separators separating traffic traveling in opposite directions) and channelizing islands (separating traffic traveling in the same general direction) physically prevent vehicles from crossing or entering the median or channelizing island by means of a raised curb, pavement edge, or raised channelizing device. Both are considered islands, which is a defined area between traffic lanes for control of vehicular movements or for pedestrian refuge, including all end protection and approach treatments.

Design Parameters

01 **On roadways with centerline markings, non-traversable medians shall have no passing-zone markings preceding the start of the non-traversable median according to Section 211.**

02 *The ends of non-traversable medians and channelizing islands first approached by traffic should be preceded by diverging longitudinal pavement markings on the roadway surface to guide vehicles into desired paths of travel along the median or island edge.*

03 *A normal solid line of the appropriate color should be installed adjacent to a non-traversable median or channelizing island (Figure 281-A).*

04 A wide solid line of the appropriate color may be installed adjacent to a non-traversable median or channelizing island for additional emphasis. Transverse median bars may be used in the neutral area upstream from non-traversable medians according to Section 260. Chevron bars may be used in the neutral area upstream from non-traversable channelizing islands according to Section 270.

05 *Non-traversable medians should have retroreflective solid yellow markings placed on the ends of the non-traversable median first approached by traffic (Figure 281-A, 281-B, and 281-C).*

06 *Channelizing islands should have retroreflective solid white markings placed on the ends of the channelizing island first approached by traffic (Figure 281-A).*

07 Raised pavement markers of the appropriate color may be placed on the top of approach ends and along the length of non-traversable medians and channelizing islands as a supplement to or as a substitute for retroreflective curb markings (see Section 133).

08 Surface mounted tubular markers may be placed on the top of approach ends and along the length of non-traversable medians and channelizing islands to add emphasis to retroreflective curb markings and/or raised pavement markers (see Section 140).

09 *Surface mounted tubular markers should be placed on the top of approach ends of non-traversable medians and channelizing islands where plowing occurs multiple times annually if the non-traversable median or channelizing island is not marked with an object marker or similar warning sign.*

10 *A two-way left turn lane should transition to a traversable median upstream from the beginning of a non-traversable median a distance determined by engineering judgement (see Figure 281-C).*

11 Non-traversable medians may be colored yellow. Channelizing islands may be colored white.

12 Non-traversable medians and channelizing islands should not have curb markings within 2 feet of a detectable warning surface (DWS), except for the end first approached by traffic.

13 Non-traversable medians and channelizing islands should not have curb markings on the flared side of curb ramps.

14

Design Issues

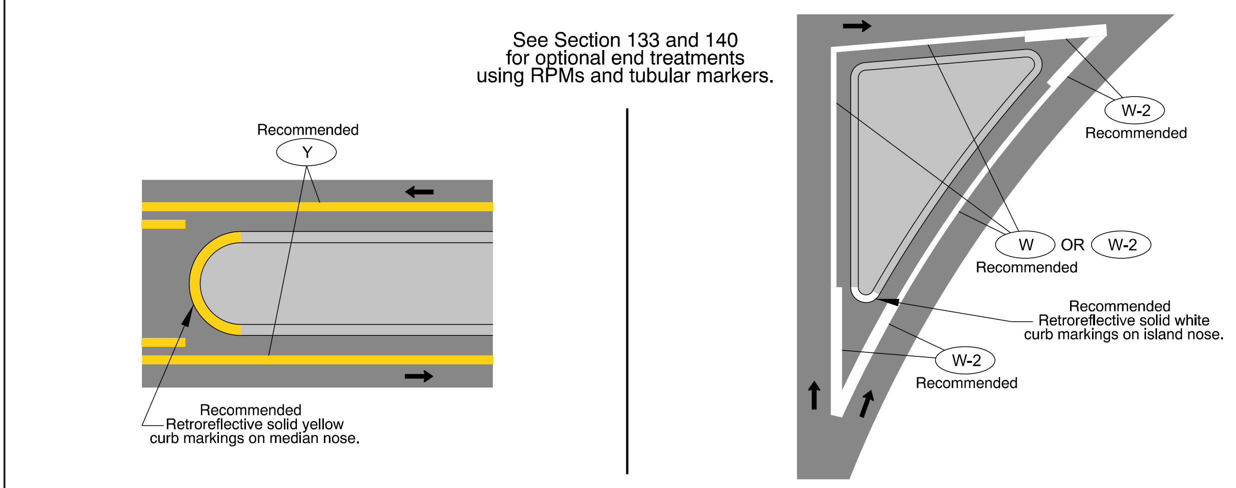
Due to striping equipment limitations, a line typically cannot be placed closer than 1.5 feet from the face of a physical barrier. Some equipment might allow the line to be placed closer; some might require farther placement. Check with the region striping manager to confirm equipment limitations when designing a line within 3 feet of a physical barrier to ensure the line can be maintained after installation.

Snow can obscure pavement and median markings. See Part 2 of the MUTCD for other signing related to non-traversable medians and channelizing islands.

When designing a non-traversable median or channelizing island with a cut through for pedestrians, consideration should be given to the conspicuity of any DWSs that are part of the project. It is beneficial to have a distance between a yellow DWS and yellow curb markings. The distance gives more contrast which helps pedestrians see where their path is.

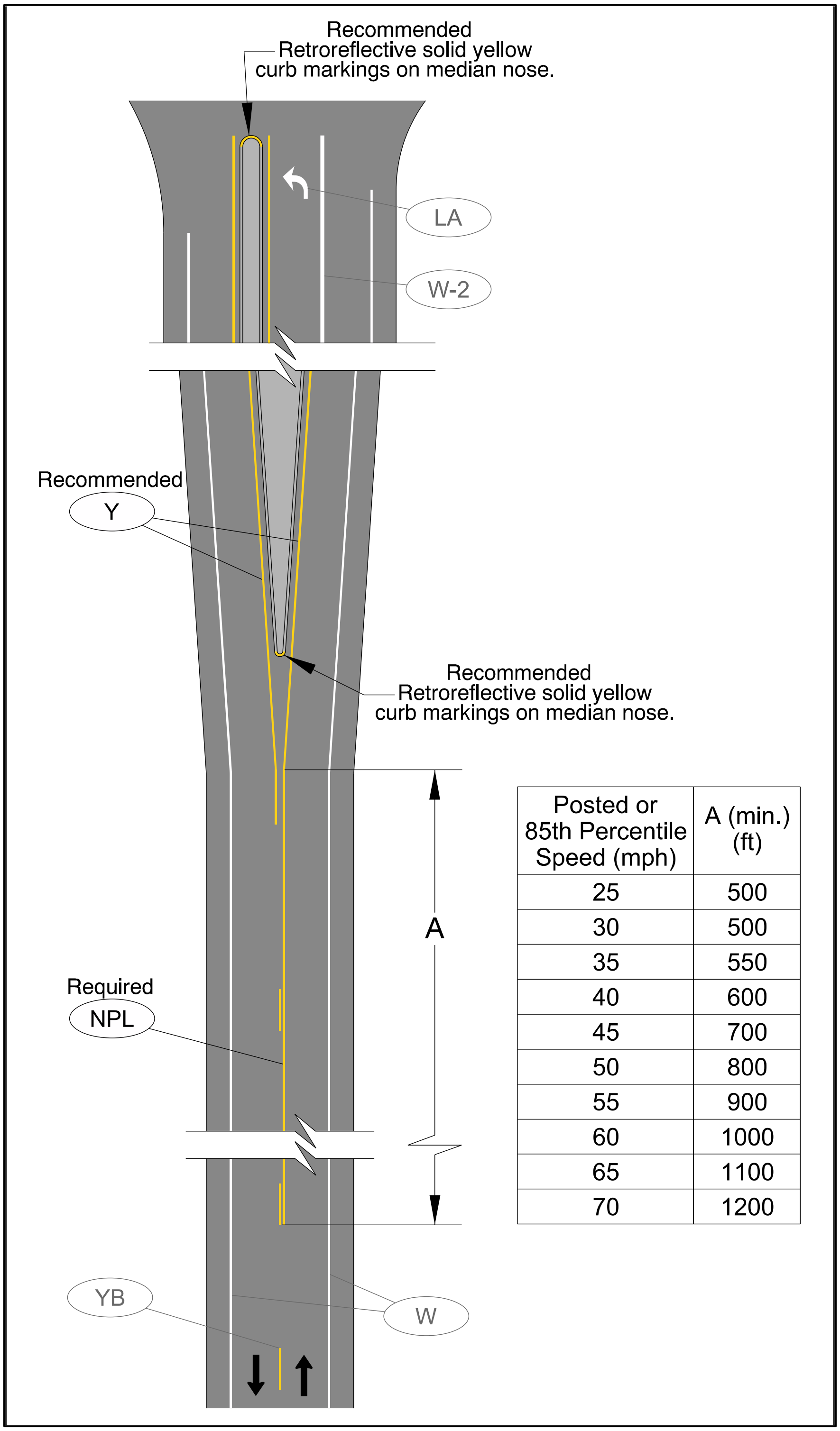
Figures & Tables

Figure 281-A: Typical Non-Traversable Median and Non-Traversable Channelizing Island



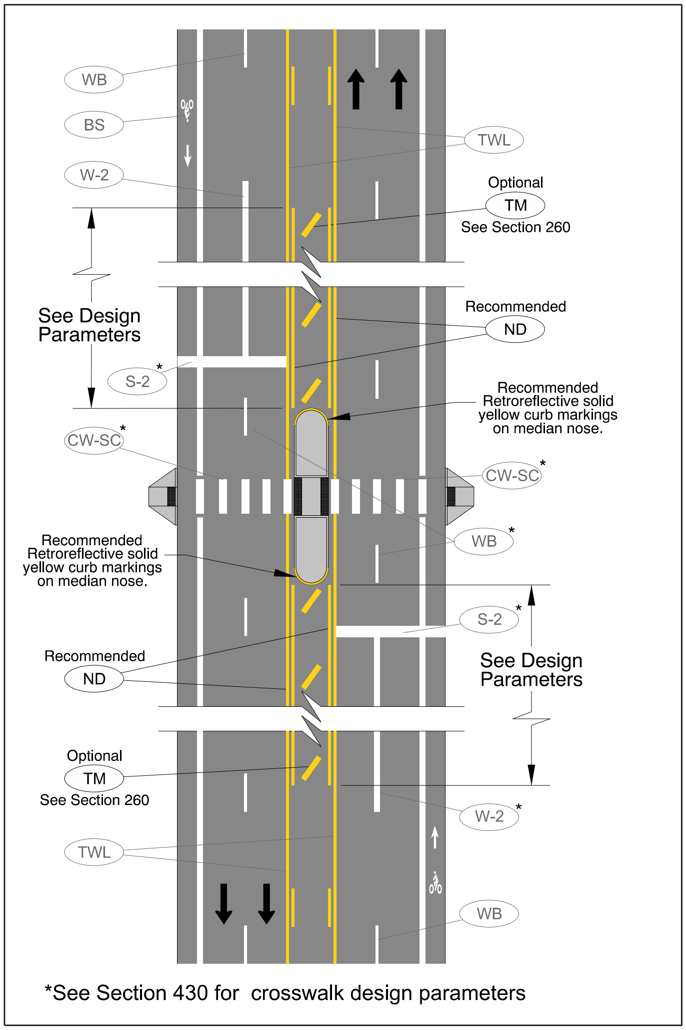
Detail A: Typical Non-Traversable Median **Detail B: Typical Non-Traversable Channelizing Island**

Figure 281-B: Typical Non-Traversable Median Approach



Posted or 85th Percentile Speed (mph)	A (min.) (ft)
25	500
30	500
35	550
40	600
45	700
50	800
55	900
60	1000
65	1100
70	1200

Figure 281-C: Typical Two-Way Left Turn Lane to Non-Traversable Median Transition



Support

Non-traversable medians and channelizing islands often consist of a raised curb and are delineated as islands according to Chapter 3I and Section 3B.23 in the 2009 MUTCD (*1*).

The leading edge or nose of unmarked raised curbs can be difficult to see, especially for older road users. Clear delineation of these features is especially important at high-speed approaches and medians used as pedestrian refuges (*2*).

Chapter 3H of the 2009 MUTCD allows the use of surface mounted tubular markers for general traffic control purposes, like adding emphasis to raised medians or islands. Chapter 3H does not cover substituting surface mounted tubular markers for island end treatments, like a painted nose or RPMs. Surface mounted tubular markers at the ends of islands provide good guidance that there is an obstacle in the road. However, they might not show the size of the island and can be frequently knocked off island ends, especially at intersections where large vehicles turn left. A painted nose or RPMs can reliably provide delineation even after it is hit.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Raised Pavement Markers .... Section 130
Typical Layouts for RPMs .... Section 133
Surface Mounted Tubular Markers .... Section 140
Stop Bars .... Section 150
Center Lines .... Section 210
No-Passing Zone Markings .... Section 211
Traversable Medians .... Section 260
Two-Way Left Turn Lanes .... Section 261
Approach to a Fixed Obstruction .... Section 280
Left Turn Lanes .... Section 310
Roundabouts .... Section 350
Bicycle Lane Buffers .... Section 412
Marked Crosswalks .... Section 430

Key References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
2. Brewer, M., D. Murillo, and A. Pate. Handbook for Designing Roadways for the Aging Population. Washington, D.C., FHWA-SA-14-015, 2014. http://safety.fhwa.dot.gov/older_users/handbook/aging_driver_handbook_2014_final%20.pdf.

Left Turn Lanes Section 310

Introduction

A left turn lane is a lane for the exclusive use of left turning vehicles that is formed on the approach to the location where the turn is to be made. A through lane that becomes a turn lane is considered a dropped lane rather than a turn lane.

Design Parameters

01 **A left turn lane shall include:**

- **A wide white line (W-2) separating the left turn lane from adjacent travel lanes traveling in the same general direction.**
- **A lane use arrow at the start of the wide white line (W-2).**
- **A reversing curve entry taper at the beginning of the left turn lane (Figure 310 Detail A).**

02 **The storage length "L" shown in Figure 310 shall be determined by an engineering study and shall not be less than 100 feet long.**

03 **On undivided two-lane, two-way roadways, a minimum length "A" of no-passing zone markings (see Figure 310) shall precede the start of the median taper.**

04 *A lane use arrow should be used in a left turn lane at the intersection (see Figure 310).*

05 *The length of the wide white line (W-2) used to separate a left turn lane from an adjacent lane(s) should be determined according to Figure 310.*

06 *Where the wide white line (W-2) separating the left turn lane from adjacent lanes is longer than 400 feet, an additional lane use arrow should be used at the mid-point of the left turn lane.*

07 *If the entry taper to the left turn lane is located on a horizontal curve or crest vertical curve, a dotted line should extend across the entry taper ("T" in Figure 310).*

08 **If used, the dotted line across the entry taper of a left turn lane ("T" in Figure 310) shall be a normal width white dotted line (WD).**

09 The break entry taper (Figure 310 Detail B) may be used instead of a reversing curve entry taper at a single-lane left turn lane when any or all of the following apply:

- Located on a horizontal tangent.
- Not within a crest vertical curve.
- The "X" distance shown in Figure 310 is 15 feet or less.
- Opposing-direction left turn traffic will not conflict with the operations of the left turn lane.

10 Transverse median bars (TM) may be used in the neutral area of a wide traversable median according to Section 260.

Required Approvals

An engineering study and state traffic-roadway engineer approval is required for:

- Multiple left turn lanes.
- Left turn lanes at new signalized intersections.

Region traffic engineer/manager approval is required for use of the “break” layout (Figure 310 Detail B) instead of a reversing curve.

An engineering study and region traffic engineer/manager approval is required for:

- Left turn lanes at unsignalized intersections.
- Addition or removal of left turn lanes at existing signalized intersections.

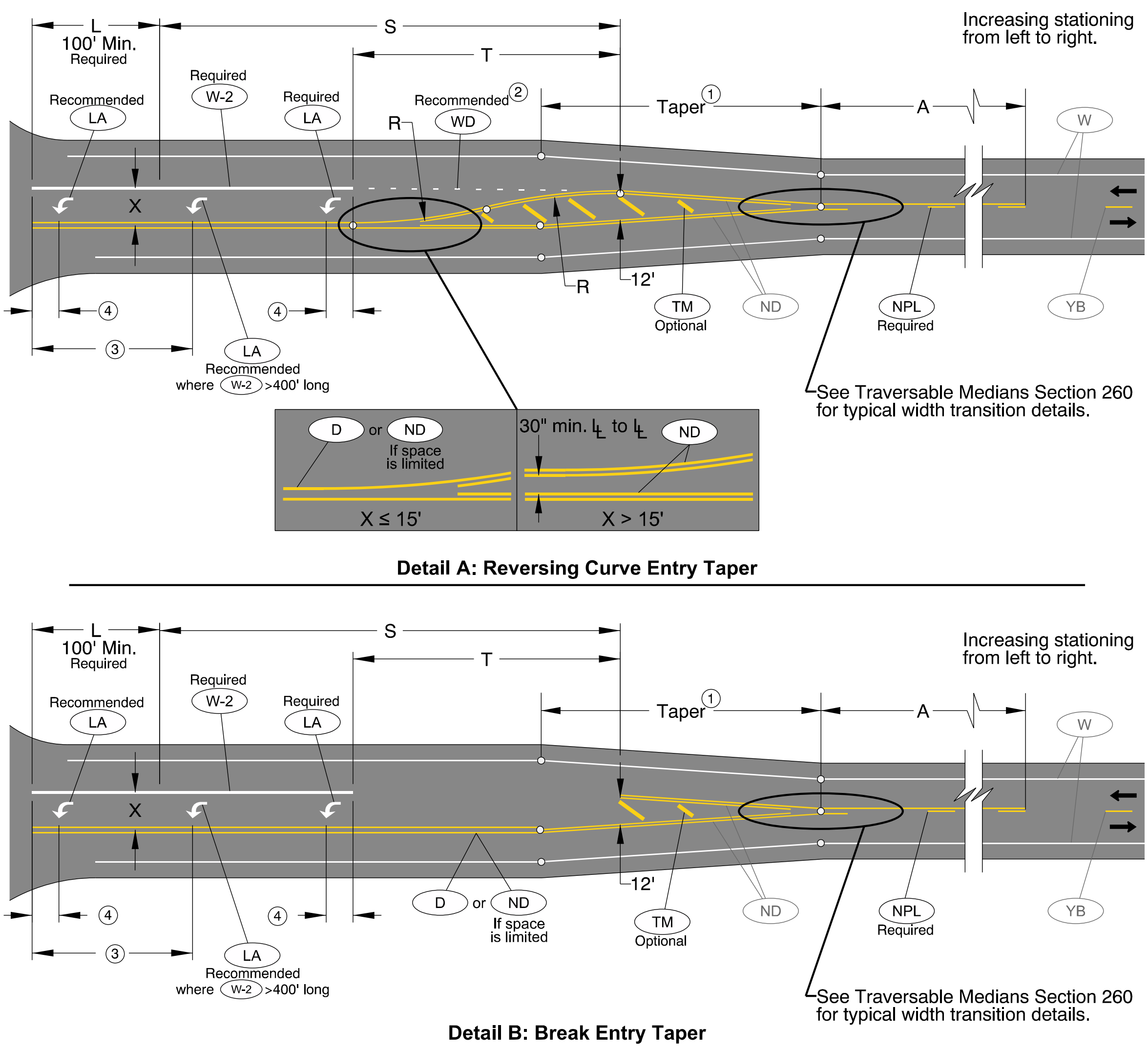
A roadway design exception is required for a storage length less than 100′. State traffic roadway engineer approval will not be required for this required design parameter because it will be documented through the roadway design exception.

Design Issues

Depending on the configuration and location of an uncontrolled crosswalk a stop bar may be recommended for use. See Section 150 and Section 430 when there is an uncontrolled marked crosswalk near a dedicated left turn lane.

Figures & Tables

Figure 310: Typical Left Turn Lane Layouts for Two-Lane Undivided Roadway



Design Speed (mph)	① Taper Rate	T (ft)	S (ft)	X (ft)
25	15:1	100	120	14
30	15:1	100	120	14
35	25:1	110	130	14
40	30:1	120	170	14
45	45:1	135	215	14
50	50:1	145	265	14
55	55:1	160	320	14
60	55:1	170	385	16
65	55:1	180	450	16
70	55:1	180	520	16

Increasing stationing from left to right.

① See Taper Rates in left table.

② See design parameters for (WD) recommendation.

③ ½ length of (W-2)

④ 10' if using (LA); 15' if using (E-LA)

Where:

T = Distance to develop left turn lane (ft)

S = Deceleration distance (ft)

L = Storage length (ft), determined by engineering study (100' min.)

X = Median width (ft), Lane Line to Lane Line

R = Radius of reversing curve = $\frac{T^2+d^2}{4d}$

d = Lateral distance of reversing curve (see figure 8-9 of the Highway Design Manual)

Posted or 85th Percentile Speed (mph)	A (min.) (ft)
25	500
30	500
35	550
40	600
45	700
50	800
55	900
60	1000
65	1100
70	1200

Support

Left turn lane layouts are taken from the ODOT Highway Design Manual (*1*). The layouts shown in Figure 310 are typical when the median is widened on both sides of the roadway to develop the left turn lane; there are similar but different methods available to develop the left turn lane. See the Highway Design Manual for more information on siting, layout, and dimensions used for left turn lanes. The ODOT Analysis Procedures Manual (APM) (*2*) contains information on estimating the storage length "L" shown in Figure 310.

Using a white dotted (WD) line across the left turn lane development taper ("T" shown in Figure 310) can help keep road users properly aligned in their travel lane if the opening for the turn lane is at a horizontal curve or vertical crest curve. This can help reduce the likelihood of a road user following the yellow traversable median line, drifting into the turn lane, and then making a sudden correction to get back into the through lane.

The reversing curve entry taper helps guide road users into the left turn lane. This is important at multiple left turn lanes (because of the very wide transition), where a horizontal curve affects the entry path to the left turn lane, and where a crest vertical curve affects sight distance at the left turn lane entry. The reversing curve entry taper also provides separation from other median functions, such as an opposing-direction left turn lane (i.e.: "end-to-end left turn lanes").

While the reversing curve entry taper is beneficial for safe and efficient operations, it does require extra out-of-direction maneuvering of striping equipment. The break entry taper layout allows for easier re-tracing by letting the striping equipment stay aligned with the through lane. Road users typically do not need a reversing curve entry taper into single-lane left turn lanes if it is located on a horizontal tangent, not located within a crest vertical curve, and not "end-to-end" with an opposing-direction left turn lane. In these cases, using the break entry taper can help reduce maintenance needs and costs.

In long left turn lanes, an additional arrow at the mid-point of the wide solid white line (W-2) provides confirmation to road users of the function of the lane. While there is no research specifically investigating this practice, it is common in other states (*3*). In Oregon, 400 feet of wide solid white line (W-2) has been the point at which an additional arrow is used. This value was based on the length of wide solid white line (W-2) at a design speed of 60 mph (400 feet) at the time the design parameter was developed. Since most left turn lanes are designed at or below 60 mph design speed, and because two arrows provide adequate guidance to road users in turn lanes 400 feet long or less (based on field observations), 400 feet and greater has been a reasonable definition of a "long" left turn lane.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Transverse Markings .... Section 125
Raised Pavement Markers .... Section 130
RPMs Used for Positioning Guides .... Section 132
Typical Layouts for RPMs .... Section 133
Stop Bars .... Section 150
Lane Use Arrows .... Section 160
Center Lines .... Section 210
No-Passing Zone Markings .... Section 211
Lane Lines .... Section 220
Traversable Medians .... Section 260
Two-Way Left Turn Lanes .... Section 261
Non-Traversable Medians & Channelizing Islands .... Section 281
Dropped Lanes and Auxiliary Lanes on Conventional Roads .... Section 330
Line Extensions Through Intersections .... Section 340
Marked Crosswalks .... Section 430

Key References

1. Oregon Department of Transportation. *Highway Design Manual*. Oregon Department of Transportation, Salem, Oregon, 2012.
2. Oregon Department of Transportation. *Analysis Procedures Manual*, 2nd ed. Oregon Department of Transportation, Salem, Oregon, 2016. http://www.oregon.gov/ODOT/Planning/Pages/APM.aspx.
3. Friedman, B. E. NCHRP Synthesis 356: Pavement Markings - Design and Typical Layout Details. Washington, D.C., ISBN 0-309-09763-0, 2006. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_356.pdf.

Added Right Turn Lanes Section 320

Introduction

An added right turn lane is a lane for the exclusive use of right turning vehicles that is formed prior to the intersection typically by widening the roadway. This does not include a channelizing island or separate right-turn roadway. See Section 321 for information on channelized right turn lanes and Section 330 for information on dropped turn lanes (where a through lane becomes a mandatory turn lane).

Design Parameters

01 **An added right turn lane shall include:**

- **A wide white line (W-2) separating the right turn lane from adjacent lanes traveling in the same general direction beginning where full lane width is developed prior to the intersection (see Figure 320).**
- **A lane use arrow at the start of the right turn lane (Figure 320).**

02 **A through bicycle lane shall not be positioned to the right of a right turn lane unless conflicting movements are controlled by a traffic control signal.**

03 **If motor vehicles cross a bicycle lane to enter the added right turn lane, wide white dotted lines (WD-2) shall be used to mark the extension of the bicycle lane across the taper section (see Figure 320).**

04 *A lane use arrow should be used in the right turn lane at the intersection (see Figure 320).*

05 *At signalized intersections, the storage length "L" shown in Figure 320 should be determined by an engineering study.*

06 *At unsignalized intersections, the wide white line (W-2) used to separate the right turn lane from an adjacent lane(s) should be at least 50 feet long.*

07 *Where the wide white line (W-2) separating the right turn lane from adjacent lane(s) is longer than 400 feet, an additional lane use arrow should be used at the mid-point of the right turn lane (see Figure 320).*

08 *If an edge line is used upstream from the right turn lane taper and a curb is not present along the edge of the roadway, an edge line should be used along the right turn lane taper and full-width right turn lane.*

09 *If the entrance to the right turn lane is located on a horizontal curve or crest vertical curve where a bicycle lane is not present, a white dotted line (WD) should be used across the taper section (see Figure 320).*

10 A white dotted line (WD) may be used across the taper section (see Figure 320) if a bicycle lane is not present.

Required Approvals

See the Traffic Manual for approvals related to right turn lanes.

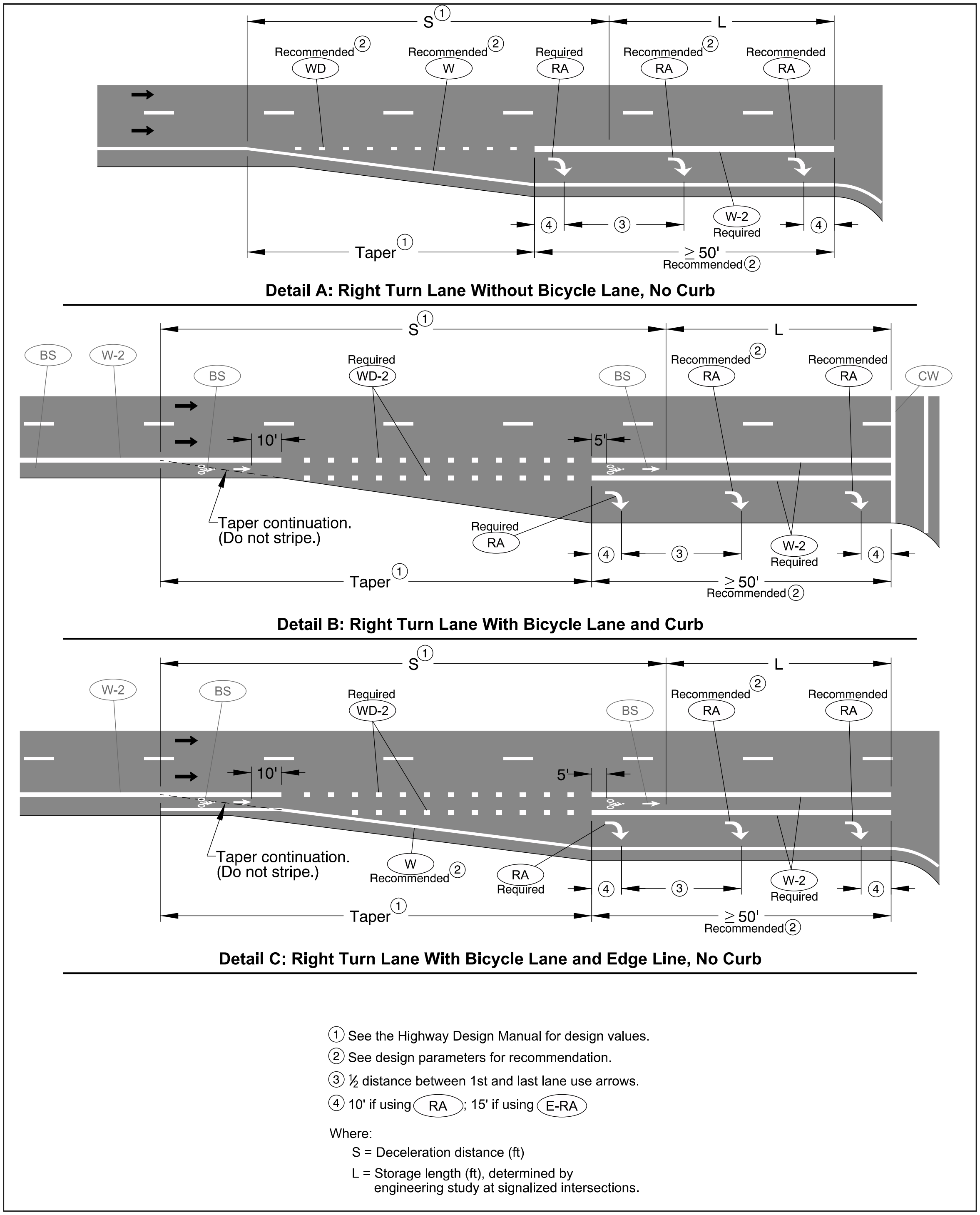
A roadway design exception is required for a storage length less than 50’ at unsignalized intersections. Region traffic engineer approval will not be required for this recommended design parameter because it will be documented through the roadway design exception.

Design Issues

Depending on the configuration and location of an uncontrolled crosswalk a stop bar may be recommended for use. See Section 150 and Section 430 when there is an uncontrolled marked crosswalk near a dedicated right turn lane.

Figures & Tables

Figure 320: Added Right Turn Lane Layouts



Support

Right turn lane layouts are taken from the ODOT Highway Design Manual (*1*). See the Highway Design Manual for more information on siting, layout, and dimensions used for right turn lanes. The ODOT Analysis Procedures Manual (APM) (*2*) contains information on estimating the storage length “L” shown in Figure 320.

Using a white dotted (WD) line across the right turn lane development taper (Detail A in Figure 320) can help keep road users properly aligned in their travel lane if the opening for the turn lane is at a horizontal curve or vertical crest curve. This can help reduce the likelihood of a road user following the edge line, drifting into the turn lane, and then making a sudden correction to get back into the through lane.

In long right turn lanes, an additional arrow at the mid-point of the wide solid white line (W-2) provides confirmation to road users of the function of the lane. While there is no research specifically investigating this practice, it is common in other states (*3*). In Oregon, 400 feet of wide solid white line (W-2) has been the point at which an additional arrow is used. This threshold was developed primarily for left turn lanes. For uniformity, this threshold is also applied to right turn lanes. Based on field observations, 400 feet and greater has been a reasonable definition of a “long” right turn lane.

Cross References

Key References

1. Oregon Department of Transportation. *Highway Design Manual*. Oregon Department of Transportation, Salem, Oregon, 2012.
2. Oregon Department of Transportation. *Analysis Procedures Manual*, 2nd ed. Oregon Department of Transportation, Salem, Oregon, 2016. http://www.oregon.gov/ODOT/Planning/Pages/APM.aspx.

3. Friedman, B. E. NCHRP Synthesis 356: Pavement Markings - Design and Typical Layout Details. Washington, D.C., ISBN 0-309-09763-0, 2006. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_356.pdf.

Channelized Right-Turn Lanes Section 321

Introduction

A channelized right-turn lane is a lane for the exclusive use of right turning vehicles that uses a channelizing island (see Section 270).

Design Parameters

01 **At signal-controlled channelized right-turn lanes, a stop bar shall be used to indicate the point behind which vehicles are required to stop according to Section 150.**

02 *At stop-controlled channelized right-turn lanes, a stop bar should be used to indicate the point behind which vehicles are required to stop (see Section 150).*

03 At yield-controlled channelized right-turn lanes, a yield line may be used to indicate the point behind which vehicles are required to yield (see Section 151).

04 **A traversable channelizing island used to form a channelized right-turn lane shall be marked according to Section 260.**

05 **A non-traversable channelizing island used to form a channelized right-turn lane shall be marked according to Section 281.**

06 **Except as provided in paragraph 07, if a crosswalk is marked across a channelized right-turn lane, the crosswalk shall be marked according to Section 430.**

07 *Staggered continental crosswalk markings should be used for marked crosswalks across signal-controlled channelized right turn lanes if an advance stop bar is used upstream of the marked crosswalk.*

Required Approvals

See the ODOT Traffic Manual (*1*) for approval related to Channelized Right-Turn Lanes.

Design Issues

See the ODOT Traffic Manual (*1*) for design and control options for channelized right-turn lanes.

Figures & Tables

Figure 321-A: Signal-Controlled Channelized Right-Turn Lane

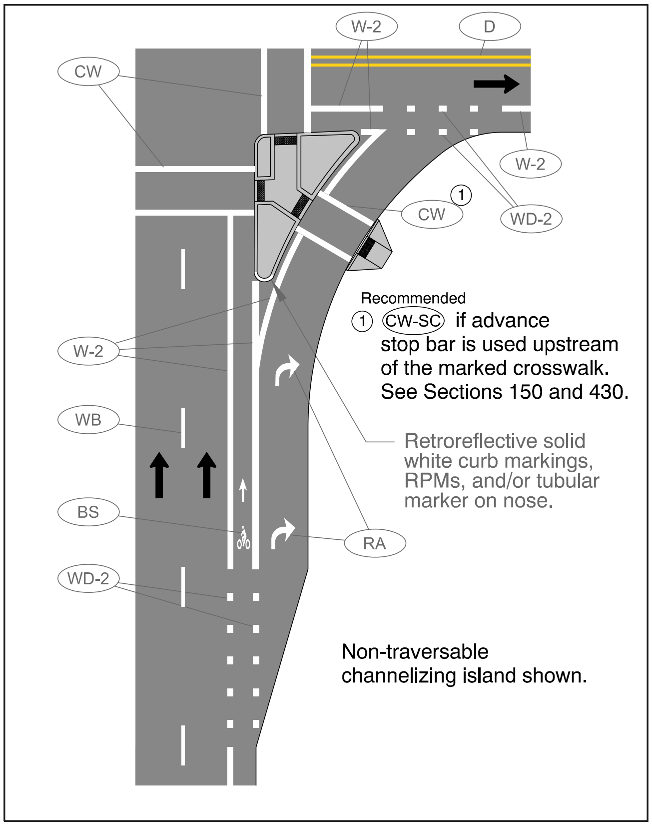


Figure 321-B: Typical Stop-Controlled Channelized Right-Turn Lane from Minor Roadway (Stop Controlled) to Major Roadway (Free-Flow)

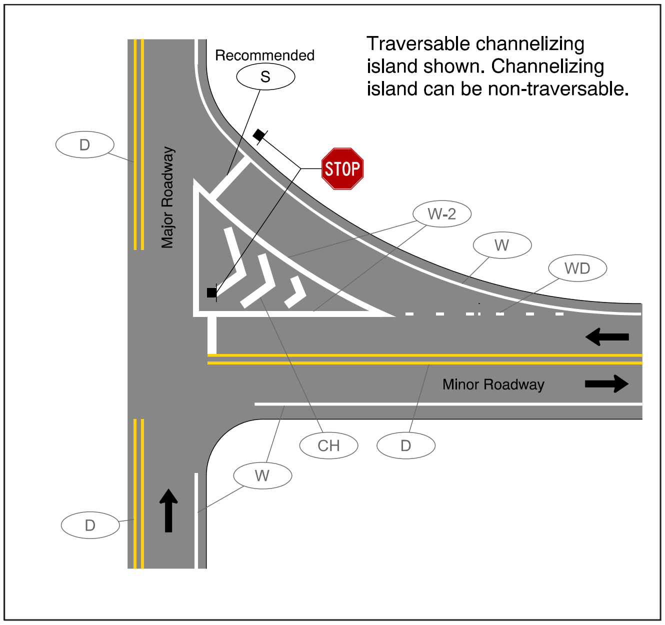
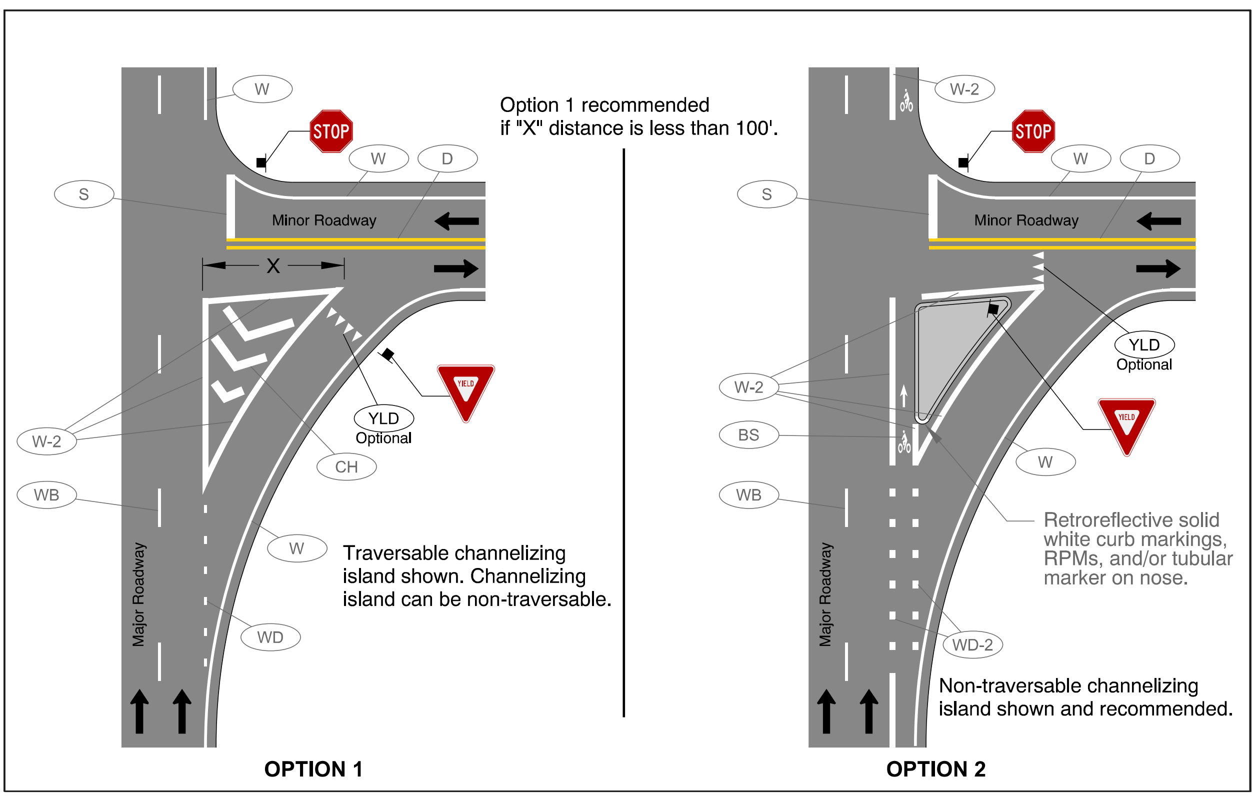


Figure 321-C: Typical Yield-Controlled Channelized Right-Turn Lane from Major Roadway (Free-Flow) to Minor Roadway (Stop Controlled)



Support

Channelized right-turn lanes are used in rural and urban contexts to improve operational efficiencies of intersections (*2*).

However, channelized right-turn lanes can be very challenging to cross for blind pedestrians. Inconsistent and high ambient noise levels from motor vehicles at the main intersection can make it difficult for a blind pedestrian to discern vehicles in the channelized right-turn lane from other traffic. Additionally, right-turning vehicle paths are curved, making it more difficult to judge approach directions. Geometric designs and treatments used to reduce vehicle speeds can help blind pedestrians make safe crossing judgments and reduce the severity of injury in the event of a collision (*3*).

Consistency in crosswalk placement can help improve expectations of all road users, especially visually impaired pedestrians. Crosswalks across unsignalized channelized right-turn lanes are located in the turn lane 25 to 40 feet before the point where motorists stop or yield for the cross road. This practice is relatively consistent across the country and offers some advantages to motorists, pedestrians, and roadway designers: 1) this reduces crossing distance compared to crosswalks parallel with the intersecting roadways; 2) this can enhance sight lines between approaching motorists and pedestrians; 3) this enhances sight lines for turning motorists as they wait for a gap in conflicting traffic; 4) this separates different driving tasks (looking for and yielding to pedestrians, and looking for gaps in conflicting traffic) in space and time; 5) this allows for storage of one vehicle downstream of the crosswalk; and 6) depending on turning radii and design speed this is likely where turning speed is the slowest (*2*) (*3*).

Crosswalks across signalized channelized right-turn lanes are located at or beyond the stop bar for consistency with other signalized approaches and to give pedestrians the safety benefits of a signalized crossing. Continental-style crosswalks are recommended where the marked crosswalk is beyond the stop bar to minimize confusion of where to stop for the signal (an advance stop bar is usually done to keep the signal heads visible from the stop bar). Other stop-controlled channelized right-turn lanes that intersect with the cross roadway at nearly a right-angle could also benefit from the crosswalk being located at the stop bar for consistency with other right-angle intersections (*2*).

Stop- or yield-controlled channelized right-turn lanes at signalized intersections are also a significant obstacle for pedestrians. Motorist yielding behavior to pedestrians at these types of channelized right-turn lanes can be very low (15-18 percent) and driver speeds can be higher during signal phases where no conflicting traffic is expected in the receiving lane (s). These crossings are also even more difficult for blind pedestrians to use sound to judge whether or not it is safe to cross. Signalization of the channelized right-turn lane could be needed where high traffic volumes and speeds result in risky and high-delay crossing environments (*3*).

At signalized intersections, raised islands at channelized right-turn lanes can also provide a refuge for people on bicycles in a bicycle lane stopped at the signal. The island provides physical separation from right-turning motorists and can be a foot rest while stopped.

Traversable (painted) channelizing islands could be preferable to raised channelizing islands in some circumstances, including: 1) intersections with high-speed approaches; 2) areas where there is no pedestrian traffic; 3) areas where there is no illumination; 4) areas where supports for signals, signs, or luminaires are not needed; and 5) areas requiring significant snow plowing. The AASHTO Green Book provides additional information about the design of channelized right-turn lanes and channelizing islands (*4*). Other information about channelization using markings is available in Section 270.

Cross References

Colors .... Section 110
Lane Lines .... Section 220
Edge Lines .... Section 230
Bicycle Lanes .... Section 410

Key References

1. Oregon Department of Transportation. Traffic Manual, 2016 Edition. January 2016. http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Traffic-Manual-v2016.pdf. Accessed July 3, 2017.
2. Potts, I. B., D. W. Harwood, K. M. Bauer, D. K. Gilmore, J. M. Hutton, D. J. Torbic, J. F. Ringert, A. Daleiden, and J. M. Barlow. NCHRP Web-Only Document 208: Design Guidance for Channelized Right-Turn Lanes. Transportation Research Board of the National Academies, Washington, D.C., 2011. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w208.pdf.
3. Schroeder, B., R. Hughes, N. Rouphail, C. Cunningham, K. Salamati, R. Long, D. Guth, R. W. Emerson, D. Kim, J. Barlow, B. L. Bentzen, L. Rodegerdts, and E. Myers. NCHRP Report 674: Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities. Transportation Research Board of the National Academies, Washington, D.C., ISBN 978-0-309-15530-4, 2011. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_674.pdf.
4. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*, 6th ed. Washington, D.C., 2011.

At-Grade Acceleration Lanes Section 322

Introduction

An at-grade acceleration lane is an added lane for vehicles turning from a side street at an at-grade intersection that lets the turning vehicle accelerate from the turning speed to highway speed, typically on rural limited access highways.

Design Parameters

01 **An at-grade acceleration lane shall include:**

- **A wide white solid line (W-2) separating the acceleration lane from adjacent travel lanes traveling in the same general direction. The wide white solid line shall start at the beginning of the acceleration lane and extend to one-quarter the distance to the end of the taper (see Figures 322-A and 322-B).**
- **A white dotted lane line (DLL) from the end of the wide white line (W-2) to a distance equal to one-half the distance between the beginning of the acceleration lane and the end of the taper (see Figures 322-A and 322-B).**

02 **If an at-grade right turn acceleration lane is on a two-lane undivided highway,**

- **One-direction no-passing zone markings shall be used in the direction of the acceleration lane prior to the intersection a minimum length "A" shown in Figure 322-B.**
- **Double no pass markings (D) shall be used from the intersection to the end of the taper (see Figure 322-B).**
- **One-direction no-passing markings shall be used starting at the end of the taper and continuing to a distance shown in Figure 322-B.**

03 *Two lane reduction arrows should be used in the acceleration lane (see Figure 322-A and 322-B).*

04 *An edge line should be used at an at-grade right turn acceleration lane from the beginning of the acceleration lane to beyond the end of the taper (see Figure 322-B).*

05 *Transverse median bars should be used in the runout area of at-grade left turn acceleration lanes (see Figure 322-A).*

06 If the length of the white dotted lane line (DLL) is greater than 400 feet, an additional lane reduction arrow may be used between the two recommended lane reduction arrows.

Required Approvals

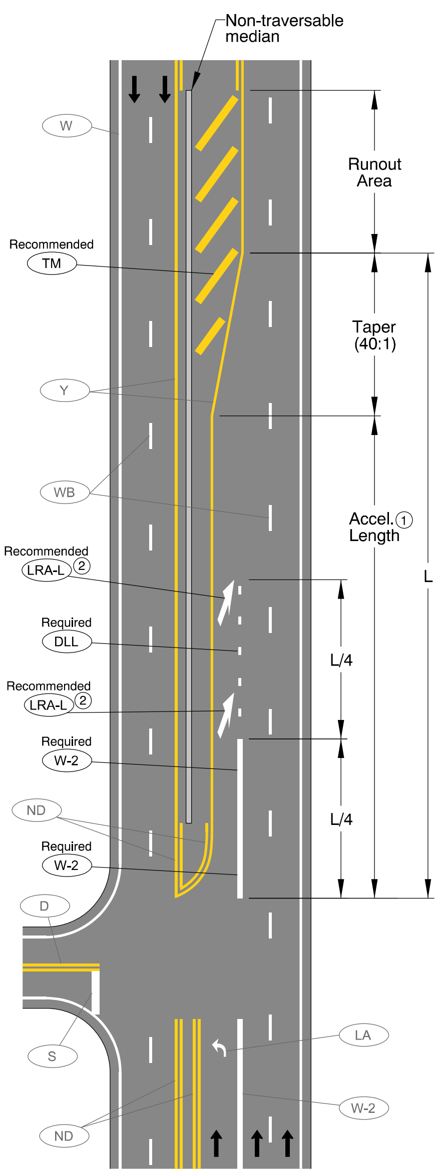
An engineering study, roadway design exception, and state traffic-roadway engineer approval is required for acceleration lanes from at-grade intersections.

Design Issues

See the ODOT Highway Design Manual (*1*) and ODOT Traffic Manual (*2*) for design issues and considerations related to at-grade acceleration lanes.

Figures & Tables

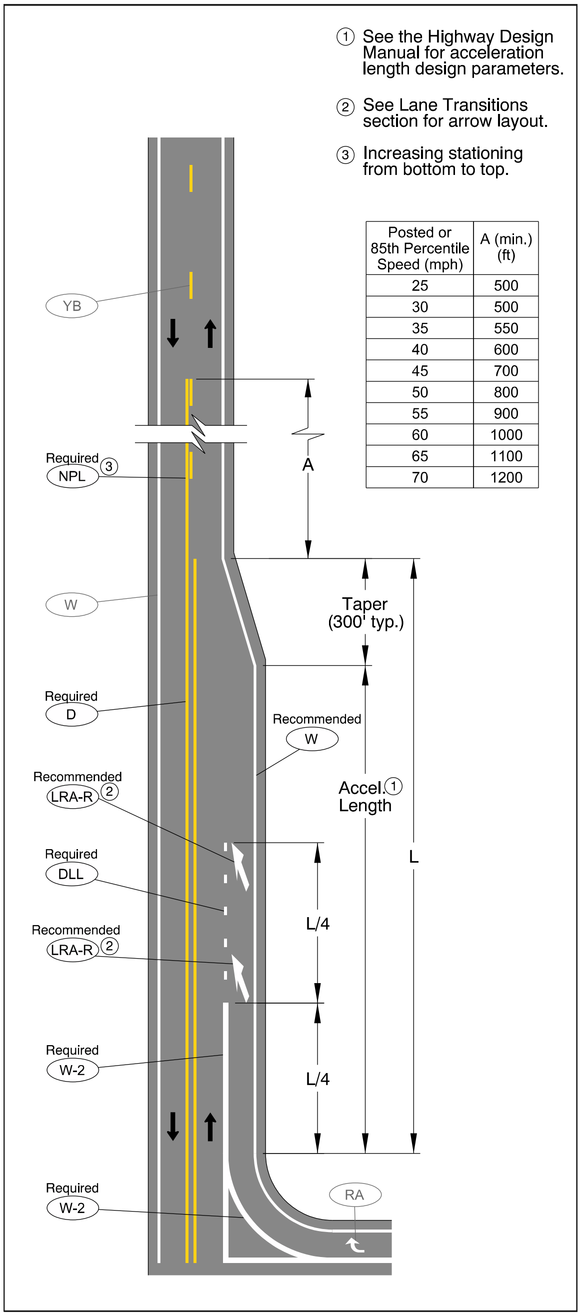
Figure 322-A: Typical Median Acceleration Lane



① See the Highway Design Manual for acceleration length design parameters.

② See Lane Transitions section for arrow layout.

Figure 322-B: Typical At-Grade Right Turn Acceleration Lane



Posted or 85th Percentile Speed (mph)	A (min.) (ft)
25	500
30	500
35	550
40	600
45	700
50	800
55	900
60	1000
65	1100
70	1200

Support

The pavement marking layout for an at-grade acceleration lane is consistent with Section 3B.04 and 3B.20 in the 2009 MUTCD (3).

As is used at a grade-separated parallel acceleration lane, a lane line separates the acceleration lane from through lanes for half the length of the acceleration lane (including the taper). A wide solid line (W-2) is used at the beginning of the acceleration lane to encourage turning drivers to accelerate before merging with through traffic, minimizing speed differential at the merge point. A normal width dotted lane line (DLL) is used for the remainder of the lane line length to communicate that the acceleration lane does not continue ahead, as is used at a grade-separated parallel acceleration lane.

Lane reduction arrows are added to the acceleration lane to emphasize to turning drivers that they must merge and that the acceleration lane is ending. Transverse median bars are used at left turn at-grade acceleration lanes to further emphasize the acceleration lane ends. This is particularly useful if a left turn lane or two-way left turn lane is located downstream from the acceleration lane.

An edge line is used to show where the acceleration lane ends. This is consistent with how edge lines are used at lane reduction transitions and grade-separated acceleration lanes.

Cross References

Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Transverse Markings .... Section 125
Lane Use Arrows .... Section 160
Center Lines .... Section 210
No-Passing Zone Markings .... Section 211
Lane Lines .... Section 220
Edge Lines .... Section 230
Lane Reduction Transitions .... Section 250
Traversable Medians .... Section 260
Channelizing Lines and Traversable Channelizing Islands .... Section 270
Non-Traversable Medians & Channelizing Islands .... Section 281
Left Turn Lanes .... Section 310
Added Right Turn Lanes .... Section 320
Channelized Right-Turn Lanes .... Section 321

Key References

1. Oregon Department of Transportation. *Highway Design Manual*. Oregon Department of Transportation, Salem, Oregon, 2012.
2. Oregon Department of Transportation. Traffic Manual, 2016 Edition. January 2016. http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Traffic-Manual-v2016.pdf. Accessed July 3, 2017.
3. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.

Dropped Lanes and Auxiliary Lanes on Conventional Roads Section 330

Introduction

A dropped lane is a through lane that becomes a mandatory turn lane on a conventional road. Reductions in the number of thru lanes that do not involve a mandatory turn or exit are not considered dropped lanes.

Design Parameters

01 **A wide dotted lane line (DLL-2) shall be used to separate a through lane that continues beyond an intersection from an adjacent dropped lane or an auxiliary lane that is 1 mile or less long.**

02 *The wide dotted lane line (DLL-2) should begin a distance in advance of the intersection that is determined by engineering judgement as suitable to enable drivers who do not desire to make the mandatory turn to move out of the lane being dropped prior to reaching the queue of vehicles that are waiting to make the turn. The wide dotted lane line (DLL-2) should begin no closer to the intersection than the most upstream regulatory or warning sign associated with the lane drop.*

03 In locations where intersections are closely spaced, the wide dotted lane line (DLL-2) may begin in advance of intersections where the dropped lane or auxiliary lane is not required to turn.

04 **A dropped turn lane shall include:**

- **A wide white line (W-2) separating the dropped turn lane from adjacent lanes traveling in the same general direction, and**
- **A lane use arrow at the beginning of the dropped turn lane and one at the intersection (Figure 330).**

05 **Where the wide white line (W-2) separating the dropped turn lane from adjacent travel lane(s) is longer than 400 feet, an additional lane use arrow shall be used at the mid-point of the dropped turn lane.**

06 *ONLY word markings should be used half-way between lane use arrows in the dropped turn lane (Figure 330).*

07 **A through bicycle lane shall not be positioned to the right of a right turn lane or to the left of a left turn lane unless conflicting movements are controlled by a traffic control signal.**

08 *If a through bicycle lane is adjacent to a dropped right turn lane, bicycle lane markings should stop at least 100 feet before the beginning of the dropped right turn lane (Figure 330). A shared lane marking and wide white dotted line extensions (WD-2) should be used in the transition area according to Figure 330. Through bicycle lane markings should resume to the left of the dropped right turn lane.*

09 If a bicycle lane is adjacent to a dropped right turn lane, a bicycle symbol may be used in the bicycle lane before the bicycle lane ends according to Figure 330.

10 *At signalized intersections, the storage length "L" shown in Figure 330 should be determined by an engineering study.*

11 *At unsignalized intersections, the wide white line (W-2) used to separate the dropped turn lane from an adjacent lane(s) should be at least 100 feet long.*

Required Approvals

No approval is required to install the recommended shared lane marking shown in Figure 330 Detail B.

Design Issues

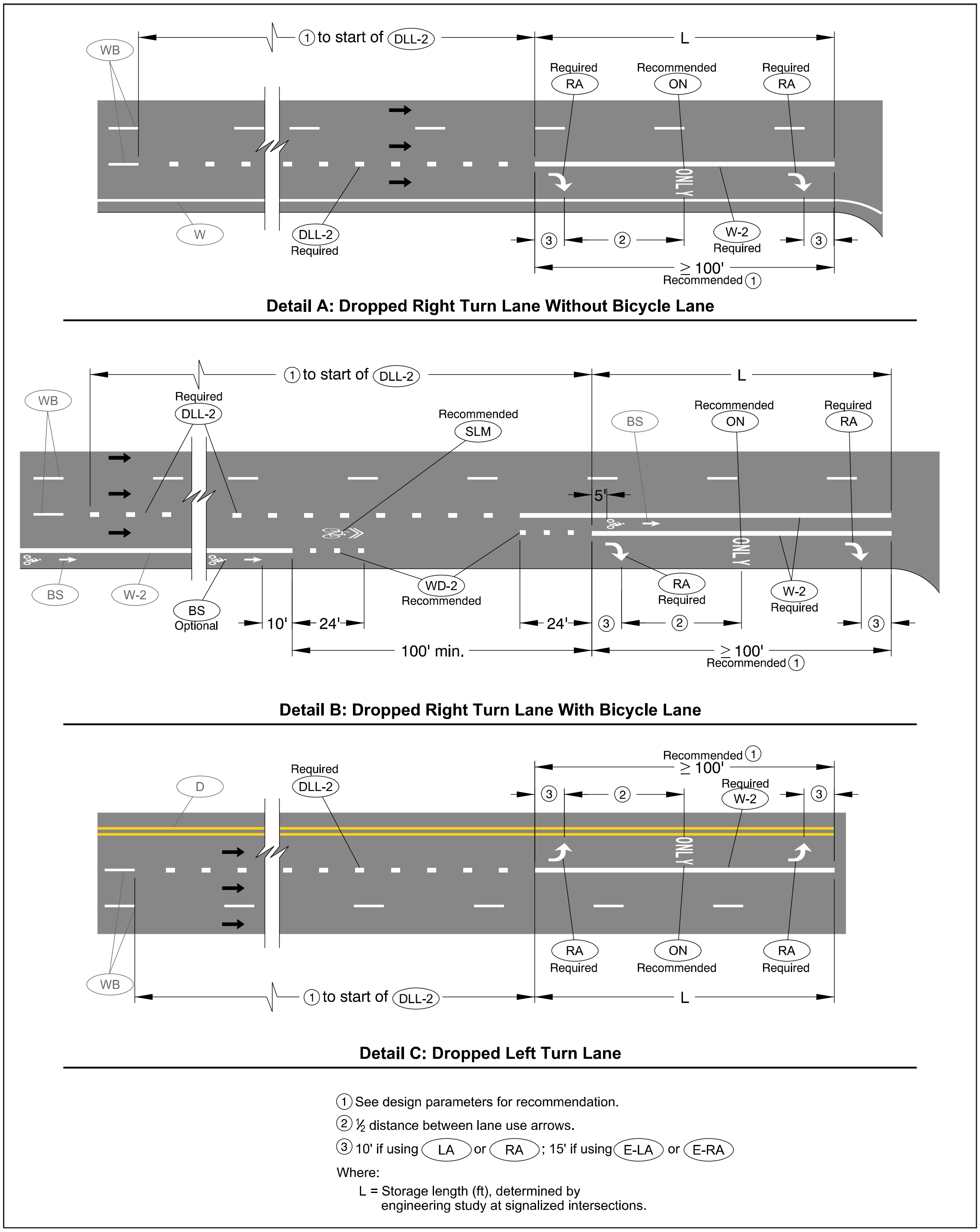
A bike lane is not striped diagonally across the weave area because this incorrectly suggests that people on bicycles do not need to yield to motorists in the transition area (*1*), limits where people on bicycles can choose a gap to move to the left, and can give the perception that the dropped lane is ending in a taper.

The roadway that ends at a T-intersection is not typically considered to have dropped lanes on its approach.

Depending on the configuration and location of an uncontrolled crosswalk a stop bar may be recommended for use. See Section 150 and Section 430 when there is an uncontrolled marked crosswalk near a dedicated turn lane.

Figures & Tables

Figure 330: Typical Dropped Turn Lane Layouts



Support

Using a wide dotted lane line (DLL-2) in advance of a dropped lane improves driver understanding that he or she must exit soon but still has time to change lanes. The studies related to using a dotted lane line in advance of a dropped lane (*2*) (*3*) focused primarily on freeway exit only lanes, but the principle applies to conventional roads too – a lane is going to take the road user away from the current road. In freeway applications, researchers observed an upstream shift in the location where drivers made lane changes in advance of the dropped lanes, fewer drivers changing lanes near gore points, and fewer drivers making erratic maneuvers at gore areas (*3*). These changes in lane line patterns, along with advance signing and lane use arrows, helps communicate the upcoming change and needed actions.

In detail B of Figure 330, the short dotted line extensions through the bicycle transition area are consistent with layouts recommended in the AASHTO Guide for the Development of Bicycle Facilities (*1*) and the NACTO Urban Bikeway Design Guide (*4*). The shared lane marking at the beginning of the transition area helps warn motorists that people on bicycles may be in their lane as they weave to the left, and may encourage people on bicycles to move to the left to better align themselves with the bicycle lane positioned to the left of the dropped right turn lane.

This bicycle transition movement can be difficult and high stress, depending on traffic volumes, speed, and heavy vehicle composition. People on bicycles must find a gap in the traffic stream and merge left to enter the re-positioned bicycle lane. Depending on the demand for the bicycle route, a lower stress alternative is to separate right turning motor vehicles and thru bicycles with separate signal phasing. In this case the bicycle lane is kept to the right of the right turn lane up to the signal.

The ODOT Analysis Procedures Manual (APM) (*5*) contains information on estimating the storage length “L” shown in Figure 330.

In long right turn lanes, an additional arrow at the mid-point of the wide solid white line (W-2) provides confirmation to road users of the function of the lane. While there is no research specifically investigating this practice, it is common in other states (*6*). In Oregon, 400 feet of wide solid white line (W-2) has been the point at which an additional arrow is used. This threshold was developed primarily for left turn lanes. For uniformity, this threshold is also applied to right turn lanes. Based on field observations, 400 feet and greater has been a reasonable definition of a “long” right turn lane.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Transverse Markings .... Section 125
Stop Bars .... Section 150
Lane Use Arrows .... Section 160

Lane Lines .... Section 220
Edge Lines .... Section 230
Left Turn Lanes .... Section 310
Added Right Turn Lanes .... Section 320
Channelized Right-Turn Lanes .... Section 321
Roundabouts .... Section 350
Bicycle Lanes .... Section 410
Shared Lane Markings .... Section 420
Marked Crosswalks .... Section 430

Key References

1. American Association of State Highway and Transportation Officials. *Guide for the Development of Bicycle Facilities*, 4th ed. Washington, D.C., 2012.
2. Fitzpatrick, K., M. Ogden, and T. Lienau. Motorists' Comprehension of Exit Lane Drop Signs and Markings. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1464, 1994, pp. 51-59. http://onlinepubs.trb.org/Onlinepubs/trr/1994/1464/1464-007.pdf.
3. Fitzpatrick, K., M. Lance, and T. Lienau. Effects of Pavement Markings on Driver Behavior at Freeway Lane Drop Exits. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1495, 1995, pp. 17-27. http://onlinepubs.trb.org/Onlinepubs/trr/1995/1495/1495-003.pdf.
4. National Association of City Transportation Officials. *NACTO Urban Bikeway Design Guide*, 2nd ed. Island Press, New York, New York, 2014. http://nacto.org/cities-for-cycling/design-guide/.
5. Oregon Department of Transportation. *Analysis Procedures Manual*, 2nd ed. Oregon Department of Transportation, Salem, Oregon, 2016. http://www.oregon.gov/ODOT/Planning/Pages/APM.aspx.
6. Friedman, B. E. NCHRP Synthesis 356: Pavement Markings - Design and Typical Layout Details. Washington, D.C., ISBN 0-309-09763-0, 2006. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_356.pdf.

Line Extensions Through Intersections Section 340

Introduction

Dotted lines provide guidance through breaks and are normally used in situations where the intended path may be unclear to road users, such as at skewed intersections and intersections with multiple turn lanes.

Design Parameters

01 **When used, dotted lines shall be at least the same width and color of the line being extended.**

02 *Dotted line extensions should be used to extend longitudinal lines through an intersection:*

- *On a horizontal curve on the major roadway where the longitudinal line's gap length divided by the curve radius is greater than 0.100 (see Figure 340-C).*
- *Where an offset or skew shifts a lane through the intersection at a taper rate or offset greater than the values shown in Table 340-1 (see Figure 340-A). The line that would be crossed if the road user continued straight should be extended.*
- *Where a vertical curve obscures longitudinal lines on the far side of the intersection.*

03 **Wide dotted lines (WD-2) shall be used as lane line extensions for multiple turn lanes at an intersection (Figure 340-B). Where greater restriction is needed, a wide solid white line (W-2) should be used.**

04 A wide dotted line (WD-2) or a wide solid line (W-2) may extend a lane line to direct turning traffic into a different receiving lane than the nearest receiving lane based on engineering judgement (Figure 340-B).

05 A normal width white dotted line (WD) may be used to extend a wide solid white line (W-2) through an intersection.

06 **Where a double line is extended through an intersection, a single, normal width dotted line shall be used (Figure 340-C).**

07 Dotted lines may be used:

- As lane line extensions through an intersection based on engineering judgement.
- To extend edge lines at a wide, complex intersection or at an intersection on a horizontal curve.

08 **Solid lines shall not be used to extend edge lines into or through intersections or major driveways, except as provided in Section 230.**

09 **When a signalized intersection has a protected right turn movement with a permissive or protected/permissive opposing left turn movement sharing the same departure direction, except where raised channelization clearly indicates which departure lane to use, lane line extensions shall be used to clearly indicate which departure lane to use (Figure 340-D).**

10 A wide solid white line (W-2) separating parallel departure lanes may be used to further define the proper departure lane to use (Figure 340-D).

Design Issues

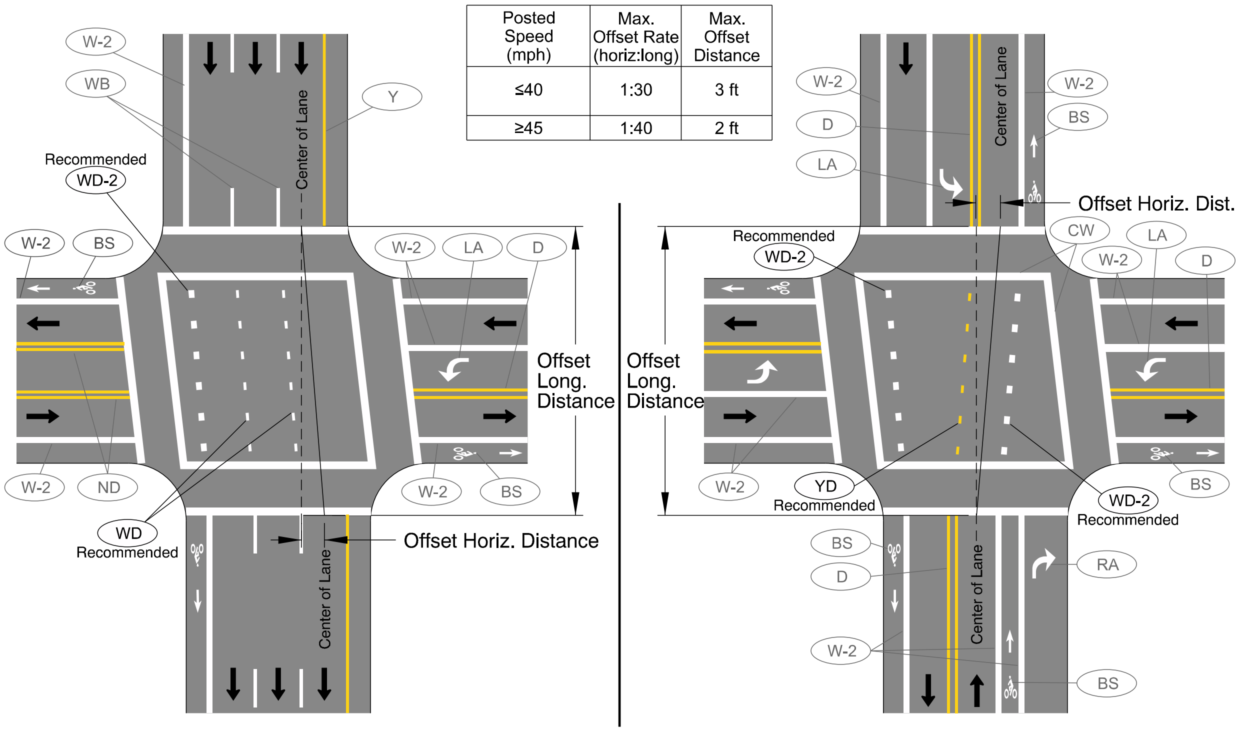
The values in Table 340-1 are set to be more conservative than the maximum offsets allowed in roadway design by the ODOT Highway Design Manual (*1*). The Highway Design Manual does not allow lane offsets through intersections where the posted speed is over 45 mph. Table 340-1 includes guidance for these high speed intersections where the existing lane alignments are offset and where it is not practical to correct the existing offset.

Figures & Tables

Figure 340-A: Typical Line Extensions through Offset Intersections

Table 340-1. Maximum Offset Rates and Offset Distances Across an Intersection without Line Extensions

Posted Speed (mph)	Max. Offset Rate (horiz:long)	Max. Offset Distance
≤40	1:30	3 ft
≥45	1:40	2 ft



Detail A - Offset Intersection, 1-Way Road **Detail B - Offset Intersection, 2-Way Road**

Figure 340-B: Typical Line Extensions for Multiple Turn Lanes

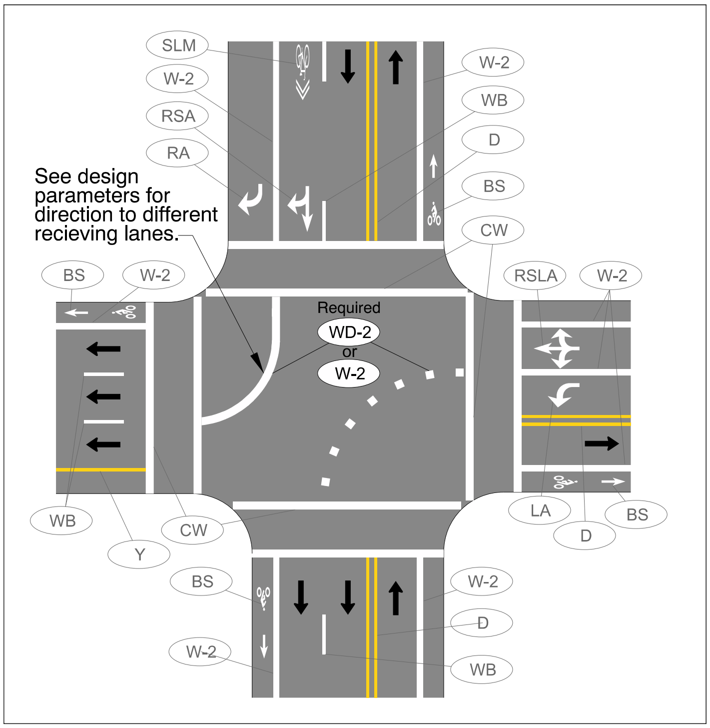


Figure 340-C: Typical Line Extensions for an Intersection on a Horizontal Curve

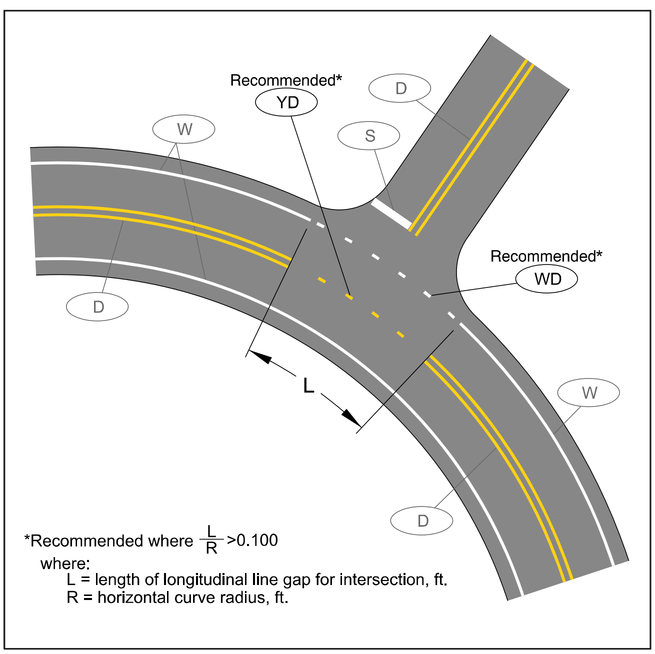
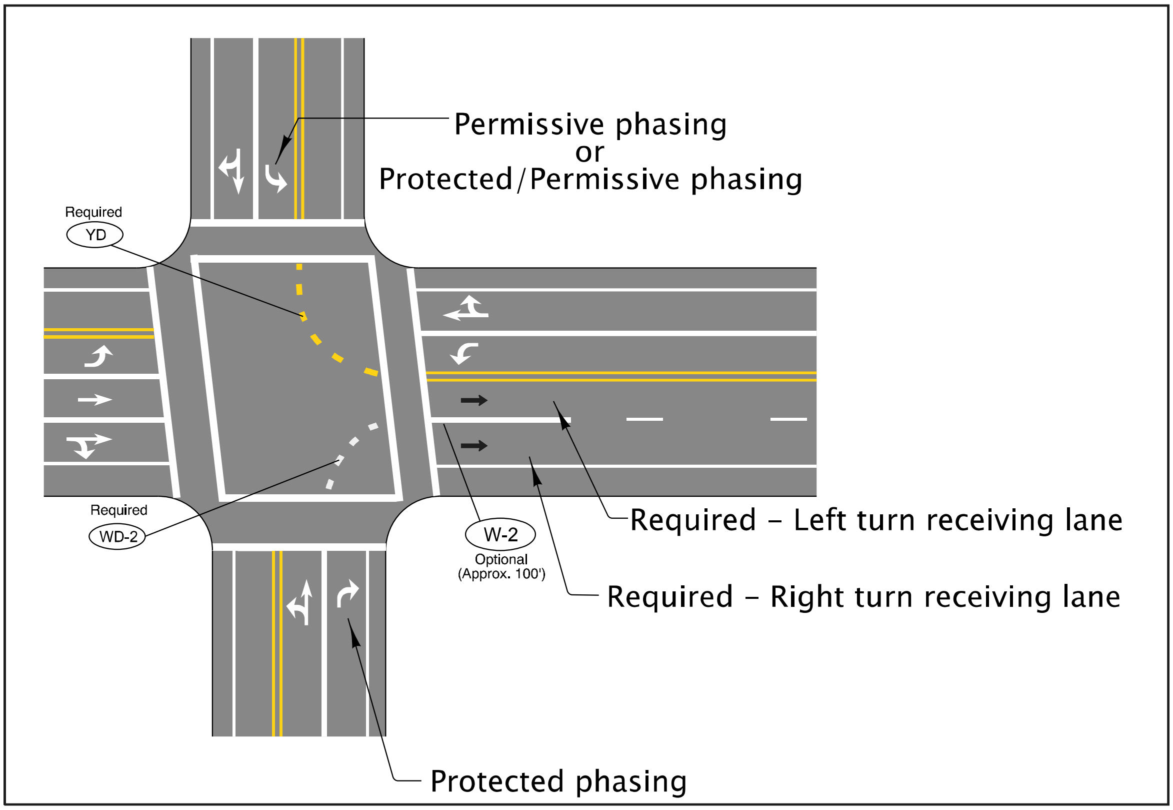


Figure 340-D: Typical Lane Line Extensions for Right Turn Overlap Phasing



Support

To the extent possible, lane alignments need to remain straight and constant through an intersection (*1*). In many cases, small changes in lane alignment upstream and downstream of the intersection can be achieved with longitudinal lines to keep lanes aligned through the intersection. This is especially important at signalized intersections; signal heads are typically centered over receiving lanes on the far side of the intersection (*2*).

However, when site constraints make it infeasible to keep lane alignments consistent (e.g.: downtown grid), lanes might need to be shifted through the intersection. In these locations, extending lane lines and/or the centerline through the intersection can help guide road users through the shift and into the appropriate receiving lane.

Lane lines and/or centerline extensions are not typically used through minor shifts, but there is a practical limit where providing an extension is recommended. There is little literature available on when a line needs to be extended for offset lanes; the values in Table 340-1 are set to be more conservative than the maximum offsets allowed in roadway design by the ODOT Highway Design Manual (*1*).

Similar extensions might be needed at intersections located within a horizontal curve. During curve entry and negotiation, drivers spend most of their time looking at a tangent point ahead on the inside of the curve (*3*); the center line or edge line is an important reference point for this task. Long centerline and/or edge line breaks for an intersection, relative to the curve radius, can momentarily remove this lane-positioning guidance.

There is little literature available on when a line needs to be extended for a horizontal curve. Human factors studies estimate road users need to see the path ahead a minimum of 2 to 3 seconds to maintain lane position and 3 to 5 seconds to feel comfortable with upcoming changes in the road path. Vehicle control demands also increase as curve radius decreases (*3*). To maintain this minimum preview time and account for greater driving demands in tighter curves, the design parameters recommend a line extension for intersections where the longitudinal line gap length divided by the curve radius is greater than 0.100 (greater than about 5.7° of curve arc). Without sufficient published research on this subject, this value is based on past practice on state highways around the state and ensures sufficient preview time across a wide range of curve radii.

Extensions through intersections located on crest vertical curves might be needed as well, though this is not common. Road users need to be able to see longitudinal lines on the far side of the intersection to maintain or adjust their path to be in line with their receiving lane. If the crest vertical curve hides the far-side lines, an extension can provide continuous guidance to road users through the intersection and into their receiving lane.

Turning vehicles are ordinarily required to turn into the nearest receiving lane at an intersection (ORS 811.355 and ORS 811.340). At some intersections with multiple turn lanes it could be beneficial to direct turning traffic into a receiving lane other than the nearest receiving lane. This is typically based on origin-destination patterns, traffic volumes, and/or design vehicle turning radii. For example, directing turning traffic into a far receiving lane could keep road users aligned with a major destination route that will minimize the number of lane changes downstream of the intersection. In this case, drivers are following the direction of a longitudinal pavement marking, which is traffic control device (ORS 801.540 and ORS 811.265).

It is important to work with the signal designer to check if the phasing requires lane line extensions. More information on signal phasing and requirements can be found in the Traffic Signal Design Manual (*2*). The wide solid white line (W-2) used in figure 340-D is used when it is desirable to discourage lane changing in the immediate vicinity of the intersection.

Cross References

Left Turn Lanes .... Section 310
Roundabouts .... Section 350
Interchange Ramps: Ramp Terminals .... Section 361
Bicycle Lanes .... Section 410
Bicycle Lane Buffers .... Section 412

Key References

1. Oregon Department of Transportation. *Highway Design Manual*. Oregon Department of Transportation, Salem, Oregon, 2012.
2. Oregon Department of Transportation. *Traffic Signal Design Manual*, 2016 ed. Oregon Department of Transportation, Salem, OR, 2016. http://www.oregon.gov/ODOT/Engineering/Pages/Signal-Design-Manual.aspx.
3. Campbell, J. L., M. G. Lichty, J. L. Brown, C. M. Richard, J. S. Graving, J. Graham, M. O'Laughlin, D. Torbic, and D. Harwood. NCHRP Report 600: Human Factors Guidelines for Road Systems. 2012. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_600Second.pdf. Accessed October 23, 2012.
4. Neuman, T. R., R. Pfefer, K. L. Slack, K. K. Hardy, D. W. Harwood, I. B. Potts, D. J. Torbic, and E. R.K. Rabbani. NCHRP Report 500 Volume 5: A Guide for Addressing Unsignalized Intersection Collisions. Transportation Research Board of the National Academies, Washington, D.C., ISBN 0-309-08760-0, 2003. http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_500v5.pdf.

Roundabouts Section 350

Introduction

A roundabout is a circular intersection with yield control at the entering lanes.

Design Parameters

01 **Except as provided in this section, roundabout splitter islands shall be delineated according to Section 281 (Non-Traversable Medians & Channelizing Islands).**

02 **Multi-lane approaches to roundabouts shall have lane lines. A through lane on a roadway that becomes a dropped lane (mandatory turn lane) at a roundabout shall be marked according to Section 330. An added left turn lane at a roundabout shall be marked according to Section 310. An added right turn lane at a roundabout shall be marked according to Section 320.**

03 *Lane lines on roundabout approaches and departures should be wide solid white lines (W-2). Except for dropped lanes and added turn lanes, the wide solid white line (W-2) should begin a sufficient distance to minimize lane changes on the roundabout approach according to engineering judgement.*

04 *Multi-lane roundabouts should have wide lane lines within the circulatory roadway to channelize traffic to the appropriate exit lane.*

05 **Continuous concentric lane lines shall not be used within the circulatory roadway.**

06 *A wide white edge line (W-2) should be used on the outer (right) edge of the circulatory roadway along the splitter islands. The edge line should be extended across entering lanes with a wide white dotted line (WD-2).*

07 **Edge lines and edge line extensions shall not be placed across the exits from the circulatory roadway.**

08 A yellow edge line (Y) may be used around the inner (left) edge of the circular roadway and may be used to channelize traffic.

09 Lane-use arrows may be used on any approach to and within the circulatory roadway of a roundabout.

10 **Normal style lane use arrows shall be used on multi-lane approaches to roundabouts at the beginning of the wide solid white lane line (W-2) (see Figure 350-C).**

11 *Additional normal style lane use arrows should be used on multi-lane approaches to roundabouts in advance of the marked crosswalk (or yield line if there is no marked crosswalk). Standard or elongated lane use arrows should be used within the circulatory roadway of multi-lane roundabouts (see Figure 350-C).*

12 *A white yield line (YLD) should be used to indicate the point behind which vehicles are required to yield at the entrance to the roundabout.*

13 **Bicycle lanes shall not be provided on the circulatory roadway of a roundabout.**

14 *Bicycle lane markings should stop at least 165 feet before the yield line, or if no yield line is present, at least 165 feet before the edge of the circulatory roadway. A wide white dotted line (WD-2) should be used in the bicycle lane reduction area (see Figure 350-B).*

15 **Crosswalks shall not be marked to or from the central island of a roundabout.**

16 *If sidewalks or multi-use paths are provided at a roundabout, crosswalks should be marked across roundabout entrances and exits with staggered continental-style crosswalk markings. Crosswalks should be located 25 to 40 feet in advance of the yield line (or edge of the circulatory roadway if no yield line is present). Stop bars should not be used in advance of crosswalks that cross an approach to or departure from a roundabout.*

Figures & Tables

Figure 350-A: Typical Pavement Markings at a Single-Lane Roundabout

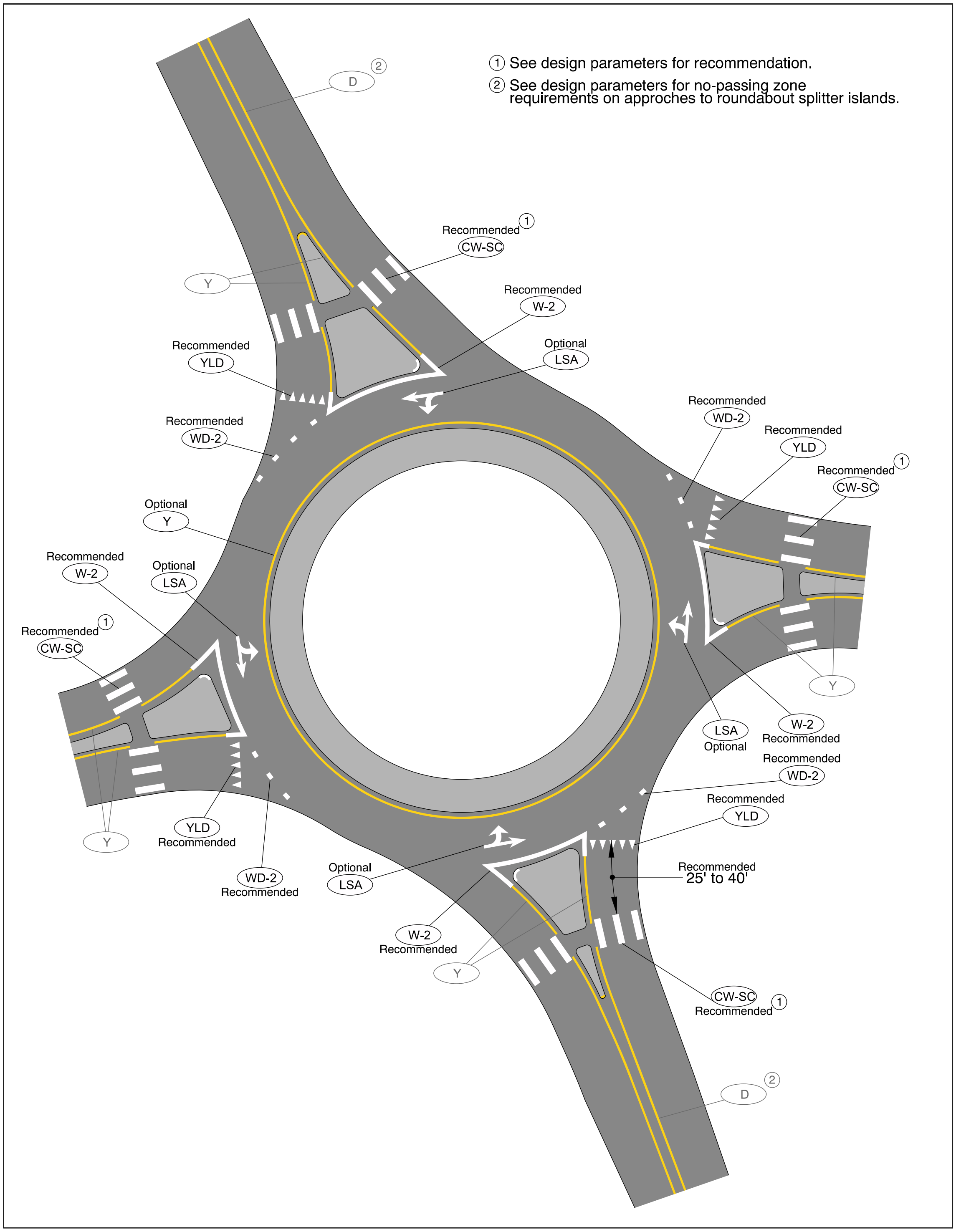


Figure 350-B: Typical Roundabout Approach with Bicycle Lane Curb Cut

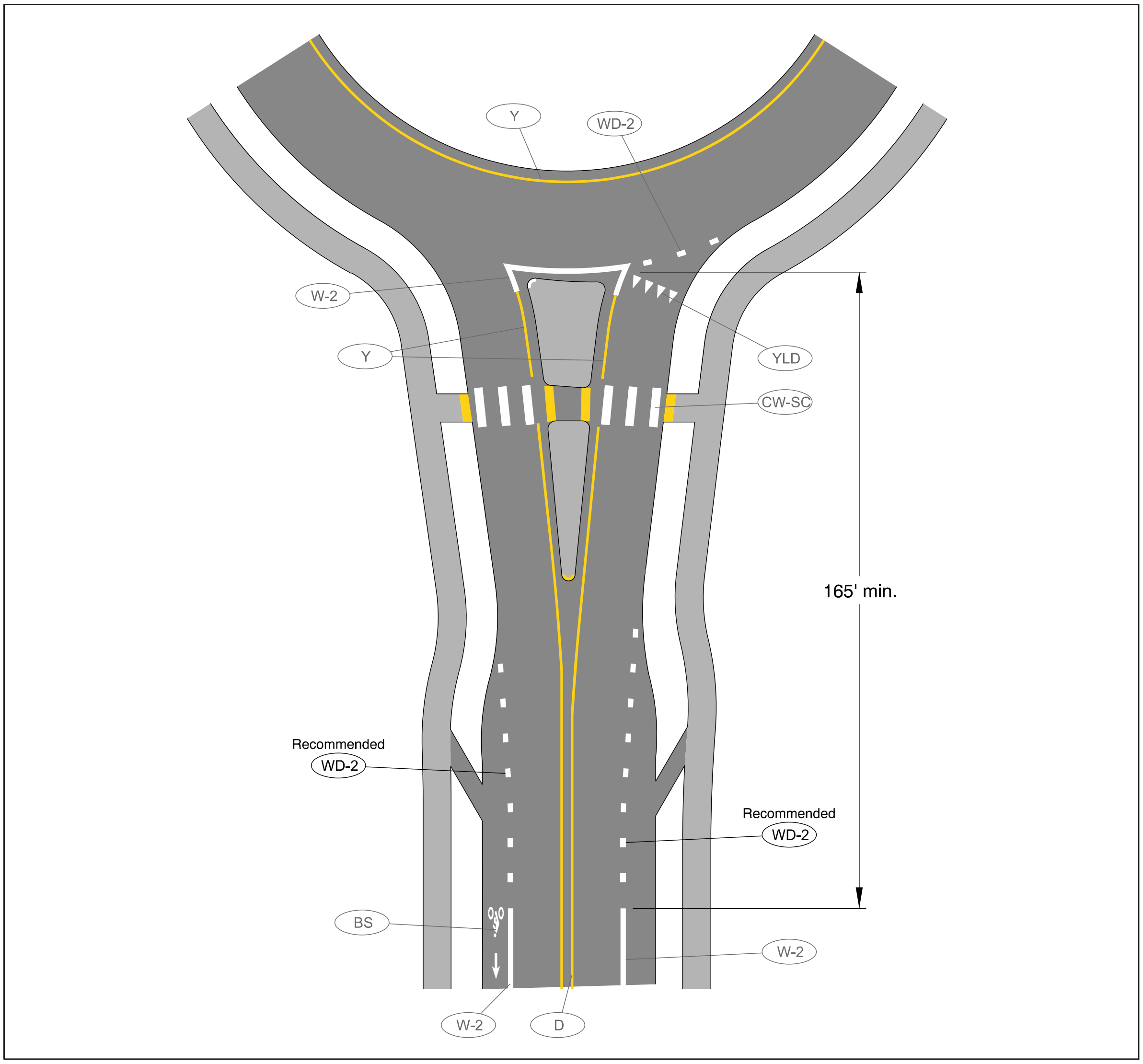
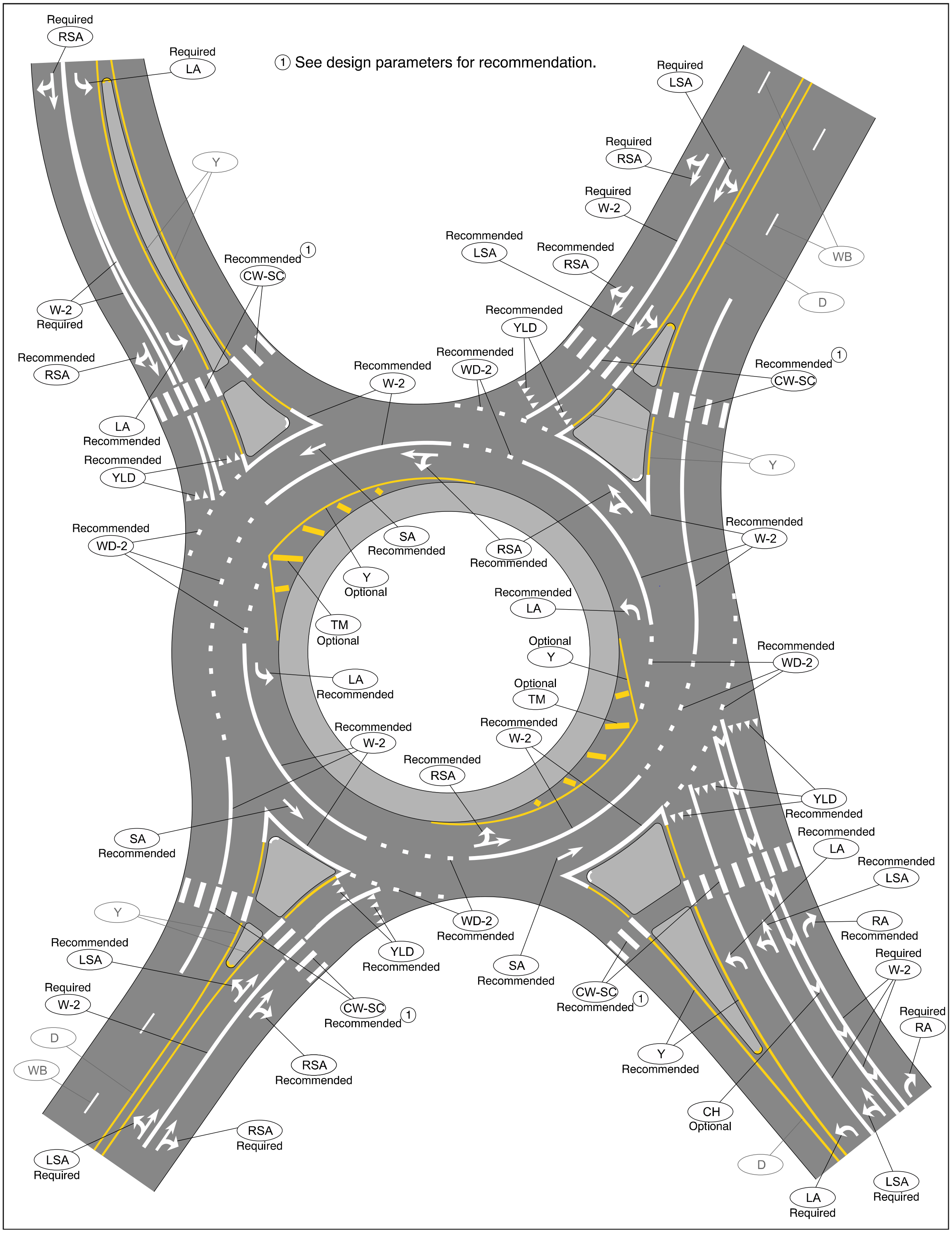


Figure 350-C: Typical Pavement Markings at a Multi-Lane Roundabout



Support

Pavement markings are an important component of safe operations at roundabouts. Along with geometric design and signing, pavement markings define lane use, yield points, exit points, and crosswalks. With the importance of pavement markings in roundabouts extra consideration should be given to the use of groove installed markings in locations where plowing is common, which can extend the life of the marking. Another this to consider in roundabouts with light colored pavements like new concrete, black borders around white and yellow markings can increase contrast and improve marking visibility

At multi-lane roundabouts, lane lines provide important direction for road users. On the approach to and in the roundabout, wide solid lane lines and dotted extensions help improve safety by reducing the possibility of sideswipe crashes caused by last-minute lane changes, discourages road users from cutting across lanes for a shorter path, and discourages lane changes before crosswalks to reduce the possibility of multiple-threat pedestrian crashes (*1*).

Crosswalks are marked at roundabouts with pedestrian facilities to eliminate any legal ambiguity on the location of the crosswalk (*1*). Current ORS language defining the location of an unmarked crosswalk at an intersection does not readily translate to a roundabout, so the crosswalk needs to be defined by marking it. Staggered continental-style markings are used at the crosswalk because that style is less likely to be confused with the entrance line or yield line of the roundabout (*1*) and because the approach to these crosswalks is uncontrolled and needs to be more visible (*2*).

Bicycle lane markings stop at 165 feet from the circulatory roadway or yield line in order to give people on bicycles enough time to find a gap to merge into the general travel lane or take the ramp to the sidewalk. The ODOT Highway Design Manual (*3*) sets the standard distance for the diagonal ramp to the sidewalk at 100 feet from the circulatory roadway or yield line, and the end of the bicycle lane 65 feet upstream from this point to provide decision time. A wide dotted line is extended in this bicycle transition area to give advance notice to road users that the bicycle lane is ending (*1*).

At multi-lane roundabouts, lane use arrows define lane functions on the approach to and in the roundabout. This helps road users choose a lane early and minimize last-minute lane changes that can cause sideswipe crashes (*1*). Arrows closest to the roundabout are positioned before the crosswalk to reinforce lane function before reaching the yield line (*1*). Circulatory roadway arrows are typically located at the beginning of the solid lane lines to communicate lane function as road users enter the lane.

Left turn lanes (either thru-left option or left turn only) at multi-lane roundabouts use left turn arrows or left-thru arrows (instead of a single thru arrow) because this leads to better road user comprehension of the lane function, and greater road user confidence that they picked the correct lane. This reduces the likelihood of a sideswipe crash at the exit point (*1*) (*5*). Lane use arrows on their own are not likely to reduce wrong-way entry to roundabouts; good geometric design is the best deterrent to wrong-way movements at roundabouts (*5*).

The edge line extensions across entry lanes define the yield point for entering vehicles and guides road users on the circulatory roadway through the roundabout. The 2009 MUTCD (*6*) specifies a wide dotted line for this extension. ODOT's standard cycle length for dotted lines is 8 feet, which provides sufficient guidance for road users on the circulatory roadway but may not provide enough line segments to clearly define the yield point for entering vehicles. NCHRP 672 (*1*) recommends shortening the dotted line gap to 2 to 3 feet to provide a more defined entry point (the lower limit allowed by the MUTCD for a dotted line gap). Instead of using a different dotted line pattern than the standard (2' line segment with 6' gap), a yield line is used in addition to the dotted line extension to clearly show where road users need to yield.

See additional roundabout layouts in Chapter 3C of the 2009 MUTCD (*6*).

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Transverse Markings .... Section 125
Yield Lines .... Section 151
Lane Use Arrows .... Section 160
Center Lines .... Section 210
No-Passing Zone Markings .... Section 211
Lane Lines .... Section 220
Edge Lines .... Section 230
Traversable Medians .... Section 260
Channelizing Lines and Traversable Channelizing Islands .... Section 270
Non-Traversable Medians & Channelizing Islands .... Section 281
Left Turn Lanes .... Section 310
Added Right Turn Lanes .... Section 320
Channelized Right-Turn Lanes .... Section 321
Dropped Lanes and Auxiliary Lanes on Conventional Roads .... Section 330
Line Extensions Through Intersections .... Section 340
Bicycle Lanes .... Section 410
Bicycle Lane End Transitions .... Section 411
Marked Crosswalks .... Section 430
Shared-Use Path Markings .... Section 440

Key References

1. Rodegerdts, L., J. Bansen, C. Tiesler, J. Knudsen, E. Myers, M. Johnson, M. Moule, B. Persaud, C. Lyon, S. Hallmark, H. Isebrands, R. B. Crown, B. Guichet, and A. O'Brien. *NCHRP Report 672: Roundabouts: An Informational Guide*, 2nd ed. Transportation Research Board of the National Academies, Washington, D.C., 2010. http://www.trb.org/Main/Blurbs/164470.aspx.
2. Campbell, J. L., M. G. Lichty, J. L. Brown, C. M. Richard, J. S. Graving, J. Graham, M. O'Laughlin, D. Torbic, and D. Harwood. NCHRP Report 600: Human Factors Guidelines for Road Systems. 2012. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_600Second.pdf. Accessed October 23, 2012.

3. Oregon Department of Transportation. *Highway Design Manual*. Oregon Department of Transportation, Salem, Oregon, 2012.
4. Molino, J. A., V. W. Inman, B. J. Katz, and A. Emo. Lane Restriction Signing and Marking for Double-Lane Roundabouts. Turner-Fairbank Highway Research Center, McLean, Virginia, 2007. www.pooledfund.org/Document/Download/1226.
5. Hanscom, F. R. Drivers' Understanding of Innovative Roundabout Traffic Control Devices. *ITE Journal*, Vol. 80, no. 7, July 2010, pp. 40-44. https://trid.trb.org/view.aspx?id=933416.
6. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.

Interchange Ramps: Exit & Entrance Ramps Section 360

Introduction

Markings on exit and entrance ramps provide positive direction of traffic movements to and from limited access roadways.

Design Parameters

01 **Exit ramps shall include wide white lines (W-2) from the painted gore point to the physical gore point (Figures 360-A, 360-B, and 360-C).**

02 **Exit ramps with dropped lane(s) shall include:**

- **A wide white line (W-2) starting 100 feet (minimum) to 300 feet (standard) prior to the painted gore point (Figures 360-B and 360-C).**
- **A wide dotted lane lines (DLL-2) in advance of the wide white line (W-2) (Figures 360-A and 360-B).**

03 *The wide white dotted lane line (DLL-2) used in advance of dropped lane(s) should start at least ½ mile in advance of the painted gore point and continue to the wide white line (W-2). Where this distance is not available the wide white dotted lane line (DLL-2) should be extended as long as possible.*

04 *Exit ramps with a tapered deceleration lane should include a dotted edge line extension from the upstream end of the taper to the painted gore point (Figure 360-A).*

05 **If used, the dotted line across exit ramps, including left-hand exit ramps, shall be a white dotted line. The width of the dotted line shall be at least the same as the width of the line it extends.**

06 **Entrance ramps shall include:**

- **Wide white channelizing lines (W-2) from the physical gore point to the painted gore point.**
- **A white dotted lane line (DLL) for a parallel acceleration lane from the painted gore point to a point at least one-half the distance from the painted gore point to the end of the taper (Figure 360-E).**
- **A white broken line (WB) from the painted gore point for an added lane (Figure 360-D). If the added lane is an auxiliary lane that is 2 miles or less in length, a wide white dotted lane line (DLL-2) shall be used instead.**

07 For parallel acceleration lanes, a white dotted lane line (DLL) or white dotted line (WD) may be used from the downstream end of the white dotted lane line (DLL) to the beginning of the taper (Figure 360-E).

08 Chevron bars (CH) may be used in the neutral area to discourage road users from using this area.

Required Approvals

An engineering study and region traffic engineer approval is required for any modifications to the entrance ramp markings shown in Figures 360-D and 360-E, including but not limited to extending the wide white channelizing line (W-2) beyond the painted gore point.

Design Issues

An exit lane with a parallel deceleration lane (a lane developed shortly before the gore point) is not typically used in Oregon. Contact the Traffic-Roadway Section for guidance in these cases.

A tapered acceleration lane is characterized by a tangent entrance ramp without an acceleration lane section (both Figures 360-D and 360-E have an acceleration lane parallel to the thru lanes). ODOT currently does not design this type of entrance ramp; however, there may be existing entrance ramps with this type of design. Contact the Traffic-Roadway Section for guidance in these cases.

Figures & Tables

Figure 360-A: Typical Freeway Exit Ramp Markings (Tapered Deceleration Lane)

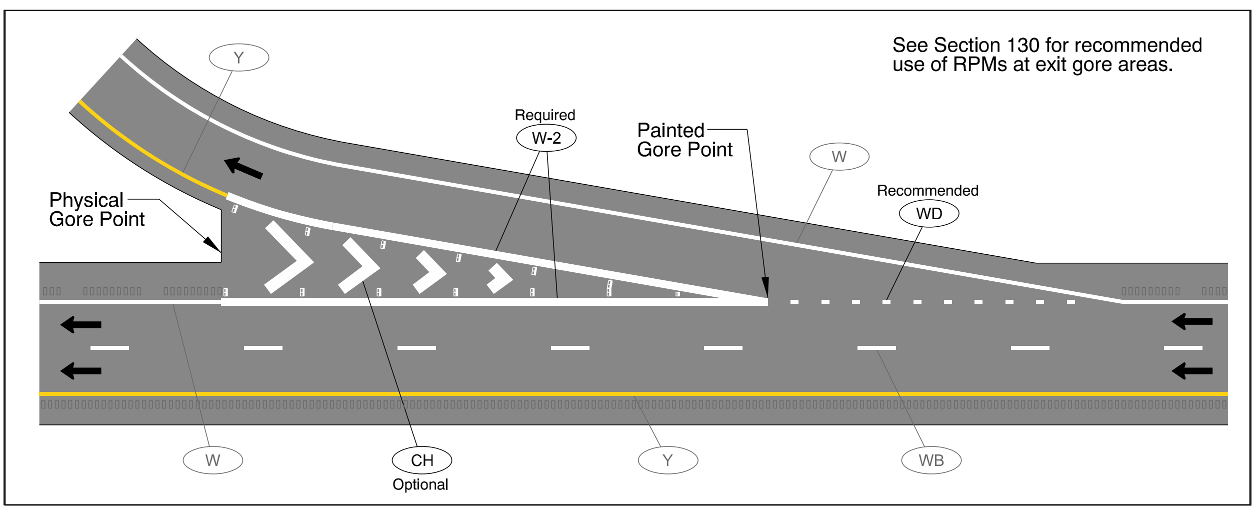


Figure 360-B: Typical Freeway Exit Ramp Markings (Single Lane Drop)

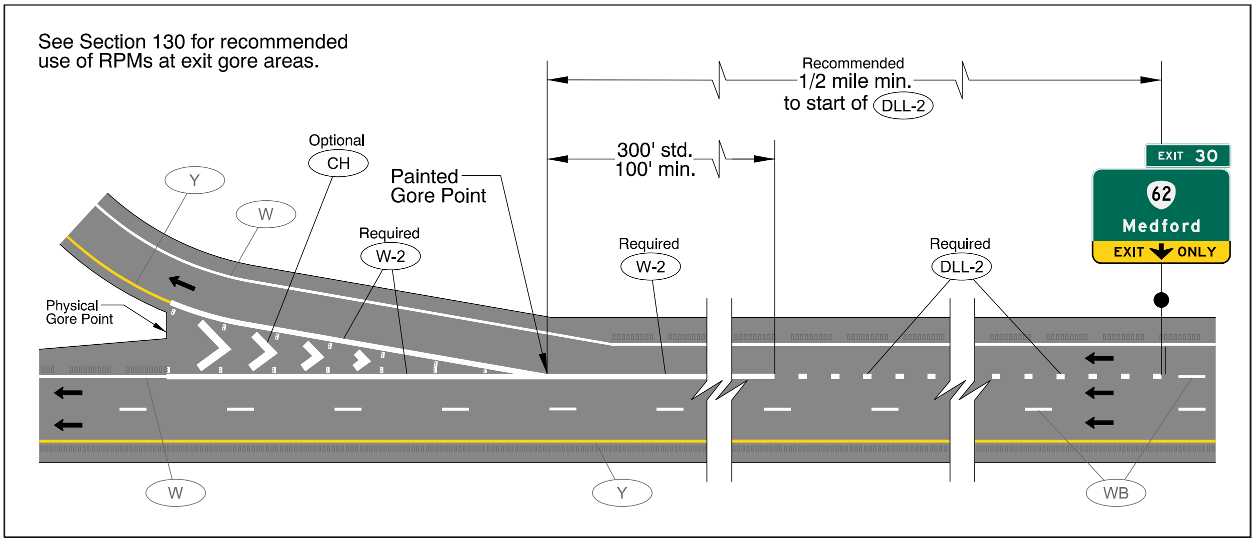
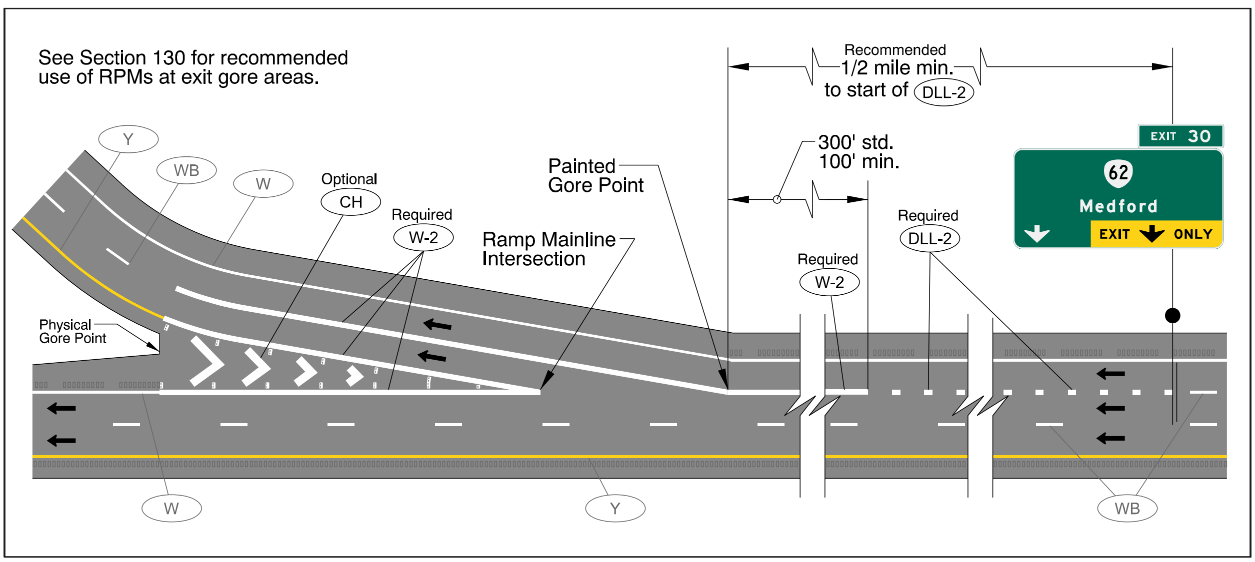
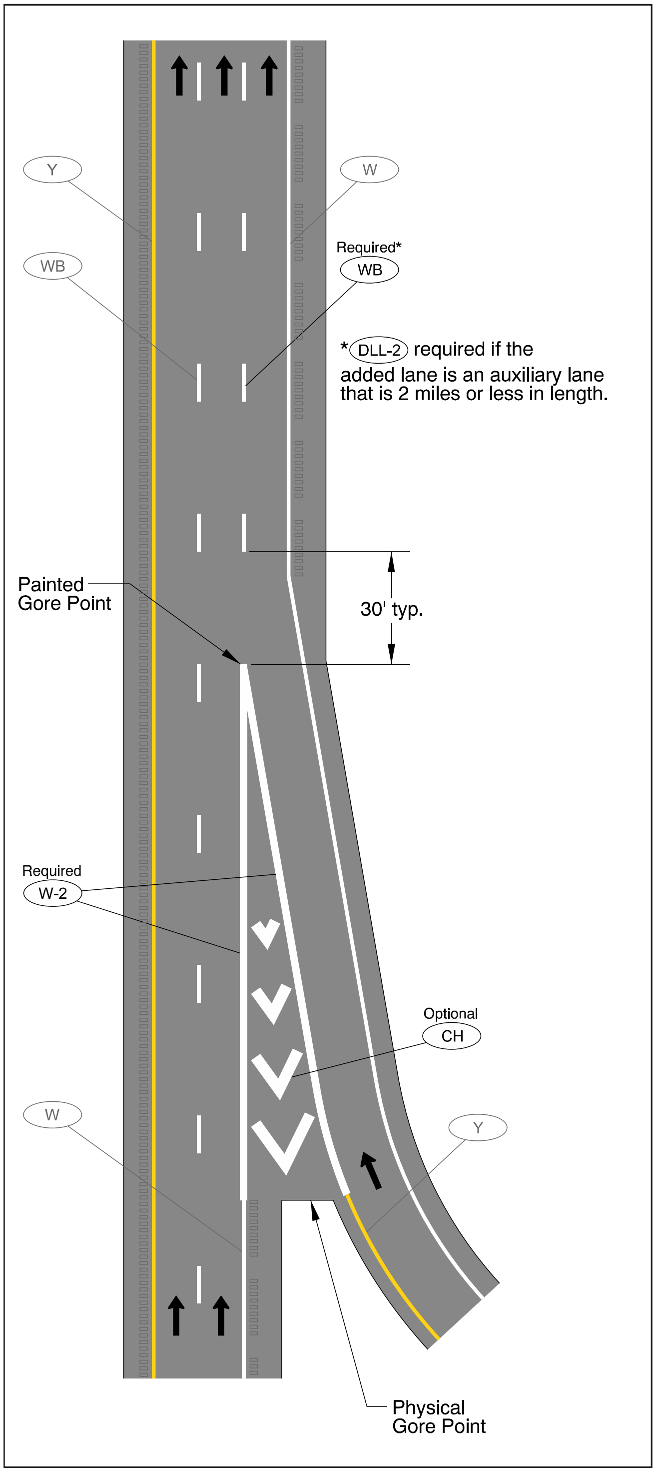


Figure 360-C: Typical Freeway Exit Ramp Markings (Two-Lane Exit with Single Lane Drop)



56 Figure 360-D: Typical Freeway Entrance Ramp Markings (With Added Lane)



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58 Figure 360-E: Typical Freeway Entrance Ramp Markings (With Parallel Acceleration Lane)

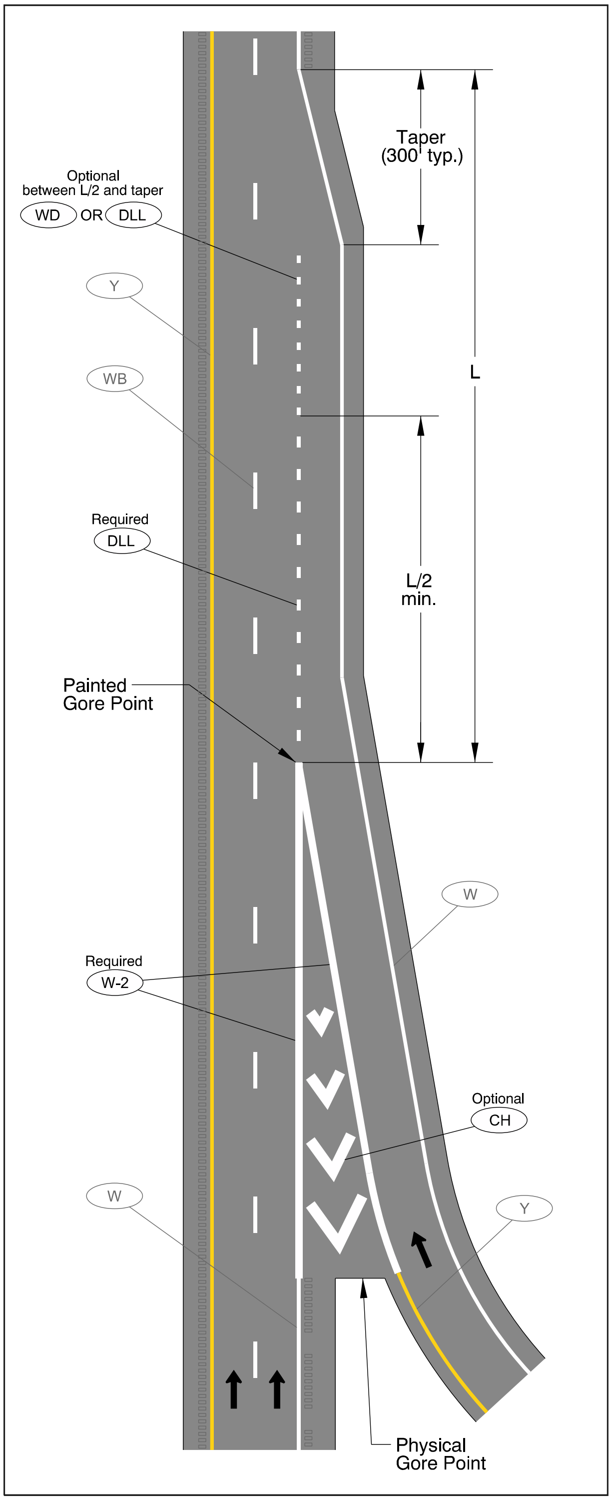

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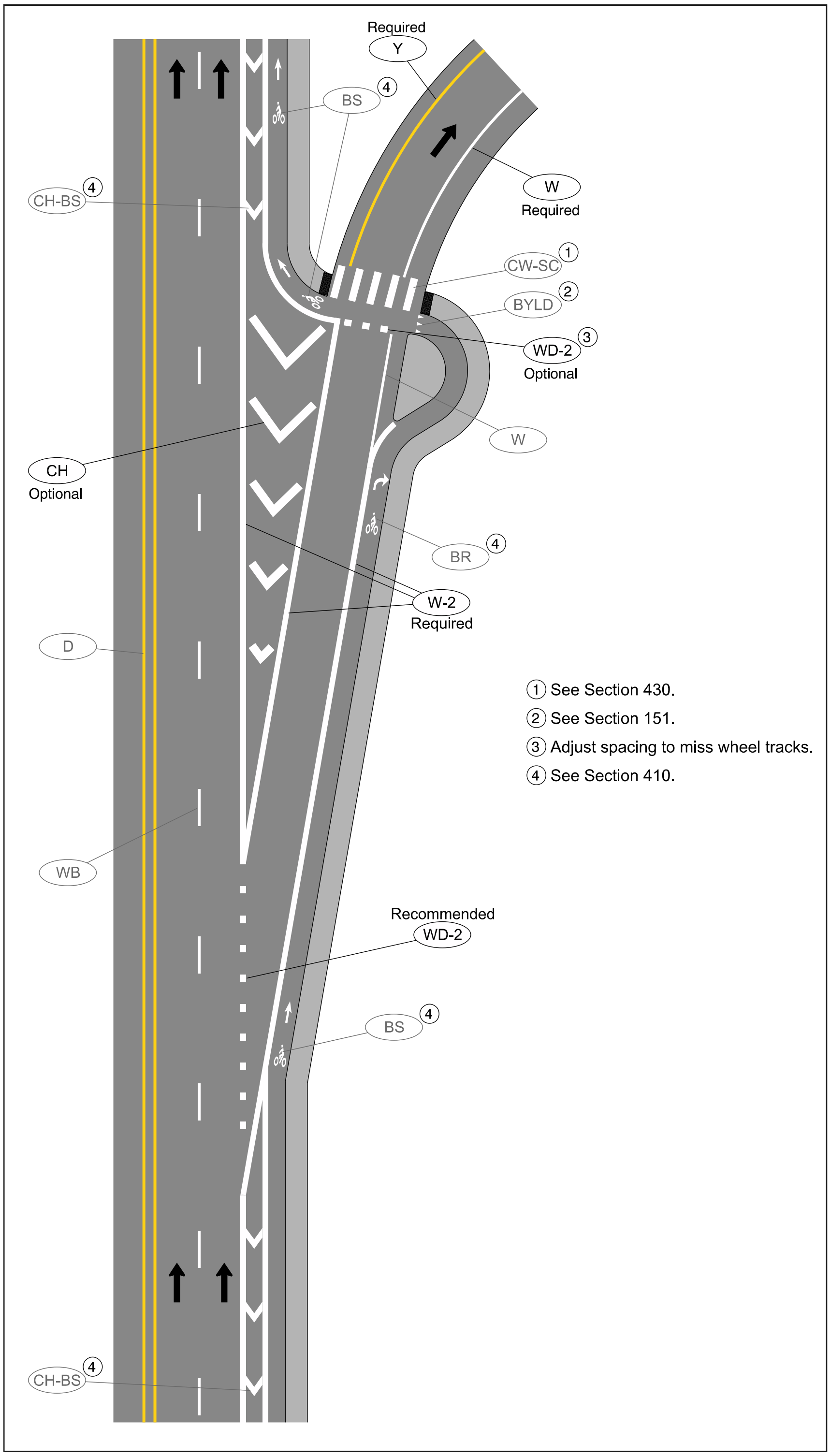
Figure 360-F: Typical Markings for Perpendicular Crossing of Through Bicycle and Pedestrian Facilities Across a Ramp



Support

Clear guidance through signing and markings is needed to safely and efficiently guide drivers through interchange areas. This is especially true at complex, unfamiliar interchanges where multiple simultaneous driving tasks can be expected of a driver (reading signs, finding gaps, changing lanes, responding to slower traffic, etc.). A driver's workload and stress increases when they do not receive the information they expect, if they are surprised, or need to execute multiple lane changes in a short distance. Drivers expect sufficient advance warning through signing and markings of critical decision points to make any lane changes in a safe and timely manner (*1*). Adequate and consistent information provided by signing and striping in advance of and at interchanges helps drivers know if they need to take action or if other drivers around them need to act (*2*).

Using a wide dotted lane line (DLL-2) in advance of a dropped lane improves driver understanding that he or she must exit soon but still has time to change lanes. This understanding of an impending dropped lane improves with the use of a solid line (*3*). A field study (*4*) confirmed this understanding by changing broken lines in advance of several freeway dropped lanes to dotted lanes with a solid line shortly before the painted gore. Researchers observed an upstream shift in the location where drivers made lane changes in advance of the dropped lanes, fewer drivers changing lanes near the gore points, and fewer drivers making erratic maneuvers at the gore areas. These changes in lane line patterns, along with advance overhead signing, helps communicate the upcoming change and needed actions.

Chevrons in gore areas could be beneficial at locations where additional path guidance is needed due to a dropped lane, crash history, unusual vertical and/or horizontal geometry, or complex interchanges, though there is little research qualifying the benefits of gore area chevrons at this time.

Use of a dotted lane line at an acceleration lane (instead of a broken line like past MUTCD practice) is intended to communicate that the acceleration lane does not continue ahead (*5*).

The taper length at the end of the parallel acceleration lane (Figure 360-E) is typically 300 feet, which comes from the AASHTO Green Book (*6*). This taper length, which is shorter than the lane reduction tapers used in Section 250, is intended to give drivers a clear visual cue that the acceleration lane is ending with sufficient length to make an emergency stop if needed (*7*). See the AASHTO Green Book and the Highway Design Manual (*8*) for more information.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Typical Layouts for RPMs .... Section 133
Yield Lines .... Section 151
Lane Lines .... Section 220

Key References

1. Richard, C. M., and M. G. Lichty. Driver Expectations When Navigating Complex Interchanges. Federal Highway Administration Office of Safety Research and Development, McLean, VA, Final Report FHWA-HRT-13-048, 2013. https://www.fhwa.dot.gov/publications/research/safety/13048/13048.pdf.
2. Campbell, J. L., M. G. Lichty, J. L. Brown, C. M. Richard, J. S. Graving, J. Graham, M. O'Laughlin, D. Torbic, and D. Harwood. NCHRP Report 600: Human Factors Guidelines for Road Systems. 2012. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_600Second.pdf. Accessed October 23, 2012.
3. Fitzpatrick, K., M. Ogden, and T. Lienau. Motorists' Comprehension of Exit Lane Drop Signs and Markings. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1464, 1994, pp. 51-59. http://onlinepubs.trb.org/Onlinepubs/trr/1994/1464/1464-007.pdf.
4. Fitzpatrick, K., M. Lance, and T. Lienau. Effects of Pavement Markings on Driver Behavior at Freeway Lane Drop Exits. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1495, 1995, pp. 17-27. http://onlinepubs.trb.org/Onlinepubs/trr/1995/1495/1495-003.pdf.
5. Washington, D.C.: United States Government Publishing Office, 2009, p. 66796. https://www.gpo.gov/fdsys/pkg/FR-2009-12-16/pdf/E9-28322.pdf.
6. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*, 6th ed. Washington, D.C., 2011.
7. Reilly, W. R., R. C. Pfefer, R. M. Michaels, A. Polus, and J. M. Schoen. NCHRP Project 3-35: Speed-Change Lanes. Northwestern University, Washington, D.C., Final Report 1989. http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP03-35_FR.pdf.
8. Oregon Department of Transportation. *Highway Design Manual*. Oregon Department of Transportation, Salem, Oregon, 2012.

Interchange Ramps: Ramp Terminals Section 361

Introduction

Markings at ramp terminals provide positive direction and reinforcement to minimize wrong-way turns.

Design Parameters

01 **Exit ramps shall:**

- **Include lane use arrows in each lane at the terminal intersection.**
- **Include lane use arrows in each lane at the beginning of the wide white line (W-2) when there is more than one lane on the exit ramp approaching the terminal intersection (Figures 361-A and 361-B).**
- **Be marked with edge lines and a traversable median on the two-way portion for ramps that carry two-way traffic on some of its length (such as folded diamond interchanges) as shown in Figure 361-D. One-way portions shall be marked with standard edge lines.**

02 *A wrong-way arrow may be used instead of a lane use arrow on one-lane exit ramps and at locations where lane-use arrows are not appropriate to show the correct direction of traffic flow.*

03 *If used, a wrong-way arrow should be installed within 50 feet of the "DO NOT ENTER" sign(s) or in a location where an engineering study demonstrates the wrong-way arrow will be clearly visible to potential wrong-way road users.*

04 *At ramps that carry two-way traffic on some of its length (such as folded diamond interchanges) where channelization or ramp geometrics do not make wrong-way movements difficult:*

- *A dotted line extension should be used from a left turn lane on the crossroad to the entrance ramp (Figure 361-D).*
- *A wrong-way arrow should be used on single-lane exit ramps in addition to the lane use arrow located at the terminal intersection (Figure 361-D).*

05 *Multi-lane exit ramps should include a lane line as soon as the pavement width is sufficient for two lanes with adequate shoulders. If this point is located prior to storage requirements, a white broken line (WB) should be used as the lane line until the beginning of turn lanes at the ramp terminal. For ramps with three or more lanes, the lane line should guide drivers into the lane that will minimize lane changes or into the lane containing the heaviest movement (Figure 361-A).*

06 *If a stop bar is used across an exit ramp, it should be a wide stop bar (S-2).*

07 *On two-lane, two-way crossroads, crossroad approaches to the terminal intersection should include no-passing zone markings in the approach direction a minimum distance from the terminal intersection listed in Table 211-2 in Section 211.*

08 Exit ramps may include an additional wrong-way arrow at a location upstream of the terminal intersection to discourage wrong way movement.

Required Approvals

Region traffic engineer approval is required for use of red-backed raised pavement markers used for wrong-way treatments.

Design Issues

Installation and maintenance of in-lane arrows are generally close to the ramp terminal where wrong-way drivers can see the arrow as they enter the ramp, and where vehicle speeds are significantly less than a location closer to the gore point. Red-backed RPMs can require significant attention from maintenance crews with less benefit compared to in-lane arrows.

Figures & Tables

Figure 361-A: Typical Exit Ramp Lane Addition Transition

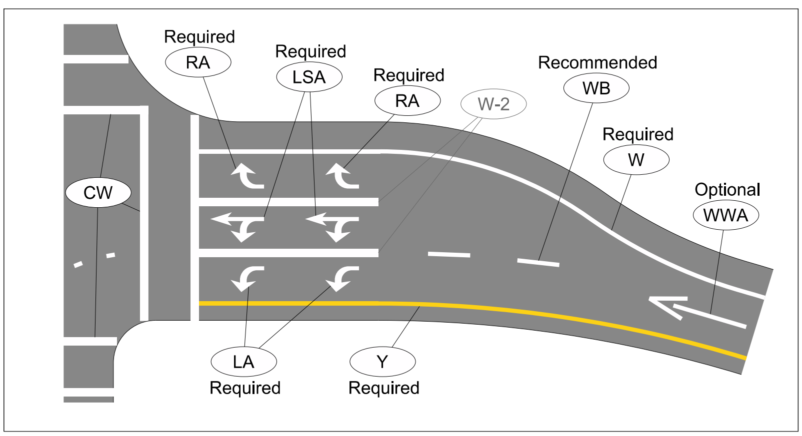


Figure 361-B: Directional Arrow Marking Types

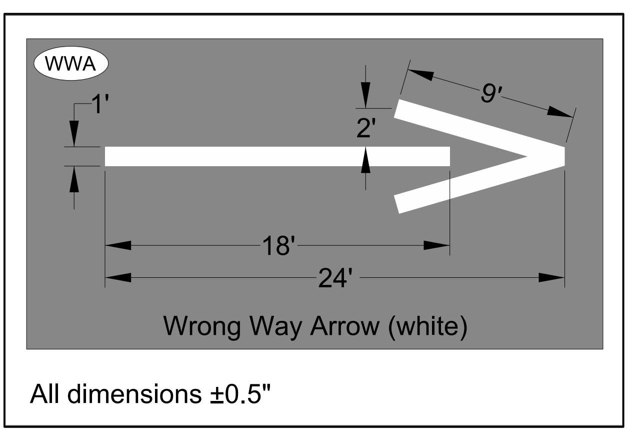


Figure 361-C: Typical Rural, Non-Signalized Ramp Terminal Markings

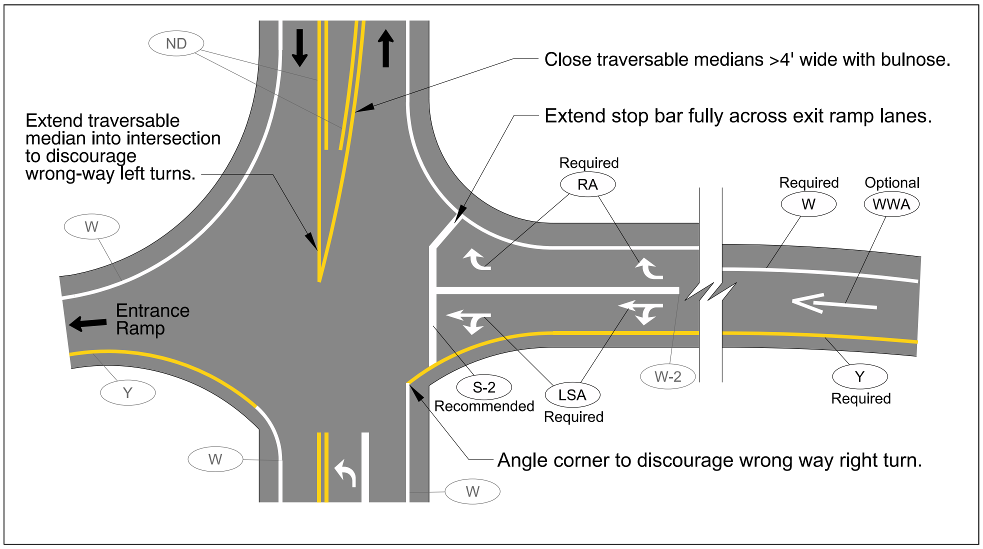
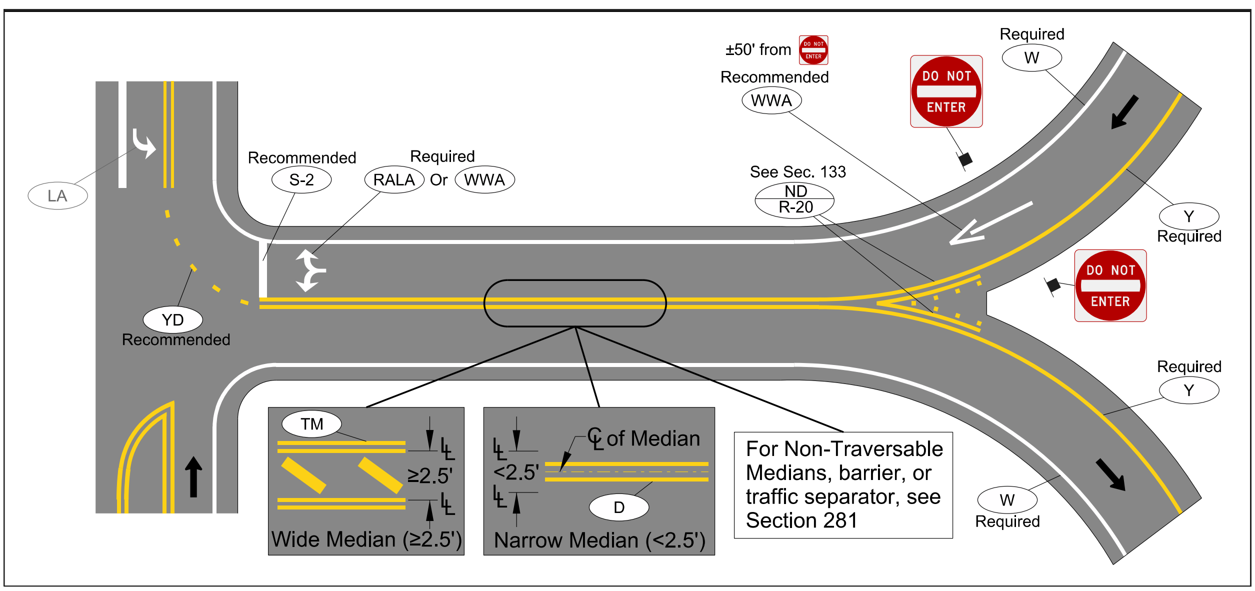


Figure 361-D: Typical Two-Way Ramp Terminal Markings



Support

Wrong-way events are rare and unpredictable and often result in severe and newsworthy crashes. However, there are some trends that help put these events in context. There have been numerous domestic and international research efforts to determine contributing factors for wrong-way driving (*1*) (*2*) (*3*) (*4*) (*5*) (*6*) (*7*) (*8*). These efforts are consistently finding:

- Wrong-way crashes are more likely to occur during early morning hours and on weekends.
- Wrong-way crashes are more severe than other freeway crashes.
- Older drivers and male drivers are overrepresented in wrong-way crashes.
- Impaired driving is a significant factor in the majority of wrong-way driving.
- Most wrong-way entries are made at freeway exit ramps. Certain interchange types are more susceptible to wrong-way entries, including partial cloverleaf and folded diamond interchanges.
- Most wrong-way vehicles are passenger cars, used for personal purposes, and have a single occupant.

Other factors that were not as consistent but still mentioned in the literature included driver inattention, insufficient knowledge of the road or loss of bearings, and insufficient lighting, signing, and pavement markings.

In-lane arrows overwhelmingly improve understanding of lane directionality and add significant value where road users could be confused about the proper direction of traffic flow (*9*). Because of this high level of road user understanding, literature on mitigating wrong-way movements consistently recommends in-lane arrows as an effective low-cost mitigation (*5*) (*3*) (*10*) (*11*) (*8*). Section 2B.41 in the 2009 MUTCD (*12*) also recommends lane use arrows in each lane of an exit ramp near the ramp terminal where they will be clearly visible to potential wrong-way road users.

Red-backed raised pavement markers (RPMs) have been used in varying degrees and configurations by some states since the 1970s. However, red-backed RPMs are not universally understood and in-lane arrows communicate wrong-way direction much better (*13*). Some states use red-backed RPMs to simulate a wrong-way arrow, but this configuration requires more maintenance than a standard wrong-way arrow to make sure the arrow is always present and legible (*2*).

If it is desired to use red-backed RPMs, see section 406.1 Wrong-Way Treatments of the Traffic Manual (*14*) for more information on wrong-way treatments and considerations. The red side of a red-backed RPM is be placed so that it is visible to vehicles that would be traveling in the wrong direction. With the many designs of ramps used, the design of red-backed RPMs will vary depending on location. It is also important to work with maintenance forces when planning to install red-backed RPMs.

Some left turn lanes on cross roadways at ramp terminals extend beyond the other ramp terminal and can be confusing to drivers where they turn left to access the freeway/expressway (*2*). In these cases, installing a straight arrow and additional guide signs in the portion of the left turn lane upstream from the other ramp terminal can help provide positive guidance to the proper intersection to make a left turn.

Ramps with two-way traffic can also be confusing for drivers making a left turn to the entrance ramp. Using a left-turn intersection guide line can help guide turning motorists into the correct lane (Figure 361-D), especially when the ramp's lanes are separated by a non-traversable median (*3*) (*6*) (*8*). Extending stop bar fully across one-way ramp terminals can also help discourage wrong-way entry (*15*).

Road user surveys suggest drivers use color of centerlines to determine directionality of a two-lane roadway but some 20-30 percent of surveyed road users did not know the centerline color communicated directionality (yellow for two-way, white for one-way) (*9*). These findings support marking the left side of ramps yellow but this is generally not considered an effective wrong-way countermeasure because of the high misinterpretation of color meaning.

Cross References

Colors .... Section 110
Center Lines .... Section 210
Lane Lines .... Section 220
Edge Lines .... Section 230
Left Turn Lanes .... Section 310

Key References

1. Cooner, S. A., A. S. Cothron, and S. E. Ranft. Countermeasures for Wrong-Way Movements on Freeways: Overview of Project Activities and Findings. Texas Transportation Institute, Texas A&M University, Austin, Texas, FHWA/TX-04/4128-1, 2004. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/4128-1.pdf.
2. North Texas Tollway Authority. Keeping NTTA Roadways Safe: Wrong-Way Driver Task Force Staff Analysis. Plano, TX, 2009. https://www.ntta.org/newsresources/safeinfo/wrongway/Documents/WWDAnalysisAUG2011.pdf.
3. Zhou, H., J. Zhao, R. Fries, M. R. Gahrooei, L. Wang, B. Vaughn, K. Bahaaldin, and B. Ayyalasomayajula. Investigation of Contributing Factors Regarding Wrong-Way Driving on Freeways. Department of Civil and Environmental Engineering, Illinois Center for Transportation, Springfield, Illinois, ICT-12-010, 2012. http://cetrans.isg.siue.edu/wwd/FHWA-ICT-12-010.pdf.
4. Braam, A. C. Wrong way Crashes: Statewide Study of Wrong Way Crashes on Freeways in North Carolina. 2006. https://connect.ncdot.gov/resources/safety/Documents/Crash%20Data%20and%20Information/WrongWayCrash.pdf.
5. Neuman, T. R., J. J. Nitzel, N. Antonucci, S. Nevill, and W. Stein. NCHRP Report 500, Volume 20: A Guide for Reducing Head-On Crashes on Freeways. Washington, D.C., 2008. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_500v20.pdf.
6. National Transportation Safety Board. Highway Special Investigation Report: Wrong-Way Driving. Washington, D.C., NTSB/SIR-12/01, 2012. https://www.ntsb.gov/doclib/safetystudies/SIR1201.pdf.
7. Lathrop, S. L., T. B. Dick, and K. B. Nolte. Fatal Wrong-Way Collisions on New Mexico's Interstate Highways, 1990-2004. *Journal of Forensic Sciences*, Vol. 55, no. 2, March 2010, pp. 432-437. http://www.ce.siue.edu/faculty/hzhou/ww/paper/Fatal%20wrong-way%20on%20new%20mexico_2010.pdf.

8. Monsere, C., S. Kothuri, and A. Razmpa. Wrong Way Driving Analysis and Recommendations. Portland State University, Portland, Oregon, 2017. http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Wrong-Way-Driver-Report.pdf.

9. Hawkins, H. G., A. H. Parham, and K. N. Womack. NCHRP Report 484: Feasibility Study for an All-White Pavement Marking System. Texas Transportation Institute, Washington, D.C., ISBN 0-309-06772-3, 2002. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_484.pdf.

10. Cooner, S. A., A. S. Cothron, and S. E. Ranft. Countermeasures for Wrong-Way Movement on Freeways: Guidelines and Recommended Practices. Texas Transportation Institute, Texas A&M University, Austin, Texas, FHWA/TX-04/4128-2, 2004. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/4128-2.pdf.

11. Schrock, S. D., H. G. Hawkins, and S. T. Chrysler. Effectiveness of Lane Direction Arrows as Pavement Markings in Reducing Wrong-Way Movements on Two-Way Frontage Roads. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, no. 1918, 2005, pp. 63-67. http://trrjournalonline.trb.org/doi/10.3141/1918-08.

12. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.

13. Miles, J. D., P. J. Carlson, B. Ullman, and N. Trout. Red Retroreflective Raised Pavement Markings: Driver Understanding of Their Purpose. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2056, 2008, pp. 34-42. http://trb.metapress.com/content/82wx451g816p37mn/fulltext.pdf.

14. Oregon Department of Transportation. Traffic Manual, 2021 Edition. January 2021. https://www.oregon.gov/odot/Engineering/Docs_TrafficEng/Traffic-Manual-2021.pdf. Accessed September 2, 2021.

15. Vaswani, N. K. Measures for Preventing Wrong-Way Entries on Highways. University of Virginia, Charlottesville, Virginia, VHRC 72-R41, 1973. http://www.virginiadot.org/vtrc/main/online_reports/pdf/72-r41.pdf.

Bicycle Lanes Section 410

Introduction

A bicycle lane is a portion of the roadway designated by pavement markings and/or signs for the preferential or exclusive use of people riding bicycles.

Design Parameters

01 **Bicycle lane markings shall consist of:**

- **A wide longitudinal white lane line (W-2) to separate motor vehicle lanes from a bicycle lane traveling in the same direction.**
- **A double yellow line (D or ND) to separate motor vehicle lanes from a bicycle lane traveling in the opposite direction.**
- **Bicycle stencils or "Bicycle Lane" signs placed after intersections.**

02 **Except at dropped lanes (see Section 330), wide white dotted lines (WD-2) shall be used to extend longitudinal bicycle lane lines through areas where motor vehicles weave across a bicycle lane.**

03 *At signalized intersections where the crossing distance between crosswalks is greater than 60 feet, the bicycle lane line should be extended through the intersection with a wide dotted line (WD-2) (see Figure 410-C). If both intersecting roadways have bicycle lanes and the crossing distance of both roadways is greater than 60 feet, only the bicycle lane line on the major roadway should be extended.*

04 *At unsignalized intersections, the bicycle lane line on an uncontrolled approach should be extended through the intersection with a wide dotted line (WD-2) where the distance between the wide solid white bicycle lane lines (W-2) is greater than 60 feet (see Figure 410-D).*

05 *Additional bicycle stencils or signs should be installed on long sections of roadway with no intersections at an approximate spacing (in feet) of 40 times the posted speed (in mph).*

06 Bicycle stencils or signs may be omitted immediately after intersections where blocks are short.

07 **A through bicycle lane shall not be positioned to the right of a right-turn lane or to the left of a left turn lane unless conflicting movements are controlled by a traffic control signal.**

08 *When adjacent to parallel on-street parking, a buffer should be provided according to Section 412 between the bicycle lane and parked vehicles so the right edge of the bicycle lane is at least 11 feet from the face of the curb, or from the edge of the pavement where there is no curb.*

09 *Where a bicycle lane is 7 feet wide or wider, the bicycle lane width should be reduced with a buffer according to Section 412, an edge line to the right of the bicycle lane according to Section 230, or a white dotted lane line (DLL) to create two adjacent bicycle lanes according to Section 220.*

10 At an intersection with a left turn bicycle lane, a wide white dotted line (WD-2) may be used to extend the bicycle lane line through the intersection if there is a receiving bicycle lane (see Figure 410-E).

11 *A white solid line (W) should be used as shown in Figure 440-C where it is not practical to eliminate an obstruction or drain grate located within the bicycle lane that is inappropriate for bicycle travel.*

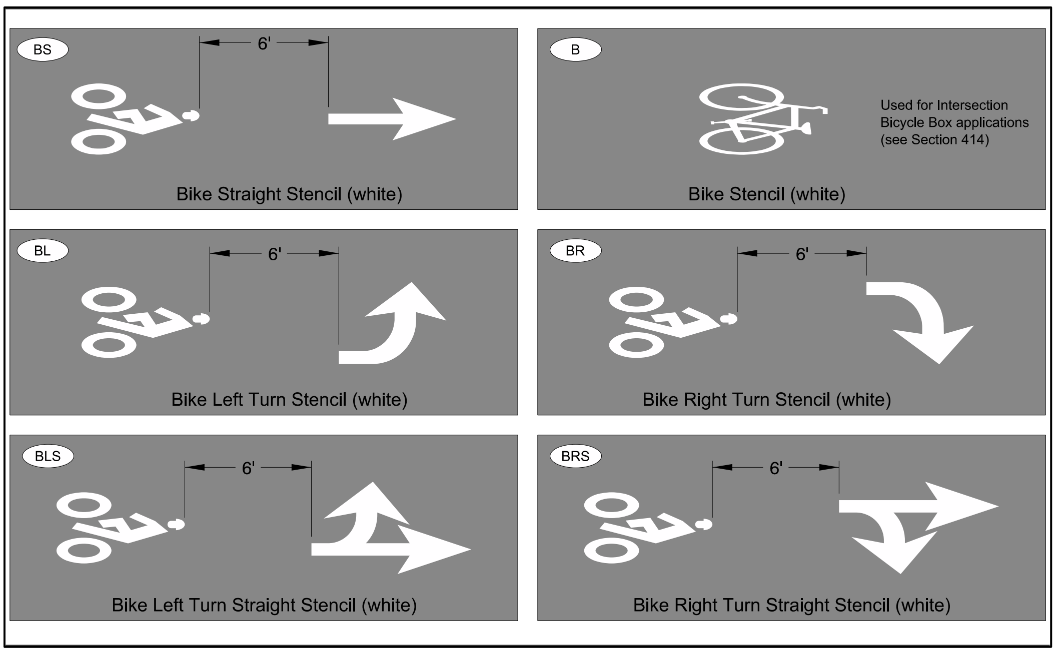
Design Issues

Low raised devices (e.g.: raised pavement markers) can cause steering difficulties for people on bicycles if they need to leave the bicycle lane to avoid debris or make a turn (*1*)

See Section 330 for design parameters related to bicycle lanes at dropped right turn lanes. See Section 350 for design parameters related to bicycle lanes at roundabouts. See Section 411 for information on ending bicycle lanes.

Figures & Tables

Figure 410-A: Bicycle Lane Stencil Types



Bicycle Lanes

Figure 410-B: Bicycle Lane Stencil Dimensions

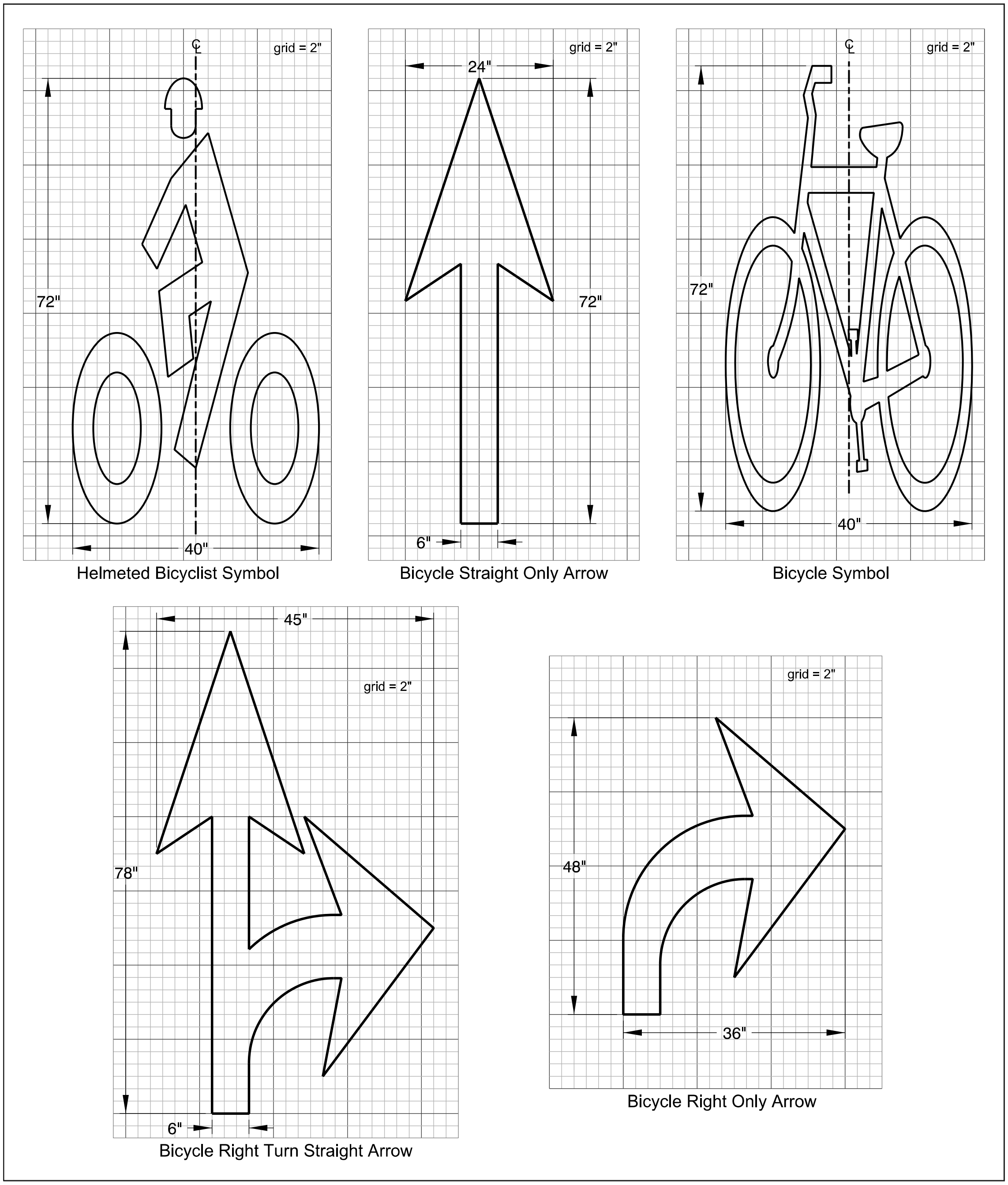


Figure 410-C: Typical Bicycle Lane Markings at a Signalized Intersection

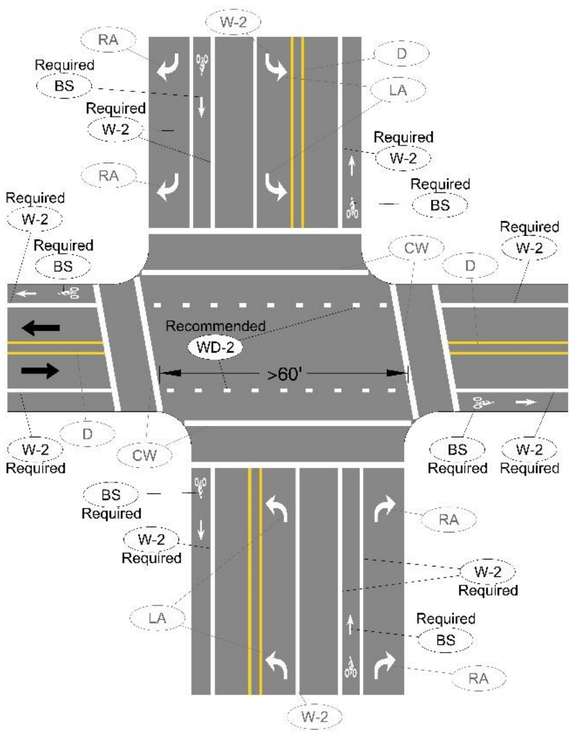


Figure 410-D: Typical Bicycle Lane Markings at an Unsignalized - Long Bicycle Crossing

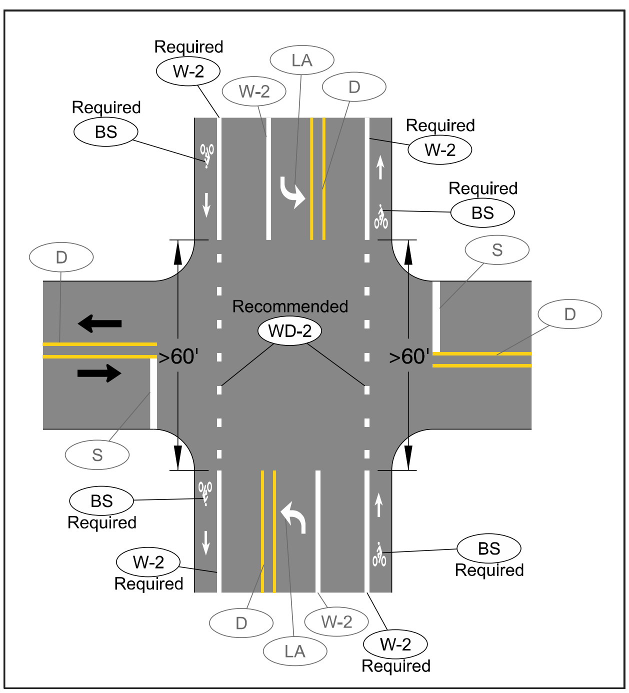


Figure 410_E Typical Bicycle Lane Markings at a Signalized T-Intersection

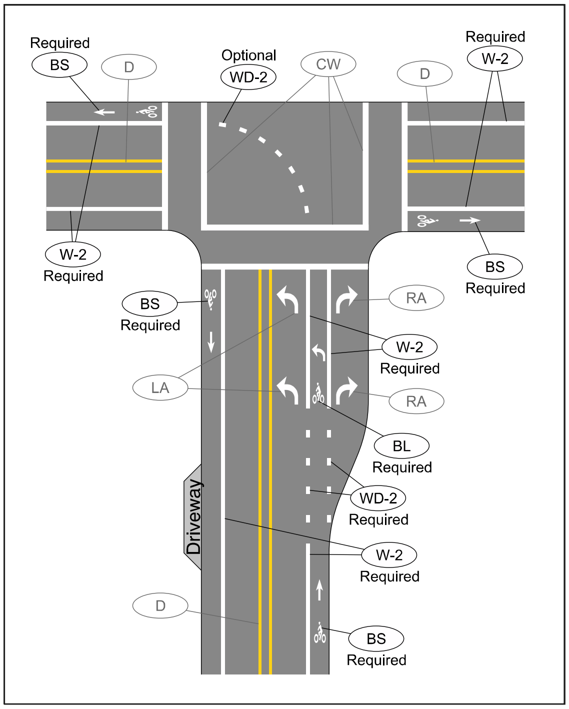


Figure 410-F: Typical 2-Way Separated Bicycle Lane Crossing - Road Stop Controlled

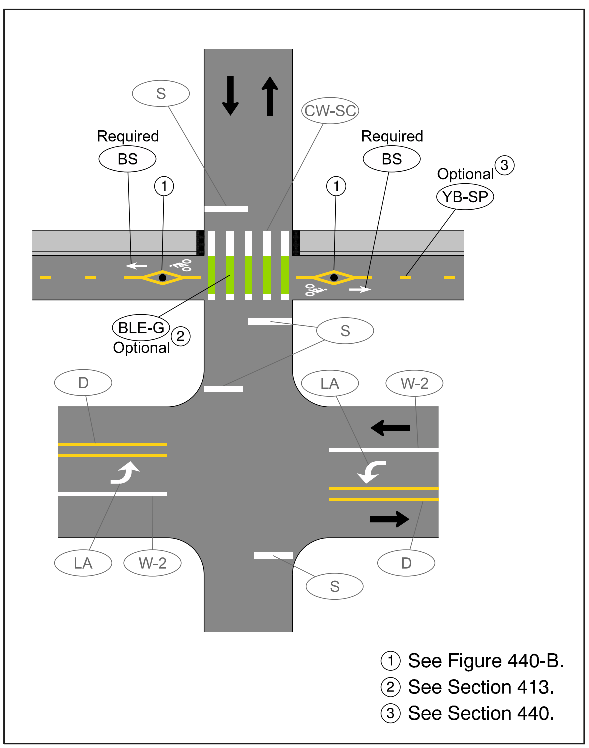


Figure 410-G: Typical 2-Way Separated Bicycle Crossing - Bicycle Lanes Yield Controlled

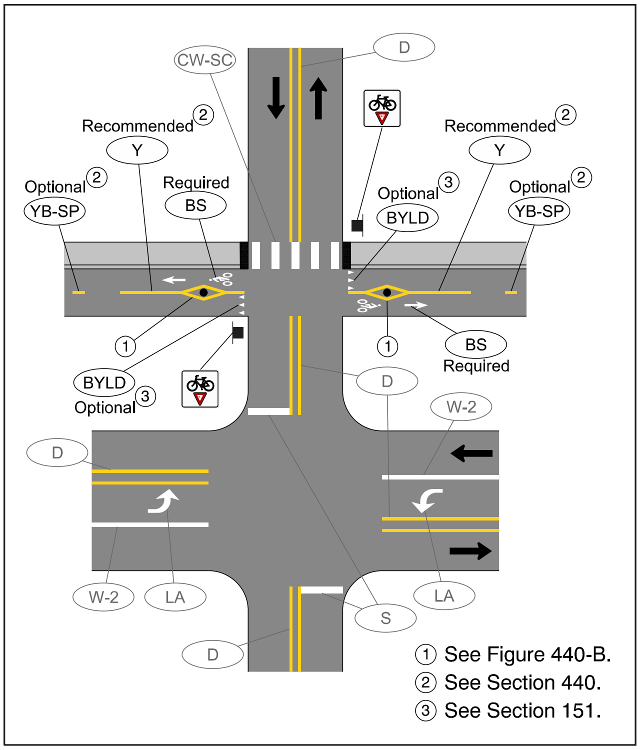
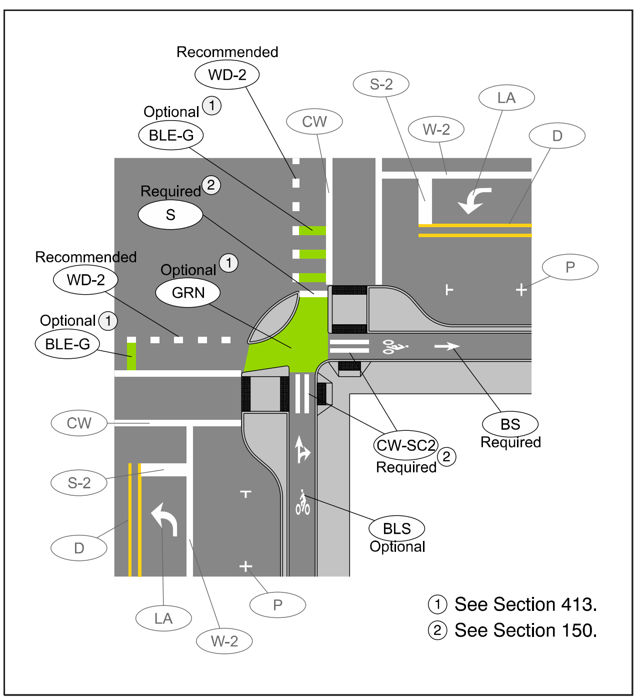


Figure 410-H: Example Separated Bicycle Lane Markings at a Signalized Intersection



Support

Bicycle lanes are one-way lanes specifically for cycling that let people on bicycles ride at their preferred speed. By providing a designated place to ride, people on bicycles generally position themselves and behave more predictably in bicycle lanes and reduce sidewalk riding (*1*) (*2*). Bicycle lanes typically run in the same direction as adjacent travel lanes, but could run counter-flow on one-way roadways for route connectivity and to minimize out-of-direction travel. Bicycle lanes are typically most helpful on roadways with an ADT of 3000 vehicles per day or greater, roadways with a posted speed of 25 mph or greater, and on streets with high transit use (*3*).

The width of a bicycle lane directly affects the safety and comfort of the facility. Several factors affect the operating space of a bicycle lane, including speed of adjacent motor vehicles, proportion of heavy vehicles, adjacent parked vehicles, storm grates, debris, and uneven longitudinal surfaces. As traffic volume, speed, and heavy vehicle percentages increase, people on bicycles tend to move further from the motor vehicle lane toward parked vehicles, the curb, or edge of pavement. There is also natural side-to-side movement that varies with bicycle speed, wind, and rider proficiency. All these variables require a wider bicycle lane than the width the bicycle physically occupies (*2*).

The standard width of a bicycle lane is 6 feet. The minimum width of a bicycle lane with open shoulders is 4 feet. The minimum width of a bicycle lane against curb, guardrail, or parked cars is 5 feet (*4*).

"Right-hook" crashes are a common crash type in urban areas. This crash type occurs where a right turning driver crosses over the bicycle lane and hits a cyclist. Recent simulator research suggests providing a dotted line across the intersection and a bicycle stencil at the right-hook conflict point improves driver searching and crash avoidance of this crash type (*5*). A dotted line extension also adds path guidance for drivers and cyclists through skewed intersections, intersections through horizontal curves, and long intersection crossings. A 60-foot intersection crossing is about 3 to 5 seconds travel time for a typical adult cyclist on level grade (*1*). There is insufficient research on preview needs for cyclists; this crossing length recommendation for a dotted line extension is based on human factors studies that estimate drivers need to be able to preview the road 2 to 3 seconds ahead to maintain lane position (*6*).

"Dooring" crashes are also a severe crash type for people on bicycles (*7*). This crash type occurs where a bicycle lane is positioned next to parallel parking and open vehicle doors extend into the bicycle lane. To avoid this crash type, a very high level of concentration is required by the cyclist to continually check parked vehicles ahead, which can reduce a cyclist's ability to asses other hazards. Avoiding an opening door also requires a complex and rapid reaction, simultaneously swerving to avoid the door, checking surrounding traffic, and possibly rapid braking (*7*). Without a buffer between parked vehicles and the bicycle lane, cyclists tend to position themselves in this "door zone," likely to move away from moving traffic (*2*); a buffer helps reduce the need to continuously monitor parked vehicles and focus on other upcoming hazards (*8*). If only markings are used to mitigate dooring crashes, a buffer between parallel parking and the bicycle lane is more effective at moving bicyclists outside the door zone than simply providing a wider bicycle lane (*2*) (*9*). For standard parking widths, 95th percentile vehicle displacement, and an open door width of 45 inches, the open door zone width of parked vehicles extends to approximately 11 feet from the curb (*2*).

Obstructions within a bicycle lane such as bollards need to be clearly marked to guide cyclists around the obstruction. Abrupt sunken grates or other obstructions unsafe for bicycling might need temporary delineation if it cannot be corrected in a timely manner. Grates within 0.25 inch below the path surface are generally sufficient for bicycle traffic (*1*) (*4*).

See the ODOT Bicycle and Pedestrian Design Guide (*4*), AASHTO Guide for the Development of Bicycle Facilities (*1*), NCHRP Report 766 (*2*), and NACTO Urban Bikeway Design Guide (*3*) for more details on bicycle lane design. See the Oregon Supplement to the MUTCD for more Oregon-specific info (*10*).

Cross References

Key References

1. American Association of State Highway and Transportation Officials. *Guide for the Development of Bicycle Facilities*, 4th ed. Washington, D.C., 2012.

2. Torbic, D. J., K. M. Bauer, C. A. Fees, D. W. Harwood, R. V. Houten, J. LaPlante, and N. Roseberry. NCHRP Report 766: Recommended Bicycle Lane Widths for Various Roadway Characteristics. Transportation Research Board of the National Academies, Washington, D.C., ISBN 978-0-309-28416-5, 2014. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_766.pdf.

3. National Association of City Transportation Officials. *NACTO Urban Bikeway Design Guide*, 2nd ed. Island Press, New York, New York, 2014. http://nacto.org/cities-for-cycling/design-guide/.
4. Oregon Department of Transportation. *Bicycle and Pedestrian Design Guide*, 3rd ed. Oregon Department of Transportation, Salem, Oregon, 2011. http://www.oregon.gov/ODOT/Engineering/Documents_RoadwayEng/HDM_L-Bike-Ped-Guide.pdf.
5. Hurwitz, D. H., C. Monsere, M. Jannat, J. Warner, and A. Razmpa. Towards Effective Design Treatment for Right Turns at Intersections with Bicycle Traffic. Oregon State University and Portland State University, Salem, Oregon, Final Technical Report FHWA-OR-RD-16-06, 2015. http://www.oregon.gov/ODOT/Programs/ResearchDocuments/SPR767_FinalReport_070815.pdf.
6. Campbell, J. L., M. G. Lichty, J. L. Brown, C. M. Richard, J. S. Graving, J. Graham, M. O'Laughlin, D. Torbic, and D. Harwood. NCHRP Report 600: Human Factors Guidelines for Road Systems. 2012. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_600Second.pdf. Accessed October 23, 2012.
7. Johnson, M., S. Newstead, J. Oxley, and J. Charlton. Cyclists and Open Vehicle Doors: Crash Characteristics and Risk Factors. *Safety Science*, Vol. 59, November 2013, pp. 135-140. http://www.sciencedirect.com/science/article/pii/S0925753513001057. DOI: http://dx.doi.org/10.1016/j.ssci.2013.04.010
8. Monsere, C. M., N. McNeil, and J. Dill. Multiuser Perspectives on Separated, On-Street Bicycle Infrastructure. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2314, 2012, pp. 22-30. http://trrjournalonline.trb.org/doi/abs/10.3141/2314-04. DOI: http://dx.doi.org/10.3141/2314-04
9. Duthie, J., J. F. Brady, A. F. Mills, and R. B. Machemehl. Effects of On-Street Bicycle Facility Configuration on Bicyclist and Motorist Behavior. *Transortation Researhc Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2190, 2010, pp. 37-44. http://trrjournalonline.trb.org/doi/abs/10.3141/2190-05. DOI: http://dx.doi.org/10.3141/2190-05
10. Oregon Department of Transportation. *Oregon Supplement to the 2009 MUTCD*, 2009 ed. Oregon Department of Transportation, Salem, Oregon, 2011. http://www.oregon.gov/ODOT/Engineering/Documents_TrafficStandards/MUTCD-OR-Supplement.pdf.

Bicycle Lane End Transitions Section 411

Introduction

The end of a bicycle lane is a critical transition area where there is not sufficient riding space on the shoulder or other separate cycling facility downstream from the transition. Like a motor vehicle lane reduction, a standard layout for ending bicycle lanes provides advance warning of the transition and encourages cyclists to take advantage of sufficient gaps in traffic before reaching the taper.

Design Parameters

01 *Except on an approach to a roundabout, the bicycle lane end transition markings shown in Figure 411 should be used where a bicycle lane ends on roadways with a posted or 85th percentile speed of 35 mph or greater and where the shoulder or other separate cycling facility downstream of the transition does not provide at least 4 feet of clear riding space.*

02 *A wide white dotted line (WD-2) should be used between the bicycle lane and general lane a distance "d" from the beginning of the taper and continue to the beginning of the taper. The transition taper length should be computed by the formula L=WS (see Figure 411).*

03 Where a curb clearly defines the roadway edge in the taper area, the edge line shown in Figure 411 may be omitted in the taper area as determined by engineering judgement.

04 A different "d" value may be used based on engineering judgement if the "d" value in Figure 411 is not practical.

05 A shared lane marking may be used after the bicycle lane end transition according to Section 415.

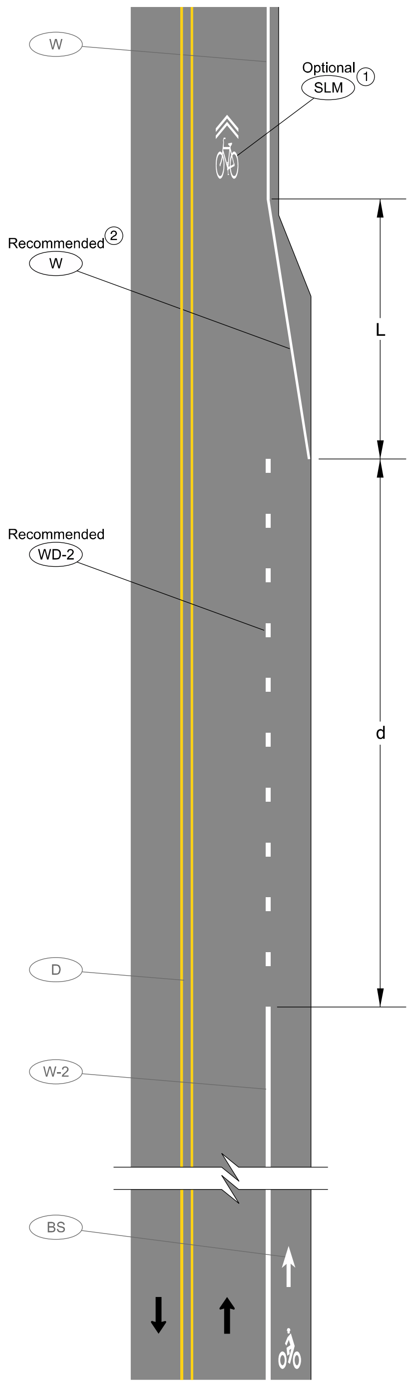
Design Issues

Where a wide shoulder or other riding space is provided after the bicycle lane ends so cyclists do not need to merge into the motor vehicle lane, the bicycle lane can be ended by transitioning from a bicycle lane line (W-2) to a standard edge line (W).

A "Bicycle Lane Ends" warning sign (OBW1-9) (*1*) might need to be used in advance of the taper to provide advance warning to cyclists to find a gap in traffic and merge into the travel lane and warn drivers of merging cyclists. See the MUTCD (*2*) for advance placement of warning signs. For example, an advance warning distance using Condition B decelerating to 10 mph might be sufficient to give drivers advance warning of merging cyclists and cyclists enough time to find a gap to merge.

Figures & Tables

Figure 411: Typical Bicycle Lane End Transition, Narrow Downstream Shoulder



① See Section 420.
② See design parameters for areas with curb.
③ Motor vehicle speed adjacent to bicycle lane.

Posted or 85th Percentile Speed (mph) ③	d (ft)	L (ft)
20	128	L=WS
25	152	
30	176	
35	184	
40	192	
45 and greater	200	

Where:
L= taper length (feet)
W = width of bicycle lane being reduced (feet)
S = bicycle approach speed (mph)

"d" distances given are for level roads. Corrections should be made for grades.

Support

Like standard lane reductions, the end of a bicycle lane can be a complex driving and riding situation. Some roads with bicycle lanes can have a segment of narrow width, such as at a narrow bridge, but then widen back out with bicycle lanes on the far side. Bicycle lanes end at other locations where it has been provided for a long distance, such as a suburban fringe or entering a downtown area. In each case, drivers need to be given enough time to watch for bicycles merging into their lane, bicyclists need to find an acceptable gap in traffic and merge, and all road users need to know where to expect the merge.

Because of the lack of national guidance on these transitions, the layout given in Figure 411 is based on guidance in the AASHTO Guide for the Development of Bicycle Facilities (*3*) for terminating bicycle lanes at roundabouts. The taper length comes from standard obstruction markings at the edge of path or roadways for biking given in Figure 9C-8 of the 2009 MUTCD (*2*).

Changing the wide solid bicycle lane line to a wide dotted line can encourage cyclists to take advantage of gaps in traffic to merge, rather than delay to a point where, if there are no gaps in traffic, the only practical alternative is to stop and wait for one (*3*). The "d" distance of dotted line derives from the travel time in a standard lane reduction between the end of the lane line and beginning of the taper (0.75d, between 5 and 10 seconds) at a high typical riding speed on level terrain (15 mph) (*3*) and is consistent with recommended dotted line distance at roundabouts in the AASHTO Guide for the Development of Bicycle Facilities (*3*). Distances are rounded up to the nearest multiple of 8 feet to accommodate the standard 8-foot cycle length for dotted lines.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Edge Lines .... Section 230
Lane Reduction Transitions .... Section 250
Bicycle Lanes .... Section 410
Shared Lane Markings .... Section 420

Key References

1. Oregon Department of Transportation. Sign Policy and Guidelines. July 2014. http://www.oregon.gov/ODOT/HWY/TRAFFIC-ROADWAY/docs/pdf/entire_sign_policy.pdf. Accessed November 25, 2014.
2. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
3. American Association of State Highway and Transportation Officials. *Guide for the Development of Bicycle Facilities*, 4th ed. Washington, D.C., 2012.

Bicycle Lane Buffers Section 412

Introduction

A bicycle lane buffer is a neutral space between a bicycle lane and a motor vehicle lane. This space improves road user comfort by separating cyclists from motor vehicles more than a standard bike lane (*1*).

Design Parameters

01 A buffer may be marked between a bicycle lane and an adjacent lane where roadway width allows.

02 **A marked buffer between a bicycle lane and another lane traveling in the same general direction shall consist of a wide white line (W-2) along both edges of the buffer (Figure 412-A).**

03 **Buffers separating opposing directions of traffic shall be marked according to Section 260.**

04 **A marked buffer between a bicycle lane and a parking lane shall consist of a normal white line (W) along the bicycle lane side of the buffer and on-street parking markings (P) on along the parking lane side of the buffer according to Section 630 (Figure 412-A).**

05 *If used, a buffer between a bicycle lane and another travel lane should not be less than 2 feet wide and should not be greater than 6 feet wide.*

06 *Where a buffer space is 3 feet wide or wider and separates traffic traveling in the same general direction, crosshatch markings should be used in the buffer.*

07 **Where crosshatch markings are used to separate traffic flows in the same general direction, they shall be white buffer space chevron bars (CH-BS) (Figure 412-A).**

08 *The longitudinal spacing of the chevrons should be determined using engineering judgement considering factors such as speeds and desired visual impacts.*

09 **Except as provided in paragraph 10 and Section 340, buffer markings shall not continue across intersections and major driveways, including private drive approaches.**

10 *If a buffer line is extended through an intersection according to Section 340 with no horizontal curvature or lane offset, the line closest to the bicycle lane should be extended through the intersection (Figures 412-B and 412-C).*

11 *Buffer markings should continue across minor driveways (private or public) and alleys.*

12 Tubular markers or other channelizing devices may be used within buffers based on engineering judgement (see Section 140).

Design Issues

In Oregon, it is illegal to cross a traversable median with yellow transverse median bars. Contact the region access management engineer when considering yellow transverse median bars near accesses.

If tubular markers are used in the buffer, use a type that is easily removed and replaced for maintenance activities (sweeping, replacement of damaged markers, restriping, etc.). Consider maintenance needs of roadway elements in and near the buffer and bike lane and needs of surrounding land uses when choosing the location of tubular markers (additional pavement markings, stormwater facilities, utilities, business deliveries, oversize freight, etc.).

Figures & Tables

Figure 412-A: Bicycle Lane Buffer Types

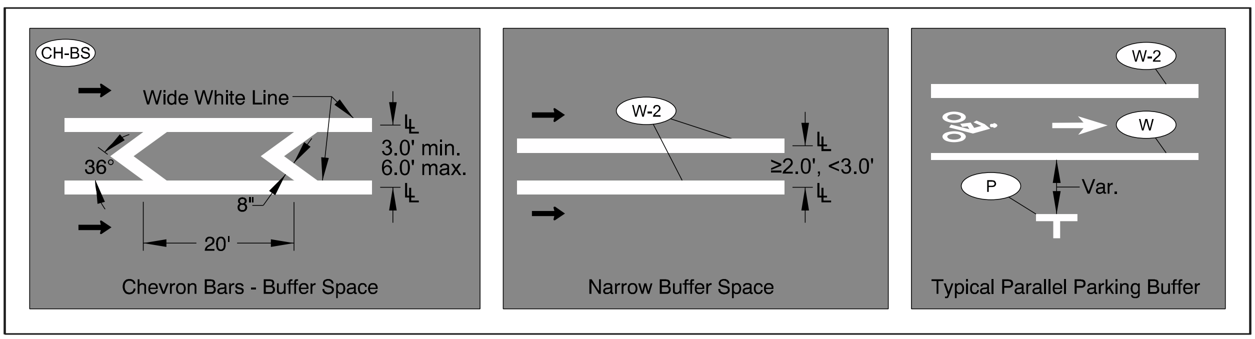


Figure 412-B: Typical Buffered Bicycle Lanes, Low & High Right Turn Volumes

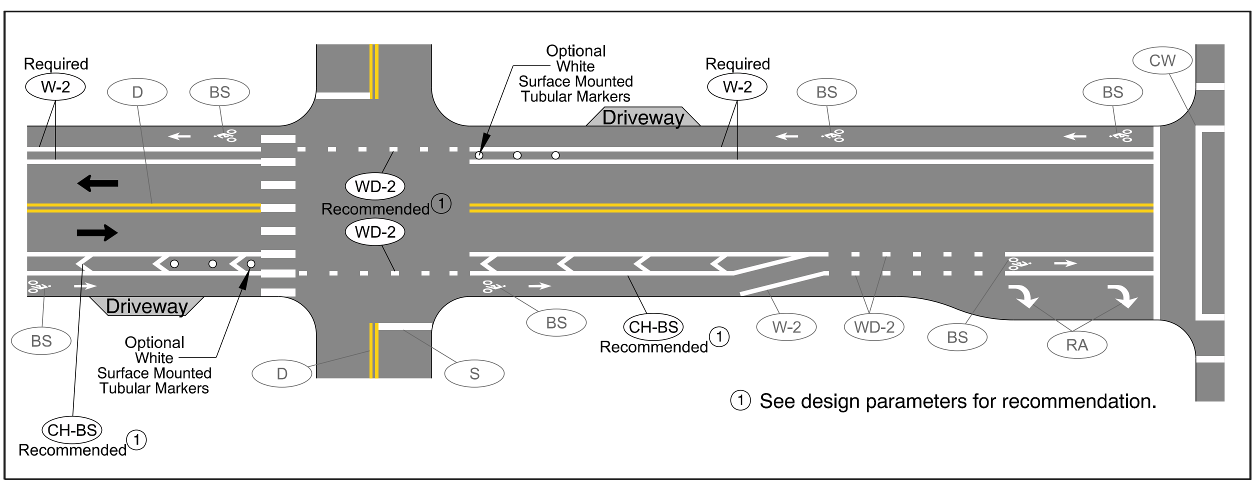


Figure 412-C: Typical Buffered Contraflow Bicycle Lane Markings

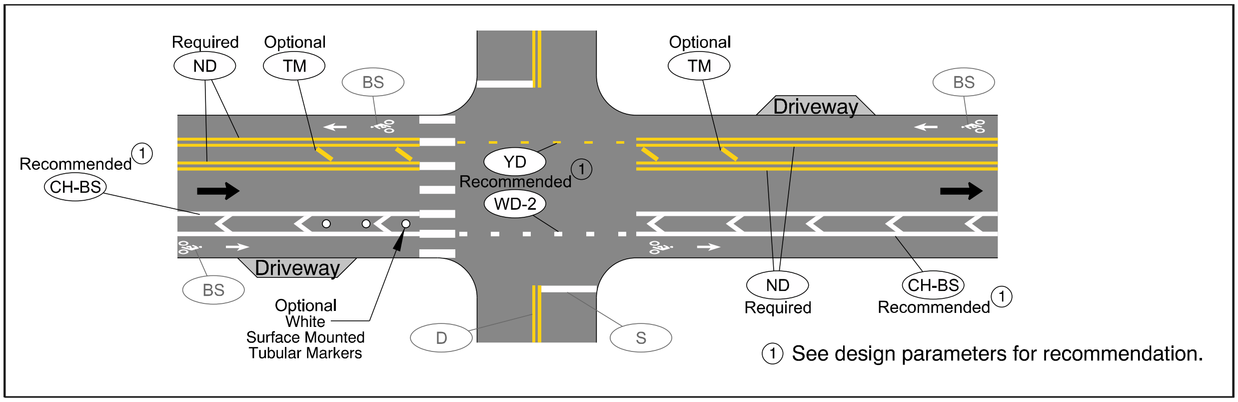
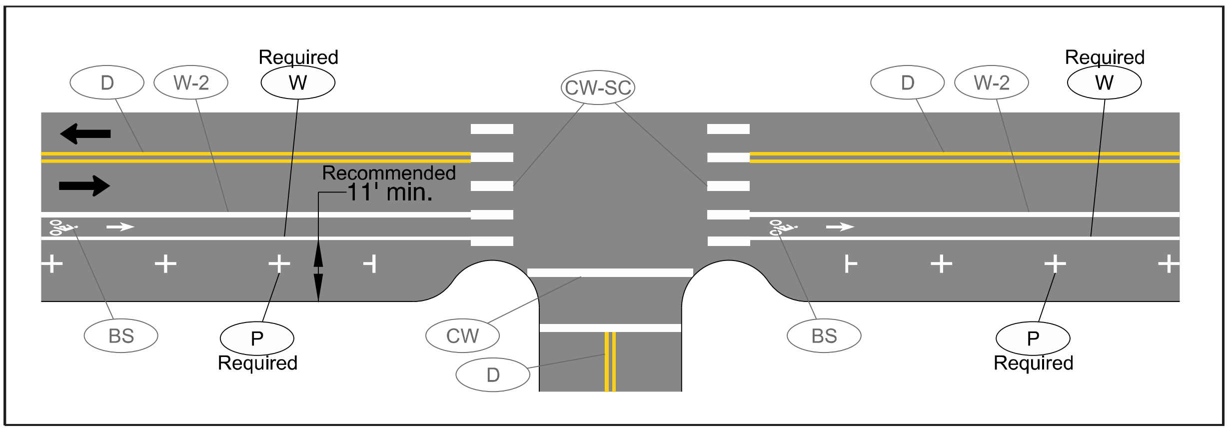


Figure 412-D: Typical Buffer Between Bicycle Lane and Parallel Parking



Support

Greater separation between people on bicycles and motor vehicles as traffic volume and motor vehicle speed increase is a widely recognized design recommendation. A buffer between a bicycle lane and motor vehicles is one way to provide this separation. This additional space can improve cyclist comfort, increase the number of people biking (*1*) (*2*), and can improve cyclist safety when properly designed (*3*) (*4*), all of which are stated goals and policies in ODOT's Bicycle and Pedestrian Plan (*5*). Painted buffers (even buffers with tubular markers) provide minimal additional separation with no changes to the road cross-section; some road contexts may need other separation measures to meet local needs and goals.

Buffered bicycle lanes are still relatively new and can be confusing to road users if not properly designed. When first implemented on Portland streets, there appeared to be confusion on how and where motorists were allowed to use the buffered bicycle lane, especially at intersections with no right turn lane and at parallel parking (*1*). Crosshatching in the buffer and additional bicycle lane stencils can help define the function of the buffer space and bicycle lane between intersections. Providing a right turn lane (even if it removes a short section of buffer), extending the bicycle lane line through the intersection, separate signal phases, or tubular markers or other vertical elements can help positively guide road users at intersections.

"Dooring" crashes are a severe crash type for people on bicycles (*6*). Providing a buffer between a bicycle lane and parallel parking can help move cyclists outside the door zone significantly better than a wide bicycle lane alone (*3*) (*7*), and can let cyclists focus on other upcoming riding hazards. See Section 410 for additional support.

Vertical elements in the buffer, such as tubular markers, can improve cyclist comfort and help open new cycling routes to "interested but concerned" riders (*1*) (*2*) (*4*) (also in support of policies stated in ODOT's Bicycle and Pedestrian Plan (*5*)). In narrow bicycle lanes, vertical or raised devices in the buffer need to be placed far enough outside the bicycle lane to avoid creating a collision potential for cyclists (*8*). The minimum operating width for a typical upright adult cyclist is 4 feet (handlebar to handlebar) to account for natural side-to-side movement (*9*). Tubular marker height also needs to be considered; the typical adult bicycle has a handlebar height 36 to 44 inches above the pavement (*9*) and most tubular markers come in standard heights of 28, 36, 42, or 48 inches.

Vertical or raised devices also need to be placed far enough outside a motor vehicle lane to minimize maintenance of the device and to allow enough space for striping equipment to maintain the buffer line on the motor vehicle side. Striping equipment typically cannot maintain a line placed closer than 1.5 feet from the face of a vertical object.

Past practice has recommended crosshatching (chevrons or diagonal bars) in buffers 4 feet wide or wider based on recommendations in the Motor Vehicle Preferential Lane Markings section of the 2009 MUTCD (Chapter 3D.02) (*8*). This section is focused on separating lanes of motor vehicle traffic, especially on high speed, high volume, and limited access highways. Because bicycles operate in a smaller space than motor vehicles, small buffers with no crosshatching can begin to look like a bicycle lane in urban contexts at lower speeds, so the purpose of buffer spaces can be less clear compared to high speed limited access contexts. For these reasons and accounting for practical limits on narrow buffer markings, crosshatching is recommended for buffers as narrow as 3 feet in the design parameters.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Transverse Markings .... Section 125
Surface Mounted Tubular Markers .... Section 140
Center Lines .... Section 210
Lane Lines .... Section 220
Traversable Medians .... Section 260
Channelizing Lines and Traversable Channelizing Islands .... Section 270
Non-Traversable Medians & Channelizing Islands .... Section 281
Line Extensions Through Intersections .... Section 340
Bicycle Lanes .... Section 410
Colored Pavement in Bicycle Lanes .... Section 413
Parking Space Markings .... Section 630

Key References

1. Monsere, C. M., N. McNeil, and J. Dill. Multiuser Perspectives on Separated, On-Street Bicycle Infrastructure. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2314, 2012, pp. 22-30. http://trrjournalonline.trb.org/doi/abs/10.3141/2314-04. DOI: http://dx.doi.org/10.3141/2314-04
2. McNeil, N., C. M. Monsere, and J. Dill. Influence of Bike Lane Buffer Types on Perceived Comfort and Safety of Bicyclists and Potential Bicyclists. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2520, January 2015, pp. 132-142. http://trrjournalonline.trb.org/doi/abs/10.3141/2520-15. DOI: http://dx.doi.org/10.3141/2520-15
3. Torbic, D. J., K. M. Bauer, C. A. Fees, D. W. Harwood, R. V. Houten, J. LaPlante, and N. Roseberry. NCHRP Report 766: Recommended Bicycle Lane Widths for Various Roadway Characteristics. Transportation Research Board of the National Academies, Washington, D.C., ISBN 978-0-309-28416-5, 2014. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_766.pdf.
4. Federal Highway Administration. *Separated Bike Lane Planning and Design Guide*. U.S. Department of Transportation, Washington, D.C., 2015. https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/separated_bikelane_pdg/separatedbikelane_pdg.pdf.
5. Oregon Department of Transportation. *Oregon Bicyle and Pedestrian PLan*. Oregon Department of Transportation, 2016. https://www.oregon.gov/odot/Planning/Documents/OBPP.pdf.
6. Johnson, M., S. Newstead, J. Oxley, and J. Charlton. Cyclists and Open Vehicle Doors: Crash Characteristics and Risk Factors. *Safety Science*, Vol. 59, November 2013, pp. 135-140. http://www.sciencedirect.com/science/article/pii/S0925753513001057. DOI: http://dx.doi.org/10.1016/j.ssci.2013.04.010
7. Duthie, J., J. F. Brady, A. F. Mills, and R. B. Machemehl. Effects of On-Street Bicycle Facility Configuration on Bicyclist and Motorist Behavior. *Transortation Researhc Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2190, 2010, pp. 37-44. http://trrjournalonline.trb.org/doi/abs/10.3141/2190-05. DOI: http://dx.doi.org/10.3141/2190-05
8. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
9. American Association of State Highway and Transportation Officials. *Guide for the Development of Bicycle Facilities*, 4th ed. Washington, D.C., 2012.

Colored Pavement in Bicycle Lanes Section 413

Introduction

Green colored pavement is an optional way to enhance the conspicuity of bicycle lanes and extensions of bicycle lanes through conflict areas with motor vehicles. ODOT is generally reserving green colored pavement to conflict areas with motor vehicles to prevent diluting the unique message green colored pavement provides, to minimize maintenance costs, and where pavement markings are used to provide color, to minimize friction concerns over the life of the marking material. Other applications of green colored pavement might require experimental approval.

Design Parameters

01 **If used, green colored pavement shall only be used within a bicycle lane or within an extension of a bicycle lane. Green colored pavement shall not be used instead of the longitudinal line(s), symbol(s), and arrow markings required for bicycle lanes in Section 410.**

02 Green colored pavement may be used to enhance the conspicuity of the bicycle lane or extension of a bicycle lane where cycling has the right-of-way and one or more of the following conditions:

- There is a bicycle-motor vehicle conflict area with one or more motor vehicle-bicycle crashes in the last 5 years associated with that conflict area.
- There is a bicycle-motor vehicle conflict area on a bicycle route to bicycle trip generators, such as schools, libraries, colleges, business districts, large parks, etc.
- There is a transition from a separated cycling facility to an on-roadway conflict area where additional delineation is needed to create a clear, visible, predictable, and distinct travel path for cyclists.
- There is a bicycle-motor vehicle conflict area at a raised or curb-separated cycling facility.

03 *If used, green colored pavement should fill the full width of the bicycle lane and should match the pattern of the white longitudinal line(s) the green colored pavement supplements (see Figure 413-A).*

04 *If used at a conflict area where the upstream travel paths for motor vehicles and bicycles are in the same general direction, a bicycle stencil (BS) should be used upstream from the green colored pavement, and green colored pavement should begin a distance "A" before the conflict area and continue at least 4 feet beyond the conflict area, as shown in Figure 413-B and 413-C.*

Required Approvals

An engineering study and region traffic engineer approval is required for installation of green colored pavement.

Design Issues

Use of green colored pavement is currently allowed under FHWA interim approval for all roadways in Oregon (*1*). Applications of green colored pavement outside the conditions of FHWA's interim approval will require experimental approval. Currently the interim approval for green is specific that green markings are to be used in bike lanes and bike lane extensions. For example, green pavement used with shared lane markings or within crosswalks currently requires FHWA experimental approval, because these use green outside of a bike lane or extension of a bike lane. Contact the Traffic-Roadway Section with any questions about green marking use, approval, or experimentation. Green channelizing devices, delineators, posts, or retroreflective elements thereof are currently not allowed (*2*).

When possible, separate legends from green pavement markings to simplify installation and maintenance.

Figures & Tables

Figure 413-A: Green Supplemented Bicycle Lane Types

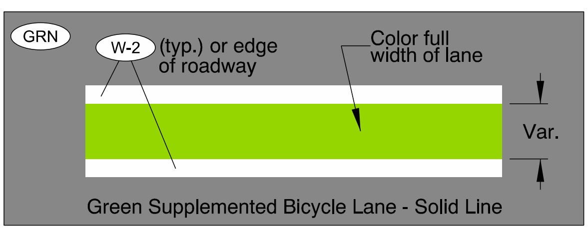
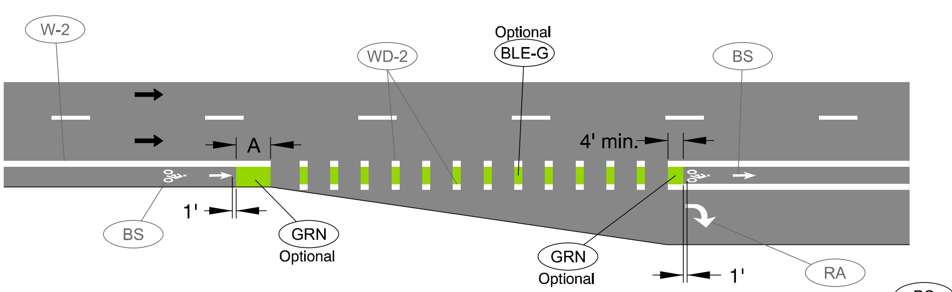


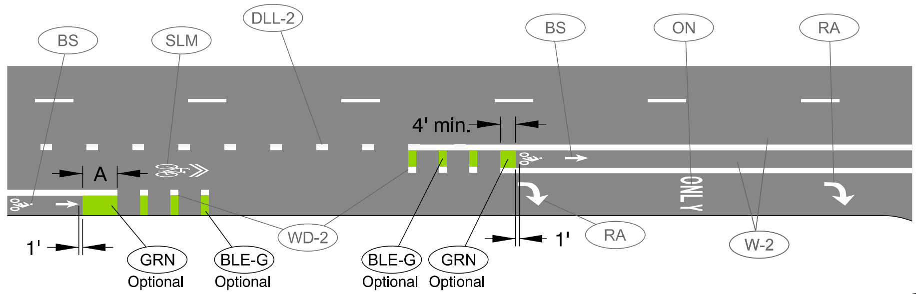
Figure 413-B: Typical Green Supplemented Bicycle Lane Across an Added Right Turn Lane Taper



Posted Speed (mph)	A* (ft.) (min.)
35 and less	9
40	30
45	50
50	70
55	90

*Add 20 feet if BS does not preceed GRN.

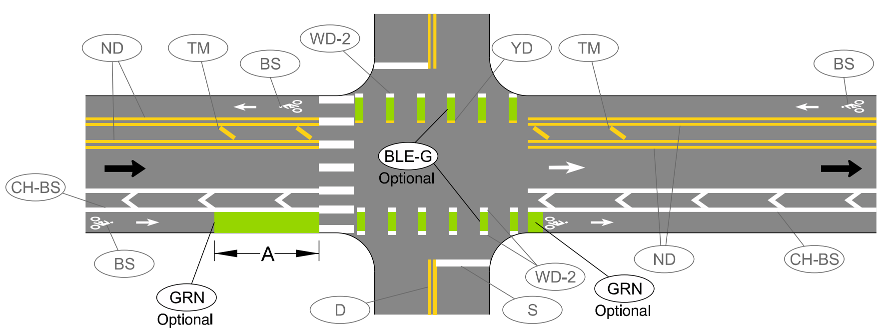
Figure 413-C: Typical Green Supplemented Bicycle Lane at a Dropped Right Turn Lane



Posted Speed (mph)	A* (ft.) (min.)
35 and less	9
40	30
45	50
50	70
55	90

*Add 20 feet if BS does not preceed GRN.

Figure 413-D: Typical Green Supplemented Buffered Bicycle Lane at an Intersection



Posted Speed (mph)	A* (ft.) (min.)
35 and less	9
40	30
45	50
50	70
55	90

*Add 20 feet if BS does not preceed GRN.

Support

Green colored pavement is a way to highlight space used for cycling. The FHWA interim approval for use of green colored pavement (*1*) allows green markings in marked bicycle lanes and in extensions of bicycle lanes through intersections and other traffic conflict areas. Green markings are not a substitute for greater separation and good geometric design. In high speed, high volume areas green markings might not have a significant impact on operations or safety (*3*).

People on bicycles tend to position themselves and behave more predictably in bicycle lanes supplemented with green markings. Cyclists also report feeling safer when green markings are used, and motorists report green markings increase their awareness that a cyclist might be present and where those cyclists are likely to be positioned on the road (*4*) (*5*) (*3*). For these reasons, and to minimize installation and maintenance costs, green markings are generally being reserved by road authorities to highlight conflict areas where people on bicycles have the right-of-way, locations where a bicycle lane is in an unusual location or configuration, and features intended for the exclusive use of bicycling (e.g.: bike boxes, left turn queue boxes).

Green colored pavement is recommended to match the longitudinal lines it supplements because road users might interpret solid green areas differently from dotted green areas (*6*). This is generally supported in field applications (*7*) (*5*) that have shown road users tend to misinterpret solid coloring in conflict areas as an area where motorists are not allowed to cross – crossing the bicycle lane before or after the intended conflict area. Matching the pattern of the white longitudinal markings can better communicate where motorists are supposed to cross the bicycle lane at conflict areas.

Full-width coloring is recommended because nearly all applications and studies of green pavement markings have been full-width coloring, national guidance (*1*) (*8*) shows and describes full-width coloring, and recent National Committee on Uniform Traffic Control Devices recommendation on MUTCD language for colored pavements is to apply color to the full width of the lane (*9*). Full-width applications clearly communicate a warning to road users about the presence of the bicycle lane, and a potential conflict area. It also maximizes the legibility distance for approaching road users.

Surface treatments like green markings change the riding surface's friction available for maneuvering and stopping. This is primarily why retroreflectivity (achieved by covering the surface with glass beads) is not typically used. Construction specifications ensure a minimum friction level is provided when the marking is new. However, applications of green colored pavement are not installed along long lengths of bicycle lanes because surface friction changes over time, to reduce maintenance, reduce installation costs, and protect how green colored pavement can highlight areas road users need to watch for conflicts.

The upstream extension distance "A" in Figures 413-A, 413-B, 413-C, and 413-D is based on motor vehicle approach speeds, a perception-reaction time for drivers of 2.5 seconds, a bicycle stencil (BS) length of 18 feet, a marking legibility distance (to the bicycle stencil) of 100 feet, and a motor vehicle deceleration to 10 mph when the driver reaches the conflict area. The advance bicycle stencil provides context for the green colored pavement immediately downstream. For posted speeds under 35 mph (where most bicycle lanes are located), this layout fits into the existing standard layout for added right turn lanes without needing to remove, move, or replace existing markings. This also allows flexibility to use green colored materials that may not be compatible with preformed thermoplastic – commonly used for bicycle stencils.

The minimum downstream extension distance of 4 feet highlights the end of the conflict area without requiring removal and replacement of the required bicycle stencil (BS) typically 5 feet after the conflict area.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Transverse Markings .... Section 125
Added Right Turn Lanes .... Section 320

Key References

1. Kehrli, M. R. MUTCD - Interim Approval for Optional Use of Green Colored Pavement for Bike Lanes (IA-14). June 29, 2011.

2. U.S. Department of Transportation Federal Highway Administration. Bicycle Facilities and the Manual on Uniform Traffic Control Devices. *Federal Highway Administration Bicycle and Pedestrian Program*, December 15, 2015. http://www.fhwa.dot.gov/environment/bicycle_pedestrian/guidance/mutcd/index.cfm. Accessed August 24, 2016.

3. Sadek, A. W., A. Dickason, and J. Kaplan. Effectiveness of a Green, High-Visibility Bike Lane and Crossing Treatment. in *Transportation Research Board 86th Annual Meeting Compendium of Papers CD-ROM*, Washington, D.C., 2007. https://wiki.cecs.pdx.edu/pub/ItsWeb/BikeBoxes/07-0990.pdf.

4. Hunter, W. W., D. L. Harkey, R. Stewart, and M. L. Birk. Evaluation of Blue Bike-Lane Treatment in Portland, Oregon. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1705, 2000, pp. 107-115. http://trrjournalonline.trb.org/doi/pdf/10.3141/1705-16.

5. Brady, J., A. Mills, J. Loskorn, J. Duthie, and R. Machemehl. Effects of Colored Lane Markings on Bicyclist and Motorist Behavior at Conflict Areas. Center for Transportation Research, University of Texas at Austin, Austin, Texas, 2010. http://library.ctr.utexas.edu/ctr-publications/iac/COAbike_ColoredLanes-final.pdf.

6. Hurwitz, D. H., C. Monsere, M. Jannat, J. Warner, and A. Razmpa. Towards Effective Design Treatment for Right Turns at Intersections with Bicycle Traffic. Oregon State University and Portland State University, Salem, Oregon, Final Technical Report FHWA-OR-RD-16-06, 2015. http://www.oregon.gov/ODOT/Programs/ResearchDocuments/SPR767_FinalReport_070815.pdf.

7. Hunter, W. W., R. Srinivasan, and C. A. Martell. Evaluation of a Green Bike Lane Weaving Area in St. Petersburg, Florida. Highway Safety Research Center, University of North Carolina, Tallahassee, Florida, 2008. http://nacto.org/wp-content/uploads/2011/01/Evaluation_of_Green_Bike_Lane_Weaving.pdf.

8. National Association of City Transportation Officials. *NACTO Urban Bikeway Design Guide*, 2nd ed. Island Press, New York, New York, 2014. http://nacto.org/cities-for-cycling/design-guide/.

9. Markings Technical Committee of the National Committee on Uniform Traffic Control Devices. Colored Pavements (Yellow, White, Green, Red, and Purple). National Committee on Uniform Traffic Control Devices, Suprise, Arizona, 2014. http://www.ncutcd.org/Documents/Meetings/June_2016/Attach%20No.23%20Markings%20Interim%20No.%202.pdf.

Intersection Bicycle Box Section 414

Introduction

An intersection bicycle box is a designated area on the approach to a signalized intersection between an advance stop line and the crosswalk intended to provide people on bicycles a space to wait in front of stopped motor vehicles during a red signal phase. At intersections with high bicycle volumes and high right-turning motor vehicle volumes, this can improve signal operations by letting bicycle queues discharge faster compared to a typical bicycle lane.

Design Parameters

01 **Where used, a bicycle box shall be formed by the following parameters:**

- **A wide advance stop bar (S-2) placed at least 10 feet in advance of the intersection stop line.**
- **At least one bicycle symbol placed within the bicycle box (see Figure 414-A and 414-B).**

02 *At least 50 feet of bicycle lane should be provided on the approach to a bicycle box.*

03 *Green colored pavement should be used within a bicycle box and for at least 30 feet in the approach bicycle lane, where one is provided (see Figure 414-A and 414-B).*

04 *A bicycle box should not extend across more than one motor vehicle lane.*

Required Approvals

An engineering study and state traffic-roadway engineer approval is required for installation of an intersection bicycle box at a state highway intersection.

Design Issues

Use of an intersection bicycle box is currently allowed under FHWA interim approval for all roadways in Oregon. Use of intersection bicycle boxes outside the conditions of FHWA's interim approval will require experimental approval.

See the interim approval (*1*) for other required traffic control devices for an intersection bicycle box, such as right turn on red prohibitions, countdown pedestrian signals where bike boxes extend across more than one motor vehicle lane, and other ADA considerations when upgrading pedestrian signals.

Placement of signal detection is based on distance from the stop bar and partially based on signal head height. Signal detection will need to be modified at retrofit installations of bicycle boxes to ensure motor vehicles are detected at the advance stop bar and bicycles are detected within the bicycle box. Signal timing will also need to be adjusted.

High motor vehicle volume and poor pavement conditions can lead to rapid deterioration and discoloration of bicycle box markings (2).

At intersections with a receiving bicycle lane and regular bicycle traffic, but where bicycle queues are not significantly impacting signal operations, a motor vehicle advance stop bar (Section 150) and bicycle lane coloring (Section 413) might improve awareness and visibility of cyclists similar to a bicycle box (2).

Bicycle boxes can reduce right-hook conflicts at the onset of the green phase, but might not significantly reduce right-hook conflicts once traffic is moving (*3*). Downhill intersection approaches can contribute to bicycles overtaking motor vehicles at a higher speed during a green phase which might increase right-hook collisions or conflicts, regardless of the presence of a bicycle box, after the initial onset of green (approximately the first 5 seconds of green) (*4*).

Figures & Tables

Figure 414-A: Typical Intersection Bicycle Box Layouts without a Right Turn Lane

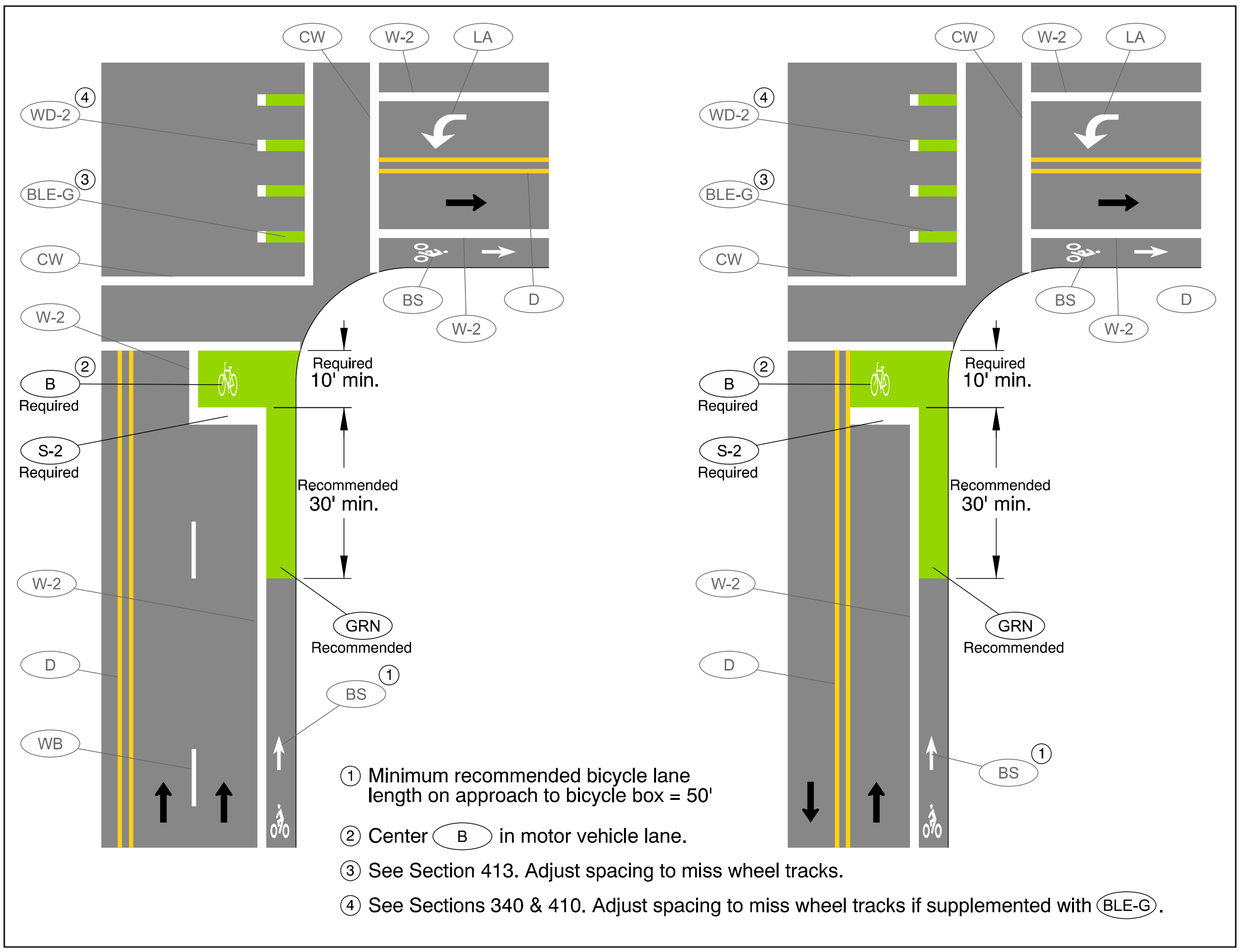
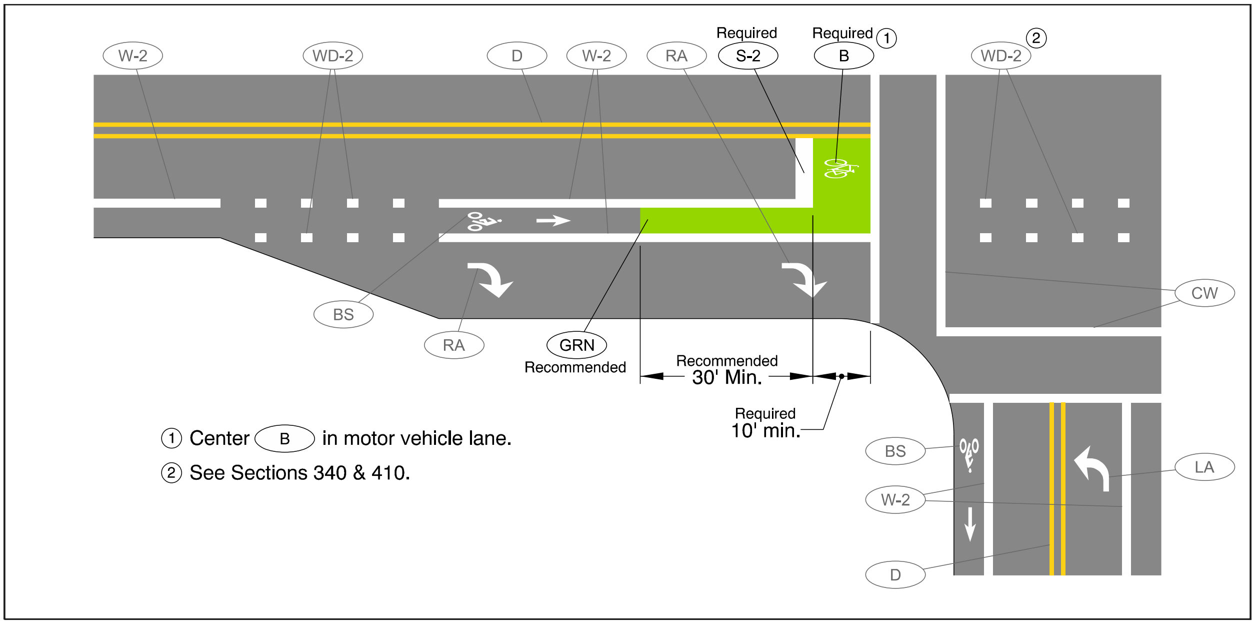


Figure 414-B: Typical Intersection Bicycle Box Layout with a Right Turn Lane



Support

FHWA gave statewide interim approval for use of intersection bicycle boxes according to the conditions of the interim approval in February 2017.

At intersections with high bicycle volumes, bicycle boxes can improve signal operations. Bicycle queues discharge faster because cyclists can queue in a group within the box instead of in a line in a typical bicycle lane. In lane configurations like shared right-through lanes to the left of a bicycle lane, this can improve intersection capacity and reduce delay to motor vehicle drivers (*5*).

Bicycle boxes place cyclists at the front of a queue at signalized intersections, which allows cyclists to take a more visible stopping position in front of drivers (*2*) (*6*). Through the experimentation process in the United States, bicycle boxes have been shown to reduce conflicts between people on bikes and turning drivers, reduce the number of avoidance maneuvers between road users, and reduce encroachment by cyclists and motorists into crosswalks (*1*).

Bicycle boxes can reduce right-hook conflicts at the onset of the green phase but might not significantly reduce right-hook conflicts once traffic is moving (*3*). Downhill intersection approaches can contribute to bicycles overtaking motor vehicles at a higher speed during a green phase which might increase right-hook collisions or conflicts, regardless of the presence of a bicycle box, after the initial onset of green (*4*).

Unless there are multiple cyclists in the queue, people on bicycles tend to stay aligned with the bicycle lane when stopped in a bicycle box (not in the box directly in front of motor vehicles).

This minimizes cyclists' out-of-direction travel and still places them in a visible location to motorists who are stopped at the advance stop bar (*2*) (*6*).

Green colored pavement in the bicycle lane a short distance on the approach to the bicycle box and in bicycle box itself might improve operational predictability for all road users. Both cyclists and motorists tend to stop where they're intended to stop more consistently with colored bicycle boxes – i.e. cyclists tend to stop ahead of motor vehicles and stay outside the crosswalk, and motorists tend to stop more consistently at the advance stop bar without encroaching on the bicycle box (*2*) (*6*).

On intersection approaches where a bicycle lane ends at the intersection (shared lane on the downstream side of the intersection, especially shared lanes too narrow to operate side-by-side), a bicycle box can reduce merging conflicts in the intersection between cyclists and drivers at the beginning of the green signal phase (*2*). This lets cyclists position themselves at the front of the queue instead of attempting to merge with motor vehicle traffic in the intersection before reaching the narrower roadway section. Bicycle queues still need to be large enough and motor vehicle speeds low enough to support a bicycle box in this situation.

Some installations of bicycle boxes have been used to transition from right-side to left-side bicycle lanes, position cyclists ahead of a left turn lane, or make other cross-intersection movements (*7*). This application typically requires extending the bicycle box across all approach lanes of the intersection. While this is allowed under the FHWA Interim Approval, this is not recommended at ODOT-owned intersections because it requires cyclists to judge whether or not they have enough time during a red phase to maneuver across motor vehicle lanes in the bicycle box before the beginning of the green phase. The FHWA Interim Approval requires use of countdown pedestrian signals for bicycle boxes across multiple lanes to show this remaining time. This can require the pedestrian phase to be recalled every cycle which can reduce operational efficiency in some cases. This also might not let cyclists make this maneuver safely near the end of the red phase and through the green phase; cyclists will either need to make a two-stage maneuver with the cross street or merge into motor vehicle lanes (*8*). Other ADA considerations are also needed when upgrading pedestrian signal heads. Other strategies like a bicycle signal or experimental two-stage left turn box might allow for safer operations.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Transverse Markings .... Section 125
Stop Bars .... Section 150
Lane Lines .... Section 220
Line Extensions Through Intersections .... Section 340
Roundabouts .... Section 350
Bicycle Lanes .... Section 410
Colored Pavement in Bicycle Lanes .... Section 413

Key References

1. Arnold, R. E. MUTCD - Interim Approval for Optional Use of an Intersection Bicycle Box (IA-18). October 12, 2016. http://mutcd.fhwa.dot.gov/resources/interim_approval/ia18/ia18.pdf. Accessed October 24, 2016.
2. Loskorn, J., A. F. Mills, J. F. Brady, J. C. Duthie, and R. B. Machemehl. Effects of Bicycle Boxes on Bicyclist and Motorist Behavior at Intersections in Austin, Texas. *ASCE Journal of Transportation Engineering*, Vol. 139, no. 10, October 2013, pp. 1039-1046. http://dx.doi.org/10.1061/(ASCE)TE.1943-5436.0000584.
3. Hurwitz, D. H., C. Monsere, M. Jannat, J. Warner, and A. Razmpa. Towards Effective Design Treatment for Right Turns at Intersections with Bicycle Traffic. Oregon State University and Portland State University, Salem, Oregon, Final Technical Report FHWA-OR-RD-16-06, 2015. http://www.oregon.gov/ODOT/Programs/ResearchDocuments/SPR767_FinalReport_070815.pdf.
4. Farley, W. R. An Analysis of Bicycle-Vehicle Interactions at Signalized Intersections with Bicycle Boxes. Portland State University, Portland, Oregon, Dissertations and Theses Paper 1618, 2014. http://archives.pdx.edu/ds/psu/11016.
5. Monsere, C., M. Figliozzi, S. Thompson, and K. Paulsen. SPR 747: Operational Guidance for Bicycle-Specific Traffic Signals in the United States. Portland State University, Portland, Oregon, FHWA-OR-RD-14-06, 2013. http://www.oregon.gov/ODOT/TD/TP_RES/.
6. Dill, J., C. M. Monsere, and N. McNeil. Evaluation of Bike Boxes at Signalized Intersections. *Accident Analysis & Prevention*, Vol. 44, no. 1, January 2012, pp. 126-134. http://dx.doi.org/10.1016/j.aap.2010.10.030.
7. Hunter, W. Evaluation of Innovative Bike-Box Application in Eugene, Oregon. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1705, 2000, pp. 99-106. http://trrjournalonline.trb.org/doi/abs/10.3141/1705-15. DOI: http://dx.doi.org/10.3141/1705-15
8. National Association of City Transportation Officials. *NACTO Urban Bikeway Design Guide*, 2nd ed. National Association of City Transportation Officials, New York, New York. http://nacto.org/cities-for-cycling/design-guide/.

Two-Stage Turn Bicycle Box Section 415

Introduction

See FHWA's Interim Approval for Optional Use of Two-Stage Bicycle Turn Boxes (IA-20) (*1*) for all requirements to use two-stage bicycle turn boxes.

Required Approvals

An engineering study and state traffic-roadway engineer approval is required for installation of two-stage bicycle turn boxes at a state highway intersection.

Key References

1. Knopp, M. C. MUTCD - Interim Approval for Optional Use of Two-Stage Bicycle Turn Boxes (IA-20). July 13, 2017. https://mutcd.fhwa.dot.gov/resources/interim_approval/ia20/ia20.pdf. Accessed April 17, 2020.

Bicycle Detector Markings Section 416

Introduction

The bicycle detector pavement marking shows people on bikes where to position themselves for passive detection at a traffic signal.

Design Parameters

01 A bicycle detector symbol (see Figure 416-A) may be placed on the pavement indicating the optimum position for a bicyclist to actuate a traffic signal (see Figures 416-B and 416-C).

Design Issues

Where non-intrusive detection is used instead of inductive loops (e.g.: video, infrared, radar, etc.), contact the region signal operations engineer for assistance locating the optimum detection location for application of the bicycle detector marking.

Circular loop detectors have two optimum detection zones for bicycles (*1*); place the bicycle detector symbol on the right side so cyclists can stay as far to the right as practical as required in ORS 814.430.

See the 2009 MUTCD (2) for additional signing associated with bicycle detector markings.

Figures & Tables

Figure 416-A: Bicycle Detector Pavement Marking Types

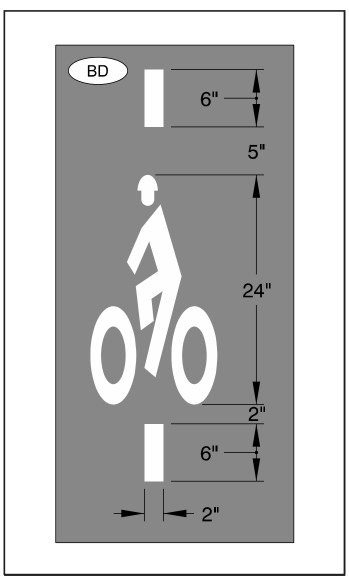


Figure 416-B: Typical Bicycle Detector Placement at 6-Foot Loop Detector

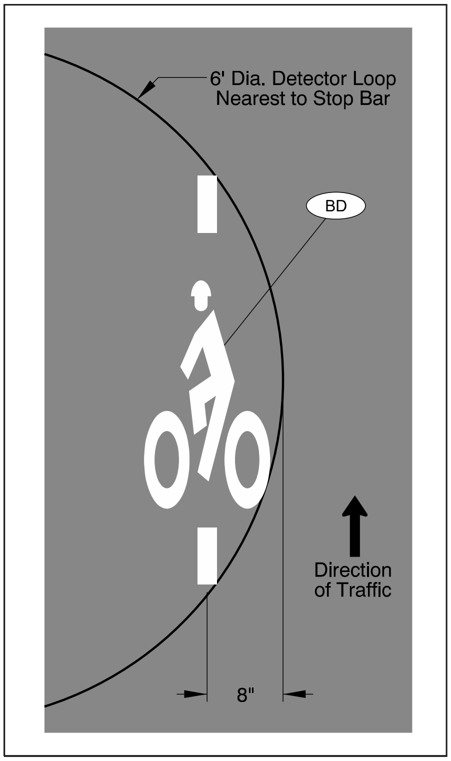
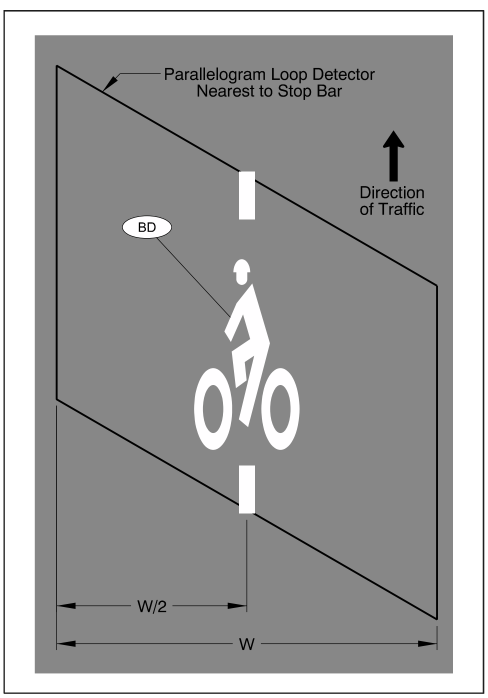


Figure 416-C: Typical Bicycle Detector Placement at Parallelogram Loop Detector



Support

There are many different kinds of signal detectors and the location for optimum bicycle detection can be difficult to find for cyclists, especially if the detection area is out of the normal riding path, where induction loops are paved over, or where non-intrusive detection is used (e.g.: video, infrared, etc.). If a cyclist does not position themselves where they will be detected by a traffic signal they will either have to wait until a motor vehicle is detected or they might grow impatient and run the red light (*3*). ORS 811.360 allows a cyclist to go against a red light if the signal does not detect the cyclist after one cycle.

The bicycle detector marking from Figure 9C-7 in the 2009 MUTCD (*2*) is intended to show cyclists where to position their bicycles to actuate a traffic signal. The meaning of the symbol is not well known at this time; less than half of cyclists surveyed in Portland understood the meaning of the marking, and field installations in Portland only slightly improved cyclist positioning for detection, even with supplemental signing (*4*).

At inductive loops, bicycles are best detected when both wheels are on or very near the perimeter of the detector (*1*). Placing the marking 8 inches from the edge of a 6-foot circular loop detector positions the bicycle in this optimum detection area. Bicycles are typically detected best at parallelogram loop detectors when positioned over the loop's center (*5*).

Cross References

Colors .... Section 110
Bicycle Lanes .... Section 410

Key References

1. Kidarsa, R., T. Pande, S. V. Vanjari, J. V. Krogmeier, and D. M. Bullock. Design Considerations for Detecting Bicycles with Inductive Loop Detectors. *Transportation Research Record: Journal of the Transportation Rsearch Board of the National Academies*, Vol. 1978, 2006, pp. 1-7. http://trrjournalonline.trb.org/doi/abs/10.3141/1978-03. DOI: http://dx.doi.org/10.3141/1978-03
2. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Federal Highway Administration, Washington, D.C., 2012. https://mutcd.fhwa.dot.gov/.
3. Boudart, J., R. Liu, P. Koonce, and L. Okimoto. Assessment of Bicyclist Behavior at Traffic Signals with a Detector Confiration Feedback Device. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2520, 2015, pp. 61-66. http://trrjournalonline.trb.org/doi/abs/10.3141/2520-08. DOI: http://dx.doi.org/10.3141/2520-08
4. Bussey, S., C. M. Monsere, and P. Koonce. Paper 15-2501: Does the Bicycle Detector Symbol Change Cyclist Queuing Position at Signalized Intersections? in *Transportation Research Board 94th Annual Meeting*, Washington, D.C., 2015. http://amonline.trb.org/trb57535-2015-1.1793793/t024-1.1811852/593-1.1812263/15-2501-1.1812276/15-2501-1.1940644?qr=1.
5. Nordback, K., S. Kothuri, M. Figliozzi, T. Phillips, C. Gorecki, and A. Schrope. Investigation of Bicycle and Pedestrian Continuous and Short Duration Count Technologies in Oregon. Portland State University, Portland, Oregon, FHWA-OR-RD-16-15, 2016. http://www.oregon.gov/ODOT/Programs/ResearchDocuments/SPR772_Bicycle_PedestrianTechnologies.pdf.

Shared Lane Markings Section 420

Introduction

Shared lane markings, also known as “sharrows,” are used to communicate a shared lane environment for biking and driving. The markings assist bicyclists with lane positioning and remind motorists they can expect people on bikes in the lane.

Design Parameters

01 **A shared lane marking shall consist of a bicycle symbol and two chevrons as shown in Figure 420-A.**

02 Shared lane markings may be used to:

- Assist bicyclist lateral positioning in a shared lane with on-street parallel parking to reduce the chance of a bicyclist’s impacting the open door of a parked vehicle.
- Assist with lateral positioning in lanes that are too narrow for a motor vehicle and a bicycle to travel side by side within the same traffic lane.
- Alert motorists of the lateral location bicyclists are likely to occupy within the traveled way.
- Encourage safe passing of bicyclists by motorists.
- Reduce wrong-way biking.

03 **Shared lane markings shall not be used on shoulders, in designated bicycle lanes, or in travel lanes adjacent to a bicycle lane traveling in the same direction.**

04 *Shared lane markings should not be placed on roadways that have a speed limit above 35 mph or in areas with limited sight distance.*

05 **If shared lane markings are used on roadway segments with a speed limit above 35 mph or in areas with limited sight distance, other traffic control devices that warn drivers of the shared roadway condition shall be used.**

06 *If used in a shared lane without on-street parking, shared lane markings should be positioned in the middle of the shared lane. If used in a shared lane with adjacent on-street parking, shared lane markings should be placed in the middle of the shared lane so the center of the marking is at least 11 feet from the face of the curb, or from the edge of the pavement where there is no curb (Figure 420-B).*

07 *If used, shared lane markings should be placed immediately after an intersection and spaced at intervals not greater than 250 feet thereafter.*

Required Approvals

An engineering study and state traffic-roadway engineer approval is required for applications of shared lane markings on roadway segments with posted speeds above 30 mph, or an 85th percentile operating speed above 35 mph, that has limited alternative routes and high bicycle volumes where the narrow roadway width requires bicyclists to ride in the travel lane (e.g.: narrow bridges, tunnels, etc.).

An engineering study and region traffic engineer review is recommended for applications of shared lane markings on roadway segments with posted speeds up to 30 mph and an 85th percentile operating speed up to 35 mph.

Design Issues

The MUTCD recommends spacing 250 feet between markings so bicyclists can see the next marking (*1*); longer spacing could be appropriate based on engineering judgement.

Figures & Tables

Figure 420-A: Shared Lane Marking Detail

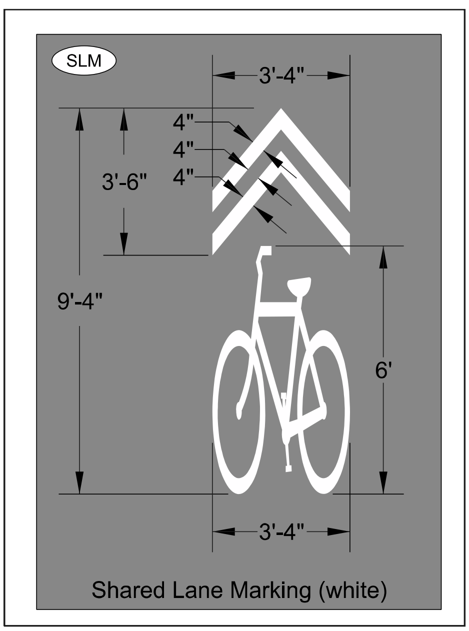
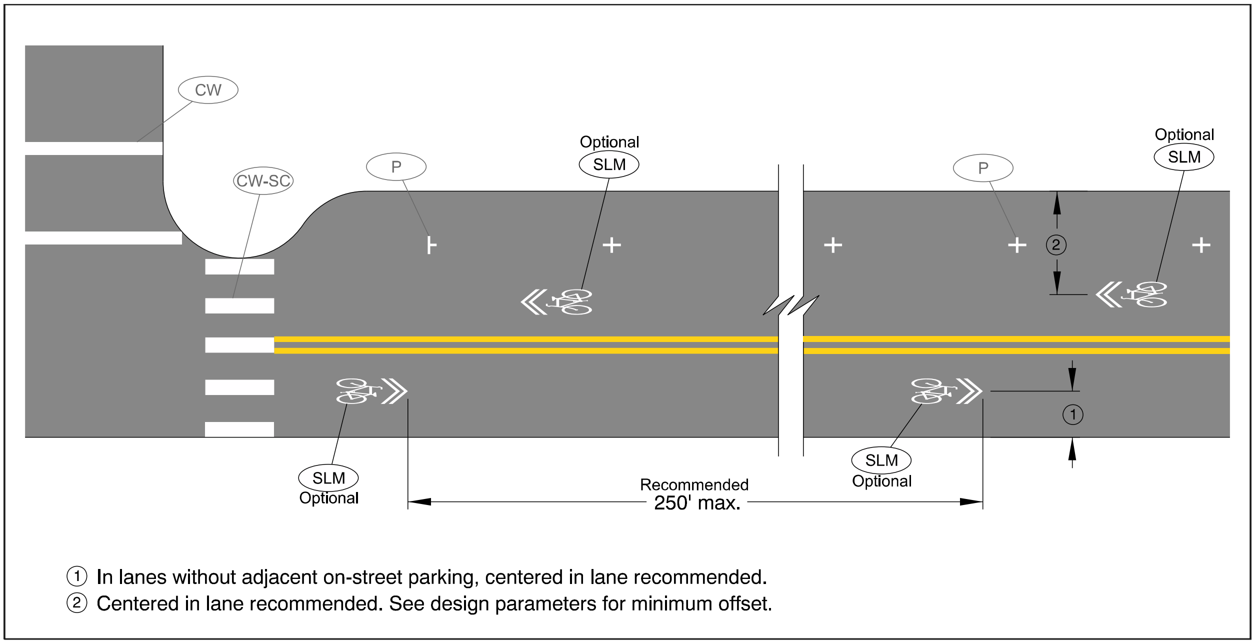


Figure 420-B: Typical Urban Shared Lane Marking Layout



Support

When applied appropriately, shared lane markings generally (2) (3):

- Alert motorists of the potential presence of people on bikes.
- Guide bicyclists to a safer position within the lane.
- Alert motorists of the lateral position people on bikes are likely to occupy.
- Encourage safer passing practices by motorists.
- Reduce wrong-way and sidewalk biking.
- Supplement wayfinding along bike routes and bikeways.

The AASHTO Guide for the Development of Bicycle Facilities (2) includes additional guidance including a list of typical applications or scenarios where shared lane markings could be beneficial.

Shared lane markings are not cycling infrastructure and does not substitute for cycling infrastructure (bike lanes or separated bikeways) when those are a preferable and feasible solution. Application of shared lane markings does not change the responsibilities of road users and does not lessen any need for bike lanes or other separated facilities. The markings could give a false sense of safety to people on bikes if used on high speed roadways or in areas with limited sight distance. In these cases, other warning devices are more appropriate.

In many cases, the best location for the shared lane marking is in the middle of the travel lane for suggested bicycle positioning and reduced maintenance needs. Placement needs to encourage bicyclist to fully occupy a narrow lane where a motor vehicle cannot safely pass a bike without leaving the shared lane, but without contradicting the expectation of ORS 814.430 that bicyclists ride as far to the right as “practicable.”

Early use of the shared lane markings included experimentation with different orientations of chevrons for wayfinding and direction of bikeways. Shared lane markings are not intended to communicate a direction message; the FHWA has disallowed experimentation with alterations of the shared lane marking symbol, including its chevrons (*4*).

Cross References

Colors .... Section 110
Transverse Markings .... Section 125
Dropped Lanes and Auxiliary Lanes on Conventional Roads .... Section 330
Bicycle Lanes .... Section 410
Bicycle Lane End Transitions .... Section 411

Key References

1. *Federal Register: Volume 74, Number 240*. Washington, D.C.: United States Government Publishing Office, 2009, p. 66860. https://www.gpo.gov/fdsys/pkg/FR-2009-12-16/pdf/E9-28322.pdf.
2. American Association of State Highway and Transportation Officials. *Guide for the Development of Bicycle Facilities*, 4th ed. Washington, D.C., 2012.
3. National Association of City Transportation Officials. *NACTO Urban Bikeway Design Guide*, 2nd ed. Island Press, New York, New York, 2014. http://nacto.org/cities-for-cycling/design-guide/.
4. U.S. Department of Transportation Federal Highway Administration. Bicycle Facilities and the Manual on Uniform Traffic Control Devices. *Federal Highway Administration Bicycle and Pedestrian Program*, December 15, 2015. http://www.fhwa.dot.gov/environment/bicycle_pedestrian/guidance/mutcd/index.cfm. Accessed August 24, 2016.

Marked Crosswalks Section 430

Introduction

See the ODOT Traffic Manual (*1*) for criteria and considerations on marking crosswalks.

Design Parameters

01 **Unless officially closed, crosswalks shall be marked at signalized intersections (all crossings with pedestrian "WALK/DON'T WALK" indications) and at established school crossings (see Sec. 610).**

02 *Crosswalks should be marked across roundabout entrances and exits if sidewalks or multi-use paths are provided at the roundabout (see Section 350).*

03 Crosswalks may be marked across roadway approaches controlled by a stop sign, unsignalized channelized right turn lanes (see Section 321), rural roundabouts (see Section 350), and at other locations approved by the state traffic-roadway engineer (e.g.: mid-block).

04 *Staggered continental crosswalk markings (Figure 430-B) should be used for all marked crosswalks across uncontrolled approaches, yield-controlled approaches, midblock crosswalks, roundabouts, unsignalized channelized right turn lanes, and crossings using a pedestrian activated flashing beacon.*

05 **If the staggered continental crosswalk is skewed, the staggered continental bars shall run parallel to the direction of motor vehicle traffic to miss wheel tracks.**

06 *Transverse crosswalk markings (Figure 430-A) should be used for marked crosswalks across stop-controlled approaches (other than a channelized right-turn lane) and at signalized intersections.*

07 **Marked crosswalks shall have ADA compliant curb ramps or blended transitions at each end of the crosswalk, and shall have the throat of the ADA curb ramp (the portion flush with the pavement surface) or blended transition entirely inside the crosswalk markings.**

08 *At non-signal controlled channelized right turn lanes, marked crosswalks should be located 25 to 40 feet from the yield line, stop bar, or island gore point (Figure 430-D).*

09 *Except at roundabouts, marked crosswalks across uncontrolled, multi-lane approaches should include wide advance stop bars (S-2) 20 to 50 feet (typically 30 feet) from the nearside crosswalk edge (Figure 430-E). A wide solid lane line (W-2) should be used a length "B" in Figure 430-E in advance of the stop bar where the posted or 85^{th} percentile approach speed is greater than or equal to 35 mph and at school crossings.*

10 At marked crosswalks across uncontrolled, multi-lane approaches

- A wide solid lane line (W-2) may be included a length "B" in advance of the stop bar where the posted or 85^{th} percentile approach speed is less than 35 mph (Figure 430-E).
- The broken line (WB) may be omitted between the wide advance stop bar (S-2) and the staggered continental crosswalk (CW-SC) (Figure 430-E).

- If a wide solid lane line (W-2) is used in advance of the stop bar it may be extended past the wide advance stop bar (S-2) to the staggered continental crosswalk (CW-SC) (Figure 430-E).

11 Marked crosswalks across uncontrolled, single-lane approaches may include wide advance stop bars (S-2) 20 to 50 feet (typically 30 feet) from the nearside crosswalk edge.

12 The distance between transverse crosswalk bars (in Figure 430-A, measured from inside to inside of the bars) may be narrowed to less than 10 feet to a minimum of 6 feet if a wide advance stop bar is used.

13 **On roadways with centerline markings, no-passing zone markings shall be used on approaches to marked crosswalks a minimum distance shown in Table 211-2 in Section 211.**

Required Approvals

- See the ODOT Traffic Manual (*1*) for approvals related to Marked Crosswalks.

Figures & Tables

Figure 430-A" Standard Crosswalk (Two 1' White Bars)

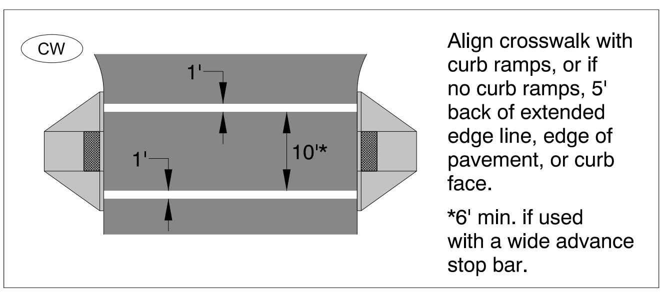


Figure 430-B: Staggered Continental Crosswalk (2' White Bars)

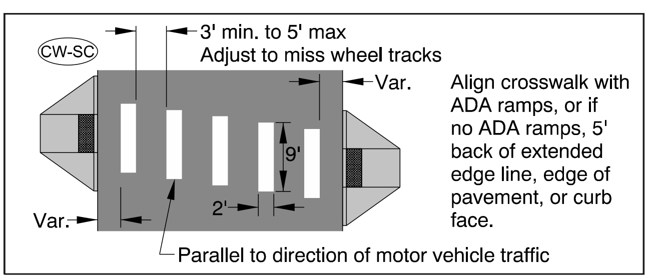


Figure 430-C: Typical Signalized or Stop-Controlled Intersection Crosswalk Markings

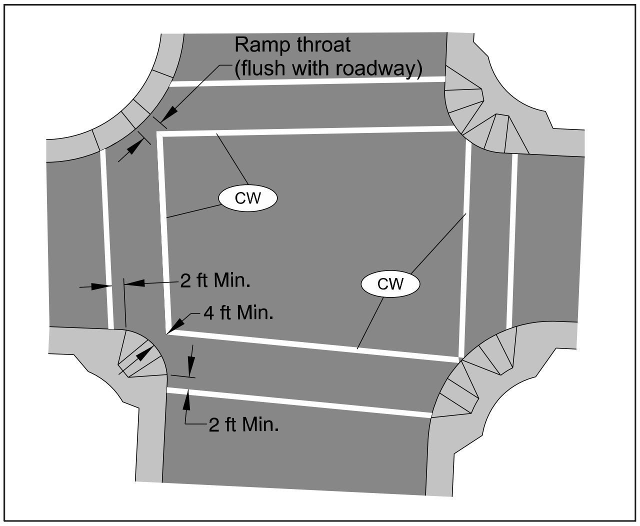


Figure 430-D: Typical Marked Crosswalk at Unsignalized Channelized Right Turn Lane

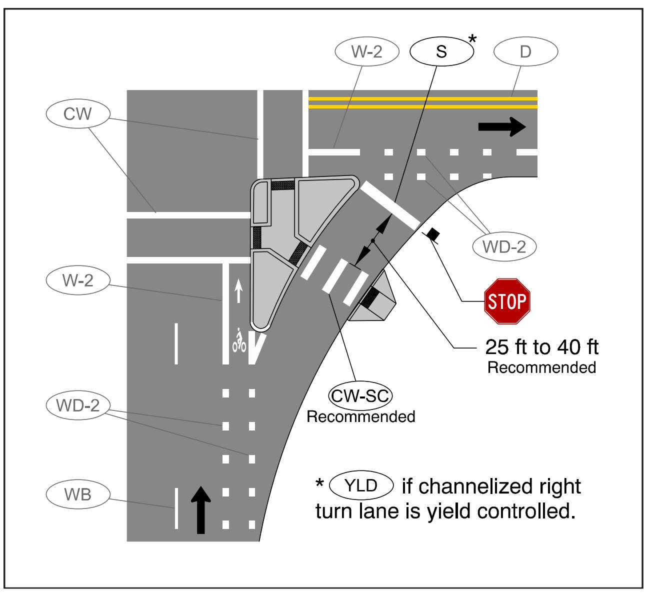
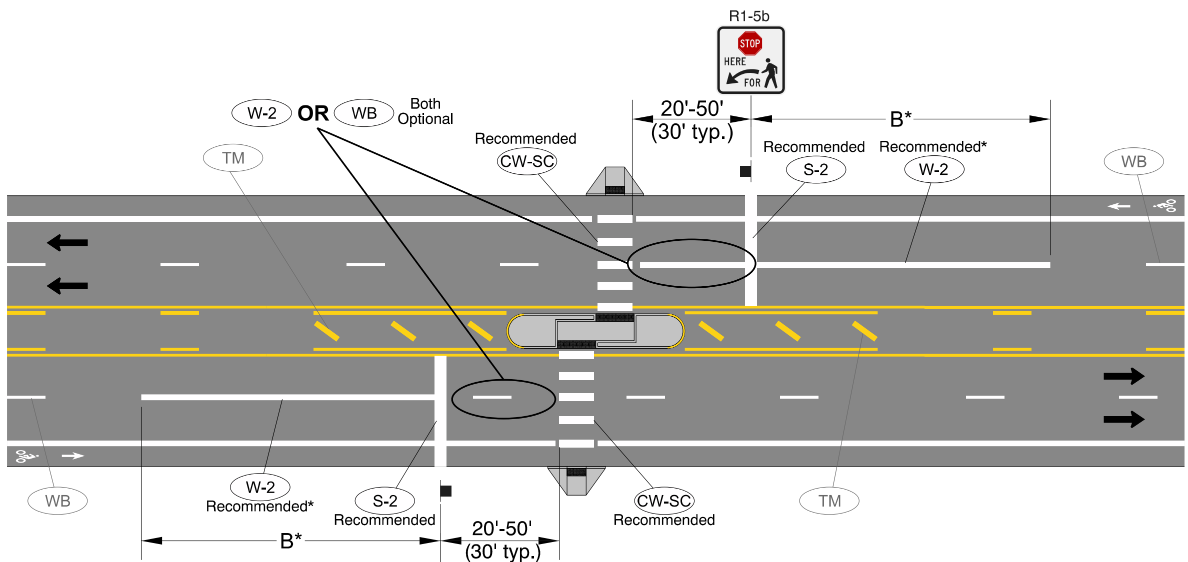


Figure 430-E: Typical Multi-Lane Midblock Crosswalk Markings



* W-2 at school crossings and for posted or 85th percentile speeds greater than or equal to 35 mph. Otherwise WB.

Posted or 85th Percentile Speed (mph)	20	25	30	35	40	45	50	55
B (ft) (min)	40	60	90	120	155	195	240	295

Support

Crosswalk markings are just one part of an effective pedestrian crossing. Simply marking a crosswalk could be insufficient to improve pedestrian safety, particularly on high-speed, high-volume, and multilane roadways. On low volume (<12,000 ADT) two-lane roadways, marked crosswalks generally do not have any positive or negative effect on pedestrian crash rates, but choose even these locations carefully; additional traffic control measures could be needed. Advance signing, pavement markings, removing parking, illumination, curb extensions, median refuge islands, traffic signals/beacons, and traffic calming measures are some tools to help pedestrians cross the roadway safely (*2*).

Drivers are much more likely to stop at a crosswalk when they have a clear line of sight to the pedestrian. Crosswalks across multilane, uncontrolled approaches are prone to “multiple-threat” crash types. This occurs when a vehicle stops for the pedestrian too close to the crosswalk, blocking sight lines of drivers approaching from the same direction in an adjacent lane. Advance stop bars paired with other treatments help reduce this crash type and improve compliance of approaching drivers (*3*). Advance stop bars and crosswalk signing are considerably more effective if parking is removed between the crosswalk and advance stop bar by improving sight lines between pedestrians and drivers (*4*) (*5*) (*6*). Risk of fatal injury for a pedestrian hit by a motor vehicle increases above 45 percent as speeds exceed 30 mph (*7*) (*8*); discouraging lane changes on higher-speed approaches can help reduce the chance of a crash due to a lane change to pass a vehicle slowing for the pedestrian. "B" is the braking distance from the Green Book (*9*).

Transverse ("standard") crosswalk markings are the preferred style on controlled approaches (stop sign and signal controlled). In these locations the crosswalk marking is a secondary traffic control device that often doubles as a stop bar. Drivers at these approaches are required to stop at all times (stop sign) or part of the time (traffic signal) regardless of the presence of a pedestrian.

Continental crosswalk markings are the preferred style on uncontrolled approaches because they are visible from a significantly greater distance than transverse crosswalk markings (*10*). This gives drivers more preview time to scan for pedestrians as they approach a crosswalk and determine if they need to stop. Uniform use of continental crosswalk markings across uncontrolled approaches also helps reinforce different duties of drivers to pedestrians at these locations compared to stop-controlled approaches. Continental crosswalk markings require more material and labor to install, but they will typically not require as much maintenance if they are installed to avoid wheel tracks.

Special emphasis for particular crosswalks can be added through other traffic control devices and design strategies such as school zone signs, school markings, curb extensions, median refuge islands, etc. The added preview time of continental crosswalk markings makes them an important tool at all uncontrolled approaches to highlight an area where a pedestrian could cross.

It is ODOT's policy not to install textured or colored crosswalks. If colored or textured treatment is desired for a crosswalk, ensure the materials used for the coloring are subdued and non-retroreflective, texturing will not cause tripping and is a non-slip material, and the whole system does not diminish the effectiveness of the white pavement markings used to establish the marked crosswalk (*11*). Avoid pavers and textures that tend to shift and settle and make traversing difficult, especially for people with walkers, in wheelchairs, and sight impaired people using canes (*7*).

On diagonal curb ramps, the 4 foot minimum distance from the throat of the ramp allows people in wheelchairs to enter and exit the crosswalk while remaining completely in the crosswalk (*12*).

In some cases, the crosswalk might need to be wider than standard to satisfy ADA design requirements.

For more information on criteria and considerations for marking and closing crosswalks on state highways, see the ODOT Traffic Manual (*1*), Section 3B.18 in the 2009 MUTCD (*13*) and Oregon Supplement to the MUTCD (*14*).

For uncontrolled, multi-lane approaches to crosswalks, the wide advance stop bar has an allowed range of placement. Depending on where this advance stop bar is placed it may result in no broken line or partial broken line markings between the stop bar and the crosswalk. Due to this variance of distance WB markings may be removed in the section between the advance stop bar and the crosswalk. It may also be desired to remove the broken line marking to give the advance stop bar more of an intersection feel to drivers. There is also the option to add a wide solid lane line in this location at the crosswalk. This marking would discourage changing lanes near the crosswalk and it also gives the opportunity to match the look of a turn bay if the scenario has multiple through lanes and a dedicated turn lane.

Cross References

Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Transverse Markings .... Section 125
Stop Bars .... Section 150
No-Passing Zone Markings .... Section 211
Lane Lines .... Section 220
Non-Traversable Medians & Channelizing Islands .... Section 281
Channelized Right-Turn Lanes .... Section 321
Roundabouts .... Section 350
Shared-Use Path Markings .... Section 440
School Markings .... Section 610

Key References

1. Oregon Department of Transportation. Traffic Manual, 2016 Edition. January 2016. http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Traffic-Manual-v2016.pdf. Accessed July 3, 2017.
2. Zegeer, C. V., J. R. Stewart, H. H. Huang, P. A. Lagerwey, J. Feaganes, and B. J. Campbell. Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines. University of North Carolina, Chapel Hill, NC, FHWA-HRT-01-100, 2005. https://www.fhwa.dot.gov/publications/research/safety/04100/04100.pdf.
3. Zegeer, C., R. Srinivasan, B. Lan, D. Carter, S. Smith, C. Sundstrom, N. J. Thirsk, C. Lyon, B. Persaud, J. Zegeer, E. Ferguson, and R. V. Houten. NCHRP Research Report 841: Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments. Transportation Research Board of the National Academies, Washington, D.C., ISBN 978-0-309-44626-6, 2017. http://www.trb.org/Publications/Blurbs/175381.aspx. DOI: http://dx.doi.org/10.17226/24627
4. Samuel, S., M. R.E. Romoser, L. R. Gerardino, M. Hamid, R. A. Gomez, M. A. Knodler, Jr., J. Collura, and D. L. Fisher. Effect of Advance Yield Markings and Symbolic Signs on Vehicle-Pedestrian Conflicts: Field Evaluation. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2393, 2013, pp. 139-146. http://trrjournalonline.trb.org/doi/pdf/10.3141/2393-16. DOI: 10.3141/2393-16
5. Gomez, R. A., S. Samuel, L. R. Gerardino, M. R.E. Romoser, J. Collura, M. Knodler, and D. L. Fisher. Do Advance Yield Markings Increase Safe Driver Behaviors at Unsignalized, Marked Midblock Crosswalks? *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2264, 2011, pp. 27-33. http://trrjournalonline.trb.org/doi/pdf/10.3141/2264-04. DOI: 10.3141/2264-04
6. Van Houten, R., J.E. L. Malenfant, and D. McCusker. Advance Yield Markings: Reducing Motor Vehicle - Pedestrian Conflicts at Multilane Crosswalks with Uncontrolled Approach. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1773, 2001, pp. 69-74. http://trrjournalonline.trb.org/doi/pdf/10.3141/1773-08.
7. American Association of State Highway and Transportation Officials. *Guide for the Planning, Design, and Operation of Pedestrian Facilities*. American Association of State Highway and Transportation Officials, Washington, D.C., 2004.

8. American Association of State Highway and Transportation Officials. *Highway Safety Manual*, 1st ed. AASHTO, Washington, D.C., 2010.
9. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*, 6th ed. Washington, D.C., 2011.
10. Fitzpatrick, K., S. T. Chrysler, V. Iragavarapu, and E. S. Park. Crosswalk Marking Field Visibility Study. Texas Transportation Institute, Texas A&M University, McLean VA, Technical Report FHWA-HRT-10-068, 2010. http://www.fhwa.dot.gov/publications/research/safety/pedbike/10068/10068.pdf.
11. Lindley, J. A. (2013, August) MUTCD - Official Ruling 3(09)-24(I)-Application of Colored Pavement. Memorandum. [Online]. http://mutcd.fhwa.dot.gov/resources/interpretations/pdf/3_09_24.pdf.
12. U.S. Architectural and Transportation Barriers Compliance Board (Access Board). *Americans with Disabiulities Act (ADA) Accessibility Guidelines for Buildings and Facilities*, 2004 ed. U.S. Architectural and Transportation Barriers Compliance Board (Access Board), Washington, D.C., 1991. https://www.access-board.gov/guidelines-and-standards/buildings-and-sites/about-the-ada-standards/background.
13. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Washington, D.C., 2009.
14. Oregon Department of Transportation. *Oregon Supplement to the 2009 MUTCD*, 2009 ed. Oregon Department of Transportation, Salem, Oregon, 2011. http://www.oregon.gov/ODOT/Engineering/Documents_TrafficStandards/MUTCD-OR-Supplement.pdf.

Shared-Use Path Markings Section 440

Introduction

A shared-use path is outside the traveled way and physically separated from motor vehicle traffic by an open space or barrier and either within the highway right-of-way or within an independent alignment. Unlike separated bicycle lanes, shared use paths are also used by pedestrians (including skaters, users of manual and motorized wheelchairs, and joggers) and other authorized users.

Design Parameters

01 **Markings used on shared-use paths shall be retroreflectorized.**

02 On shared-use paths 10 feet wide or wider, a solid yellow centerline (Y) may be used to separate two directions of travel where passing is not permitted, and a broken yellow line may be used where passing is permitted.

03 *Broken lines on shared use paths should consist of a 3-foot line segment with 9-foot gaps.*

04 *A solid yellow centerline should be used on shared use paths 10 feet wide or wider:*

- *Where conditions make it desirable to separate two directions of travel at particular locations to indicate no passing and no traveling to the left of the line.*
- *On an approach to a bikeway stop sign or yield sign a distance "A" shown in Figure 440-E.*

05 *Markings shown in Figures 440-B and 440-C should be used where obstructions are located in the path, including vertical elements intended to prevent unauthorized vehicles from entering the path.*

06 Arrows used for bicycle lanes may be used on shared-use paths where arrows are needed (see Section 410). Four-foot tall word legends may be used on shared-use paths where word legends are needed.

07 A stop bar should be placed on the shared use path where bicycle traffic is required to stop in compliance with a standard bikeway stop sign (OBR1-1 or R1-1).

08 **Where used on a shared-use path, a stop bar shall consist of a solid white 12-inch wide line extending across approach lanes to indicate the point at which a stop is intended or required to be made.**

09 A yield line may be placed on the shared use path where bicycle traffic is required to yield in compliance with a standard bikeway yield sign (OBR1-2 or R1-2).

10 **Where used on a shared-use path, a yield line shall be marked using the bicycle yield line according to Section 151.**

11 If a shared-use path does not include a centerline on the approach to a stop bar or yield line, the stop bar or yield line may extend across the full width of the shared-use path.

12 **If marked, shared-use path crossings shall be marked across roadways according to Section 430.**

13 **Shared-use paths shall be marked according to Section 510 at railroad grade crossing.**

14 A normal width solid white line may be used on shared-use paths:

- As an edge line.
- To separate different types of users.

Design Issues

Shared-use paths serve a wide variety of users. Speed variability of each mode effects design treatments at path-roadway intersections. Consider needs for the fastest vehicles on approaches and needs of slower users (typically pedestrians) at crossings due to greater exposure to traffic. See the AASHTO Guide for the Development of Bicycle Facilities (*1*) for more on design considerations.

Figures & Tables

Figure 440-A: Shared Use Path Line Types

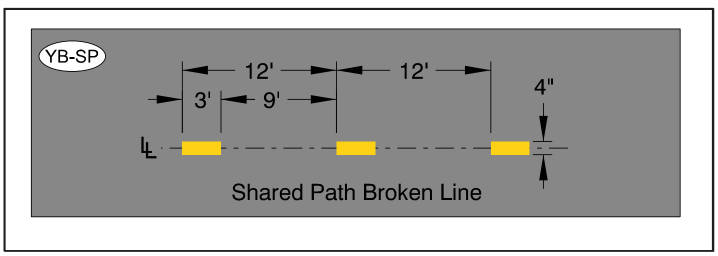


Figure 440-B: Typical Markings for Obstruction within Path

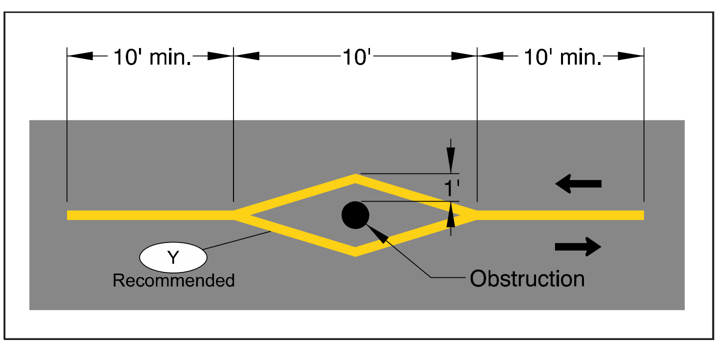


Figure 440-C: Typical Markings for Obstruction at Edge of Path or Lane

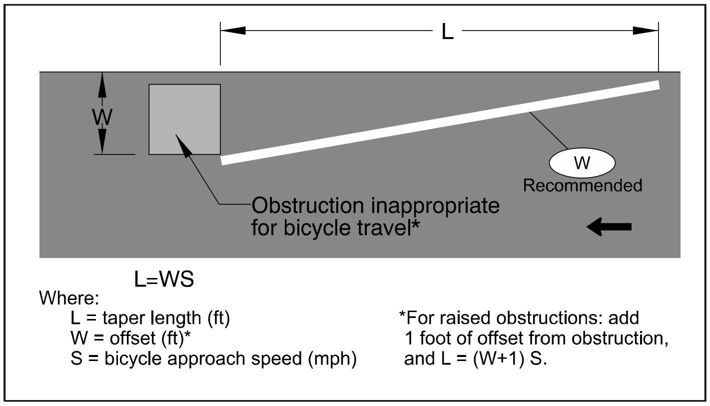


Figure 440-D: Typical Path Centerline for Insufficient Horizontal Sight Distance

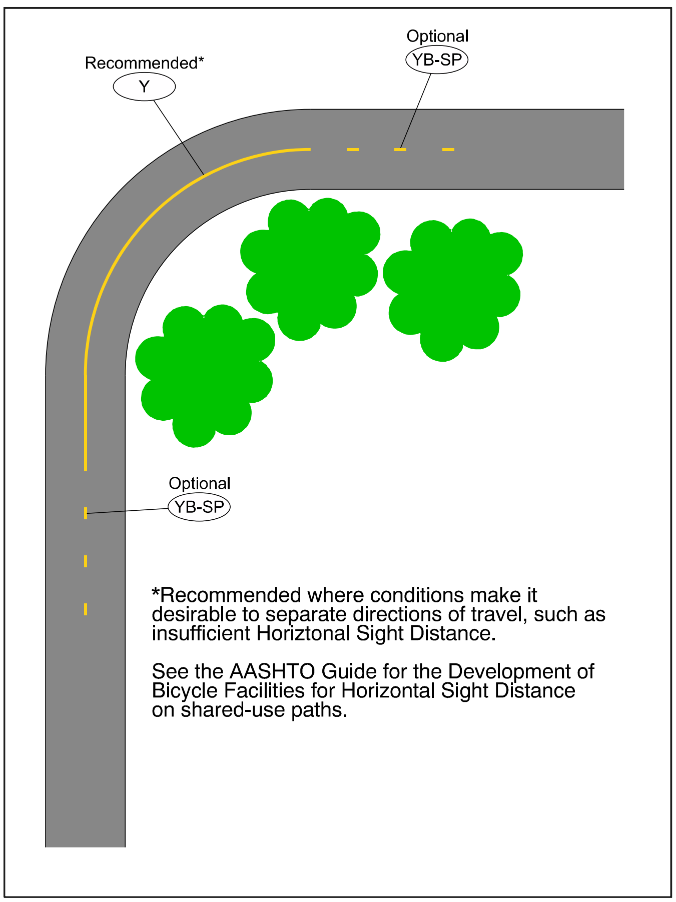


Figure 440-E: Typical Path Markings at a Mid-Block Intersection with a Roadway

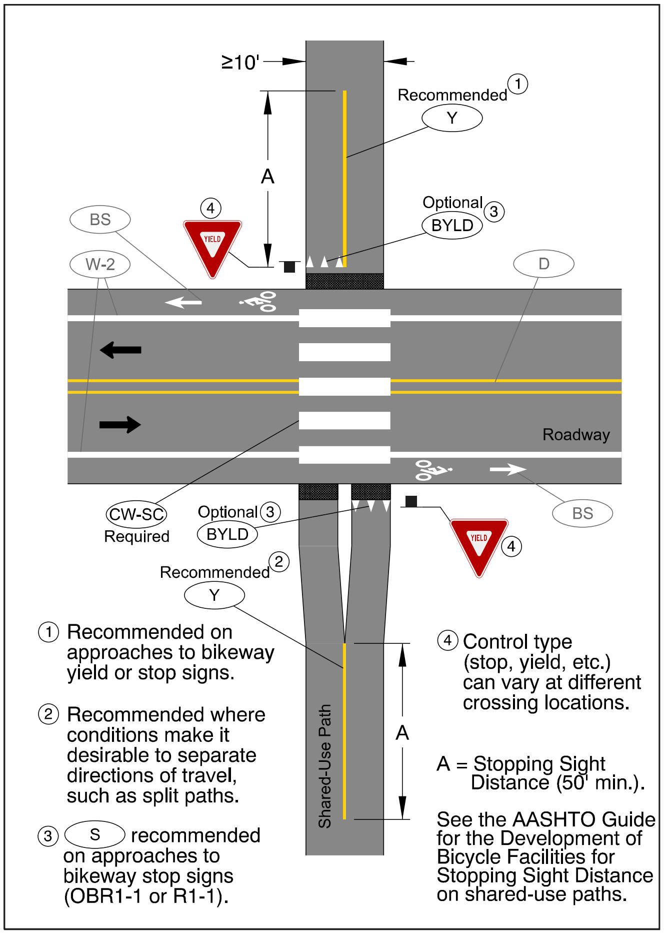


Figure 440-F: Typical Sidepath Markings at Minor Street Intersection with Separation from Intersection and Side Street/Access Stop Controlled

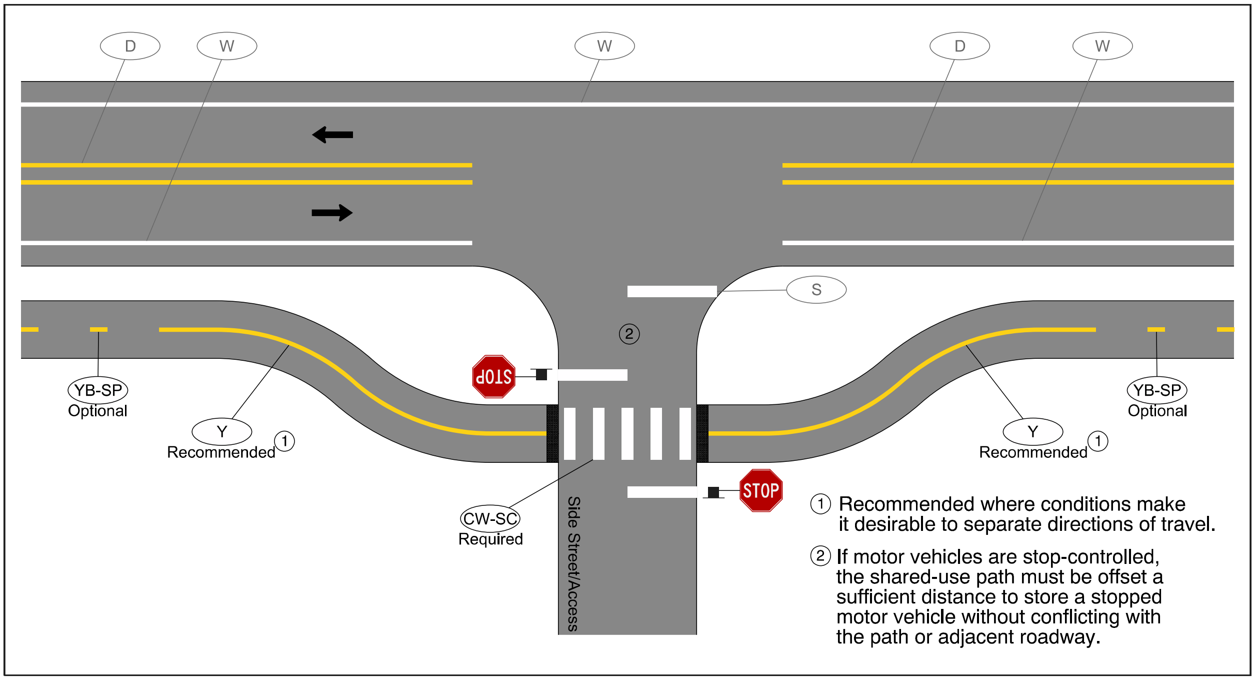


Figure 440-G: Typical Sidepath Markings at Minor Street Intersection with Separation from Intersection and Sidepath Yield Controlled

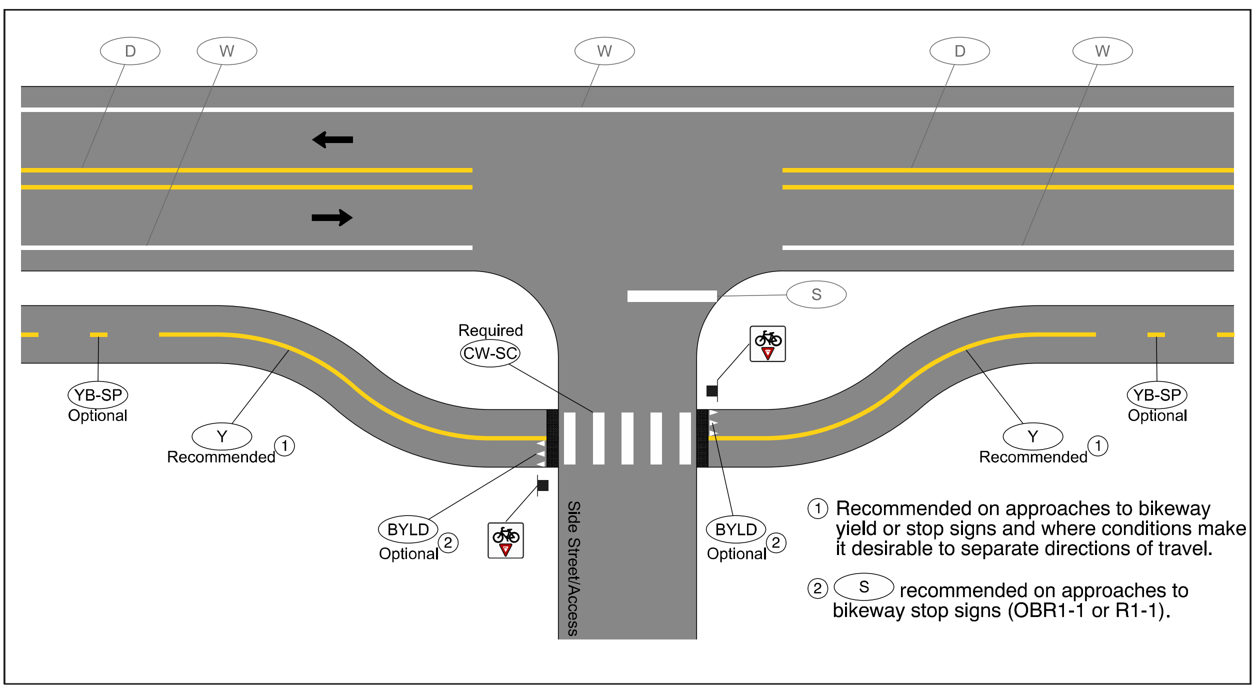
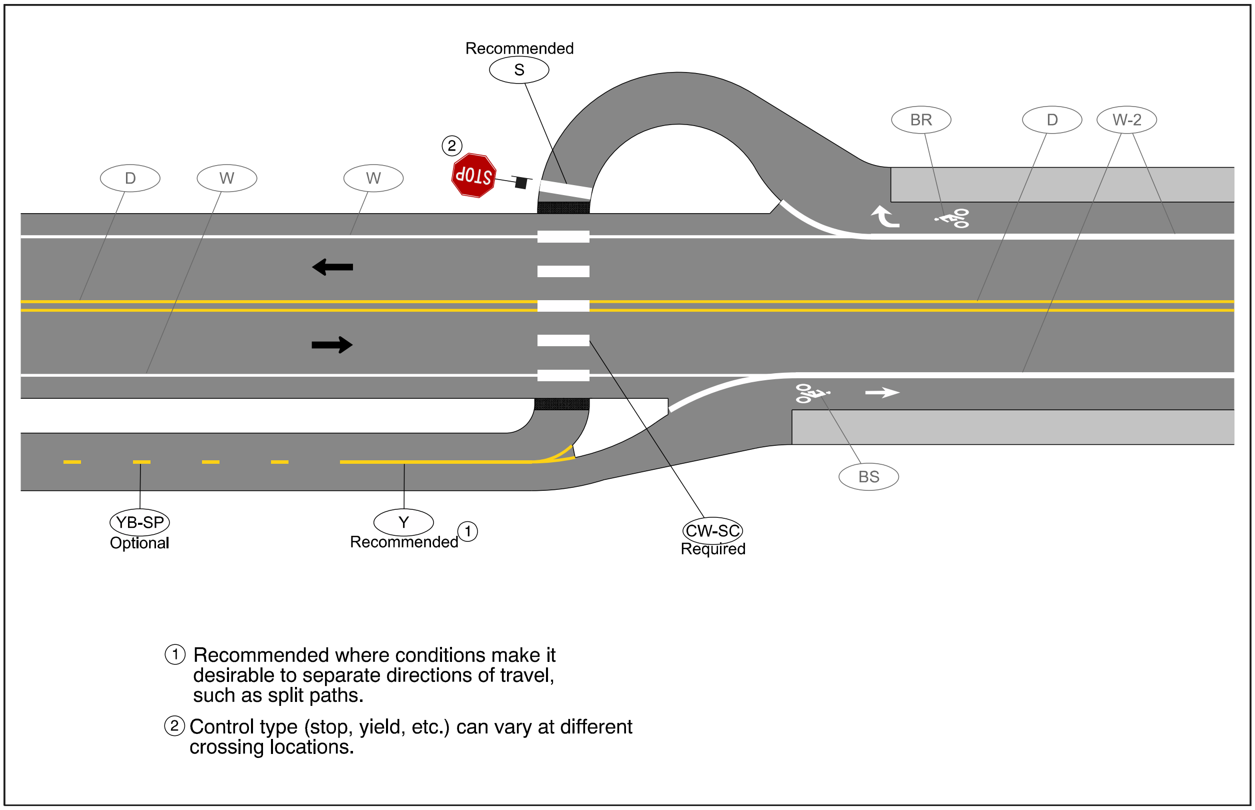


Figure 440-H: Typical Path Markings at One-Way to Two-Way Transition



Support

Shared-use paths serve a wide variety of users and transportation functions. Where needed, markings on shared-use paths can provide important guidance, warning, and regulatory information to path and road users.

A continuous centerline is typically not needed on shared use paths and might not be desirable in some contexts such as parks or other natural settings. Users can typically coexist even in areas with higher user volumes if there is sufficient sight distance. However, on paths where a centerline is not provided, appropriate locations for a centerline still need to be considered. Path users typically travel side-by-side, and on narrow paths cyclists tend to ride near the center of the path. A centerline can help clarify direction and organization of path traffic during heavy travel times or seasonal use or where other operational challenges like limited or insufficient stopping sight distance, areas with design speeds less than 14 mph, and unlit paths create safety concerns (*1*). Limiting a centerline to these areas can help increase respect for the line where it is needed (*2*). The AASHTO Guide for the Development of Bicycle Facilities (*1*) contains more information on stopping sight distance and minimum horizontal sightline offsets for horizontal curves on shared-use paths.

If used consistently on approaches to an intersection with a roadway, a centerline can also increase awareness of the upcoming intersection, discourage passing, remind users that the path is a two-way facility, and position users in a predictable location at the crossing (*1*) (*2*). This can also make the path look less like a lane for motor vehicles. The AASHTO Guide for the Development of Bicycle Facilities (*1*) recommends the centerline be solid from the path's stopping sight distance to the edge of the intersection.

Edge lines can also be beneficial on unlit paths and on approaches to intersections (*1*). Edge lines can also be helpful on unlit shared-use paths on elevated alignments, such as along dykes or approaches to bridges, and through horizontal alignment changes where there is insufficient width for a centerline.

On paths at least 15 feet wide with high use, separate travel areas for wheeled and foot users can be created with a solid white line. This path width provides a minimum space for two-way wheeled traffic (10 feet) and at least 5 feet for pedestrians. On paths with views, position the pedestrian space on the side with the view (*1*).

Right-of-way at intersections with roadways is unique given the different responsibilities between varieties of intersecting users. Because of these complexities, the need to provide uniform traffic control, and the fact that slowest users experience the most exposure while crossing these intersections, the design user at path crossings is the pedestrian (i.e.: standard crosswalk markings if the crossing is marked). The design user for approaches to path crossings is faster users like cyclists. On these approaches, like on roadways, an advance word messages like "HWY XING" supplements warning signs, a centerline helps alert users of the upcoming intersection, and stop bars and yield lines supplement appropriate signs (*1*).

Bollards are common on shared-use paths to limit motor vehicle access. However, bollards introduce a significant hazard to wheeled path users. Obstruction markings help highlight bollards and other vertical elements, especially where unlit. An alternative to bollards is a path split like in Figure 440-E. A centerline, edge lines, and/or arrows can help path users navigate through the split, especially in unlit areas. See the ODOT Bicycle and Pedestrian Design Guide (*3*) and AASHTO Guide for the Development of Bicycle Facilities (*1*) for more alternative treatments to bollards.

Other unavoidable obstructions on shared-use paths such as abutments or piers need to be clearly marked as shown in Figures 440-B and 440-C to guide cyclists around the obstruction. Abrupt sunken grates or other grates unsafe for bicycling might need temporary delineation if it cannot be corrected in a timely manner. Grates within 0.25 inch below the path surface are generally sufficient for bicycle traffic (*1*) (*3*).

Cross References

Key References

1. American Association of State Highway and Transportation Officials. *Guide for the Development of Bicycle Facilities*, 4th ed. Washington, D.C., 2012.
2. Jordan, G., and L. Leso. Power of the Line: Shared-Use Path Conflict Resolution. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1705, 2000, pp. 16-19. http://trrjournalonline.trb.org/doi/abs/10.3141/1705-03. DOI: http://dx.doi.org/10.3141/1705-03
3. Oregon Department of Transportation. *Bicycle and Pedestrian Design Guide*, 3rd ed. Oregon Department of Transportation, Salem, Oregon, 2011. http://www.oregon.gov/ODOT/Engineering/Documents_RoadwayEng/HDM_L-Bike-Ped-Guide.pdf.

Railroad Crossing Markings Section 510

Introduction

Railroad crossings and the traffic control devices used within the crossing area are under the jurisdiction of the ODOT Rail and Public Transportation Division. A rail crossing order for each public road grade crossing summarizes the obligations for all involved parties, including obligations related to pavement markings.

Design Parameters

01 **Unless otherwise authorized by the crossing order, pavement markings for approaches to railroad crossings shall be installed at all crossings and conform to the requirements established under the crossing order (see OAR 741-110).**

02 **Railroad crossing markings shall:**

- **Include no-passing zone markings on two-lane roadways where a centerline is used for traffic approaching the rail crossing.**
- **Include 2-foot wide transverse bars, extended across all approach lanes for multi-lane highways (Figure 510-C).**
- **Include RXR symbol markings (Figure 510-A) in each approach lane on all paved approaches to grade crossings (including bicycle lanes).**
- **Include a wide stop bar (S-2) at least 12 feet from the nearest rail or 1 foot in advance of the location where the gate arm crosses the roadway.**

03 *Stop bars should be perpendicular to the roadway or parallel to the gate if a gate is present (Figures 510-B, 510-C, and 510-D).*

04 On an approach to a grade crossing that is also controlled by traffic signal indications, the required stop bar may be placed closer than 40 feet from signal indications where a non-overhead supplemental signal indication is installed at a sufficient height to be seen at the closer stop location.

05 *Where a railroad crossing is close enough to a signalized intersection that vehicles must stop upstream of the railroad crossing on a red signal indication, as determined by the crossing order, the marked crosswalk parallel and closest to the railroad crossing should be continental-style.*

Required Approvals

An engineering study and ODOT Rail and Public Transportation Division approval (in consultation with Region Traffic) is required for removal or alternate placement of pavement markings for approaches to railroad crossings.

Design Issues

ODOT Rail and Public Transportation Division's jurisdiction for grade crossing regulation extends back from the stop bar for the grade crossing a distance equal to safe stopping distance (see Table 510) according to the posted or statutory speed (OAR 741-100-0005). Contact the Rail and Public Transportation Division's Crossing Safety Unit when working near grade crossings.

Figures & Tables

Figure 510-A: Typical Railroad Grade Crossing Marking Types

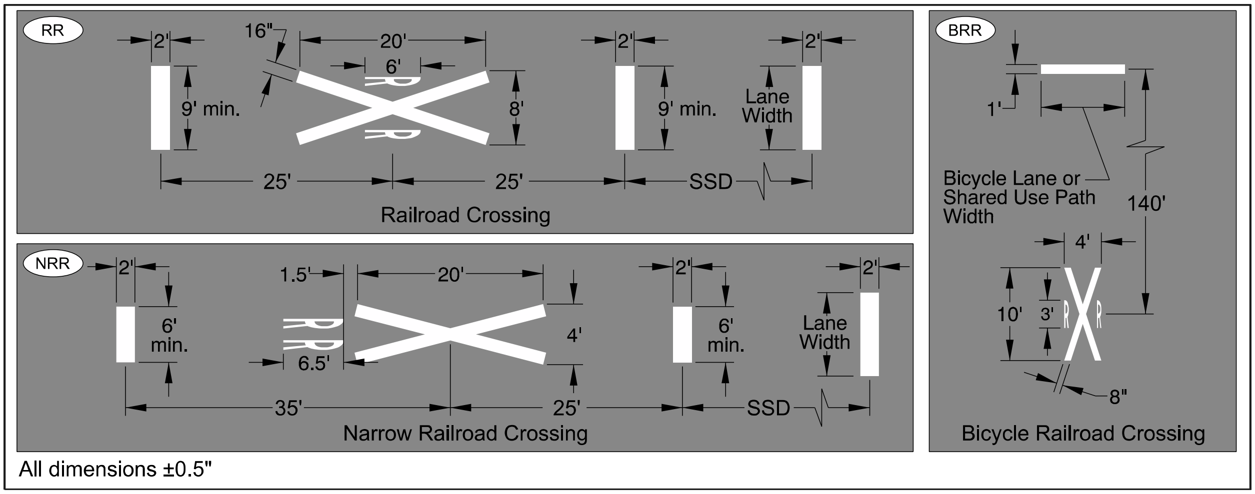


Figure 510-B: Typical Railroad Grade Crossing Markings

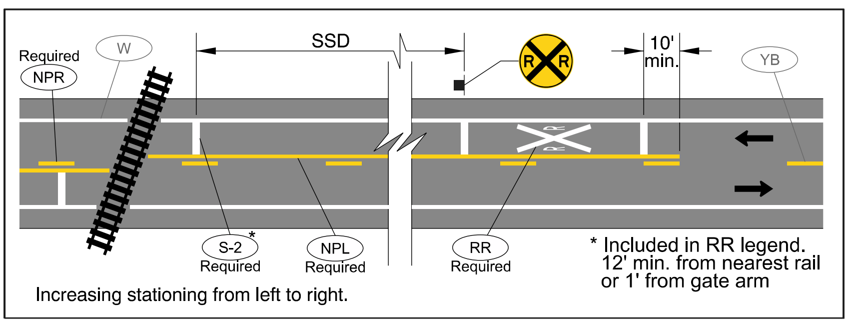


Figure 510-C: Typical Multi-Lane Railroad Grade Crossing Markings

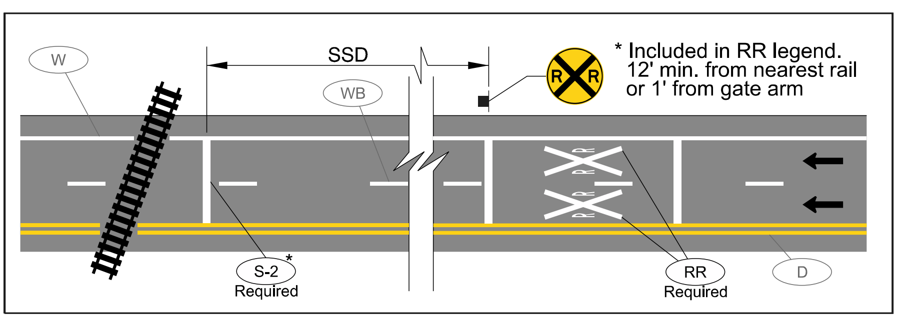


Figure 510-D: Typical Railroad Grade Crossing Truck & Bus Pullout Markings

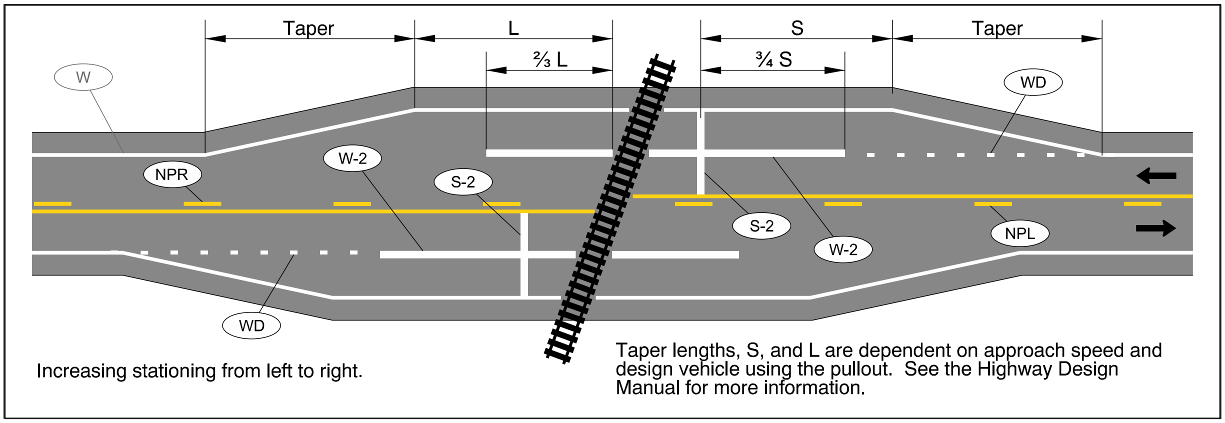


Table 510: Railroad Grade Crossing Safe Stopping Distances

Posted or 85th Percentile Speed (mph)	Safe Stopping Distance, SSD (ft.)
10	50 (100 std.)
15	80 (100 std.)
20	115
25	155
30	200
35	250
40	305
45	360
50	425
55	495
60	570
65	645
70	730
75	820

Support

Layout of railroad crossing markings in Oregon is different than the standard layout shown in the MUTCD. The placement of stop bars and the RXR legend derives from OAR 741-110-0040 and is shown in Figure 8B-6 in the Oregon Supplement to the 2009 MUTCD (*1*). All markings must be installed according to the grade crossing's crossing order issued by the ODOT Rail & Public Transportation Division.

The safe stopping distance (SSD) is stopping sight distance based on vehicle speed approaching the grade crossing on level pavement. This value is prescribed in the Oregon Supplement to the 2009 MUTCD (*1*) following OAR 741-110-0040 which is derived from the stopping sight distance table in the AASHTO Green Book (*2*).

No-passing markings are used on the approach to grade crossings to prevent a motorist from attempting to pass a decelerating vehicle (due to a train crossing) within the safe stopping distance of the rail crossing. The no-passing marking makes this maneuver illegal and enforceable. If a motorist does attempt to pass a vehicle prior to the start of the no-passing zone, there is enough room to stop their vehicle prior to the rail crossing and avoiding a collision with the train.

Bicycles usually travel at slower speeds than motor vehicles and have different stopping distance requirements than motor vehicles (*3*). People on bicycles could need to change how they operate their vehicle by slowing because of changes to the road surface (rails and gaps) and changing their travel path to be perpendicular to rails and gaps. Additionally, bicycles experience significant loss of stopping efficiency in wet conditions (*2*). Because of these considerations, a BRR legend needs to be used in bicycle lanes and on multi-use paths approaching rail grade crossings.

Placement of the BRR marking in the bicycle lane shown in Figure 510-A is conservative based on typical safe stopping distance considerations for a typical upright adult bicyclists traveling at 18 mph on wet pavement on a 1% downgrade with 2.5 seconds of perception-reaction time (design values from AASHTO Guide for the Development of Bicycle Facilities (*3*)). Some cyclists are capable of traveling faster in bicycle lanes than 18 mph, however the W10-1 RXR warning sign will be placed for motor vehicle speeds and still provides warning for these faster cyclists.

Certain vehicles (school buses, hazardous material trucks, etc.) are required to stop at railroad crossings. A pull-out lane can help reduce the risk of rear-end crashes with these special vehicles when they stop at railroad crossings and are typically considered at high speed and/or multi-lane approaches where there is a significant volume of trucks or buses required to stop (*4*). Taper rates, deceleration, and acceleration lengths are dependent on the approach speed to the rail grade crossing and the design vehicle using the pull-out. See the Highway Design Manual (*5*) for more information on these design values. See the ODOT Traffic Manual (*6*) for more information on the process for approving a pull-out lane.

At some grade crossings very close to signalized intersections, it could be beneficial to reduce the distance between signal indications and the stop bar to better coordinate with the placement of crossing gate arms. This is especially applicable at channelized right turn lanes where the railroad closely parallels the highway. To maintain a sufficient viewing angle between the stop location and the top of the signal indication, the stop bar can be moved closer to the signal indications if a non-overhead supplemental signal is installed at a lower height. See the ODOT Traffic Signal Design Manual (*7*) for more information.

At some grade crossings very close to signalized intersections, the distance between the railroad crossing and signalized intersection can be too small for a vehicle to safely queue at the intersection. At these locations, the crossing order specifies that motor vehicles must stop ahead of the railroad crossing when the signal is red. Using a continental-style crosswalk is intended to minimize confusion on the appropriate place for drivers to stop by showing only one transverse bar on the approach to the signal.

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Transverse Markings .... Section 125
Stop Bars .... Section 150
Center Lines .... Section 210
No-Passing Zone Markings .... Section 211
Lane Lines .... Section 220
Edge Lines .... Section 230
Bicycle Lanes .... Section 410

Key References

1. Oregon Department of Transportation. *Oregon Supplement to the 2009 MUTCD*, 2009 ed. Oregon Department of Transportation, Salem, Oregon, 2011. http://www.oregon.gov/ODOT/Engineering/Documents_TrafficStandards/MUTCD-OR-Supplement.pdf.
2. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*, 6th ed. Washington, D.C., 2011.
3. American Association of State Highway and Transportation Officials. *Guide for the Development of Bicycle Facilities*, 4th ed. Washington, D.C., 2012.
4. Ogden, B. D. Railroad-Highway Grade Crossing Handbook. Washington, D.C., FHWA-SA-07-010, 2007. https://www.fra.dot.gov/Elib/Details/L02829.
5. Oregon Department of Transportation. *Highway Design Manual*. Oregon Department of Transportation, Salem, Oregon, 2012.
6. Oregon Department of Transportation. Traffic Manual, 2016 Edition. January 2016. http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Traffic-Manual-v2016.pdf. Accessed July 3, 2017.
7. Oregon Department of Transportation. *Traffic Signal Design Manual*, 2016 ed. Oregon Department of Transportation, Salem, OR, 2016. http://www.oregon.gov/ODOT/Engineering/Pages/Signal-Design-Manual.aspx.

Bus Pullouts Section 520

Introduction

Bus pullouts allow buses to pull out of traffic for alighting, boarding, and long dwell times or layovers. A closed bus pullout has entrance and exit tapers into and out of the bus pullout (like in Figure 520-A). An open bus pullout is located on the immediate far side of an intersection without an entrance taper and typically includes bus exceptions if used with an upstream right turn lane (like in Figure 520-C).

Design Parameters

01 **A wide white dotted line (WD-2) shall be used to extend longitudinal bicycle lane lines at bus pullouts where buses weave across a bicycle lane (see Figures 520-A through 520-D).**

02 The bicycle lane line separating a bicycle lane and a closed bus pullout designed for one bus at a time may be omitted based on engineering judgement (see Figure 520-A).

03 *Where an edge line is used on the roadway at a bus pullout designed for one bus at a time, the edge line should be extended across the bus pullout with a white dotted line (WD) (see Figure 520-E and 520-G).*

04 *Where an edge line is used on the roadway at a closed bus pullout designed for more than one bus at a time, the edge line should be extended across the entrance and exit tapers of the bus pullout with a white dotted line (WD) and a wide white solid line (W-2) should be used to separate the bus stop area from the adjacent travel lane (see Figure 520-F).*

05 The edge line across the bus pullout in Figures 520-E and 520-F may be omitted if edge lines are not present on the roadway (for example, in an urban area with curb and sidewalk).

06 *A BUS ONLY legend should be used at the beginning of an open bus pullout (see Figures 520-C, 520-D, 520-G, and 520-H).*

07 *At an open bus pullout designed for more than one bus at a time, a wide white solid line (W-2) should be used to separate the bus stop area from the adjacent travel lane and a white dotted line (WD) should be extended across the exit taper of the bus pullout (see Figure 520-H).*

08 One or more BUS ONLY legends may be used in bus pullouts based on engineering judgement.

Design Issues

Many other bus stop designs and arrangements are used other than a bus pullout to meet the needs of all road users, transit corridors, and transit providers. Many bus stop arrangements do not need special pavement markings. Work with the local transit agency to ensure the bus stop is marked for the intended operation.

See the ODOT Highway Design Manual (*1*) and the AASHTO Guide for Geometric Design of Transit Facilities on Highways and Streets (*2*) for more information about siting and design of bus pullouts. The NACTO Transit Street Design Guide (*3*) gives information about different transit stop arrangements and how they relate to other modes (such as positioning bicycle lanes to the right of an island for a transit stop), and the AASHTO Guide for Park and Ride Facilities (*4*) gives information on park and ride facilities. See Section 530 for information on preferential lane markings.

Figures & Tables

Figure 520-A: Typical Closed Bus Pullout - One Bus Accommodation Bicycle Lane To Left of Bus Stop

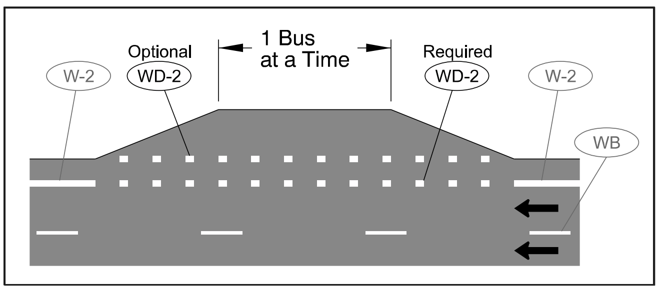


Figure 520-B: Typical Closed Bus Pullout - Multiple Bus Accommodation Bicycle Lane To Left of Bus Stop

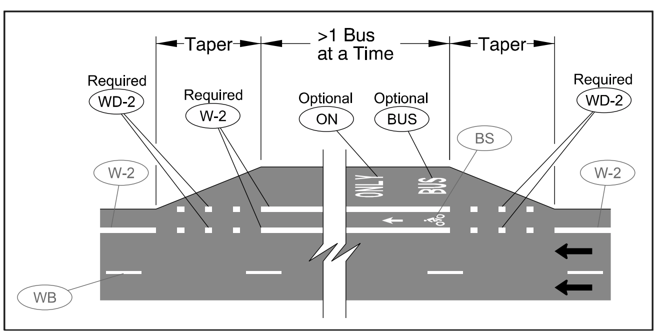


Figure 520-C: Typical Open Bus Pullout - One Bus Accommodation Bicycle Lane To Left of Bus Stop

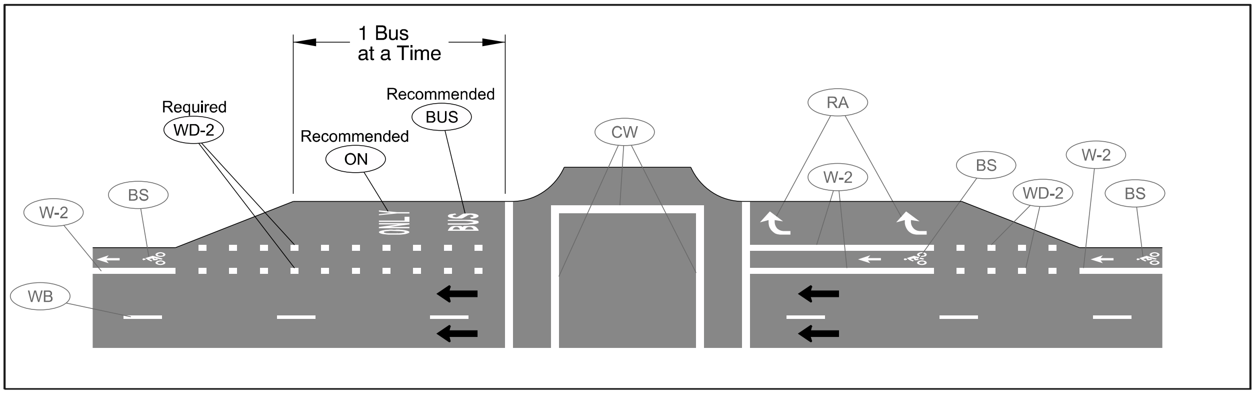


Figure 520-D: Typical Open Bus Pullout - Multiple Bus Accommodation Bicycle Lane To Left of Bus Stop

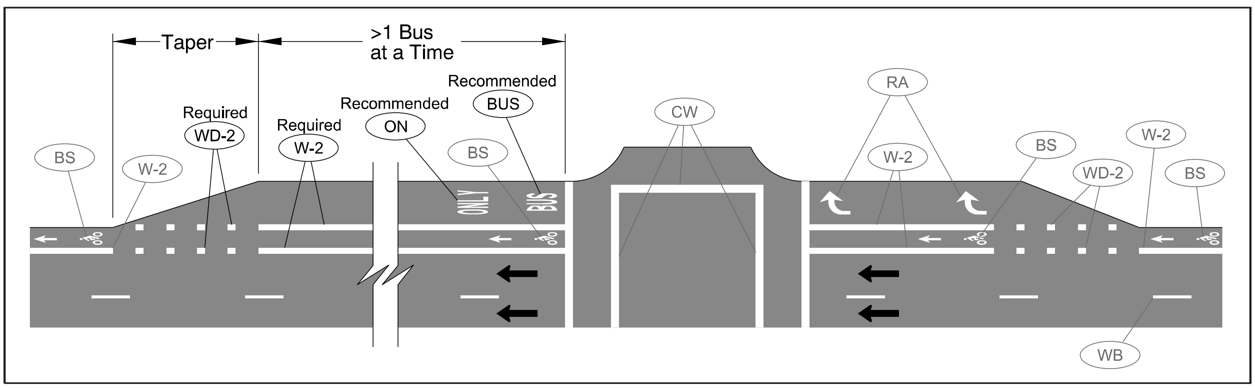


Figure 520-E: Typical Closed Bus Pullout - One Bus Accommodation No Bicycle Lane

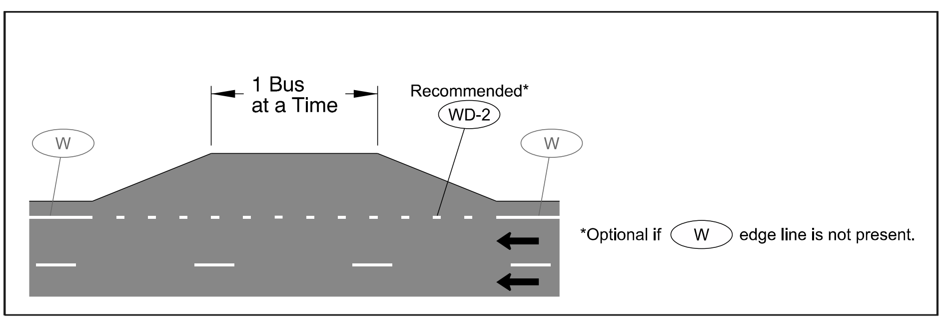


Figure 520-F: Typical Closed Bus Pullout - Multiple Bus Accommodation No Bicycle Lane

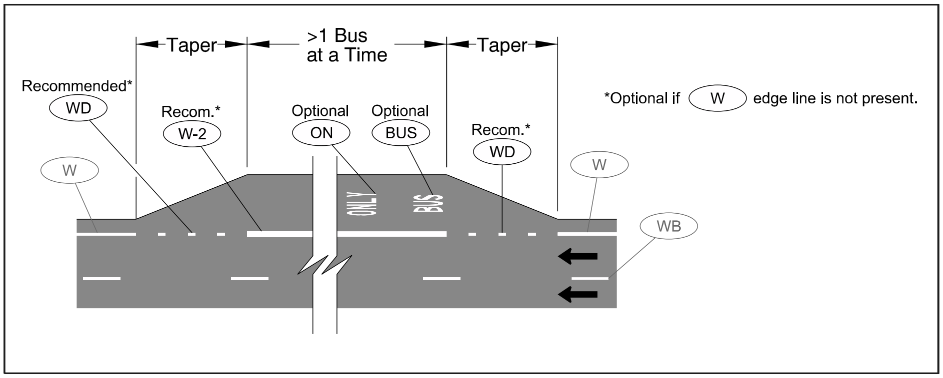


Figure 520-G: Typical One Bus Pullout - One Bus Accommodation No Bicycle Lane

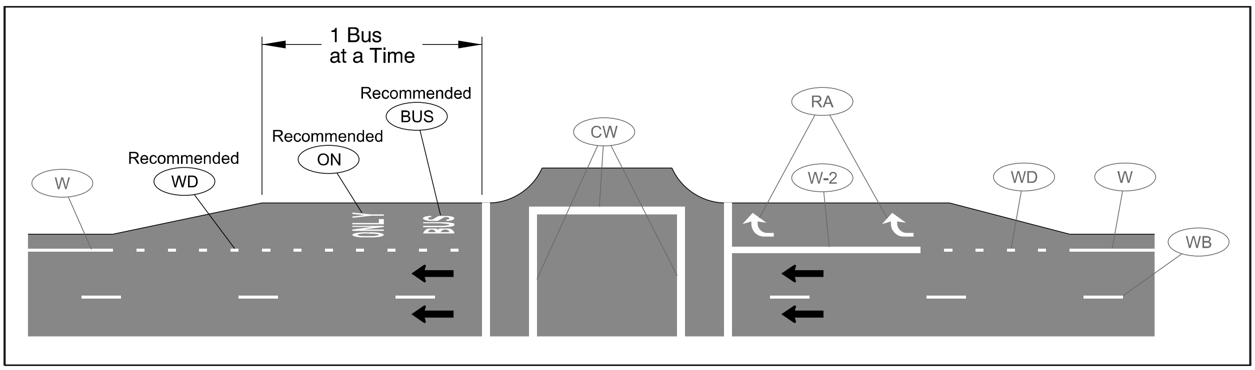
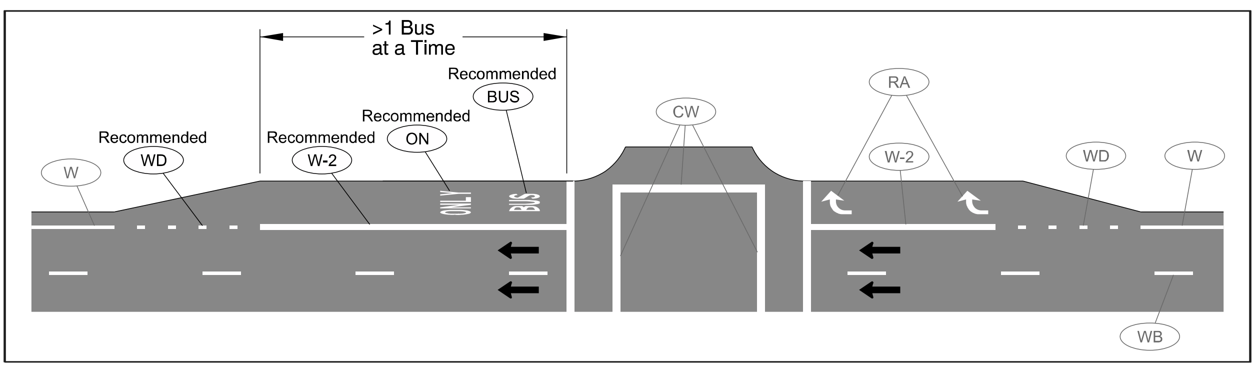


Figure 520-H: Typical Open Bus Pullout - Multiple Bus Accommodation No Bicycle Lane



Support

Edge line extensions across bus pullouts visually separate the pullout space from travel lanes.

There are several different arrangements of bus pullouts. The most common is the “closed” bus pullout (shown in Figures 520-A, 520-B, 520-E, and 520-F) and includes entrance and exit tapers at both ends of the pullout. An edge line extension at these pullouts helps prevent unintentional entrance or encroachment into the pullout.

Where used, an "open" bus pullout (shown in Figures 520-C, 520-D, 520-G, and 520-H) is commonly paired with a right turn lane on the near side of the intersection with a bus exception for right turns, or with a bus queue jump lane (2). A line separating the bus pullout from the adjacent lane and BUS ONLY stencil are recommended at these pullouts so road users can pick the correct receiving lane at the intersection, especially those turning right towards the pullout.

Like other motor vehicle-bicycle conflict areas, wide dotted lines are used where buses cross a bicycle lane (see Section 410).

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Transverse Markings .... Section 125
Lane Lines .... Section 220
Edge Lines .... Section 230
Bicycle Lanes .... Section 410
Marked Crosswalks .... Section 430
Shared-Use Path Markings .... Section 440
Railroad Crossing Markings .... Section 510
Preferential Lane Markings .... Section 530

Key References

1. Oregon Department of Transportation. *Highway Design Manual*. Oregon Department of Transportation, Salem, Oregon, 2012.
2. American Association of State Highway and Transportation Officials. *Guide for Geometric Design of Transit Facilities on Highways and Streets*. American Association of State Highway and Transportation Officials, Washington, D.C., 2014.
3. National Association of City Transportation Officials. *Transit Street Design Guide*. Island Press, Washington, D.C., 2016. http://nacto.org/publication/transit-street-design-guide/.
4. American Association of State Highway and Transportation Officials. *Guide for Park-and-Ride Facilities*, 2nd ed. American Association of State Highway and Transportation Officials, Washington, D.C., 2004. https://bookstore.transportation.org/item_details.aspx?id=121.

Preferential Lane Markings Section 530

Introduction

Preferential lanes serve a wide variety of special uses. This could include, but is not limited to, high-occupancy vehicle (HOV) lanes, bicycle lanes, bus-only lanes, and taxi-only lanes.

Design Parameters

01 **When a lane is assigned full or part time to a particular class or classes of vehicles, preferential lane markings shall be used.**

02 **All preferential lane word and symbol markings shall be white and shall be positioned laterally in the center of the preferred-use lane. Preferential lane markings shall be placed at the beginning of the preferential lane and after intersections.**

03 **Where a preferential lane use is established, the preferential lane shall be marked with one or more of the following symbol or word markings for the use specified:**

- **HOV lane –the preferential lane use marking for high-occupancy vehicle lanes shall consist of white lines formed in a diamond shape symbol shown in Figure 530.**
- **Bicycle lane – preferential lane use markings for a bicycle lane shall consist of markings according to Section 410.**
- **Bus only lane – the preferential lane use marking for a bus only lane shall consist of the word marking BUS ONLY (see Figure 530).**
- **Light rail transit lane – the preferential lane use marking for a light rail transit lane shall consist of the word marking LRT ONLY (see Figure 530).**

04 **All longitudinal pavement markings, as well as word and symbol pavement markings, associated with a preferential lane shall end where the "Preferential Lane Ends" sign (R3-12a or R3-12c) designating the downstream end of the preferential only lane restriction is installed.**

05 **Preferential lanes for motor vehicles shall be separated from other travel lanes using longitudinal markings according to Section 3D.02 of the 2009 MUTCD.**

06 **If two or more preferential lane uses are permitted in a single lane, the symbol or word marking for each preferential lane use shall be installed.**

07 *The spacing of preferential lane use markings should be based on engineering judgement that considers the prevailing speed, block lengths, distance from intersections, and other factors that affect clear communication to the road user.*

08 *In addition to a regular spacing interval, preferential lane markings should be placed at strategic locations such as major decision points, direct exit ramp departures from the preferential lane, and along access openings to and from adjacent general-purpose lanes. At decision points, preferential lane markings should be placed on all applicable lanes and should be visible to approaching traffic for all available departures. At direct exits from preferential lanes where extra emphasis is needed, the use of word markings (such as "EXIT" or "EXIT ONLY") in the deceleration lane for the direct exit and/or on the direct exit ramp itself just beyond the exit gore should be considered.*

Required Approvals

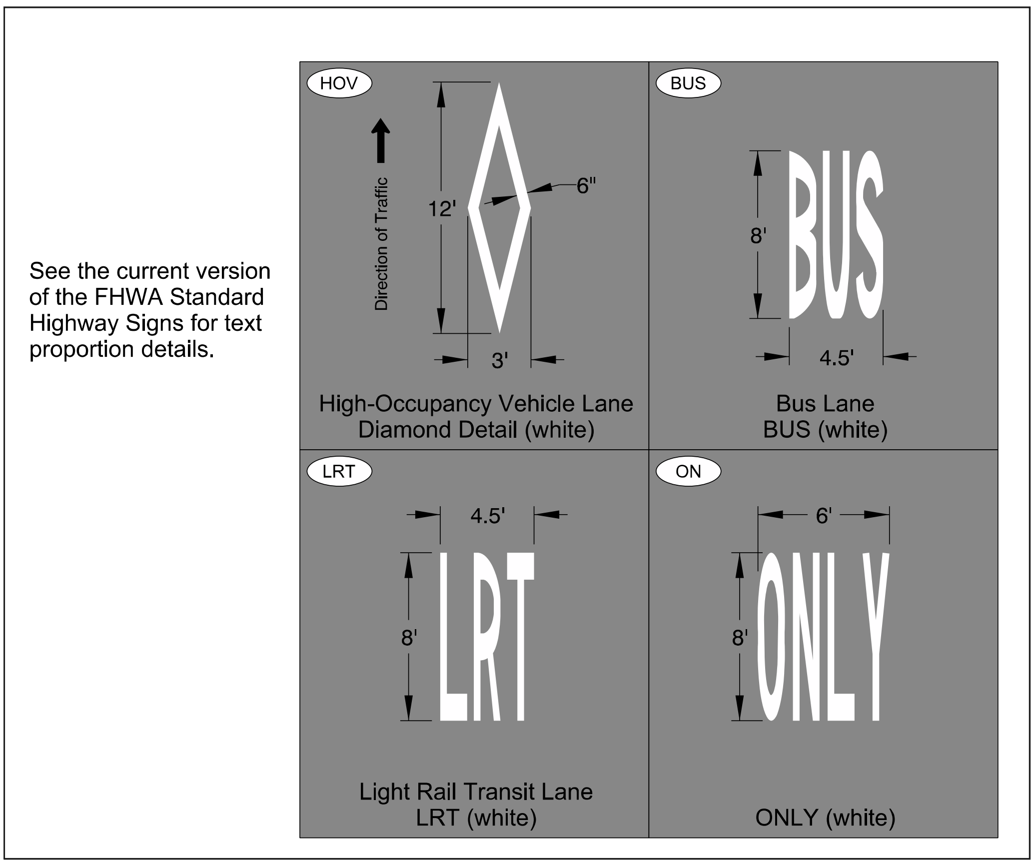
ORS 810.140 allows road authorities to designate bus or HOV lanes. On state highways, these designations are set through Oregon Administrative Rule.

Design Issues

Other traffic control devices (signing, signals, etc.) are needed for preferential lanes. See additional design parameters for marking, signing, and signals in the MUTCD (*1*).

Figures & Tables

Figure 530: Preferential Lane Marking Details



Support

The design parameters for preferential lane markings come from Chapter 3D in the 2009 MUTCD (*1*).

The only preferential lane order currently in effect on a state highway is OAR 734-020-0043 for the I-5 HOV Lanes in North Portland (milepoint 303.98 to 307.49).

Cross References

Colors .... Section 110
Transverse Markings .... Section 125
Bicycle Lanes .... Section 410
Bicycle Lane Buffers .... Section 412
Bus Pullouts .... Section 520
Ramp Meters .... Section 620

Key References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Washington, D.C., 2009.

Colored Pavement in Transit Lanes Section 531

Introduction

See FHWA's Interim Approval for Optional Use of Red-Colored Pavement for Transit Lanes (IA-22) (*1*) for all requirements to use colored pavement in transit lanes.

Required Approvals

An engineering study and state traffic-roadway engineer approval is required for installation of colored pavement in transit only lanes on a state highway.

Key References

1. Knopp, M. C. MUTCD - Interim Approval for Optional Use of Red-Colored Pavement for Transit Lanes (IA-22). December 4, 2019. https://mutcd.fhwa.dot.gov/resources/interim_approval/ia22/ia22.pdf. Accessed April 17, 2020.

School Markings Section 610

Introduction

School markings supplement other required signing in a designated school zone.

Design Parameters

01 School legends may be installed if a school sign is installed (sign S1-1).

02 **When used in advance of a marked school crossing, school markings shall include a small SCHOOL legend in combination with X-ING placed on each lane (Figure 610-B). When used where there is no marked school crossing, a SCHOOL legend shall be used alone (Figure 610-D).**

03 **On roadways with centerline markings, no-passing zone markings shall be used on the approach to and through school zones according to Table 211-2 (Figure 610-D).**

04 *When used, the word SCHOOL should be placed adjacent to the advance school warning assembly signing (Figures 610-B, 610-C, and 610-D). The word X-ING or CROSSING should be placed based on the posted speed and roadway characteristics, a minimum of 4 times the letter height to a maximum of 10 times the letter height (Figures 610-B and 610-C).*

05 When school markings are used on multi-lane roadways, a large SCHOOL legend (with CROSSING as appropriate) placed across the width of two lanes (Figure 610-C) may be used instead of the single-lane layout shown in Figure 610-B.

Required Approvals

An engineering study and state traffic-roadway engineer approval is required for new school zones.

Region traffic engineer approval is required for use of the large SCHOOL legend (with CROSSING as appropriate) shown in Figure 610-C.

Figures & Tables

Figure 610-A: School Crossing Marking Types

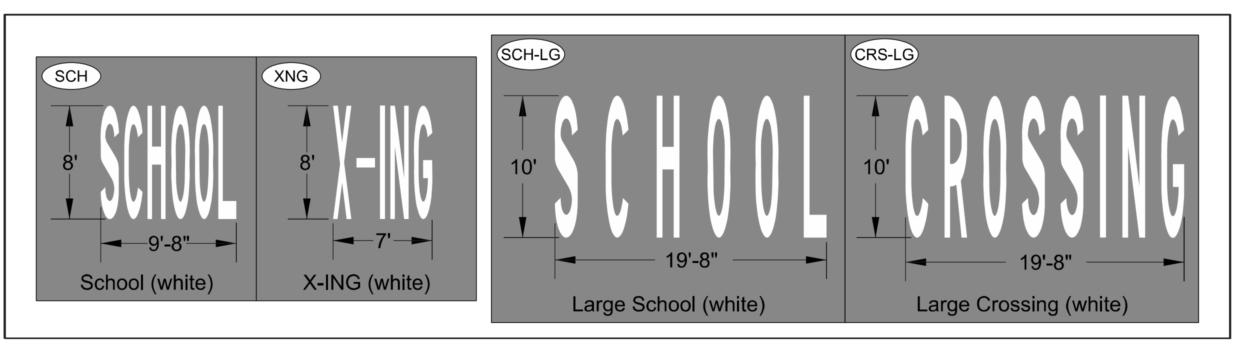


Figure 610-B: Typical School Marking Layout with Crossing

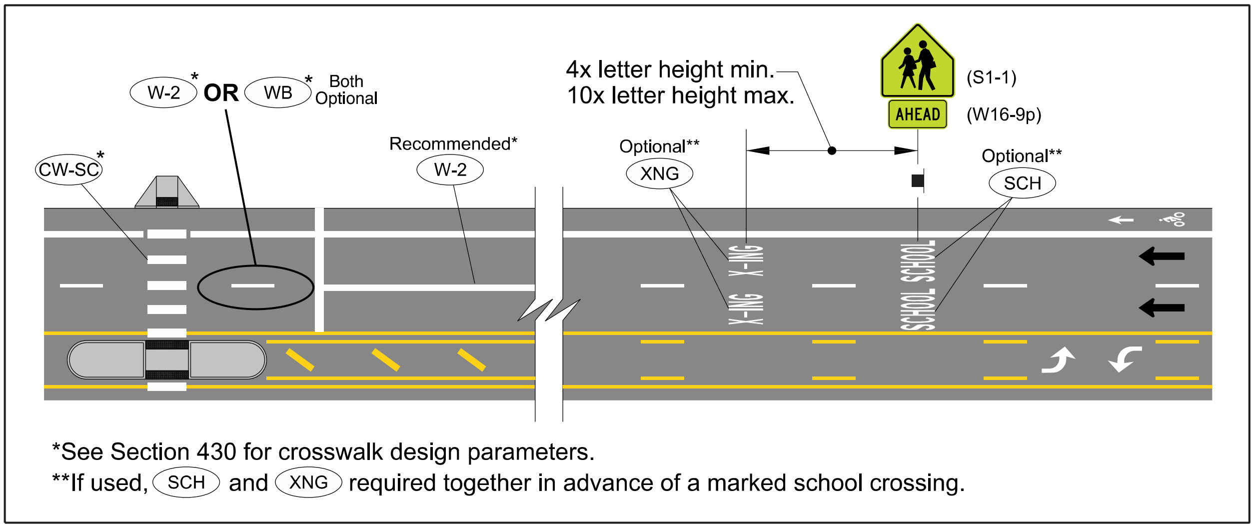


Figure 610-C: Typical Two-Lane School Marking Layout with Crossing

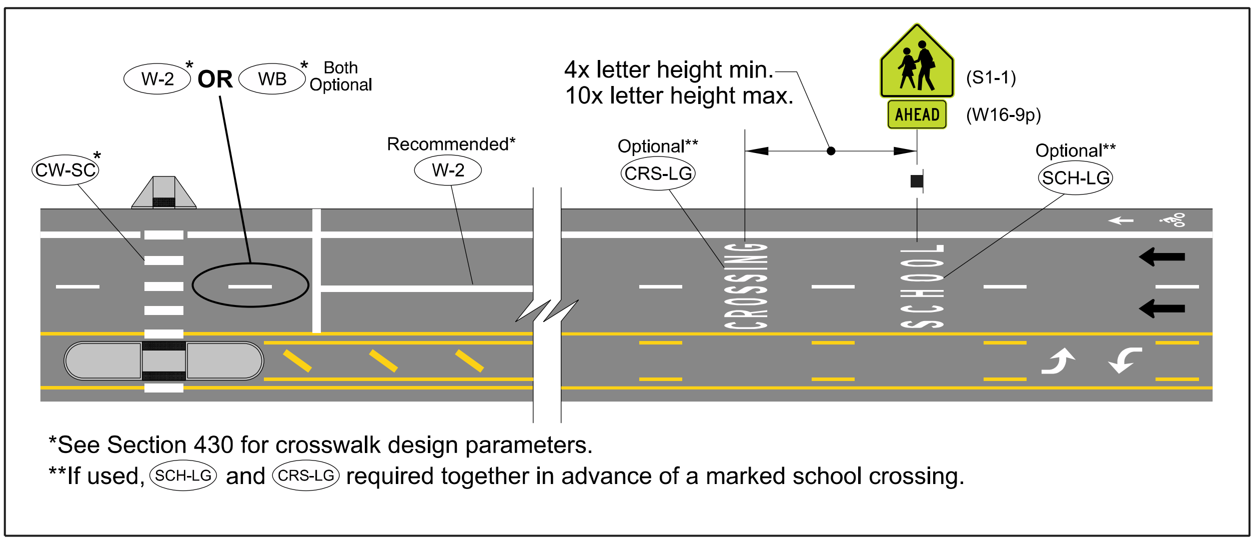
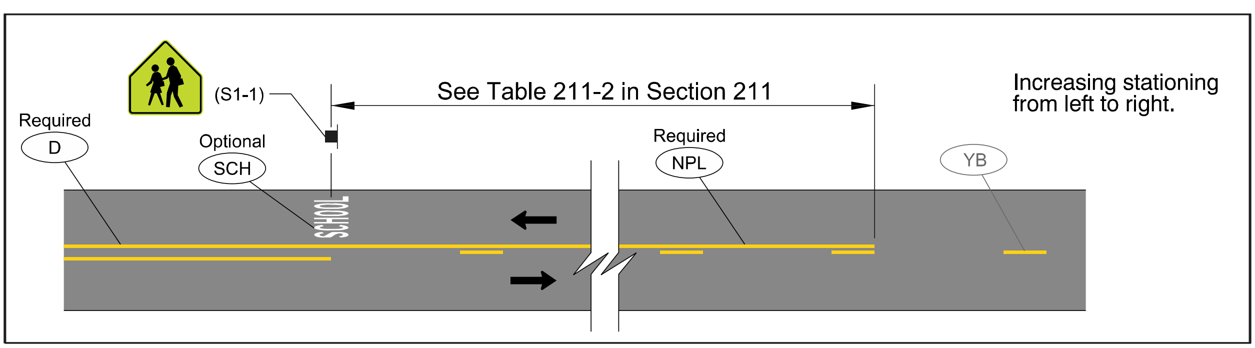


Figure 610-D: Typical One-Lane School Marking Layout without Crossing & No-Passing Markings



Support

Pavement word legends supplement and add extra emphasis to signing. For more information on benefits and limitations of transverse markings, see Section 125.

Pavement legends are just one part of an effective school zone traffic control strategy. There has been limited research directly investigating the effect legends in school zones have on road user behavior and speed; those that have studied these effects (*1*) (*2*) have shown no practical effect on speeds but only examined a limited number of locations and facilities. Other traffic control devices and strategies are summarized in ODOT's A Guide to School Area Safety (*3*).

Cross References

Colors ..... Section 110
Stop Bars ..... Section 150
No-Passing Zone Markings ..... Section 211
Marked Crosswalks ..... Section 430

Key References

1. Schrader, M. H. Study of Effectiveness of Selected School Zone Traffic Control Devices. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1692, 1999, pp. 24-29. http://trrjournalonline.trb.org/doi/pdf/10.3141/1692-04. DOI: 10.3141/1692-04
2. Radalj, T. Driver Speed Compliance within School Zones and Effects of "40" Painted Speed Limit on Driver Speed Behaviors. in *Road Safety Research, Policing and Education Conference*, Vol. 2, Adelaide, South Australia, Australia, 2002, pp. 207-14. https://trid.trb.org/view.aspx?id=702285.
3. Oregon Department of Transportation. A Guide to School Area Safety. Traffic Engineering & Operations Section and Traffic Safety Division, Oregon Department of Transportation, Salem, Oregon, 2017. http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Guide_to_School_Area_Safety.pdf.

Ramp Meters Section 620

Introduction

Ramp meters can reduce merge area turbulence by regulating vehicle flow entering the facility and regulate total freeway traffic flow through downstream bottlenecks. Ramp meter stop bars show drivers where to wait for the ramp meter signal and can guide drivers into multiple queue lanes.

Design Parameters

01 **A stop bar shall be placed at the "STOP HERE ON RED" (R10-6) sign(s) as shown in Figure 620-A.**

02 **At ramps that operate with two or more queue lanes when metered, a wide solid white line shall be used as shown in Figure 620-A to separate the queue lanes.**

03 *If a ramp shoulder is used as a third general queue lane, the shoulder edge line should be dotted (WD) where queueing traffic is intended to enter the shoulder lane and dotted (WD) after the stop bar through the taper as shown in Figure 620-C.*

04 **If a ramp meter queue lane is used as a preferential lane, preferential lane markings shall be placed according to Section 530. A wide solid white line (W-2) shall separate the preferential lane from the adjacent general lane(s) (see Figure 620-D).**

05 *If a ramp meter queue lane is used as a preferential lane, preferential lane markings should be placed at the stop bar as shown in Figure 620-D. Where the wide white line (W-2) separating the preferential lane from the adjacent lane(s) is longer than 400 feet, a preferential lane marking should be placed at the mid-point of the preferential lane.*

Required Approvals

An engineering study and region traffic engineer/manager approval are required for ramp meter installations.

Design Issues

There are other signing and signaling requirements for ramp meters. See the ODOT Traffic Manual (*1*) and ODOT Highway Design Manual (*2*) for more information on design parameters and considerations for ramp meters.

Figures & Tables

Figure 620-A: Ramp Meter Stop Bar Types

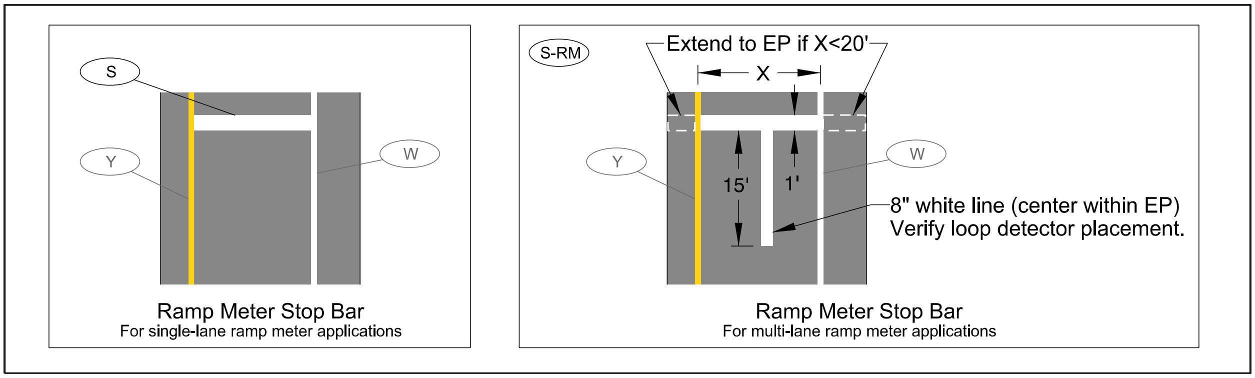


Figure 620-B: Typical Ramp Meter Layout - 2 Queue Lanes

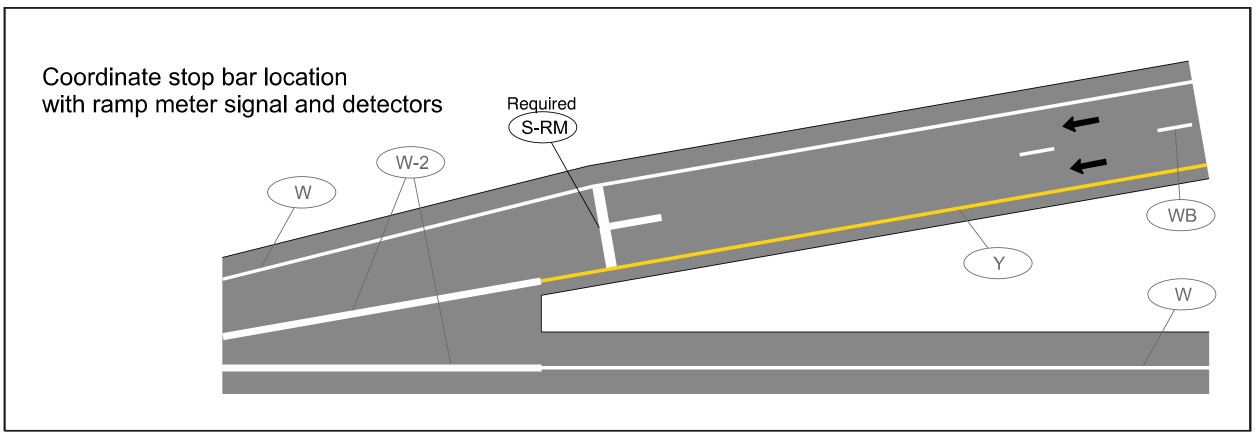


Figure 620-C: Typical Ramp Meter Layout - Shoulder Queue Lane

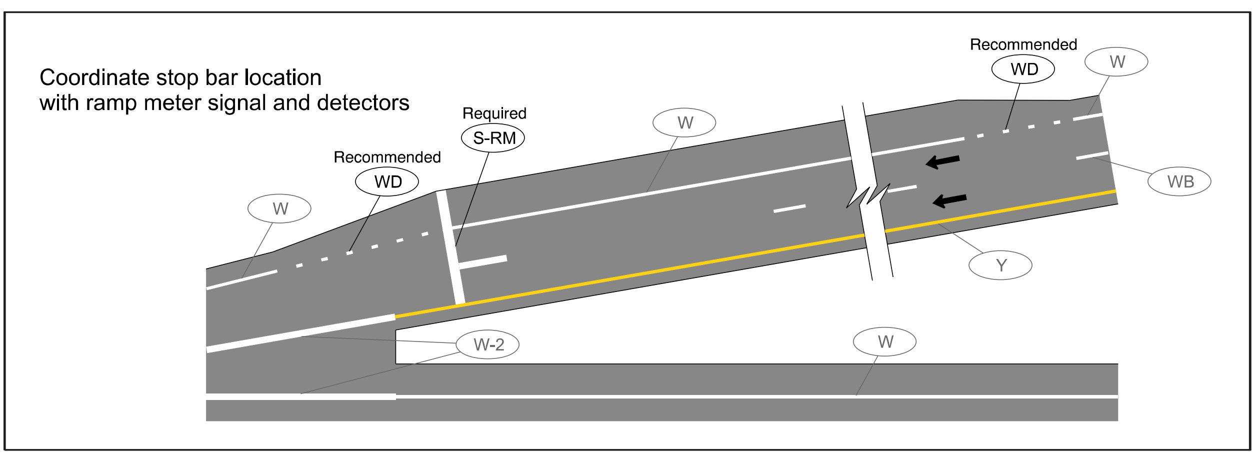
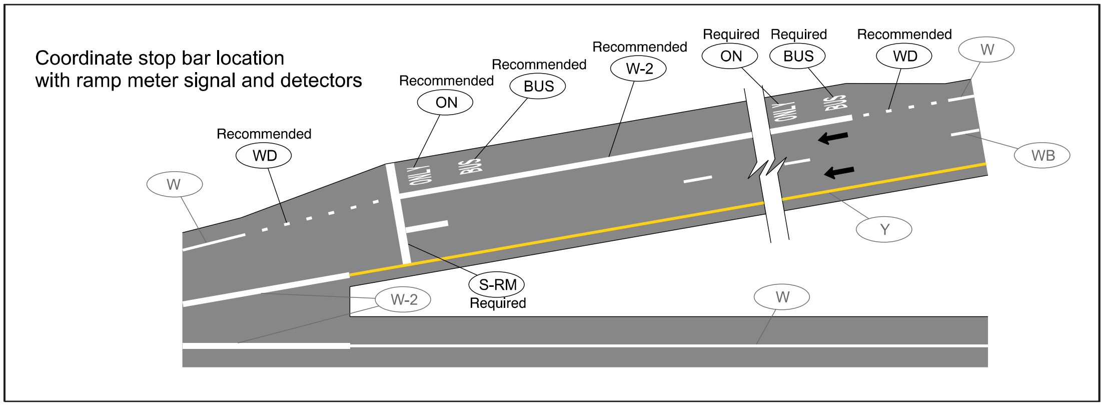


Figure 620-D: Typical Ramp Meter Layout - Bus Queue Jump Lane



Support

The ramp meter stop bar is an Oregon-unique application to allow two-lane queueing on single lane ramps in areas with existing right-of-way constraints and legacy infrastructure. The detail first appeared in the January 1994 ODOT Ramp Meter Design Guidelines (3) and has operated well in the Portland area where additional ramp width for multiple standard travel lanes is not possible. On narrower on-ramps (pavement width <20 feet) drivers form two lines by straddling the ramp's edge lines so the stop bar needs to extend to the edge of pavement. On-ramp pavement widths 20 feet and greater allow two queue lanes to comfortably form between the edge lines so the stop bar is only extend to the edge lines.

The 15-foot long 8-inch wide line centered on the paved width, in addition to signs saying form two lines, gives motorists enough direction at the beginning of the queue to form two lines; motorists behind the front vehicles queue behind without the need for a lane line. Because there are additional traffic control measures, and viewed in context clearly intended for ramp metering, this application has performed well for its intended purpose. Additionally, ramp meter stop bars are frequently installed after the ramp's white broken line is ended for a lane reduction transition and before the ramp begins to taper to one lane. The 8-inch line does not generally interfere with the lane reduction transition because it is kept short at the stop bar itself.

In some very constrained and over capacity areas, using the ramp's shoulder as a queue lane could help provide additional space for ramp meter operations. Because the shoulder operates as a normal shoulder under non-metered operations, a normal-width solid line is used as the edge line except in the areas where queueing vehicles can enter the shoulder and merge back into the ramp's lane (where it is dotted). See the ODOT Highway Design Manual (2) for more information on this type of layout.

In some locations it could be desirable to provide a transit or high-occupancy vehicle queue jump lane on metered ramps. In these cases, the lane becomes a preferential lane and needs to be defined with preferential lane markings (like BUS ONLY legends). Additional traffic control measures will be needed in addition to pavement markings (like signs and special signal designs).

Cross References

Colors .... Section 110
Functions, Widths, and Patterns of Longitudinal Lines .... Section 120
Transverse Markings .... Section 125
Stop Bars .... Section 150
Lane Lines .... Section 220
Edge Lines .... Section 230
Interchange Ramps: Exit & Entrance Ramps .... Section 360
Preferential Lane Markings .... Section 530

Key References

1. Oregon Department of Transportation. Traffic Manual, 2016 Edition. January 2016. http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Traffic-Manual-v2016.pdf. Accessed July 3, 2017.
2. Oregon Department of Transportation. *Highway Design Manual*. Oregon Department of Transportation, Salem, Oregon, 2012.
3. Oregon Department of Transportation. *Ramp Meter Design Guidelines*. Oregon Department of Transportation, 1994.

Parking Space and Curb Markings Section 630

Introduction

Parking space markings can encourage more orderly use of parking spaces where parking turnover is substantial. Marked parking spaces tend to prevent encroachment into fire hydrant zones, bus stops, loading zones, approaches to intersections, curb ramps, and clearance spaces for islands and other zones where parking is restricted (*1*) (*2*).

Design Parameters

01 Parallel on-street parking spaces may be marked with white parking tick markings (P) shown in Figure 630-A.

02 *If marked, parallel on-street parking should be installed as shown in Figure 630-B.*

03 **Parking space markings shall be white, except for the optional background color of the International Symbol of Accessibility.**

04 **Accessible parking places shall be marked according to the Oregon Transportation Commission Standards for Accessible Parking Places.**

05 Curbs may be colored to supplement standard signs for parking regulations if requested by a local jurisdiction.

06 *For construction of new parking areas in rest areas on the state highway system, large vehicle parking spaces should be installed as shown in Figure 630-C.*

07 For repaving and restriping of current rest area parking areas on the state highway system the layout of Figure 630-C may be met as long as the number of parking spaces is not reduced (see Support section for more information on large vehicle parking in rest areas).

08 Curbs markings should not be used within 2 feet of a detectable warning surface (DWS).

09 Curb markings should not be used on the flared sides of curb ramps.

Required Approvals

New installations of diagonal on-street parking require a roadway design exception.

Design Issues

The number of accessible on-street parking spaces is based on the total number of marked or metered parking spaces on the block perimeter. Marked or metered parking includes parking spaces marked on the pavement, parking designated by permissive parking signs (limited time parking or parking in a particular manner, see MUTCD Section 2B.46), or parking meters.

Accessible on-street parking spaces are generally located nearest a curb ramp – typically at either end of the block face or nearest a pedestrian crossing. The area around the accessible parking space will also need to be free from street furniture or other obstructions.

Accessible on-street parking located in a local jurisdiction might need an Intergovernmental Agreement.

Contact the Roadway Section for more information on ADA considerations around on-street parking.

Curb markings are typically not installed on state highways. If curb markings are requested by a local jurisdiction, an intergovernmental agreement will be needed stating the curb markings will be installed and maintained by the local jurisdiction. See section 281 for more information on installing curb markings near detectable warning surfaces.

ORS 811.550 prohibits parking in several places, including within 20 feet of a crosswalk at an intersection (marked or unmarked), and within 10 feet of a fire hydrant.

Since yellow and white curb markings are used for curb delineation and visibility, it is advisable to establish parking regulations with standard signs.

When determining placement of curb markings, consideration should be given to the conspicuity of any DWSs that are part of the project. It is beneficial to have a distance between a yellow DWS and yellow curb markings. The distance gives more contrast which helps pedestrians see where their path is. It is good to avoid monochromatic color schemes where DWSs and supplemental markings are installed near eachother.

Figures & Tables

Figure 630-A: Parking Marking Types

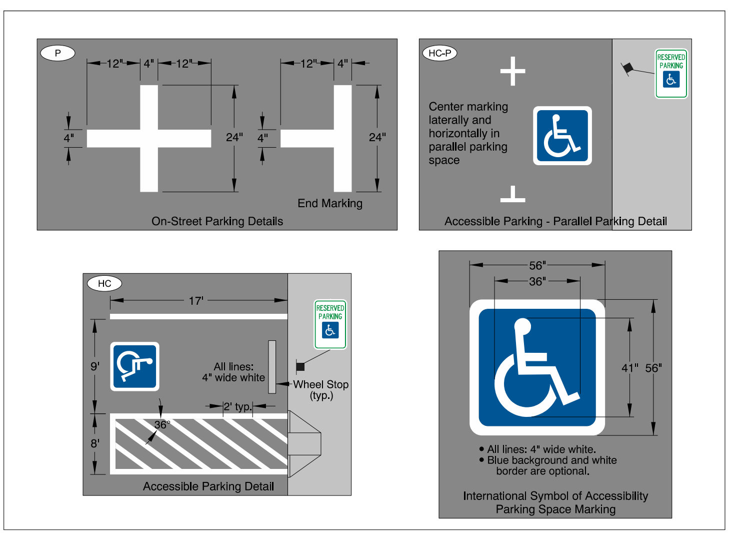


Figure 630-B: Typical Layout for Marked Parallel On-Street Parking, No Bicycle Lane

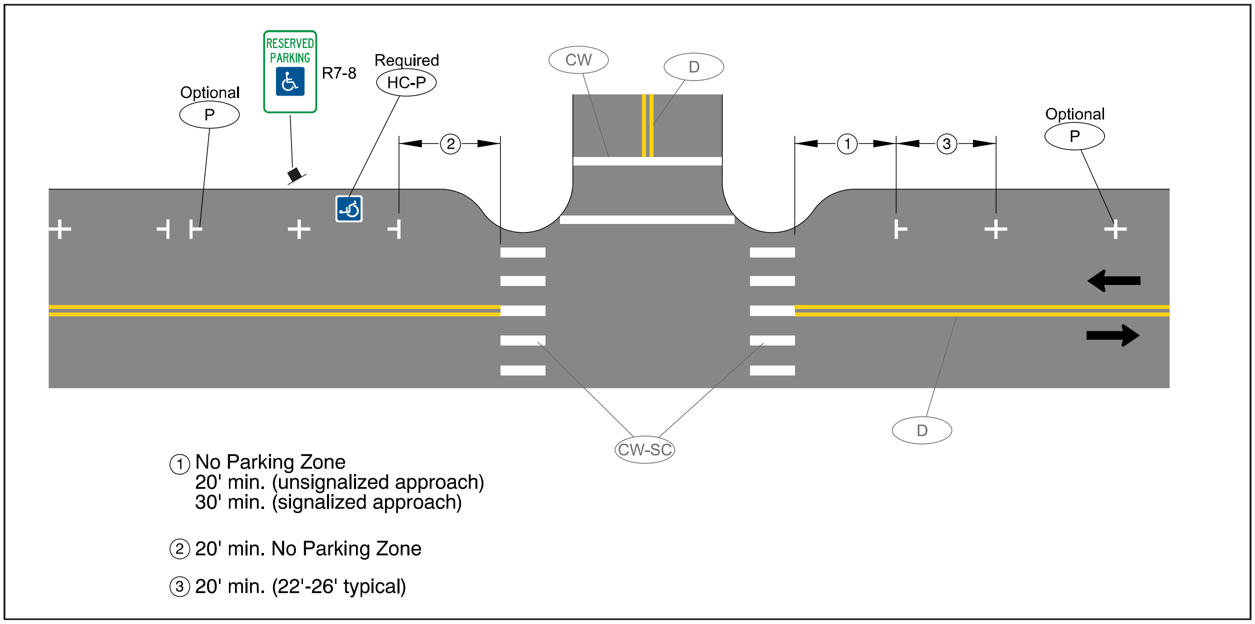
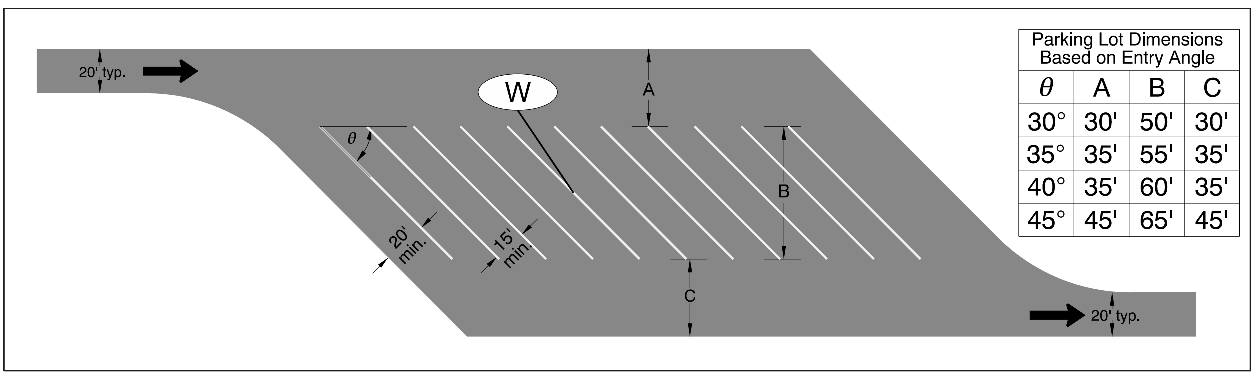


Figure 630-C: Typical Large Vehicle Parking Space Dimensions for New Rest Area Parking Areas



Parking Lot Dimensions Based on Entry Angle

θ	A	B	C
30°	30'	50'	30'
35°	35'	55'	35'
40°	35'	60'	35'
45°	45'	65'	45'

Support

On-Street Parking

If used, on-street parallel parking is typically installed on highways in downtown areas and commercial business districts. On-street parallel parking is generally more successful on low speed roadways (≤30 mph) with <15,000 ADT; higher speeds and volumes are not conducive to parking maneuvers and might not provide enough time to exit/enter a vehicle on the traffic side of the parked vehicle (*3*).

Markings for on-street parking are optional in the design parameters. The MUTCD (*1*) and Green Book (*2*) say marking on-street parking encourages more orderly and efficient use of parking spaces where turnover is substantial and prevents encroachment where parking is restricted (e.g.: fire hydrant). However, recent research (*4*) has found marked parking spaces might or might not improve parking efficiency. Areas with relatively uniform vehicle lengths can benefit from marked spaces, but in high-demand areas and long block segment, and in areas with varying vehicle lengths, unmarked parking can eventually self-organize and provide comparable efficiency. Efficiency is only one consideration for marked versus unmarked on-street parking; the researchers also pointed to customer convenience and expectation, operational costs, metered parking, and local policies and strategies as other factors to consider.

On-street parallel parking space lengths in Figure 630-B come from the 2009 MUTCD (*1*). See the ODOT Highway Design Manual (*5*) for on-street parking space width considerations.

There are several considerations for on-street angled parking, including a roadway design exception. See the ODOT Highway Design Manual for more information about angled parking considerations.

Off-Street Parking

Off-street parking is typically installed in rest areas, park-and-ride lots, and viewpoints. Designing a safe and efficient parking layout off of the highway involves many factors. For detailed information on parking layout, consult the AASHTO Guide for Park-and-Ride Facilities (*6*), AASHTO Guide for Development of Rest Areas on Major Arterials and Freeways (*7*), and the ITE Traffic Engineering Handbook (*3*).

Off-street parking space dimensions can vary depending on the design vehicle for the parking space, orientation of spaces, and how the space will be used (parking turnover, vehicle loading/unloading, door-opening clearance, user maneuverability). Off-street parking spaces for passenger vehicles are most commonly 8.5 to 9.0 feet wide, which allows for a mix of standard and compact vehicles. Length for perpendicular spaces is most commonly 18 feet, which allows for the 85th percentile vehicle length in the U.S. fleet (about 17 feet). Compact spaces can be as small as 7.5 feet wide by 15 feet long (*6*) (*7*) (*3*).

Off-street parking spaces for an interstate design vehicle (WB-67) are typically 15 feet wide and at least 80 feet long (*7*).

Accessible parking spaces are required for all affected buildings subject to the state building code per ORS 447.233. The Oregon Transportation Commission Standards for Accessible Parking Places (*8*) provides signing and pavement marking standards for all accessible parking spaces in Oregon.

Off-street parking space markings on ODOT facilities are white to be consistent with on-street markings.

Large Vehicle Parking in Rest Areas

Figure 630-C shows the ideal minimum dimension layouts for large vehicle parking in new rest areas. This is not always attainable when modifying current rest area parking areas due to limits of right of way, current paved surface, and funding. It is also not

desirable to remove current parking spaces to get closer to this standard. When repaving current rest area parking areas it can be a good opportunity to evaluate the current layout of the parking area to see if there can be an improvement to the design without reducing the number of parking spaces.

Cross References

Colors .... Section 110
Transverse Markings .... Section 125
Edge Lines .... Section 230
Bicycle Lanes .... Section 410
Bicycle Lane Buffers .... Section 412
Marked Crosswalks .... Section 430

Key References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Washington, D.C., 2009.
2. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*, 6th ed. Washington, D.C., 2011.
3. Institute of Transportation Engineers. *Traffic Engineering Handbook*, 6th ed. Institute of Transportation Engineers, Washington, D.C., 2010.
4. Dey, S. S., C. R. Dance, M. Darst, S. Dock, T. Silander, and A. Pochowski. To Demarcate or Not to Demarcate: Analysis of Marked Versus Unmarked On-Street Parking Efficiency. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2562, 2016, pp. 18-27. http://trrjournalonline.trb.org/doi/abs/10.3141/2562-03. DOI: http://dx.doi.org/10.3141/2562-03
5. Oregon Department of Transportation. *Highway Design Manual*. Oregon Department of Transportation, Salem, Oregon, 2012.
6. American Association of State Highway and Transportation Officials. *Guide for Park-and-Ride Facilities*, 2nd ed. American Association of State Highway and Transportation Officials, Washington, D.C., 2004. https://bookstore.transportation.org/item_details.aspx?id=121.
7. American Association of State Highway and Transportation Officials. *Guide for Development of Rest Areas on Major Arterials and Freeways*, 3rd ed. American Association of State Highway and Transportation Officials, Washington, D.C., 2001. https://bookstore.transportation.org/collection_detail.aspx?ID=104.
8. Oregon Transportation Commission. *Standards for Accessible Parking Places*. Oregon Department of Transportation, Salem, Oregon, August 2018. https://www.oregon.gov/odot/Engineering/DOCS_ADA/ADA_Standards-Accessible-Parking.pdf.

Freeway Median Crossovers Section 640

Introduction

Freeway median crossovers provide an opportunity for emergency and ODOT Maintenance vehicles to change directions on a freeway under certain conditions without needing to travel to an interchange. In emergency situations, these crossovers save critical time for responders; however, crossovers can be difficult for emergency drivers to locate at night or during inclement weather. Providing advance warning a crossover is ahead can help emergency drivers safely locate and use the crossover.

Design Parameters

01 *At freeway median crossovers, blue raised pavement markers (RPMs) should be used and placed as shown in Figure 640-A.*

02 If the freeway median crossover is located in an area that is frequently snowplowed, blue target identifier posts with blue targets may be used as shown in Figure 640-B instead of RPMs.

03 Blue target identifier posts may be used as shown in Figure 640-B in addition to RPMs where added conspicuity is needed based on engineering judgement.

Required Approvals

An engineering study and state traffic-roadway engineer approval is required for freeway median crossovers.

Figures & Tables

Figure 640-A: Freeway Median Crossover Advance RPM Layout

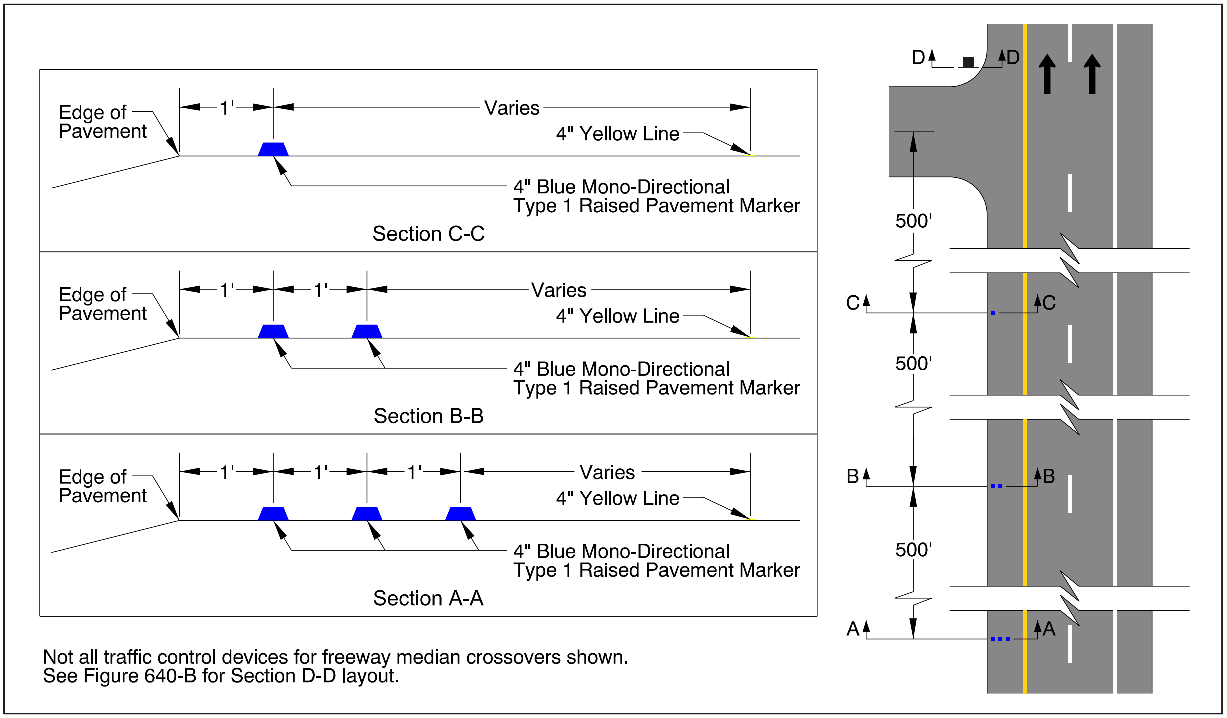
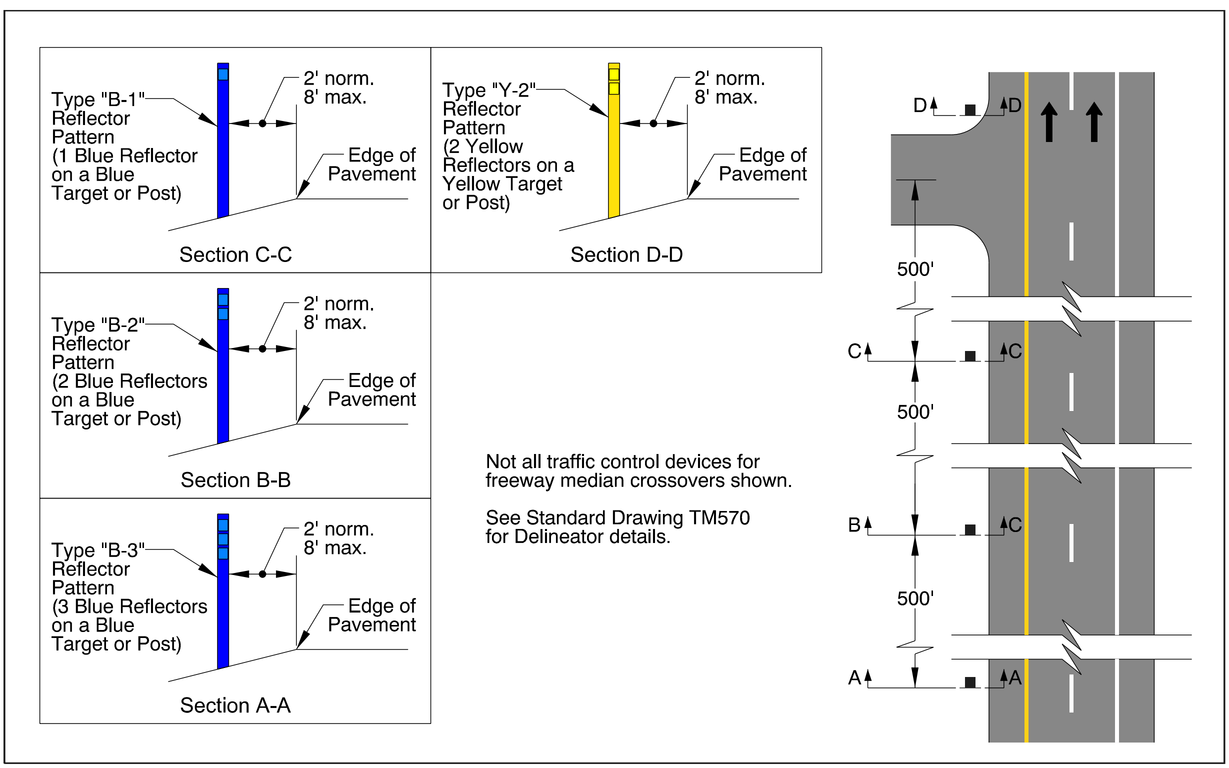


Figure 640-B: Freeway Median Crossover Advance Target Identifier Layout



Support

This design is not based on an MUTCD layout but has been used with good results by ODOT since at least 2000. Blue RPMs are used because:

1. Blue provides a unique, conspicuous marking.
2. Blue RPMs are mentioned in 2009 MUTCD Section 3B.11 (*1*) to mark locations of an important emergency services feature (fire hydrants). Since emergency personnel already look for blue RPMs to help locate emergency infrastructure and there are no known fire hydrants along ODOT freeways, blue RPMs can be used to identify freeway crossovers without causing confusion.
3. The MUTCD does not use blue RPMs to provide information for the general public and therefore would typically be ignored by the general public.

Placing three sets of RPMs 500 feet apart allows emergency drivers reasonable preview time prior to the crossover (~11-18 seconds, depending on speed). The use of a 3-2-1 countdown is simple to understand and gives emergency drivers enough information to determine how close the crossover is, even if the first one or two sets are missed.

In areas frequently plowed or where there is a wide left shoulder, blue delineators (instead of RPMs) can serve as target identifiers for emergency drivers approaching the crossover. When used in this context, the delineators are target identifiers rather than roadway delineators used by the general public. See Standard Drawings TM570 through TM577 for layout and installation details of delineator posts.

Additional signing (such as R5-11) and other traffic control devices could be needed at median crossovers. See the ODOT Traffic Manual (*2*) for more information.

Cross References

Raised Pavement Markers .... Section 130

Key References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Washington, D.C., 2009.
2. Oregon Department of Transportation. Traffic Manual, 2016 Edition. January 2016. http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Traffic-Manual-v2016.pdf. Accessed July 3, 2017.

Cattle Guard Markings Section 650

Introduction

Painted cattle guards provide a smoother driving surface and lower-cost alternative to traditional cattle guards in areas where keeping livestock contained is not critical.

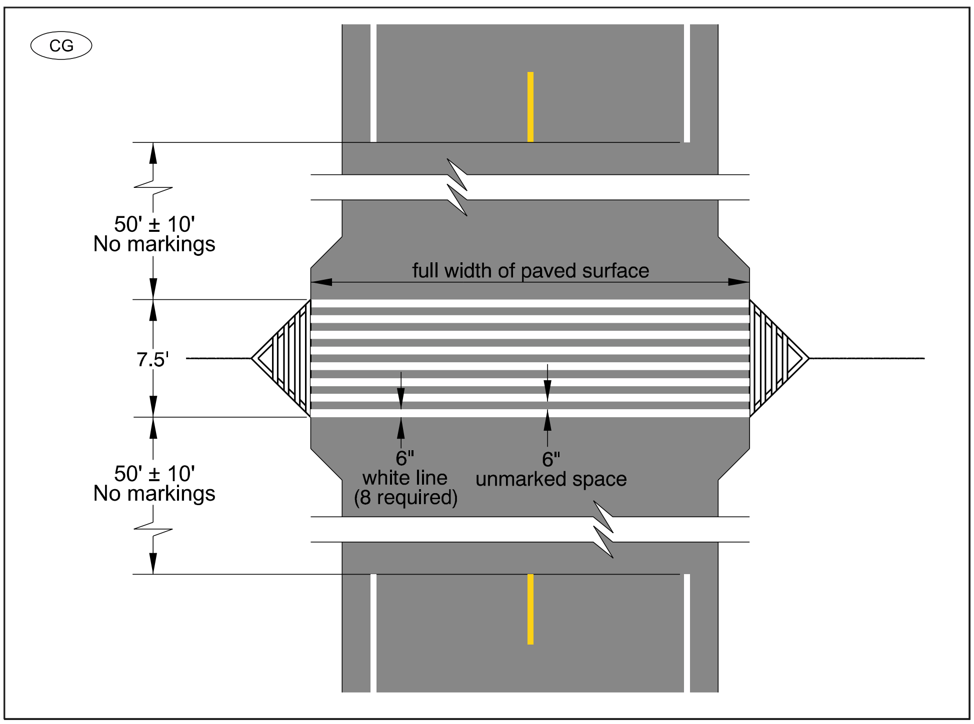
Design Parameters

01 Cattle guard markings may be used based on engineering judgement.

02 **If used, cattle guard markings shall be white and shall extend from edge of pavement to edge of pavement as shown in Figure 650.**

Figures & Tables

Figure 650: Standard Painted Cattle Guard



Support

Cattle guard markings have been used in the American West and internationally for many decades and have been used in Oregon since at least 1965.

In theory, animals perceive the contrasting white and dark pattern of a painted cattle guard as variations in the road surface like that of a traditional cattle guard. There is some anecdotal evidence that this works to deter cattle (*1*) (*2*), though painted cattle guards might not be the best tool where it is critical to keep livestock contained. Wildlife, however, does not appear to be deterred by painted cattle guards (*3*).

The design of this marking is based on past practice. Compared with traditional cattle guards, painted cattle guards are less expensive to install and maintain and they keep a smooth driving surface for high-speed highways. Wider stripes are used to give the painted cattle guard greater contrast for livestock to see; this contrast is enhanced if used on a dark pavement. It is thought the 50-foot clearance from the painted centerline to the edge of the painted cattle guard helps the cattle guard stand out as a barrier, though this has not been studied. The width of the cattle guard marking set matches the width of the cattle guard barrier located off the edge of the pavement.

Cross References

Colors .... Section 110
Center Lines .... Section 210
Edge Lines .... Section 230

Key References

1. Reuer, C. Synthesis of Animal-Vehicle Mitigation Measures. HDR Engineering, Inc., Phoenix, AZ, FHWA-AZ-07-612, 2007. https://apps.azdot.gov/ADOTLibrary/publications/project_reports/PDF/AZ612.pdf.

2. Telezhenko, E., L. Lidfors, and C. Bergsten. Dairy Cow Preferences for Soft or Hard Flooring when Standing or Walking. *Journal of Dairy Science*, Vol. 90, no. 8, August 2007, pp. 3716-3724. http://dx.doi.org/10.3168/jds.2006-876. DOI: 10.3168/jds.2006-876

3. Cramer, P. Determining Wildlife Use of Wildlife Crossing Structures Under Different Scenarios. Department of Wildland Resources and Utah Transportation Center, Utah State University, Logan, Utah, Final UT-12.07, 2012. http://www.udot.utah.gov/main/uconowner.gf?n=10315521671291686.

Slow Moving Vehicle Turnouts Section 660

Introduction

Slow moving vehicle turnouts are legacy features that are intended to allow drivers of slow moving vehicles to exit the travel lane and allow queued traffic to pass. Slow moving vehicle turnouts are shorter than a passing lane or climbing lane (*1*).

Design Parameters

01 A slow moving vehicle turnout may be marked if the slow moving vehicle turnout is signed according to the ODOT Sign Design Manual.

02 **If no slow moving vehicle turnout signs are installed, the edge line shall continue as a solid white line (W) through the widened paved shoulder area.**

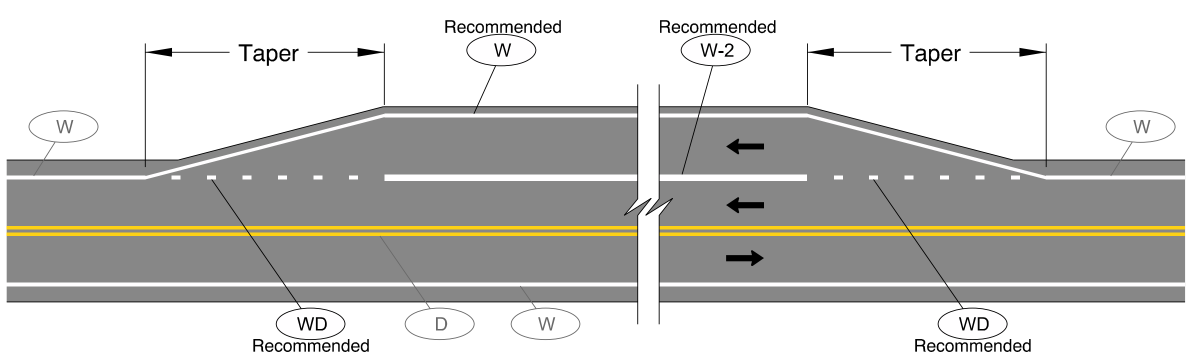
03 *A white dotted line (WD) should be used in the slow moving vehicle turnout addition and reduction tapers. A wide white solid line (W-2) should be used to separate the slow moving vehicle turnout from the adjacent travel lane. The right edge of the slow moving vehicle turnout should be marked with a solid white line (W) (Figure 660).*

Required Approvals

A roadway design exception is required for new slow moving vehicle turnouts.

Figures & Tables

Figure 660: Typical Slow Moving Vehicle Turnout



See the ODOT Sign Design Manual for required signs at slow moving vehicle turnouts.

Support

New slow moving vehicle turnouts are not typically installed in Oregon anymore, but there are legacy installations still in service.

Slow vehicle turnouts are not considered adequate for passing because they rely on the cooperation of slower drivers, are generally too short to completely break up an established queue, have little impact on percentage of following vehicles, and may not provide a net reduction in delay on the highway (*2*) (*3*). These are only considered when a passing lane is not feasible and not as an alternative to a passing lane (*4*).

Slow vehicle turnouts are short by design (*1*); the right edge of the turnout is marked with an edge line to guide the slow vehicle driver into the turnout and show where the turnout ends, especially at night and during poor weather.

The ODOT Sign Design Manual (*5*) contains more information on signs associated with slow moving vehicle turnouts.

Cross References

Colors .... Section 110
Edge Lines .... Section 230

Key References

1. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*, 6th ed. Washington, D.C., 2011.
2. Koorey, G. Passing Opportunities at Slow-Vehicle Bays. *Journal of Transportation Engineering*, Vol. 133, no. 2, February 2007, pp. 129-137. http://dx.doi.org/10.1061/(ASCE)0733-947X(2007)133:2(129).
3. Bowie, J., and J. R. Kinney. Operational Effects of Slow Vehicle Turnouts on a Rurual Highway in Alaska. in *International Conference on Transportation and Development 2016*, Houston, Texas, 2016, pp. 1087-1098. http://dx.doi.org/10.1061/9780784479926.097.
4. Oregon Department of Transportation. Traffic Manual, 2016 Edition. January 2016. http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Traffic-Manual-v2016.pdf. Accessed July 3, 2017.
5. Oregon Department of Transportation. *Traffic Sign Design Manual*, 3rd ed. Oregon Department of Transportation, Traffic-Roadway Section, Salem, Oregon, 2013. http://www.oregon.gov/ODOT/Engineering/Documents_TrafficStandards/Sign-Design-Manual.pdf.

Placeholder Appendix Appendix A

This section is reserved for future content.

ODOT Pavement Marking Contacts Appendix B

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Critical Locations for Signing & Pavement Marking Coordination Appendix C

Pavement Marking design needs to be coordinated with sign design for the following situations. Refer to the ODOT Traffic Sign Design Manual and the Manual on Uniform Traffic Control Devices (MUTCD) for more information.

- Lane addition transitions.
- Lane reduction transitions.
- Rural left-turn channelization.
- Roundabouts.
- Interchange exit ramps with drop lane(s).
- Wrong way arrows for interchange ramp terminals.
- Slow moving vehicle turnouts.
- Ramp meters.
- Mid-block crosswalks.
- School markings.
- Railroad crossing markings.
- Bike lane markings.
- Parking space markings.

References Appendix D

1. Reuer, C. Synthesis of Animal-Vehicle Mitigation Measures. HDR Engineering, Inc., Phoenix, AZ, FHWA-AZ-07-612, 2007. https://apps.azdot.gov/ADOTLibrary/publications/project_reports/PDF/AZ612.pdf.
2. American Association of State Highway and Transportation Officials. *Highway Safety Manual*, 1st ed. AASHTO, Washington, D.C., 2010.
3. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*, 6th ed. Washington, D.C., 2011.
4. American Association of State Highway and Transportation Officials. *Guide for the Development of Bicycle Facilities*, 4th ed. Washington, D.C., 2012.
5. American Association of State Highway and Transportation Officials. *Guide for the Planning, Design, and Operation of Pedestrian Facilities*. American Association of State Highway and Transportation Officials, Washington, D.C., 2004.
6. American Association of State Highway and Transportation Officials. *Guide for Geometric Design of Transit Facilities on Highways and Streets*. American Association of State Highway and Transportation Officials, Washington, D.C., 2014.
7. American Association of State Highway and Transportation Officials. *Guide for Park-and-Ride Facilities*, 2nd ed. American Association of State Highway and Transportation Officials, Washington, D.C., 2004. https://bookstore.transportation.org/item_details.aspx?id=121.
8. American Association of State Highway and Transportation Officials. *Guide for Development of Rest Areas on Major Arterials and Freeways*, 3rd ed. American Association of State Highway and Transportation Officials, Washington, D.C., 2001. https://bookstore.transportation.org/collection_detail.aspx?ID=104.
9. Arizona Department of Transportation. *ADOT Traffic Engineering Policies, Guidelines, and Procedures*. Arizona Department of Transportation, 2000. http://www.azdot.gov/business/engineering-and-construction/traffic/policies-guidelines-and-procedures-(pgp).
10. Arnold, R. E. MUTCD - Interim Approval for Optional Use of an Intersection Bicycle Box (IA-18). October 12, 2016. http://mutcd.fhwa.dot.gov/resources/interim_approval/ia18/ia18.pdf. Accessed October 24, 2016.
11. ASTM International. (2016) ASTM D6628: Standard Specification for Color of Pavement Marking Materials. [Online]. https://www.astm.org/cgi-bin/resolver.cgi?D6628. DOI: https://doi.org/10.1520/D6628-16
12. Bahar, G., C. Mollett, B. Persaud, C. Lyon, A. Smiley, T. Smahel, and H. McGee. NCHRP Report 518: Safety Evaluation of Permanent Raised Pavement Markers. Transportation Research Board, Washington, D.C., ISBN 0-309-08790-2, 2004. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_518.pdf.
13. Balk, S. A., and S. Jackson. Lane Line Markings in Advance of Lane-Reduction Transitions. Traffic Control Devices Pooled Fund Study, Washington, D.C., 2016. http://pooledfund.org/Document/Download/6265.
14. Boudart, J., R. Liu, P. Koonce, and L. Okimoto. Assessment of Bicyclist Behavior at Traffic Signals with a Detector Confiration Feedback Device. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2520, 2015, pp. 61-66. http://trrjournalonline.trb.org/doi/abs/10.3141/2520-08. DOI: http://dx.doi.org/10.3141/2520-08
15. Bowie, J., and J. R. Kinney. Operational Effects of Slow Vehicle Turnouts on a Rurual Highway in Alaska. in *International Conference on Transportation and Development 2016*, Houston, Texas, 2016, pp. 1087-1098. http://dx.doi.org/10.1061/9780784479926.097.
16. Braam, A. C. Wrong way Crashes: Statewide Study of Wrong Way Crashes on Freeways in North Carolina. 2006. https://connect.ncdot.gov/resources/safety/Documents/Crash%20Data%20and%20Information/WrongWayCrash.pdf.
17. Brady, J., A. Mills, J. Loskorn, J. Duthie, and R. Machemehl. Effects of Colored Lane Markings on Bicyclist and Motorist Behavior at Conflict Areas. Center for Transportation Research, University of Texas at Austin, Austin, Texas, 2010. http://library.ctr.utexas.edu/ctr-publications/iac/COAbike_ColoredLanes-final.pdf.

18. Brewer, M., D. Murillo, and A. Pate. Handbook for Designing Roadways for the Aging Population. Washington, D.C., FHWA-SA-14-015, 2014. http://safety.fhwa.dot.gov/older_users/handbook/aging_driver_handbook_2014_final%20.pdf.

19. Brian, R., W. Kittleson, J. Knudsen, B. Nevers, P. Ryus, K. Sylvester, I. Potts, D. Harwood, D. Gilmore, D. Torbic, F. Hanscom, J. McGill, and D. Stewart. *NCHRP Report 613: Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections*. Transportation Research Board of the National Academies, Washington, D.C., 2008. http://www.trb.org/Publications/Blurbs/160046.aspx.

20. Bussey, S., C. M. Monsere, and P. Koonce. Paper 15-2501: Does the Bicycle Detector Symbol Change Cyclist Queuing Position at Signalized Intersections? in *Transportation Research Board 94th Annual Meeting*, Washington, D.C., 2015. http://amonline.trb.org/trb57535-2015-1.1793793/t024-1.1811852/593-1.1812263/15-2501-1.1812276/15-2501-1.1940644?qr=1.

21. California Department of Transportation. *California Manual on Uniform Traffic Control Devices*. California Department of Transporation, Sacramento, California, 2014. http://www.dot.ca.gov/hq/traffops/engineering/mutcd/ca_mutcd2014.htm.

22. Campbell, J. L., M. G. Lichty, J. L. Brown, C. M. Richard, J. S. Graving, J. Graham, M. O'Laughlin, D. Torbic, and D. Harwood. NCHRP Report 600: Human Factors Guidelines for Road Systems. 2012. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_600Second.pdf. Accessed October 23, 2012.

23. Carlson, P. J., E. S. Park, and C. K. Anderson. Benefits of Pavement Markings: A Renewed Perspective Based on Recent and Ongoing Research. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2107, 2009, pp. 59-68. http://trrjournalonline.trb.org/doi/pdf/10.3141/2107-06. DOI: 10.3141/2107-06

24. Carlson, P. J., J. D. Miles, A. M. Pike, and E. S. Park. Evaluation of Wet-Weather and Constrast Pavement Marking Applications: Final Report. Texas Transportation Institute, Texas A&M University System, College Station, TX, FHWA/TX-07/0-5008-2, 2007. http://tti.tamu.edu/documents/0-5008-2.pdf.

25. Carlson, P., E.-S. Park, A. Pike, R.J. Porter, J. Miles, B. Boulanger, O. Smadi, N. Hawkins, S. Chalmers, F. Darmiento, A. Burde, B. Kuhn, and W. Ealding. Pavement Marking Demonstration Projects: State of Alaska and State of Tennessee. Texas Transportation Institute, The Texas A&M University, McLean, VA, FHWA-HRT-12-048, 2013. http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/12048/12048.pdf.

26. Carlson, P. J. Synthesis of Pavement Marking Research. Texas A&M Transportation Insititute, College Station, Texas, FHWA-SA-15-063, 2015. https://safety.fhwa.dot.gov/roadway_dept/night_visib/pavement_marking/pvmnt_mrkg_synth.pdf.

27. Chapman, J., and D. Noyce. Observations of Driver Behavior During Overtaking of Bicycles on Rural Roads. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2321, 2012, pp. 38-45. http://trrjournalonline.trb.org/doi/abs/10.3141/2321-06. DOI: 10.3141/2321-06

28. Chitturi, M. V., I. Alsghan, K. R. Santiago, and D. A. Noyce. Field Evaluation of Elongated Pavement Marking Signs. *Transportation Research Record: Journal of the Transportation Research Board Online*, Vol. 2624, 2017, pp. 28-37. http://trrjournalonline.trb.org/doi/abs/10.3141/2624-04. DOI: https://doi.org/10.3141/2624-04

29. Chrysler, S. T., and S. D. Schrock. Field Evaluations and Driver Comprehension Studies of Horizontal Signing. Texas Transportation Institute, College Station, Texas, FHWA/TX-05/0-4471-2, 2005. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-4471-2.pdf.

30. Cooner, S. A., A. S. Cothron, and S. E. Ranft. Countermeasures for Wrong-Way Movement on Freeways: Guidelines and Recommended Practices. Texas Transportation Institute, Texas A&M University, Austin, Texas, FHWA/TX-04/4128-2, 2004. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/4128-2.pdf.

31. Cooner, S. A., A. S. Cothron, and S. E. Ranft. Countermeasures for Wrong-Way Movements on Freeways: Overview of Project Activities and Findings. Texas Transportation Institute, Texas A&M University, Austin, Texas, FHWA/TX-04/4128-1, 2004. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/4128-1.pdf.

32. Cramer, P. Determining Wildlife Use of Wildlife Crossing Structures Under Different Scenarios. Department of Wildland Resources and Utah Transportation Center, Utah State University, Logan, Utah, Final UT-12.07, 2012. http://www.udot.utah.gov/main/uconowner.gf?n=10315521671291686.

33. Dey, S. S., C. R. Dance, M. Darst, S. Dock, T. Silander, and A. Pochowski. To Demarcate or Not to Demarcate: Analysis of Marked Versus Unmarked On-Street Parking Efficiency. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2562, 2016, pp. 18-27. http://trrjournalonline.trb.org/doi/abs/10.3141/2562-03. DOI: http://dx.doi.org/10.3141/2562-03

34. Dill, J., C. M. Monsere, and N. McNeil. Evaluation of Bike Boxes at Signalized Intersections. *Accident Analysis & Prevention*, Vol. 44, no. 1, January 2012, pp. 126-134. http://dx.doi.org/10.1016/j.aap.2010.10.030.

35. Duthie, J., J. F. Brady, A. F. Mills, and R. B. Machemehl. Effects of On-Street Bicycle Facility Configuration on Bicyclist and Motorist Behavior. *Transortation Researhc Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2190, 2010, pp. 37-44. http://trrjournalonline.trb.org/doi/abs/10.3141/2190-05. DOI: http://dx.doi.org/10.3141/2190-05

36. Engerg, A., and M. Pursula. Traffic Flow Characteristics on a Three-Lane Rural Highway in Finland: Results from Empirical Studies and Simulations. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1572, 1997, pp. 33-42. http://trrjournalonline.trb.org/doi/abs/10.3141/1572-05. DOI: 10.3141/1572-05

37. Farah, H., and T. Toledo. Passing Behavior on Two-Lane Highways. *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 13, no. 6, November 2010, pp. 355-364. http://www.sciencedirect.com/science/article/pii/S1369847810000653. DOI: 10.1016/j.trf.2010.07.003

38. Farah, H. Age and Gender Differences in Overtaking Maneuvers on Two-Lane Rural Highways. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2248, 2011, pp. 30-36. http://trrjournalonline.trb.org/doi/abs/10.3141/2248-04. DOI: http://dx.doi.org/10.3141/2248-04

39. Farley, W. R. An Analysis of Bicycle-Vehicle Interactions at Signalized Intersections with Bicycle Boxes. Portland State University, Portland, Oregon, Dissertations and Theses Paper 1618, 2014. http://archives.pdx.edu/ds/psu/11016.

40. Federal Highway Administration. Frequently Asked Questions - Part 3 - Markings. *Manual on Uniform Traffic Control Devices*, October 20, 2015. http://mutcd.fhwa.dot.gov/knowledge/faqs/faq_part3.htm. Accessed July 6, 2016.

41. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed. Washington, D.C., 2009.

42. Federal Highway Administration. *Separated Bike Lane Planning and Design Guide*. U.S. Department of Transportation, Washington, D.C., 2015. https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/separated_bikelane_pdg/separatedbikelane_pdg.pdf.

43. Federal Highway Administration. *Standard Highway Signs*, 2004 ed. Federal Highway Administration, Washington, D.C., 2004.

44. *Federal Register: Volume 74, Number 240*. Washington, D.C.: United States Government Publishing Office, 2009, p. 66860. https://www.gpo.gov/fdsys/pkg/FR-2009-12-16/pdf/E9-28322.pdf.

45. Fitzpatrick, K., K. Balke, D. W. Harwood, and I. B. Anderson. NCHRP Report 440: Accident Mitigation Guide for Congested Rural Two-Lane Highways. Transportation Research Board of the National Academies, Washington, D.C., ISBN 0-309-06627-7, 2000.

46. Fitzpatrick, K., S. T. Chrysler, V. Iragavarapu, and E. S. Park. Crosswalk Marking Field Visibility Study. Texas Transportation Institute, Texas A&M University, McLean VA, Technical Report FHWA-HRT-10-068, 2010. http://www.fhwa.dot.gov/publications/research/safety/pedbike/10068/10068.pdf.

47. Fitzpatrick, K., M. Lance, and T. Lienau. Effects of Pavement Markings on Driver Behavior at Freeway Lane Drop Exits. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1495, 1995, pp. 17-27. http://onlinepubs.trb.org/Onlinepubs/trr/1995/1495/1495-003.pdf.

48. Fitzpatrick, K., M. Ogden, and T. Lienau. Motorists' Comprehension of Exit Lane Drop Signs and Markings. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1464, 1994, pp. 51-59. http://onlinepubs.trb.org/Onlinepubs/trr/1994/1464/1464-007.pdf.

49. Friedman, B. E. NCHRP Synthesis 356: Pavement Markings - Design and Typical Layout Details. Washington, D.C., ISBN 0-309-09763-0, 2006. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_356.pdf.

50. Ghasemzadeh, A., and M. M. Ahmed. Drivers' Lane-Keeping Ability in Heavy Rain: Preliminary Investigation using SHRP 2 Naturalistic Driving Study Data. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2663, 2017, pp. 99-108. https://doi.org/10.3141/2663-13.

51. Glennon, J. C. New and Improved Model of Passing Sight Distance on Two-Lane Highways. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1195, 1998, pp. 132-137. http://trid.trb.org/view.aspx?id=302154.

52. Gomez, R. A., S. Samuel, L. R. Gerardino, M. R.E. Romoser, J. Collura, M. Knodler, and D. L. Fisher. Do Advance Yield Markings Increase Safe Driver Behaviors at Unsignalized, Marked Midblock Crosswalks? *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2264, 2011, pp. 27-33. http://trrjournalonline.trb.org/doi/pdf/10.3141/2264-04. DOI: 10.3141/2264-04

53. Graham, J. L., and M. C. Sharp. Effects of Taper Length on Traffic Operations in Construction Zones. Midwest Research Institute, Washington, D.C., FHWA-RD-77-162, 1977.

54. Graham, J. L., D. W. Harwood, and M. C. Sharp. Effects of Taper Length on Traffic Operations in Construction Zones. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, no. 703, 1979, pp. 19-24. https://trid.trb.org/View/145597.

55. Gross, F., R. Jagannathan, C. Lyon, and K. Eccles. Safety Effectiveness of "Stop Ahead" Pavement Markings. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2056, 2008, pp. 25-33. http://trrjournalonline.trb.org/doi/abs/10.3141/2056-04. DOI: http://dx.doi.org/10.3141/2056-04

56. Hanscom, F. R. Drivers' Understanding of Innovative Roundabout Traffic Control Devices. *ITE Journal*, Vol. 80, no. 7, July 2010, pp. 40-44. https://trid.trb.org/view.aspx?id=933416.

57. Harwood, D. W., C. J. Hoban, and D. L. Warren. Effective Use of Passing Lanes on Two-Lane Highways. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, no. 1195, 1988, pp. 79-91. http://trid.trb.org/view.aspx?id=302149.

58. Harwood, D. W., D. K. Gilmore, K. R. Richard, J. M. Dunn, and C. Sun. NCHRP Report 605: Passing Sight Distance Criteria. Transportation Research Board of the National Academies, Washington, D.C., ISBN: 978-0-309-09927-1, 2008. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_605.pdf.

59. Hassan, Y., S. M. Easa, and A. O. Abd El Halim. Passing Sight Distance on Two-Lane Highways: Review and Revision. *Transportation Research Part A*, Vol. 30, no. 6, November 1996, pp. 453-467. http://www.sciencedirect.com/science/article/pii/0965856495000321. DOI: 10.1016/0965-8564(95)00032-1

60. Hawkins, H. G., A. H. Parham, and K. N. Womack. NCHRP Report 484: Feasibility Study for an All-White Pavement Marking System. Texas Transportation Institute, Washington, D.C., ISBN 0-309-06772-3, 2002. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_484.pdf.

61. Hunter, W. W., R. Srinivasan, and C. A. Martell. Evaluation of a Green Bike Lane Weaving Area in St. Petersburg, Florida. Highway Safety Research Center, University of North Carolina, Tallahassee, Florida, 2008. http://nacto.org/wp-content/uploads/2011/01/Evaluation_of_Green_Bike_Lane_Weaving.pdf.

62. Hunter, W. W., D. L. Harkey, R. Stewart, and M. L. Birk. Evaluation of Blue Bike-Lane Treatment in Portland, Oregon. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1705, 2000, pp. 107-115. http://trrjournalonline.trb.org/doi/pdf/10.3141/1705-16.

63. Hunter, W. Evaluation of Innovative Bike-Box Application in Eugene, Oregon. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1705, 2000, pp. 99-106. http://trrjournalonline.trb.org/doi/abs/10.3141/1705-15. DOI: http://dx.doi.org/10.3141/1705-15

64. Institute of Transportation Engineers. *Traffic Control Devices Handbook*. Institute of Transportation Engineers, Washington, D.C., 2001.

65. Institute of Transportation Engineers. *Traffic Engineering Handbook*, 6th ed. Institute of Transportation Engineers, Washington, D.C., 2010.

66. Isebrands, H., S. Hallmark, and N. Hawkins. Effects of Approach Speed at Rural High-Speed Intersections: Roundabouts Versus Two-Way-Stop Control. *Transportation Research Record: Journal of the Transportation Research Board Online*, Vol. 2402, 2014, pp. 67-77. http://trrjournalonline.trb.org/doi/abs/10.3141/2402-08. DOI: https://doi.org/10.3141/2402-08

67. Johnson, M., S. Newstead, J. Oxley, and J. Charlton. Cyclists and Open Vehicle Doors: Crash Characteristics and Risk Factors. *Safety Science*, Vol. 59, November 2013, pp. 135-140. http://www.sciencedirect.com/science/article/pii/S0925753513001057. DOI: http://dx.doi.org/10.1016/j.ssci.2013.04.010

68. Jordan, G., and L. Leso. Power of the Line: Shared-Use Path Conflict Resolution. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1705, 2000, pp. 16-19. http://trrjournalonline.trb.org/doi/abs/10.3141/1705-03. DOI: http://dx.doi.org/10.3141/1705-03

69. Kehrli, M. R. MUTCD - Interim Approval for Optional Use of Green Colored Pavement for Bike Lanes (IA-14). June 29, 2011.

70. Kidarsa, R., T. Pande, S. V. Vanjari, J. V. Krogmeier, and D. M. Bullock. Design Considerations for Detecting Bicycles with Inductive Loop Detectors. *Transportation Research Record: Journal of the Transportation Rsearch Board of the National Academies*, Vol. 1978, 2006, pp. 1-7. http://trrjournalonline.trb.org/doi/abs/10.3141/1978-03. DOI: http://dx.doi.org/10.3141/1978-03

71. Koorey, G. Passing Opportunities at Slow-Vehicle Bays. *Journal of Transportation Engineering*, Vol. 133, no. 2, February 2007, pp. 129-137. http://dx.doi.org/10.1061/(ASCE)0733-947X(2007)133:2(129).

72. Lathrop, S. L., T. B. Dick, and K. B. Nolte. Fatal Wrong-Way Collisions on New Mexico's Interstate Highways, 1990-2004. *Journal of Forensic Sciences*, Vol. 55, no. 2, March 2010, pp. 432-437. http://www.ce.siue.edu/faculty/hzhou/ww/paper/Fatal%20wrong-way%20on%20new%20mexico_2010.pdf.

73. Lindley, J. A. (2013, August) MUTCD - Official Ruling 3(09)-24(I)-Application of Colored Pavement. Memorandum. [Online]. http://mutcd.fhwa.dot.gov/resources/interpretations/pdf/3_09_24.pdf.

74. Loskorn, J., A. F. Mills, J. F. Brady, J. C. Duthie, and R. B. Machemehl. Effects of Bicycle Boxes on Bicyclist and Motorist Behavior at Intersections in Austin, Texas. *ASCE Journal of Transportation Engineering*, Vol. 139, no. 10, October 2013, pp. 1039-1046. http://dx.doi.org/10.1061/(ASCE)TE.1943-5436.0000584.

75. Lyon, C., B. Persaud, N. Lefler, D. Carter, and K. A. Eccles. Safety Evaluation of Installing Center Two-Way Left-Turn Lanes on Two-Lane Roads. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2075, December 2008, pp. 34-41. http://trrjournalonline.trb.org/doi/pdf/10.3141/2075-05. DOI: http://dx.doi.org/10.3141/2075-05

76. Markings Technical Committee of the National Committee on Uniform Traffic Control Devices. Colored Pavements (Yellow, White, Green, Red, and Purple). National Committee on Uniform Traffic Control Devices, Suprise, Arizona, 2014. http://www.ncutcd.org/Documents/Meetings/June_2016/Attach%20No.23%20Markings%20Interim%20No.%202.pdf.

77. McNeil, N., C. M. Monsere, and J. Dill. Influence of Bike Lane Buffer Types on Perceived Comfort and Safety of Bicyclists and Potential Bicyclists. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2520, January 2015, pp. 132-142. http://trrjournalonline.trb.org/doi/abs/10.3141/2520-15. DOI: http://dx.doi.org/10.3141/2520-15

78. Migletz, J., and J. Grahm. NCHRP Synthesis 306: Long-Term Pavement Marking Practices. Washington, D.C., 2002. http://www.trb.org/Main/Blurbs/152126.aspx.

79. Miles, J. D., M. P. Pratt, and P. J. Carlson. Evaluation of Erratic Maneuvers Associated with Installation of Rumble Strips. *Transportation Research Record: Journal of the Transportation Research Board Online*, Vol. 1973, 2006, pp. 73-79. http://trrjournalonline.trb.org/doi/abs/10.3141/1973-11. DOI: https://doi.org/10.3141/1973-11

80. Miles, J. D., P. J. Carlson, B. Ullman, and N. Trout. Red Retroreflective Raised Pavement Markings: Driver Understanding of Their Purpose. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2056, 2008, pp. 34-42. http://trb.metapress.com/content/82wx451g816p37mn/fulltext.pdf.

81. Molino, J. A., V. W. Inman, B. J. Katz, and A. Emo. Lane Restriction Signing and Marking for Double-Lane Roundabouts. Turner-Fairbank Highway Research Center, McLean, Virginia, 2007. www.pooledfund.org/ Document/Download/1226.

82. Monsere, C., M. Figliozzi, S. Thompson, and K. Paulsen. SPR 747: Operational Guidance for Bicycle-Specific Traffic Signals in the United States. Portland State University, Portland, Oregon, FHWA-OR-RD-14-06, 2013. http://www.oregon.gov/ODOT/TD/TP_RES/.

83. Monsere, C. M., N. McNeil, and J. Dill. Multiuser Perspectives on Separated, On-Street Bicycle Infrastructure. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 2314, 2012, pp. 22-30. http://trrjournalonline.trb.org/doi/abs/10.3141/2314-04. DOI: http://dx.doi.org/10.3141/2314-04

84. Monsere, C., S. Kothuri, and A. Razmpa. Wrong Way Driving Analysis and Recommendations. Portland State University, Portland, Oregon, 2017. http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Wrong-Way-Driver-Report.pdf.

85. National Association of City Transportation Officials. *NACTO Urban Bikeway Design Guide*, 2nd ed. National Association of City Transportation Officials, New York, New York. http://nacto.org/cities-for-cycling/design-guide/.

86. National Association of City Transportation Officials. *Transit Street Design Guide*. Island Press, Washington, D.C., 2016. http://nacto.org/publication/transit-street-design-guide/.

87. National Transportation Safety Board. Highway Special Investigation Report: Wrong-Way Driving. Washington, D.C., NTSB/SIR-12/01, 2012. https://www.ntsb.gov/doclib/safetystudies/SIR1201.pdf.

88. Neuman, T. R., R. Pfefer, K. L. Slack, K. K. Hardy, D. W. Harwood, I. B. Potts, D. J. Torbic, and E. R.K. Rabbani. NCHRP Report 500 Volume 5: A Guide for Addressing Unsignalized Intersection Collisions. Transportation Research Board of the National Academies, Washington, D.C., ISBN 0-309-08760-0, 2003. http:// onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_500v5.pdf.

89. Neuman, T. R., J. J. Nitzel, N. Antonucci, S. Nevill, and W. Stein. NCHRP Report 500, Volume 20: A Guide for Reducing Head-On Crashes on Freeways. Washington, D.C., 2008. http://onlinepubs.trb.org/onlinepubs/nchrp/ nchrp_rpt_500v20.pdf.

90. Nordback, K., S. Kothuri, M. Figliozzi, T. Phillips, C. Gorecki, and A. Schrope. Investigation of Bicycle and Pedestrian Continuous and Short Duration Count Technologies in Oregon. Portland State University, Portland, Oregon, FHWA-OR-RD-16-15, 2016. http://www.oregon.gov/ODOT/Programs/ResearchDocuments/ SPR772_Bicycle_PedestrianTechnologies.pdf.

91. North Texas Tollway Authority. Keeping NTTA Roadways Safe: Wrong-Way Driver Task Force Staff Analysis. Plano, TX, 2009. https://www.ntta.org/newsresources/safeinfo/wrongway/Documents/ WWDAnalysisAUG2011.pdf.

92. Ogden, B. D. Railroad-Highway Grade Crossing Handbook. Washington, D.C., FHWA-SA-07-010, 2007. https:// www.fra.dot.gov/Elib/Details/L02829.

93. Oregon Department of Transportation. *2016 Oregon Transportation Safety Action Plan*. Oregon Department of Transportation, Salem, Oregon, 2016. http://www.oregon.gov/ODOT/Safety/Documents/TSAP_2016.pdf.

94. Oregon Department of Transportation. A Guide to School Area Safety. Traffic Engineering & Operations Section and Traffic Safety Division, Oregon Department of Transportation, Salem, Oregon, 2017. http:// www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Guide_to_School_Area_Safety.pdf.

95. Oregon Department of Transportation. *Analysis Procedures Manual*, 2nd ed. Oregon Department of Transportation, Salem, Oregon, 2016. http://www.oregon.gov/ODOT/Planning/Pages/APM.aspx.

96. Oregon Department of Transportation. *Bicycle and Pedestrian Design Guide*, 3rd ed. Oregon Department of Transportation, Salem, Oregon, 2011. http://www.oregon.gov/ODOT/Engineering/Documents_RoadwayEng/HDM_L-Bike-Ped-Guide.pdf.

97. Oregon Department of Transportation. *ODOT Pavement Marking Design Guidelines*, 2nd ed. Oregon Department of Transportation, Salem, Oregon, 2011. http://www.oregon.gov/ODOT/Engineering/Documents_TrafficStandards/Pavement-Marking-Design-Guide.pdf.

98. Oregon Department of Transportation. *Oregon Supplement to the 2009 MUTCD*, 2009 ed. Oregon Department of Transportation, Salem, Oregon, 2011. http://www.oregon.gov/ODOT/Engineering/Documents_TrafficStandards/MUTCD-OR-Supplement.pdf.

99. Oregon Department of Transportation. *Ramp Meter Design Guidelines*. Oregon Department of Transportation, 1994.

100. Oregon Department of Transportation. Traffic Manual, 2016 Edition. January 2016. http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Traffic-Manual-v2016.pdf. Accessed July 3, 2017.

101. Oregon Department of Transportation. *Traffic Sign Design Manual*, 3rd ed. Oregon Department of Transportation, Traffic-Roadway Section, Salem, Oregon, 2013. http://www.oregon.gov/ODOT/Engineering/Documents_TrafficStandards/Sign-Design-Manual.pdf.

102. Oregon Department of Transportation. *Traffic Signal Design Manual*, 2016 ed. Oregon Department of Transportation, Salem, OR, 2016. http://www.oregon.gov/ODOT/Engineering/Pages/Signal-Design-Manual.aspx.

103. Oregon Transportation Commission. *Standards for Accessible Parking Places*. Oregon Department of Transportation, Salem, Oregon, May 2012. http://www.oregon.gov/ODOT/Engineering/Documents_TrafficStandards/Striping_Accessible-Parking-Standards.pdf.

104. Oregon Department of Transportation. Sign Policy and Guidelines. July 2014. http://www.oregon.gov/ODOT/HWY/TRAFFIC-ROADWAY/docs/pdf/entire_sign_policy.pdf. Accessed November 25, 2014.

105. Parham, A. H., K. N. Womack, and H. G. Hawkins Jr. Driver Understanding of Pavement Marking Colors and Patterns. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1844, 2003, pp. 35-44. http://trrjournalonline.trb.org/doi/abs/10.3141/1844-05. DOI: http://dx.doi.org/10.3141/1844-05

106. Park, E. S., P. J. Carlson, R. J. Porter, and C. K. Anderson. Safety Effects of Wider Edge Lines on Rural, Two-Lane Highways. *Accident Analysis and Prevention*, Vol. 48, September 2012, pp. 317-325. http://dx.doi.org/10.1016/j.aap.2012.01.028.

107. Pollatschek, M. A., and A. Polus. Modeling Impatience of Drivers in Passing Maneuvers. in *Transportation and Traffic Theory: Flow, Dynamics and Human Interaction: Proceedings of the 16th International Symposium on Transportation and Traffic Theory*, College Park, Maryland, 2005, pp. 267-279.

108. Polus, A., M. Livneh, and B. Frischer. Evaluation of the Passing Process on Two-Lane Rural Highways. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1701, 2000, pp. 53-60. http://trrjournalonline.trb.org/doi/abs/10.3141/1701-07. DOI: 10.3141/1701-07

109. Potts, I. B., D. W. Harwood, K. M. Bauer, D. K. Gilmore, J. M. Hutton, D. J. Torbic, J. F. Ringert, A. Daleiden, and J. M. Barlow. NCHRP Web-Only Document 208: Design Guidance for Channelized Right-Turn Lanes. Transportation Research Board of the National Academies, Washington, D.C., 2011. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w208.pdf.

110. Radalj, T. Driver Speed Compliance within School Zones and Effects of "40" Painted Speed Limit on Driver Speed Behaviors. in *Road Safety Research, Policing and Education Conference*, Vol. 2, Adelaide, South Australia, Australia, 2002, pp. 207-14. https://trid.trb.org/view.aspx?id=702285.

111. Reilly, W. R., R. C. Pfefer, R. M. Michaels, A. Polus, and J. M. Schoen. NCHRP Project 3-35: Speed-Change Lanes. Northwestern University, Washington, D.C., Final Report 1989. http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP03-35_FR.pdf.

112. Richard, C. M., and M. G. Lichty. Driver Expectations When Navigating Complex Interchanges. Federal Highway Administration Office of Safety Research and Development, McLean, VA, Final Report FHWA-HRT-13-048, 2013. https://www.fhwa.dot.gov/publications/research/safety/13048/13048.pdf.

113. Rodegerdts, L., J. Bansen, C. Tiesler, J. Knudsen, E. Myers, M. Johnson, M. Moule, B. Persaud, C. Lyon, S. Hallmark, H. Isebrands, R. B. Crown, B. Guichet, and A. O'Brien. *NCHRP Report 672: Roundabouts: An Informational Guide*, 2nd ed. Transportation Research Board of the National Academies, Washington, D.C., 2010. http://www.trb.org/Main/Blurbs/164470.aspx.

114. Sadek, A. W., A. Dickason, and J. Kaplan. Effectiveness of a Green, High-Visibility Bike Lane and Crossing Treatment. in *Transportation Research Board 86th Annual Meeting Compendium of Papers CD-ROM*, Washington, D.C., 2007. https://wiki.cecs.pdx.edu/pub/ItsWeb/BikeBoxes/07-0990.pdf.

115. Samuel, S., M. R.E. Romoser, L. R. Gerardino, M. Hamid, R. A. Gomez, M. A. Knodler, Jr., J. Collura, and D. L. Fisher. Effect of Advance Yield Markings and Symbolic Signs on Vehicle-Pedestrian Conflicts: Field Evaluation. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2393, 2013, pp. 139-146. http://trrjournalonline.trb.org/doi/pdf/10.3141/2393-16. DOI: 10.3141/2393-16

116. Schrader, M. H. Study of Effectiveness of Selected School Zone Traffic Control Devices. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1692, 1999, pp. 24-29. http://trrjournalonline.trb.org/doi/pdf/10.3141/1692-04. DOI: 10.3141/1692-04

117. Schrock, S. D., H. G. Hawkins, and S. T. Chrysler. Effectiveness of Lane Direction Arrows as Pavement Markings in Reducing Wrong-Way Movements on Two-Way Frontage Roads. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, no. 1918, 2005, pp. 63-67. http://trrjournalonline.trb.org/doi/10.3141/1918-08.

118. Schroeder, B., R. Hughes, N. Rouphail, C. Cunningham, K. Salamati, R. Long, D. Guth, R. W. Emerson, D. Kim, J. Barlow, B. L. Bentzen, L. Rodegerdts, and E. Myers. NCHRP Report 674: Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities. Transportation Research Board of the National Academies, Washington, D.C., ISBN 978-0-309-15530-4, 2011. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_674.pdf.

119. Srinivasan, R., J. Baek, and F. Council. Safety Evaluation of Transverse Rumble Strips on Approaches to Stop-Controlled Intersections in Rural Areas. in *2010 Annual Meeting of the Transportation Research Board*, Washington, D.C., September 2010.

120. Telezhenko, E., L. Lidfors, and C. Bergsten. Dairy Cow Preferences for Soft or Hard Flooring when Standing or Walking. *Journal of Dairy Science*, Vol. 90, no. 8, August 2007, pp. 3716-3724. http://dx.doi.org/10.3168/jds.2006-876. DOI: 10.3168/jds.2006-876

121. Terhaar, E., and D. Braslau. Rumble Strip Noise Evaluation. St. Paul, Minnesota, MN/RC 2015-07, 2015. http://www.dot.state.mn.us/research/TS/2015/201507.pdf.

122. Thompson, T. D., M. W. Burris, and P. J. Carlson. Speed Changes Due to Transverse Rumble Strips on Approaches to High-Speed Stop-Controlled Intersections. *Transportation Research Record: Journal of the Transportation Research Board Online*, Vol. 1973, 2006, pp. 1-9. http://trrjournalonline.trb.org/doi/abs/10.3141/1973-03. DOI: 10.3141/1973-03

123. Torbic, D. J., D. W. Harwood, D. K. Gilmore, R. Pfefer, T. R. Neuman, K. L. Slack, and K. K. Hardy. NCHRP Report 500 Volume 7: A Guide for Reducing Collisions on Horizontal Curves. Transportation Research Board of the National Academies, Washington, D.C., ISBN 0-309-08760-0, 2004. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_500v7.pdf.

124. Torbic, D. J., J. M. Hutton, C. D. Bokenkroger, K. M. Bauer, D. W. Harwood, D. K. Gilmore, J. M. Dunn, J. Ronchetto, E. T. Donnell, H. J. Sommer Ill, P. M. Garvey, B. Persaud, and C. Lyon. NCHRP Report 641: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips. Transportation Research Board of the National Academies, Washington, D.C., ISSN 0077-5614, 2009. http://www.trb.org/Publications/Blurbs/162610.aspx.

125. Torbic, D. J., D. K. Gilmore, K. M. Bauer, C. D. Bokenkroger, D. W. Harwood, L. M. Lucas, R. J. Frazier, C. S. Kinzel, D. L. Petree, and M. D. Forsberg. *NCHRP Report 737: Design Guidance for High-Speed to Low-Speed Transition Zones for Rural Highways*. Transportation Research Board of the National Academies, Washington, D.C., 2012. http://www.trb.org/Publications/Blurbs/168309.aspx.

126. Torbic, D. J., K. M. Bauer, C. A. Fees, D. W. Harwood, R. V. Houten, J. LaPlante, and N. Roseberry. NCHRP Report 766: Recommended Bicycle Lane Widths for Various Roadway Characteristics. Transportation Research Board of the National Academies, Washington, D.C., ISBN 978-0-309-28416-5, 2014. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_766.pdf.

127. Transportation Research Board. NCHRP 05-21: Safety and Performance Criteria for Retroreflective Pavement Markers. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3859. Accessed May 4, 2017.

128. U.S. Architectural and Transportation Barriers Compliance Board (Access Board). *Americans with Disabiulities Act (ADA) Accessibility Guidelines for Buildings and Facilities*, 2004 ed. U.S. Architectural and Transportation Barriers Compliance Board (Access Board), Washington, D.C., 1991. https://www.access-board.gov/guidelines-and-standards/buildings-and-sites/about-the-ada-standards/background.

129. U.S. Department of Transportation Federal Highway Administration. Bicycle Facilities and the Manual on Uniform Traffic Control Devices. *Federal Highway Administration Bicycle and Pedestrian Program*, December 15, 2015. http://www.fhwa.dot.gov/environment/bicycle_pedestrian/guidance/mutcd/index.cfm. Accessed August 24, 2016.

130. Ullman, B. R., M. D. Finley, S. T. Chrysler, N. D. Trout, A. A. Nelson, and S. Young. Guidelines for the Use of Pavement Marking Symbols at Freeway Interchanges. Texas Transportation Institute, College Station, TX, FHWA/TX-10/0-5890-1, 2010. http://tti.tamu.edu/documents/0-5890-1.pdf.

131. Van Houten, R., J.E. L. Malenfant, and D. McCusker. Advance Yield Markings: Reducing Motor Vehicle - Pedestrian Conflicts at Multilane Crosswalks with Uncontrolled Approach. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1773, 2001, pp. 69-74. http://trrjournalonline.trb.org/doi/pdf/10.3141/1773-08.

132. Vaswani, N. K. Measures for Preventing Wrong-Way Entries on Highways. University of Virginia, Charlottesville, Virginia, VHRC 72-R41, 1973. http://www.virginiadot.org/vtrc/main/online_reports/pdf/72-r41.pdf.

133. Yang, L., H. Zhou, L. Zhu, and H. Qu. Operation Effects of Transverse Rumble Strips on Approaches to High-Speed Intersections. *Transportation Research Record: Journal of the Transportation Research Record Online*, Vol. 2602, 2016, pp. 78-87. http://trrjournalonline.trb.org/doi/abs/10.3141/2602-10. DOI: 10.3141/2602-10

134. Zegeer, C., R. Srinivasan, B. Lan, D. Carter, S. Smith, C. Sundstrom, N. J. Thirsk, C. Lyon, B. Persaud, J. Zegeer, E. Ferguson, and R. V. Houten. NCHRP Research Report 841: Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments. Transportation Research Board of the National Academies, Washington, D.C., ISBN 978-0-309-44626-6, 2017. http://www.trb.org/Publications/Blurbs/175381.aspx. DOI: http://dx.doi.org/10.17226/24627

135. Zegeer, C. V., C. Seiderman, P. Lagerwey, M. Cynecki, M. Ronkin, and R. Schneider. Pedestrian Facilities Users Guide - Providing Safety and Mobility. Highway Safety Research Center, University of North Carolina, Chapel Hill, NC, FHWA-RD-01-102, 2002. https://www.fhwa.dot.gov/publications/research/safety/01102/01102.pdf.

136. Zegeer, C. V., J. R. Stewart, H. H. Huang, P. A. Lagerwey, J. Feaganes, and B. J. Campbell. Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines. University of North Carolina, Chapel Hill, NC, FHWA-HRT-01-100, 2005. https://www.fhwa.dot.gov/publications/research/safety/04100/04100.pdf.

137. Zhou, H., J. Zhao, R. Fries, M. R. Gahrooei, L. Wang, B. Vaughn, K. Bahaaldin, and B. Ayyalasomayajula. Investigation of Contributing Factors Regarding Wrong-Way Driving on Freeways. Department of Civil and Environmental Engineering, Illinois Center for Transportation, Springfield, Illinois, ICT-12-010, 2012. http://cetrans.isg.siue.edu/wwd/FHWA-ICT-12-010.pdf.

138. Zwahlen, H. T., T. Schnell, and T. Hagiwara. Effects of Lateral Separation Between Double Center-Stripe Pavement Markings on Visibility Under Nighttime Driving Conditions. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1495, 1995, pp. 87-98. http://onlinepubs.trb.org/Onlinepubs/trr/1995/1495/1495-011.pdf.

139. Zwahlen, H. T., T. Schnell, and S. Miescher. Recognition Distances of Different Pavement Arrow Designs During Daytime and Nighttime. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1692, 1999, pp. 119-128. http://trrjournalonline.trb.org/doi/pdf/10.3141/1692-13. DOI: http://dx.doi.org/10.3141/1692-13

140. Zwahlen, H. T., and T. Schnell. Visibility of Road Markings as a Function of Age, Retroreflectivity Under Low-Beam and High-Beam Illumination at Night. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1692, 1999, pp. 152-163. http://trrjournalonline.trb.org/doi/abs/10.3141/1692-16. DOI: https://doi.org/10.3141/1692-16

141. Zwahlen, T. H., and T. Schnell. Driver Eye-Scanning Behavior as Function of Pavement Marking Configuration. *Transportation Research Record: Journal of the Transportation Research Board of the National Academies*, Vol. 1605, 1997, pp. 62-72. http://trrjournalonline.trb.org/doi/abs/10.3141/1605-08. DOI: http://dx.doi.org/10.3141/1605-08

142. . Washington, D.C.: United States Government Publishing Office, 2009, p. 66796. https://www.gpo.gov/fdsys/pkg/FR-2009-12-16/pdf/E9-28322.pdf.

143. Oregon Department of Transportation. *Highway Design Manual*. Oregon Department of Transportation, Salem, Oregon, 2012. https://www.oregon.gov/odot/Engineering/Pages/Hwy-Design-Manual.aspx.

1 Traffic Line Manual Revision History Appendix E

Revision Date	Section	Description	Update Proposal
03/2021	All	Updated to be ADA compliant	N/A
03/2021	Chapter 3	Table body	N/A
03/2021	110 – Colors	Added language for red colored pavement. Added Language for truck aprons.	N/A
03/2021	132 – RPMs Used for Positioning Guides	Added Y/R-20 to figure 132 as the positioning guide to use for typical raised medians and Y/R-40 is used for other medians.	N/A
03/2021	140 – Tubular Markers	Added use of tubular markers smaller than 28 inches for ADA purposes.	N/A
03/2021	211 – No-Passing Zone Markings	Updated Table 211-2 to have values consistent with design parameters. Updated Figures 250, 251, 260-C, 281-B, 310, and 322-B to match change.	N/A
03/2021	240 – Longitudinal Rumble Strips: General	Corrected wording	N/A
03/2021	241 – Longitudinal Rumble Strips: Rural Freeways and Divided Highways	Added language in Design Parameters for Bus Shoulder Lanes exception. Added exception for small quantity projects.	N/A
03/2021	242 – Longitudinal Rumble Strips: Rural Non-Freeways and Undivided Highways	Corrected grammar. Added exception for small quantity projects.	N/A
01/2021	245 – Transverse Rumble Strips	Corrected reference in text.	N/A
03/2021	270 – Channelizing Lines and Traversable Channelizing Islands	Change Figure 270-A title to match figure more appropriately.	
03/2021	281 – Non-Traversable Medians & Channelizing Islands	Updated Figure 281-B to be consistent with Table 211-2 update. Update Section reference # in design parameters section. Updated Figure 218-C to match change to Section 430.	
03/2021	310 – Left Turn Lanes	Corrected wording	N/A
03/2021	310 – Left Turn Lanes	Added reference in figure to HDM figure 8-9	N/A
03/2021	320 – Added Right Turn Lanes	Fixed figure reference numbers. Updated approvals required to reference Traffic Manual.	N/A

Revision Date	Section	Description	Update Proposal
03/2021	321 – Channelized Right-Turn Lanes	Changed Required Approvals section to reference Traffic Manual because the approvals are control related not marking related.	N/A
03/2021	322 – At-Grade Acceleration Lanes	Changed LRA callouts in figures to LRA-L and LRA-R.	N/A
03/2021	330 – Dropped Lanes and Auxiliary Lanes on Conventional Roads	Corrected Figure callout numbers. Added note in figure 330 referencing Shared Lane Marking Section.	N/A
03/2021	350 - Roundabouts	Change incorrect RA callout to LA in Figure 350-C.	N/A
03/2021	411 – Bicycle Lane End Transitions	Changed note 1 in Figure 411 to the correct section number.	N/A
03/2021	412 – Bicycle Lane Buffers	Corrected grammar.	N/A
03/2021	415 – Two Stage Turn Bicycle Box	Added information to this section.	N/A
03/2021	430 – Marked Crosswalks	Figure updated and language added to address confusion from difference in Figure 430-E and Figures 281-C, 610-B, and 610-C	N/A
03/2021	430 – Marked Crosswalks	Language modified to make reduced crosswalk width requirements more clear.	N/A
03/2021	430 – Marked Crosswalks	Changed language from “ADA ramp” to “curb ramp” for consistency between manuals.	
03/2021	531 – Colored Pavement in Transit Lanes	New section added.	N/A
03/2021	630 – Parking Space Markings	Removed DWS from Figure 631-A for consistency with Roadway Standards.	N/A
03/2021	Appendix A	The Delegated Authority appendix was removed and Appendix A is now a placeholder. The Traffic Manual is a more complete and up to date than this appendix was and designers need delegated authority info should go to the Traffic Manual.	N/A
03/2021	Appendix B	Updated ODOT Pavement Marking Contacts	N/A
01/2022	Chapter 1 Introduction	Added more info on purpose, effective date, and use of this manual	N/A
01/2022	Sections 130, 131, 132, 133, and 242	Updated all references of Type “1” and “1AR” RPMs to Type “I” and “IAR” for consistency in all documents	N/A

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Revision Date	Section	Description	Update Proposal
01/2022	Sections 150, 261, 281, 310, 320, 330, 430, and 610	Updated figures and language to clarify standards and options with markings associated with uncontrolled crosswalks across multi-lane approaches.	N/A
01/2022	Sections 110, 130, and 361	Approval requirement for red RPM's changed from STRE to RTE approval. And additional language added.	N/A
01/2022	Section 340	Modified Design Parameters to match the Traffic Signal Design Manual	N/A
01/2022	Section 630	Guidance for truck parking at rest areas added.	N/A
01/2023	Section 130	Language added to add emphasis on working with pavements unit when using recessed RPMs	N/A
01/2023	Section 145	Added new section for delineators.	N/A
01/2023	Section 150	Updated parameters to clarify discrepancy between this section and Section 350.	N/A
01/2023	Section 211	Fixed errors in Table 211-1 and Table 211-2.	N/A
01/2023	Section 245	Added additional support information with new reference.	N/A
01/2023	Section 260	Updated language and Figure 260-B to clarify that using transverse median bars within sets of double yellow lines makes it illegal to drive across the median.	N/A
01/2023	Section 310	Updated Figure 310 to change the minimum distance to use two sets of narrow double yellow lines to 30 in (was 28") to match Section 260 Figure 260-A.	N/A
01/2023	Section 350	Removed fish-hook arrows as option at roundabouts. Added support language after best practice discussions with OTCDC.	N/A
01/2023	Section 413	Updated Design Issues section to better match the Traffic Manual and clarify the colored bike lane interim approval.	N/A
01/2023	Section 430	Updated parameters and required approvals section to match the Traffic Manual.	N/A
01/2023	Sections 210 and 230	Added additional support language about breaking lines and intersections.	N/A

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Revision Date	Section	Description	Update Proposal
01/2023	Sections 281 and 630	Updated language to support ADA Teams request to increase conspicuity between markings and DWSs.	N/A
01/2023	Chapter 3	Removed language describing layout of the Traffic Line Manual prior to 2021.	N/A
1/2024	Sections 240 241, 242, and243	Updated to include guidance on sinusoidal rumble strips	N/A
01/2024	Section 410	Corrected typo in Figure 410-C	N/A
01/2024	Sections 310 and 320	Added information in Required Approval section about Design Exceptions.	N/A
01/2025	Section 160	Updated lane use arrow type choice for regions	N/A
01/2025	Section 240	Guidance added for rumble strip replacement for work resulting in rumble strip removal	N/A
01/2025	Sections 241 and 242	Added guidance around rumble strips and crosswalks	N/A
01/2025	Sections 281 and 630	Updated language to support ADA Teams request to increase conspicuity between markings and DWSs.	N/A

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