Left Turn Pocket Approach Taper Design Guidance

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Detailed Findings

Background

Current design guidance and standards do not adequately address the design of turn pocket approach tapers. Existing standards provide turn pocket lengths without addressing the issue of horizontal alignment for the lane shifts necessary to accommodate the added width of left turn pockets. Vehicles passing on through-movements to the right of left turns traverse a horizontal alignment change that is different than the roadway centerline alignment and should therefore be designed as such for traveler safety.

California Department of Transportation (Caltrans) is submitting a FY2022 NCHRP Problem Statement that identifies three primary goals to address these separate alignments:

1. Create guidance for treating approach tapers as independent alignments for each of the two directions of travel.
2. Create guidance and standards for highways with tangent centerline alignments. Existing design guidance typically consists of equations providing approach taper lengths dependent upon width of shift and vehicle speed; however, angle of deflection is not discussed. Most importantly, acceptable maximum angle of deflection is not addressed. Large angles of deflection can result in erratic movements other than what is expected where vehicles cross over the right edge line when entering an approach taper and the left edge double yellow striping when exiting the approach taper in order to negotiate their desired direction of travel. (See Exhibit A on page 10 for an illustration.)
3. Create guidance and standards for highways with horizontal curve centerline alignments. There is currently no existing guidance related to approach taper shifts on horizontal curves. Since angles of deflection are inappropriate for horizontal curves, use of compound curves may be a more appropriate solution and should therefore be studied. Furthermore, guidance for superelevation is needed to address changes in curve radii between adjoining curves, which may require different superelevation rates to address different alignments on adjacent directions of travel. (See Exhibit B on page 10 for an illustration.)

A literature search of recent publicly available domestic resources sought information about turn pocket approach tapers and design issues related to them. The publications below are organized into two categories:

- *National guidance*. The two NCHRP reports cited below include discussions of approach taper, however, neither report addresses the range of deflection angles or alignment issues highlighted in the FY2022 NCHRP Problem Statement Caltrans is submitting.
- *State transportation agency design guidance*. Much of the guidance cited in this section provides equations for tangent alignment approach tapers but does not offer guidance on minimum or curved alignments. Two manuals provide some guidance of interest for this problem statement:
    - Georgia DOT's Design Policy Manual, which provides minimum and desirable tangent alignments. The manual also identifies the difference between shifts on tangent alignment versus curved alignment and provides some guidance, however, it does not provide sufficient guidance and standards for curved alignments.

- Oregon DOT's Highway Design Manual is the only publication cited below that addresses the use of curves for approach tapers, however, the guidance uses reversing curves for tangent centerline alignments and does not address curved centerline alignments.

National Guidance

NCHRP Report 780: Design Guidance for Intersection Auxiliary Lanes, Kay Fitzpatrick, Marcus A. Brewer, Paul Dorothy and Eun Sug Park, 2014.
Publication available at http://www.trb.org/Publications/Blurbs/171328.aspx
Approach tapers are discussed in Chapter 2, Review of Literature and State Design Guidance, on pages 14-17 of the report (pages 23-26 of the PDF) and pages 26 and 27 of the report (pages 35 and 36 of the PDF).

Chapter 4, Typical Designs, presents "best-practice sites" that are used to demonstrate preferred design treatments for various design categories:

- Island (page 44 of the report, page 53 of the PDF). Provides a description of components and defines approach taper but does not provide discussion to assist with design.
- Deceleration lane design (page 48 of the report, page 57 of the PDF). Provides guidance on use of deceleration for turning vehicles but does not address roadway curvature.
- Double right-turn lane design (page 49 of the report, page 58 of the PDF). Specific to deceleration; no guidance applicable to approach tapers.

Appendix A, Recommended Revisions to AASHTO Green Book, begins on page 112 of the report, page 121 of the PDF. The authors note that "[p]roposed additions to existing content are shown with double underlines, and proposed deletions are shown with ~~strikethroughs~~. The proposed revisions are based on research conducted as part of this NCHRP project along with research recently completed."

Page 120 of the report (page 129 of the PDF) presents *9.6 Turning Roadways and Channelization, 9.6.3 Islands (page 9-104):*

> **Proposed Revision to Green Book**
> Delineation is especially pertinent at the approach nose of a divisional island. In rural areas, the approach should consist of a gradual widening of the divisional island as indicated in Figure 9-41. Although not as frequently obtainable, this same design also should be striven for in urban areas. Preferably, the approach should gradually change to a raised surface with texture or to jiggle bars that may be crossed readily even at considerable speed. The transition taper length should be computed with Equation 3-37 {page 3-134 in 2011 Green Book} where the posted or statutory speed limit is 70 km/h [45 mph] or greater and with Equation 3-38 (pp. 3-134 in 2011 Green Book) where the posted or statutory speed limit is less than 70 km/h [45 mph]. If this distance cannot be met, this transition section should be as long as practical. The cross sections in Figure 9-41 demonstrate the transition. The face of curb at the approach island nose should be offset at least 0.5 m [2 ft] and preferably 1 m [3 ft] from the normal edge of traveled way, and the widened pavement gradually should be transitioned to the normal width toward the crossroad.

The report includes a discussion section following this proposed revision that begins with the following:

> There is no specific guidance given regarding the length of transition except to say that it "should be as long as practical." Most state design manuals use a form of the taper equations contained on page 3-134 as Equation 3-37 and Equation 3-38 as shown in the following sources:

See the report for further details.

NCHRP 745: Left-Turn Accommodations at Unsignalized Intersections, Kay Fitzpatrick, Marcus A. Brewer, William L. Eisele, Herbert S. Levinson, Jerome S. Gluck and Matthew R. Lorenz, 2013.
Publication available at http://www.trb.org/Publications/Blurbs/168803.aspx
Chapter 3, Geometric Designs, includes a discussion of tapers that begins on page 13 of the report (page 22 of the PDF):

> Two distinct tapers are commonly defined in many guidelines: approach taper length and bay taper length. An approach taper provides space for a left-turn lane by moving traffic laterally to the right on a street or highway without a median. The bay taper length is a reversing curve along the left edge of the traveled way that directs traffic into the left-turn lane. Illustrations of the use of these tapers along with how the left-turn lane is added to the roadway are shown in the following figures:
>
> - Figure 6 shows a left-turn lane added within a median.
> - Figure 7 shows a left-turn lane that was added to an undivided two-lane highway where the through lane on the same approach as the added turn lane was shifted to the right the full width of the turn lane. This condition is known as a full-shadowed left-turn lane.
> - Figure 8 shows a partially shadowed left-turn lane where both through lanes are shifted to provide the needed space for the turn lane. With partially shadowed left-turn lanes, the offset created by the approach taper does not entirely protect or "shadow" the turn lane (*9*).
> - Figure 9 shows the condition when a lane is added to the outside edge of the approach, allowing through vehicles to pass left-turning vehicles on the right. This condition is also known as a bypass lane. The bypass lane minimizes delay to following through vehicles by allowing the vehicle following to pass the left-turning vehicle on the right, and then merge back into the through lane.

Other portions of the report that may be of interest:

- Table 5, Typical Length of Approach Taper to Add Left-Turn Lanes, provides the equations commonly used to estimate the approach taper, including comparisons for various speeds and offsets (see page 16 of the report, page 25 of the PDF).
- Chapter 5, Design Examples, provides an example of the installation of left turn lanes at an unsignalized rural intersection between a state highway and a local road (see pages 35-37 of the report, pages 44-46 of the PDF).

State Transportation Agency Design Guidance

The citations below provide design guidance related to left turn channelization, approach tapers and other guidance associated with left turn lane design from 14 states:

- Arizona.
- Colorado.
- Georgia.
- Illinois.
- Kansas.
- Kentucky.
- North Carolina.
- Ohio.
- Oregon.
- Tennessee.
- Utah.
- Virginia.
- Washington.
- Wisconsin.

Arizona

Section 408.10, Left-turn Channelization, Roadway Design Guidelines, Arizona Department of Transportation, May 2012 (revised April 2014).
https://azdot.gov/sites/default/files/2019/06/2014-roadway-design-guidelines.pdf
From Subsection B) Design Elements on page 400-28 of the guidelines (page 199 of the PDF):

> *Approach taper* - On highways with narrow or no medians, room for the left-turn lane is made by shifting traffic laterally to the right. The taper rate used to effect this shift should be V:1, where V is the design speed in mph. Thus, if the additional lane width, W, is to be gained solely from one side of the highway, the length of approach taper would be (V times W). Depending on circumstances, the additional width for the left-turn bay may be obtained from either or a combination of both sides of the highway.

Colorado

Chapter 9, Intersections, Roadway Design Guide, Colorado Department of Transportation, 2018.
https://www.codot.gov/business/designsupport/bulletins_manuals/cdot-roadway-design-guide-2018/dg18-ch09
Section 9.17, Auxiliary (Speed Change) Lanes, which begins on page 9-24 of the manual (page 27 of the PDF), includes this introduction:

> The primary purpose of auxiliary lanes at intersections is to provide storage for turning vehicles, both left and right. A secondary purpose is to provide space for turning vehicles to decelerate from the normal speed of traffic to a stopped position in advance of the intersection or to a safe speed for the turn in case a stop is unnecessary. Additionally, auxiliary lanes may be provided for bus stops or for loading and unloading passengers from passenger cars. A speed change lane is an auxiliary lane, including tapered areas, primarily for the acceleration or deceleration of vehicles entering or leaving the through traffic lanes. The terms "speed-change lane," "deceleration lane," or "acceleration lane," as used here, apply broadly to the added pavement joining the traveled way of the highway or street with that of the turning roadway and do not necessarily imply a definite lane of uniform width. Speed-change lanes may be justified on high-speed and on high-volume highways where a change in speed is necessary for vehicles entering or leaving the through traffic lanes.

On the following page, Figure 9-6, Information Guide to Basic Auxiliary Lane Elements, illustrates basic auxiliary lane elements. Other portions of this chapter to highlight:

- Section 9.17.7, Taper, which begins on page 9-29 of the manual (page 32 of the PDF), includes recommended taper ratios for speed-change lanes (see Table 9-10).

- Figure 9-8, Speed-Change Lane Taper for Continuously Curbed Medians, on page 9-30 of the report (page 33 of the PDF).
- Section 9.17.7.1, Elements of Left-Turn Design (Redirect Taper), on page 9-32 of the report (page 35 of the PDF).

Georgia

4.2.5, Transition in Number of Lanes, Design Policy Manual, Georgia Department of Transportation, August 2020.
http://www.dot.ga.gov/PartnerSmart/DesignManuals/DesignPolicy/GDOT-DPM.pdf
See page 4-10 of the manual (page 92 of the PDF) for 4.2.4. Lane Width Transitions and Shifts:

> There are two methods by which an alignment transition or "shift" may be accomplished:
>
> - The first method is to treat the transition or shift as though it were any other required alignment change. With this approach, a transition or shift would be accomplished through the use of a series of reverse curves. Quite often, the use of curve radii which do not require superelevation result in a length of transition greater than that required by providing a taper. Superelevation should be utilized if warranted by normal procedures.
> - The second method of accomplishing a transition or "shift" involves the use of tapers. Tapers are acceptable provided the following two conditions exist:
>
>   The alignment shift is consistent with the cross slope of the roadway and does not require "shifting" over the top of an existing pavement crown.
>
>   The direction of the shift is not counter to the pavement cross-slope (from a superelevation or reverse-crown consideration).

Table 4.3, Turn Lane Transition Tapers, beginning on page 4-13 of the manual (page 95 of the PDF), summarizes taper length and taper ratio requirements related to the addition of left turn and right turn lanes.

Illinois

Chapter 36, Intersections, Bureau of Design and Environmental Manual, Illinois Department of Transportation, August 2018.
https://idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Split/Design-And-Environment/BDE-Manual/Chapter%2036%20Intersections.pdf
See Section 36-3.03, Left Turn-Lane Design, which begins on page 36-3.20 of the manual (page 96 of the PDF). Sections or items that may be of particular interest include:

- Taper design. Figures 36-3.H, 36-3.J and 36-3.K illustrate the use of a straight-line taper. Figure 36-3.L illustrates the use of reverse curves for an entrance taper (see page 36-3.20 of the manual, page 96 of the PDF).
- Section 36-3.03(b) discusses parallel left-turn lanes without offset (see page 36-3.24 of the manual, page 100 of the PDF).
- Section 36-3.03(c) discusses offset left-turn lanes (see page 36-3.27 of the manual, page 103 of the PDF).

Kansas

Section 4.5, Auxiliary Lanes, KDOT Access Management Policy, Kansas Department of Transportation, January 2013.
www.ksdot.org/Assets/wwwksdotorg/PDF_Files/Access_Management_Policy_Jan2013.pdf
See Section 4.5.3, Auxiliary Lane Design, beginning on page 4-74 of the document (page 114 of the PDF), for a discussion of the four parts associated with the length of an auxiliary lane: through-lane taper, bay taper, deceleration length and storage length.

Section 4.5.3.b, Left-turn lane design, which begins on page 4-76 of the report (page 116 of the PDF), describes the through-lane taper as “the taper needed to move through traffic over to create the auxiliary lane. Through-lane tapers are not needed for right-turn lanes.” Also included is the formula used to calculate the length of the through-lane taper.

Kentucky

Subsection HD-902.13, Turn Lane Design, Section 900, Intersections, Highway Design Manual, Kentucky Department of Highways, September 2016.
https://transportation.ky.gov/Highway-Design/Highway%20Design%20Manual/HD-900.pdf
Section HD-902.13, Turn Lane Design, which begins on page 14 of the manual (page 20 of the PDF), addresses the three primary components of auxiliary left-turn lanes: approach taper, bay taper and turn lane length (including deceleration length and storage length).

From page 19 of the manual (page 25 of the PDF):

HD-902.14 Departure/Approach Taper
When adding a left-turn lane, the designer shall use an approach and departure taper to widen the pavement to the required width based on the roadway speed. The approach and departure taper length should be calculated as follows:

Speed: ≥ 45 MPH, L = W x S

< 45 MPH, L = WS2/60

Where:
L = Taper length in feet
W = Width of roadway offset for taper in feet
S = Speed in miles per hour (MPH)

HD-902.15 Bay Taper
Bay tapers are utilized to direct turning vehicles into the auxiliary lane. For left and right-turn lanes, a standard bay taper length based on the speed of the roadway should be used:

Speed: 45 MPH or greater, Bay Taper length = 100 feet

< 45 MPH, Bay Taper Length = 50 feet

North Carolina

Chapter 9, At Grade Intersections, Roadway Design Manual, North Carolina Department of Transportation, various revision dates.
https://connect.ncdot.gov/projects/Roadway/Roadway%20Design%20Manual/09.%20At%20Grade%20Intersections.pdf
See Figure F-4 on pages 13-15 of the PDF. The first two design sheets provide recommended treatments for turn lanes; right turn lane warrants are addressed on page 15.

Ohio

Section 401.6, Approach Lanes, Chapter 400, Intersection Design, Location and Design Manual, Volume 1, Roadway Design, Ohio Department of Transportation, July 2020.
http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/roadway/Location%20and%20Design%20Manual/Section%20400.pdf
Left turn lanes are discussed in Sections 401.6.1 and 401.6.2 beginning on page 400-4 of the manual (page 7 of the PDF). Guidance is provided for three tapers: approach, departure and diverging. Figure 401-7, Turning Lane Design, appears on page 400-A15 of the manual (page 53 of the PDF).

Oregon

Chapter 8, Intersections, Highway Design Manual, Oregon Department of Transportation, 2012.
https://www.oregon.gov/odot/Engineering/Documents_RoadwayEng/HDM_08-Intersections.pdf
For design details for left turn lanes, see Figure 8-9, Left-Turn Channelization, and Figure 8-10, Reversing Curve Option for Left-Turn Channelization, on pages 8-22 and 8-23 of the manual (pages 24 and 25 of the PDF).

For design details for left turn lanes at signalized intersections, see Figure 8-21, Dual Left Turn Channelization, on page 8-45 of the manual (page 47 of the PDF).

Tennessee

Chapter 1, Design Guidelines, Roadway Design Guidelines, Tennessee Department of Transportation, October 2015.
https://www.tn.gov/content/dam/tn/tdot/roadway-design/documents/design_guidelines/DG-S2.pdf
See Section 2-170.00, Guidelines for Design of Turning Lanes, beginning on page 2-36 of the guidelines (page 40 of the PDF). Guidance for the approach taper, bay taper and storage lengths appears on the following page.

Utah

Roadway Design Manual Drawings, Roadway Design Manual, Utah Department of Transportation, April 2020.
https://drive.google.com/open?id=1Mtmv82q4oyLjux9h-sPQhE2cJIhRE9w4
See RDM Drawing No. DM9.1, Intersection Geometrics, on page 9 of the PDF.

Virginia

Appendix F, Access Management Design Standards for Entrances and Intersections, Road Design Manual, Virginia Department of Transportation, July 2018.
https://www.virginiadot.org/business/resources/LocDes/RDM/AppendF.pdf
See Section 3, Turning Lanes, beginning on page F-65 of the manual (page 72 of the PDF), for turn lane criteria for single and dual lanes.

Washington

Chapter 1310, Intersections, WSDOT Design Manual, Washington Department of Transportation, September 2019.
https://wsdot.wa.gov/publications/manuals/fulltext/M22-01/1310.pdf
See Subsection 1310.03(2)(a)(4), Modifications to Left-Turn Designs, which begins on page 1310-20 of the manual (page 20 of the PDF). Exhibits 1310-10a through 1310-10e provide various median channelization designs. See also Section 1310.03(3), Right-Turn Lanes, which begins on page 1310-26 of the manual (page 26 of the PDF), for guidance on right turn lane design.

Wisconsin

Section 2.3, Turn Bays, Chapter 11, Design, Section 25, Intersections at Grade, Facilities Development Manual, Wisconsin Department of Transportation, August 2019.
https://wisconsindot.gov/rdwy/fdm/fd-11-25.pdf#fd11-25-2.3
This manual section, which begins on page 30, includes a link to Attachment 2.3, Taper Length Criteria (see page 4 of the PDF available at https://wisconsindot.gov/rdwy/fdm/fd-11-25-att.pdf#fd11-25a2.3). Included in FDM 11-25 Attachment 2.3, Taper Length Criteria:

- Table A2.1, Taper Descriptions and Formulas, which addresses merging, add lane, shifting, shoulder and turn bay tapers.
- Table A2.2, Tangent Prior to Merge and Turn Bay Taper Rates.

Exhibit A: Caltrans Highway Design Manual Fig 405.2A – Standard Left Turn Channelization

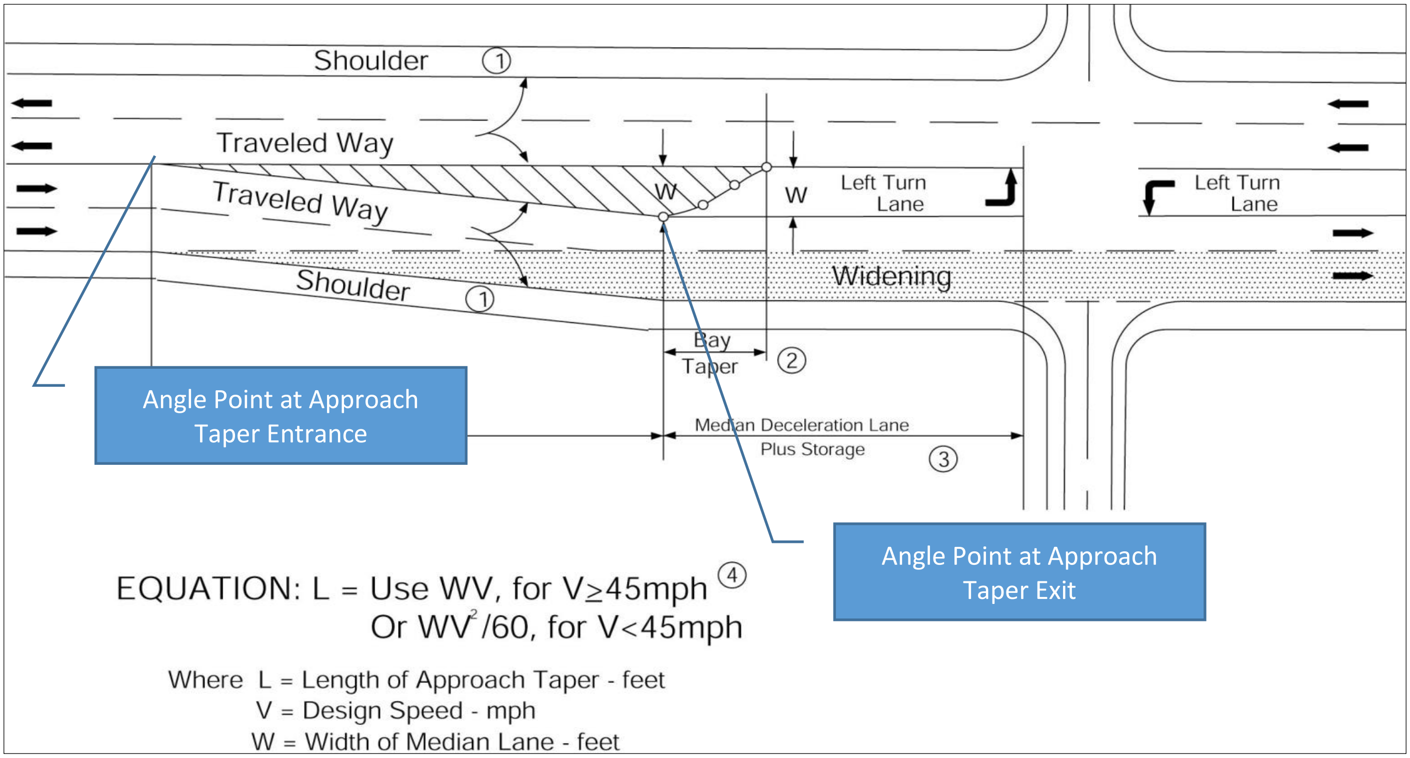

Exhibit B: Left Turn Pocket Approach Tapers on Horizontal Curves