Roadway Geometric Design 4

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PDH: 3

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INTRODUCTION

This course is the **fourth** in a series of five volumes that summarizes and highlights the geometric design process for modern roads and highways. Subjects covered include: *intersection types; alignments; profiles; sight distance; and roundabouts.* The course objective is to give engineers and designers an in-depth look at the principles to be considered when selecting and designing roads. The contents of this document are intended to serve as guidance and not as an absolute standard or rule.

The *American Association of State Highway and Transportation Officials (AASHTO)* publishes and approves information on geometric roadway design for use by individual state transportation agencies. The majority of today's geometric design research is sponsored and directed by AASHTO and the Federal Highway Administration (FHWA) through the National Cooperative Highway Research Program (NCHRP).

For this course, AASHTO's **A Policy on Geometric Design of Highways and Streets** (also known as the "Green Book") will be used primarily for fundamental geometric design principles. This text is considered to be the primary guidance for U.S. roadway geometric design.

This document is intended to explain some principles of good roadway design and show the potential trade-offs that the designer may have to face in a variety of situations, including cost of construction, maintenance requirements, compatibility with adjacent land uses, operational and safety impacts, environmental sensitivity, and compatibility with infrastructure needs.

The practice of geometric design will always be a dynamic process with a multitude of considerations: *driver age and abilities; vehicle fleet variety and types; construction costs; maintenance requirements; environmental sensitivity; land use; aesthetics; and most importantly, societal values.*

Despite this dynamic character, the primary objective of good design will remain as it has always been – **to provide a safe, efficient and cost-effective roadway that addresses conflicting needs or concerns.**

INTERSECTIONS

Intersections are unique roadway elements where conflicting vehicle streams (and sometimes non-motorized users) share the same space. This area encompasses all modes of travel – *pedestrian, bicycle, passenger vehicle, truck,* and *transit* as well as auxiliary lanes, medians, islands, sidewalks and pedestrian ramps. These may further heighten the accident potential and constrain the operational efficiency and network capacity of the urban street system. However, *the main objective of intersection design is to facilitate the roadway user and enhance efficient vehicle movement.* The need to provide extra time for drivers to perceive, decide, and navigate through the intersection is central to intersection design controls and practices.

Designing to accommodate the appropriate traffic control is critical to good intersection design. Warrants and guidelines for selection of appropriate intersection control (including stop, yield, all-stop, or signal control) may be found in the MUTCD.

Basic Elements of Intersection Design

Human Factors

Driver habits, decision ability, driver expectancy, decision/reaction time, paths of movement, pedestrian characteristics, bicyclists

Traffic Considerations

Roadway classifications, capacities, turning movements, vehicle characteristics, traffic movements, vehicle speeds, transit, crash history, bicycles, pedestrians

Physical Elements

Abutting properties, vertical alignments, sight distance, intersection angle, conflict area, speed-change lanes, geometric design, traffic control, lighting, roadside design, environmental factors, crosswalks, driveways, access management

Economic Factors

Improvement costs, energy consumption, right-of-way impacts

A range of design elements are available to achieve the functional objectives, including horizontal and vertical geometry, left- and right-turn lanes, channelization, etc.

Level of service analysis and roadway capacity are critical considerations in intersection design. Capacity is determined by constraints at intersections. Vehicle turns at intersections interrupt traffic flow and reduce levels of service.

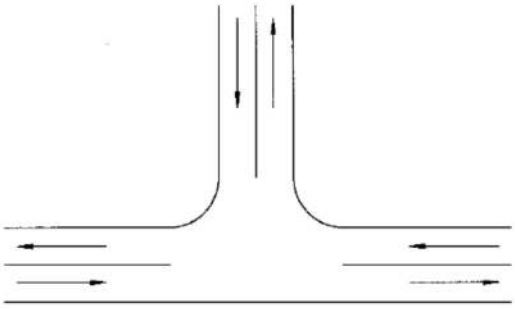
AASHTO defines intersection capacity as “the maximum hourly rate at which vehicles can reasonably be expected to pass through the intersection under prevailing traffic, roadway, and signalization

conditions". The *Highway Capacity Manual (HCM)* provides various analysis techniques for comparing different conditions at intersections.

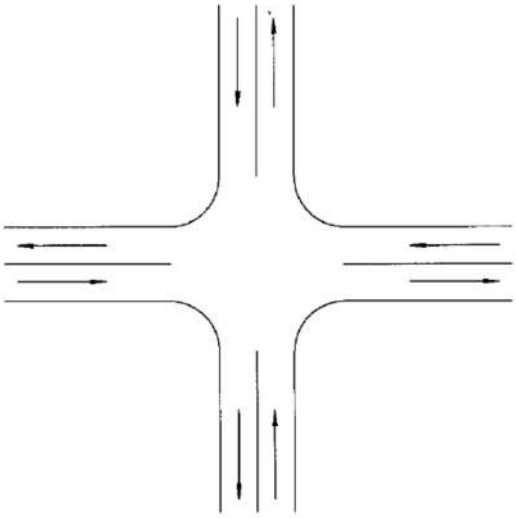
A well-designed intersection is clear to the driver with design dimensions supporting operational requirements, traffic control devices functioning as intended, and non-motorized vehicle users operating safely through the intersection.

Basic Types of Intersections

- Three-leg (T)
- Four-leg
- Multi-leg
- Roundabout



THREE-LEG INTERSECTION



FOUR-LEG INTERSECTION

These types may vary based on scope, shape, flaring (for auxiliary lanes), and channelization (separation/regulation of conflicting traffic).

Variables for determining the type of intersection to be used at a location include:

Topography	*Traffic characteristics*	*Number of legs*
Type of operation	*Roadway character*	

Three-leg

The typical three-leg intersection configuration contains normal paving widths with paved corner radii for accommodating design vehicles. The angle of intersection typically ranges from 60 to 120 degrees. Auxiliary lanes (left or right-turn lanes) may be used to increase roadway capacity and provide better operational conditions. Channelization may be achieved by increasing corner radii to separate a turning roadway from the normal traveled ways by using an island.

Four-leg

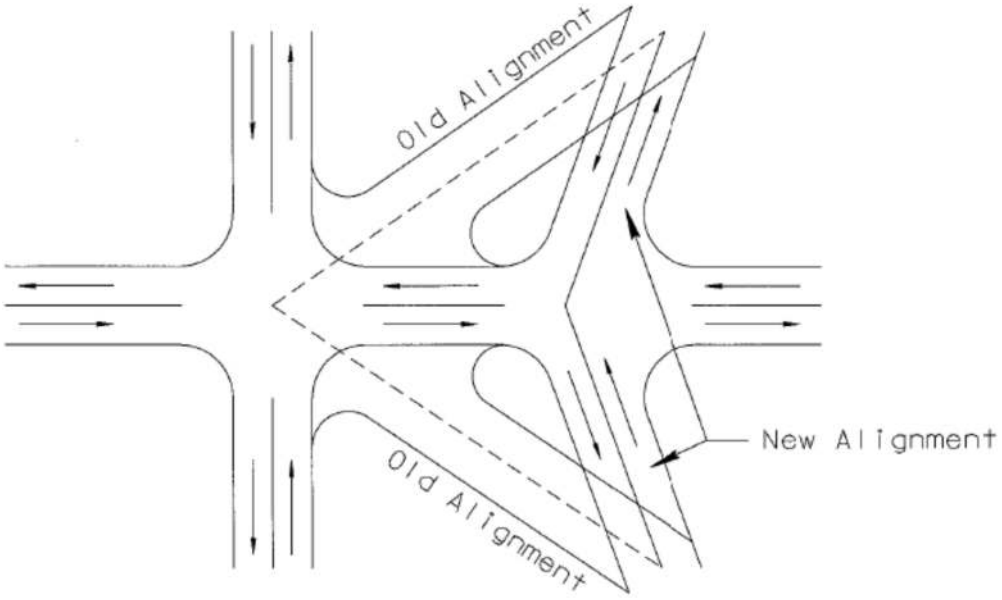
Many of the three-leg intersection design considerations (islands, auxiliary lanes, channelization, etc.) may also be applied to four-leg intersections.

Multi-leg

Intersection designs with multiple legs (5 or more) should not be used unless there is no other viable alternative. If multi-legs must be used, a common paved area where all legs intersect may be desirable for light traffic volumes and stop control. Operational efficiency can also be increased by removing major conflicting movements.

Multi-leg Reconfiguration Options

- Realigning one or more legs
- Combining traffic movements at subsidiary intersections
- Redesigning as a roundabout
- Converting legs to one-way operation



MULTILEG INTERSECTION REALIGNMENT

Alignment and Profile

Roadway geometry influences its safety performance. This has been confirmed by research showing that roadway factors are the **second** most contributing factor to roadway crashes. In the U.S., the average crash rate for horizontal curves is about three times that of other highway segments.

Conflicts tend to occur more frequently on roadways with sudden changes in their character (i.e. sharp curves at the end of long tangent roadway sections). The concept of design consistency compares adjacent road segments and identifies sites with changes that might appear sudden or unexpected. Design consistency analysis can be used to show the decrease in operating speed at a curve.

Horizontal and **vertical geometries** are the most critical design elements of any roadway. While most designers normally design the horizontal and then the vertical alignment, these should be coordinated to enhance vehicle operation, uniform speed, and facility appearance without additional costs (checking for additional sight distance prior to major changes in the horizontal alignment; revising design elements to eliminate potential drainage problems; etc.). Computer-aided design and design (CADD) is the most popular method used to facilitate the iterative three-dimensional design and coordinate the horizontal and vertical alignments.

The location of a roadway may be determined by *traffic, topography, geotechnical concerns, culture, future development, and project limits*. Design speed limits many design values (curves, sight distance) and influences others (width, clearance, maximum gradient).

Intersecting roads should be aligned at approximate right angles in order to reduce costs and potential crashes. Intersections with acute angles need larger turning areas, limit visibility, and increase vehicle exposure time. Although minor road intersections with major roads are desired to be as close to 90

degrees as practical, some deviation is allowable – angles of 60 degrees provide most of the benefits of right angle intersections (reduced right-of-way and construction costs).

Vertical grades that impact vehicle control should be avoided at intersections. Stopping and accelerating distances calculated for passenger vehicles on 3 percent maximum grades differ little from those on the level. Grades steeper than 3 percent may require modifications to different design elements to match similar operations on level roadways. Therefore, **avoid grades for intersecting roads in excess of 3 percent within intersection areas** unless cost prohibitive – then a maximum limit of 6 percent may be permissible.

AASHTO provides the following general design guidelines regarding horizontal and vertical alignment combinations:

- Vertical and horizontal elements should be balanced. A design which optimizes safety, capacity, operation, and aesthetics within the location's topography is desirable.
- Horizontal and vertical alignment elements should coincide to provide a pleasing facility for roadway traffic.
- Avoid sharp horizontal curves near the top of a crest vertical curve or near the low point of a sag vertical curve. This condition may violate driver expectations. Using higher design values (well above the minimum) for design speed can produce suitable designs.
- Horizontal and vertical curves should be flat as possible for intersections with sight distance concerns.
- For divided roadways, it may be suitable to vary the median width or use independent horizontal/vertical alignments for individual one-way roads.
- Roadway alignments should be designed to minimize nuisance in residential areas. Measures may include: depressed facilities (decreases facility visibility and noise), or horizontal adjustments (increases buffer zones between traffic and neighborhoods).
- Horizontal and vertical elements should be used to enhance environmental features (parks, rivers, terrain, etc.). The roadway should lead into outstanding views or features instead of avoiding them where possible.

Exception

Long tangent sections for sufficient passing sight distance may be appropriate for two-lane roads needing passing sections at frequent intervals.

INTERSECTION SIGHT DISTANCE

Intersection sight distance is the length of roadway along the intersecting road for the driver on the approach to perceive and react to the presence of potentially conflicting vehicles. Drivers approaching intersections should have a clear view of the intersection with adequate roadway to perceive and avoid potential hazards. Sight distance should also be provided to allow stopped vehicles a sufficient view of the intersecting roadway in order to enter or cross it. Intersection sight distances that exceed stopping

sight distances are preferable along major roads to enhance traffic operations. Methods for determining intersection sight distances are based on many of the same principles as stopping sight distance.

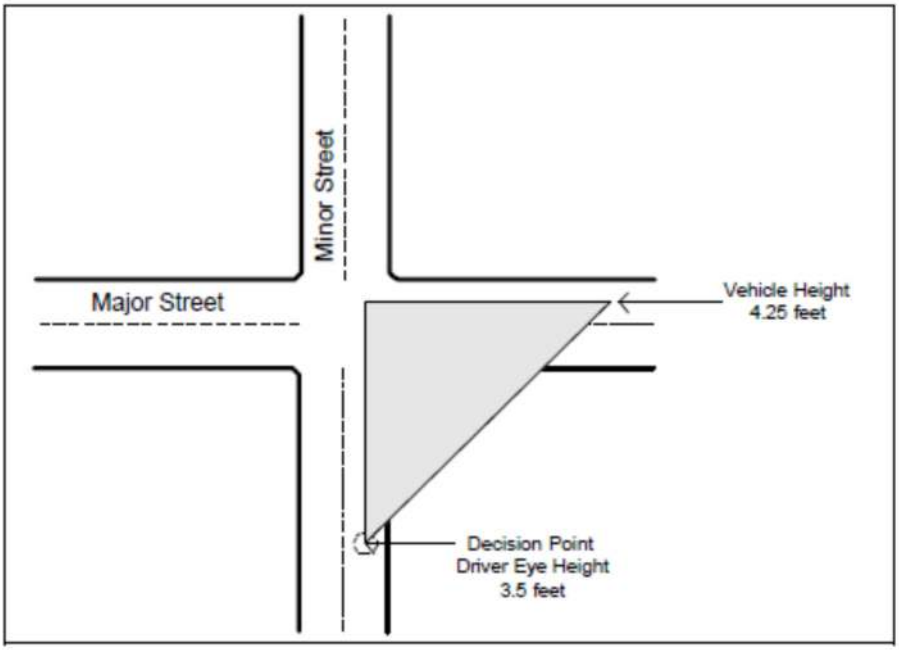


Figure 4.3. Heights Pertaining to Sight Triangles

(Ref: CTRE – Iowa State University)

Sight triangles are areas along intersection approach legs that should be clear of obstructions that could block a driver's view. The dimensions are based on driver behavior, roadway design speeds, and type of traffic control. Object height (3.50 feet above the intersecting roadway surface) is based on vehicle height of **4.35 feet** (representing the 15^{th} percentile of current passenger car vehicle heights). The height of the driver's eye is typically assumed to be 3.50 feet above the roadway surface.

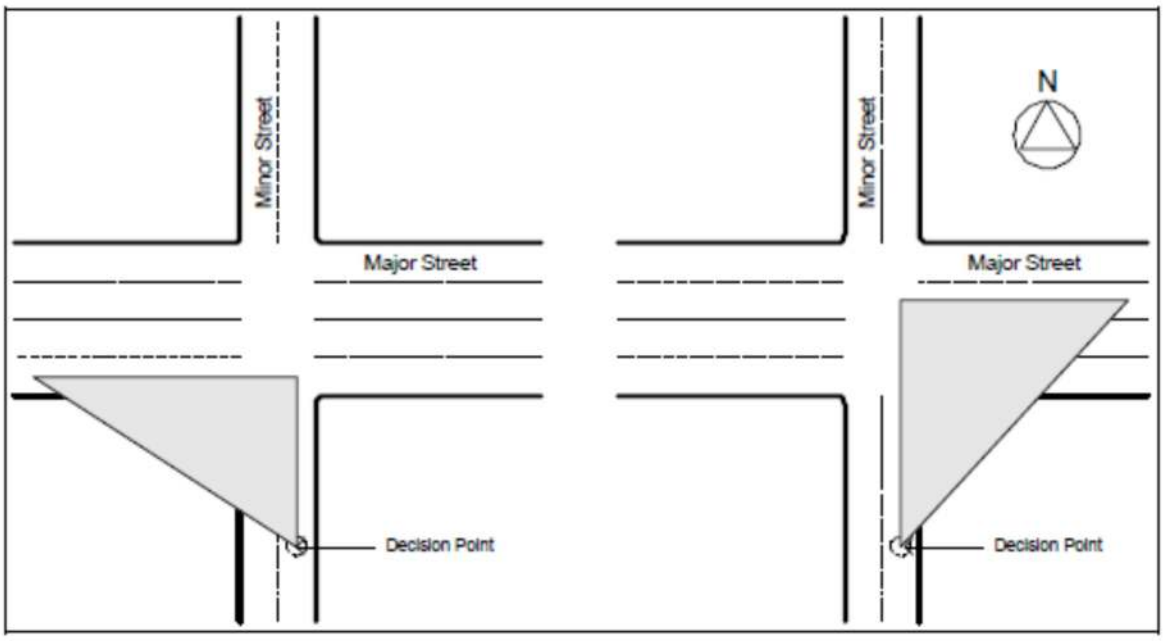


Figure 4.1. Approach Sight Triangles

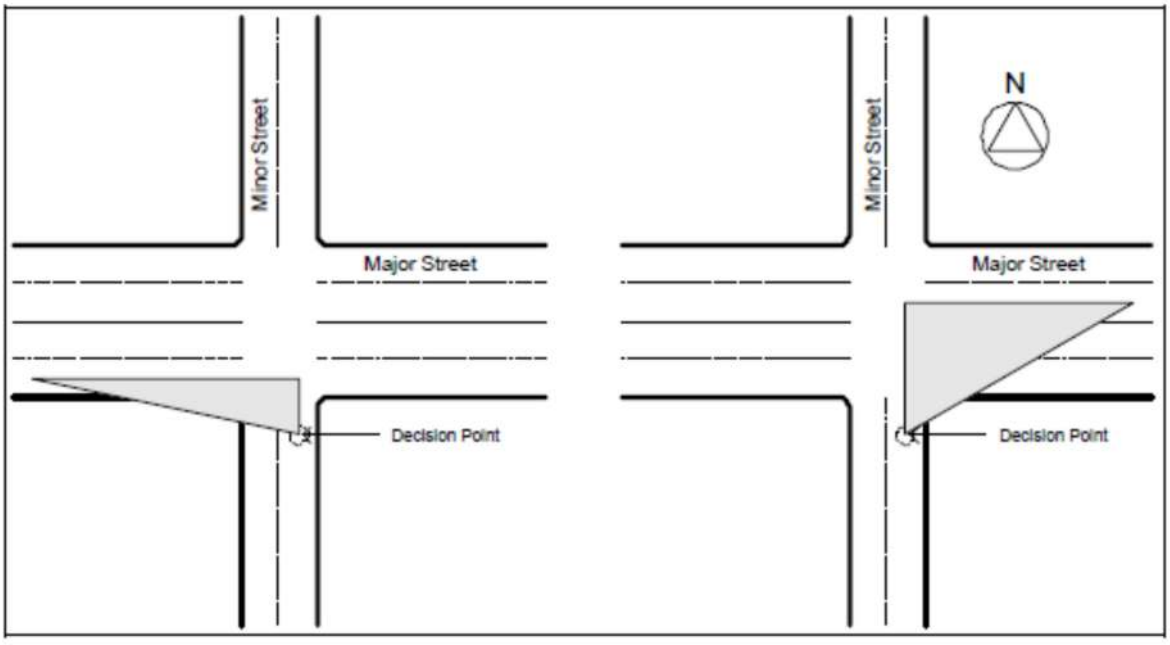


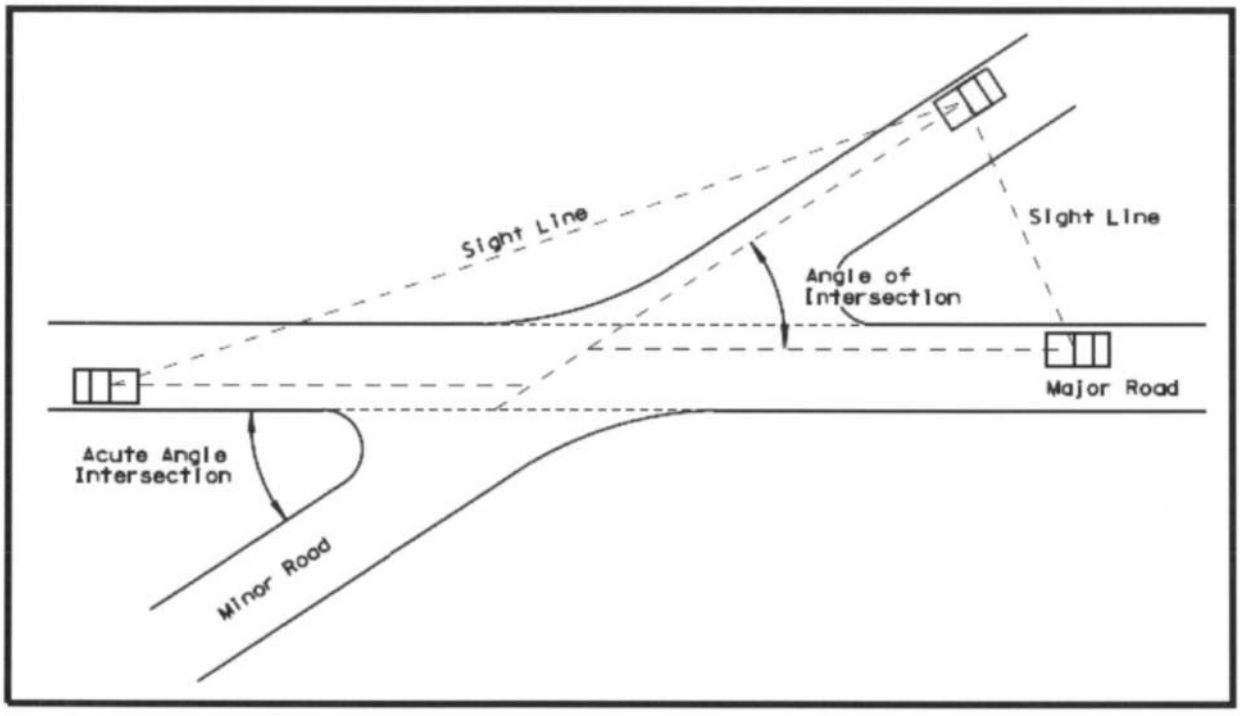
Figure 4.2. Departure Sight Triangles

(Ref:: CTRE – Iowa State University)

Recommended sight triangle dimensions vary for the following different types of traffic control:

- **Case A:** Intersections with no control
- **Case B:** Intersections with stop control on the minor road
  - **Case B1:** Left turn from the minor road
  - **Case B2:** Right turn from the minor road
  - **Case B3:** Crossing maneuver from the minor road
- **Case C:** Intersections with yield control on the minor road
  - **Case C1:** Crossing maneuver from the minor road
  - **Case C2:** Left or right turn from the minor road
- **Case D:** Intersections with traffic signal control
- **Case E:** Intersections with all-way stop control
- **Case F:** Left turns from the major road

Section 9.5.3 of the *AASHTO "Green Book"* presents specific procedures for determining sight distances in each case.



When possible, crossing roadways should intersect at an angle of 90 degrees, and not less than 75 degrees. Intersections with severe skew angles (60 degrees or less) may require adjustment of factors for determining intersection sight distance since they are prone to operational or safety problems.

TURNING ROADWAYS & CHANNELIZATION

Turning roadways are integral parts of roadway intersection design. Their widths are dependent on the types of vehicles and the turning volumes (typically right-turning traffic).

Types of Right-Turning Roadways at Intersections

- Minimum edge-of-traveled-way design
- Design with corner triangular island
- Free-flow design with simple or compound radii

Corner radii should be based on the minimum turning path of design vehicles at locations requiring minimum space (i.e. unchannelized intersections).

AASHTO "Green Book" Tables 9-15 and 9-16 show minimum edge-of-traveled-way design values for design vehicles. Figures 2-13 through 2-23 illustrate satisfactory minimum designs – these accommodate the sharpest turns for particular design vehicles. Minimum designs are better suited for sites with low turn speeds, low turn volumes, and high property values. Minimum edge-of-traveled-way designs for turns may be based on turning paths for passenger car, single-unit ruck, and semitrailer combination design vehicles.

Passenger car (P) design vehicles are used for parkway intersections requiring minimum turns, local/major road intersections with occasional turns; and intersections of two minor roads with low volumes. Single-unit truck (SU-30) is preferable if conditions permit. Minimum edge design is typically used since it better fits the design vehicle path.

Single-unit truck (SU-30 and SU-40) vehicles are recommended for minimum edge-of-traveled-way design for rural highways. Crucial turning movements (major highway, large truck volume, etc.) may require speed-change lanes and/or larger radii. Minimum travel way designs for single-unit trucks will also accommodate city transit buses.

Semitrailer combination (WB series) design vehicles are used at locations with repetitive truck combination turns. An asymmetrical setup of three-centered compound curves is better suited for sites with large volumes of smaller truck combinations. Semitrailer combination designs may need larger radii and corner triangular islands due to their large paved areas.

Corner radii for urban arterial intersections should satisfy - *driver needs, available right-of-way, angle of turn, pedestrians using the crosswalk, number/width of traffic lanes, and posted speeds.*

CHANNELIZATION

Channelization uses pavement markings and/or traffic islands to define definite travel paths for conflicting traffic. Appropriate channelization not only increases capacity and guides motorists but may also produce significant crash reductions and operational efficiencies.

Design Controls for Channelized Intersections

Type of design vehicle *Crossroads cross sections* *Projected traffic volumes*

Number of pedestrians *Vehicle speed* *Bus stop locations*

Traffic control devices

Principles of Channelization

- Do not confront motorists with more than one decision at a time
- Avoid turns greater than 90 degrees or sharp/sudden curves
- Reduce areas of vehicle conflict as much as possible
- Traffic streams that intersect without merging/weaving should intersect at approximately 90 degrees (60° to 120° acceptable)
- Turning roadways should be controlled with a minimum intersection angle of 60 degrees where distances to downstream intersections is less than desirable
- Angles of intersection between merging traffic streams should provide adequate sight distance
- Provide separate refuge areas for turning vehicles
- Channelization islands should not interfere with bicycle lanes
- Prohibited turns should be blocked by channelizing islands
- Traffic control devices should be used as part of the channelized intersection design

Further information regarding channelization devices can be found in the *MUTCD* and Chapter 10 of the *AASHTO "Green Book".*

ISLANDS

Islands are designated areas between roadway lanes used for pedestrian sanctuary and traffic control. Channelized intersections use islands to direct entering traffic into definite travel paths. There is no single physical island type within an intersection – they may be in the form of medians and outer separations or raised curbs and pavement markings.

The primary functions of islands include:

- ✓ **Channelization** - Directing and controlling traffic movements
  Island shape and size depends on intersection conditions and dimensions. Corner triangular islands used for separating right-turning traffic from through vehicles are the most common form. The proper course of travel should be obvious, easy to follow, and continuous.

- ✓ **Division** - Dividing directional traffic streams
  These islands at intersections alert drivers to any upcoming crossroads and regulate traffic. Divisional islands are advantageous for controlling left turns and separating roadways for right turns.

- ✓ **Refuge** - Providing pedestrian sanctuary
  These islands are located near crosswalks or bike paths to aid and protect users who cross the roadway. Urban refuge islands are typically used for pedestrian/bicycle crossings for wide streets, transit rider loading zones, or wheelchair ramps. Their size and location depend on crosswalk location and width, transit loading sites and size, and provisional handicap ramps.

Purposes of Channelizing Islands for Intersection Design

Separating traffic conflicts

Controlling conflict angles

Reducing excessive paving

Regulating roadway traffic

Supporting predominant traffic movements

Protecting pedestrians

Locating traffic control devices

Protecting/storing turning and crossing vehicles

Islands are typically elongated or triangular and placed out of vehicle paths. Curbed islands for intersections need to have appropriate lighting or delineation. Painted, flush medians/islands, or transversable medians may be used under certain conditions unsuited for curbs (high speeds, snow areas, small pedestrian volume, few signals, signs, or lights).

Island shapes and sizes differ from one intersection to another. These should be large enough to command attention.

Minimum Curbed Corner Island Area

Urban Intersection	50 ft^2
Rural Intersection	75 ft^2
Preferable	100 ft^2

The sides of corner triangular islands should be a minimum of 12 feet (preferably 15 feet).

Elongated or divisional islands should be a minimum of 4 feet wide and 20 to 25 feet long. These island widths may be reduced to 2 feet where space is limited. Curbed divisional islands for high speed isolated intersections should be a minimum of 100 feet in length.

AUXILIARY LANES

Auxiliary lanes are typically used for median openings or intersections with right/left-turning movements to increase capacity and reduce crashes. A minimum auxiliary lane width of 10 feet is desirable and should be equivalent to that for through lanes. Roadway shoulders should also have the same width as adjacent shoulders (6 feet preferred – rural high speed roads). Shoulder widths can be reduced or eliminated in many cases (urban areas, turn lanes, etc.). Paved shoulders of 2 to 4 feet may be required for auxiliary lane locations with heavy vehicle usage or offtracking.

While there are no definite warrants for auxiliary lanes – factors such as *roadway capacity, speed, traffic volume, truck percentage, roadway type, right-of-way availability, level of service,* and *intersection configuration* should be considered.

General Auxiliary Lane Guidance

- Auxiliary lanes are needed for high-speed, high volume roadways where a speed change is required for entering/exiting vehicles
- Directional auxiliary lanes with long tapers are adequate for typical driver behavior
- Drivers do not use auxiliary lanes the same way
- The majority of motorists use auxiliary lanes during periods of high volume
- Deceleration lanes prior to intersections may also be used successfully as storage lanes for turning traffic

DECELERATION LANES

The physical length for a deceleration lane is broken down into the following components:

Entering taper length (L_2) **Deceleration length (L_3)** **Storage length (L_4)**

Moderate rates of deceleration are typically accepted within the through lanes with taper lengths considered as a part of the deceleration.

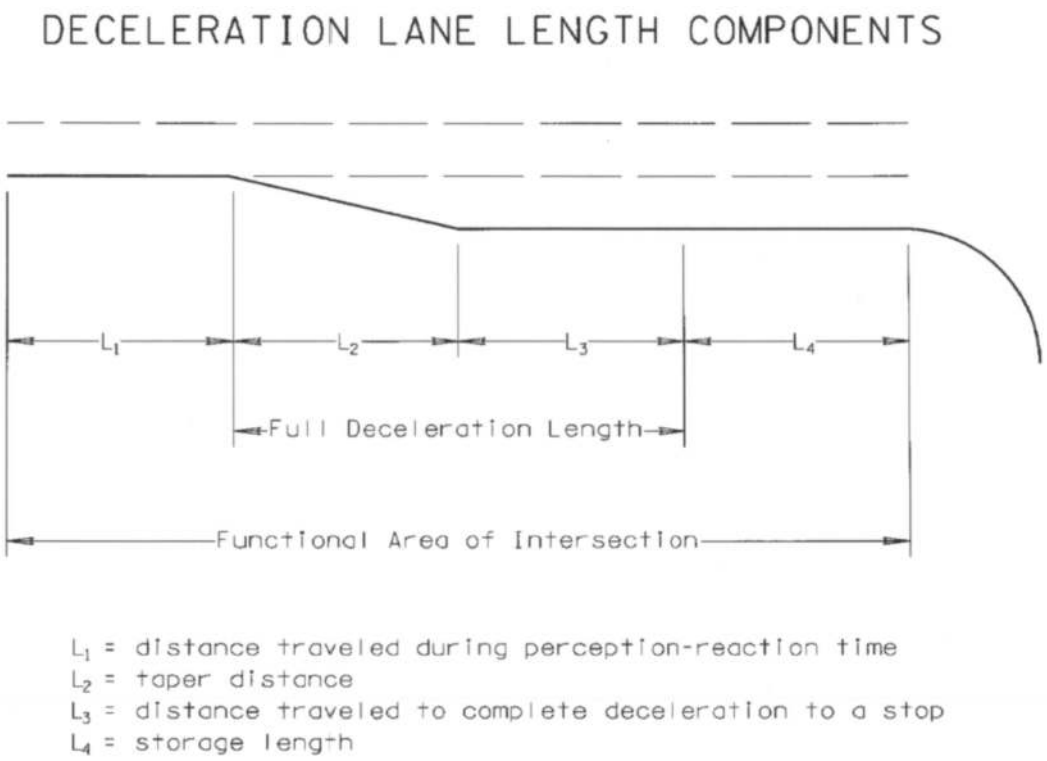


Table 9-22 (AASHTO Green Book) shows the estimated distances needed for maneuvering into a turn bay and braking to a complete stop. These values range from 70 feet at 20 mph to 820 feet at 70 mph. A speed differential of 10 mph is considered acceptable for turning vehicles and through traffic on arterial roadways. Higher speed differentials may be suitable for collector roads or streets with slow speeds or higher volumes.

Signalized Intersection Storage Length Factors

- Intersection traffic analysis
- Spiral cycle length
- Signal phasing arrangement
- Arrivals/departures of left-turning vehicles

Storage length should be based on 1½ to 2 times the average number of stored vehicles per cycle (from design volume).

The storage length for unsignalized intersections should also be determined by an intersection traffic analysis. However, this analysis needs to be based on turning vehicles arriving during an average two-minute period within the peak hour. Provisions should be made for: *minimum storage of 2 passenger cars; 10% turning truck traffic; and storing at least one car and one truck.*

LEFT-TURN LANE DESIGN

The accommodation of left-turning traffic is the single most important consideration in intersection design. The principal controls for intersection type and design are: *design-hour traffic volume ; traffic character/composition; and design speed.* **Traffic volume** (actual/relative traffic volumes for turning and through movements) is considered to be the single most significant factor in determining intersection type.

For intersection design, left-turning traffic in through lanes should be avoided, if possible. Left-turn facilities on roadways are typically used to provide reasonable service levels for intersections. Historically, using left-turn lanes has shown to reduce crash rates 20 to 65%.

Various left-turn guidelines (Highway Capacity Manual, Highway Research Record 211, NCHRP Reports 255 and 279) are based on:

number of arterial lanes design/operating speeds

left-turn volumes opposing traffic volumes

The number of crossroads and intersecting roads should be minimized to benefit through-traffic.

Median left-turn lanes are supplementary lanes used for storage or speed changes of left-turning vehicles within medians or traffic islands. These lanes should be used at locations with high left turn volumes or high vehicle speeds.

Intersections	**Median Width**	
Single median lane	*20-ft minimum*	*Desirable*
	16 to 18 feet	*Adequate*
Two median lanes	*28-ft minimum*	*Desirable*
	(two 12-ft lanes with 4-ft separator)	

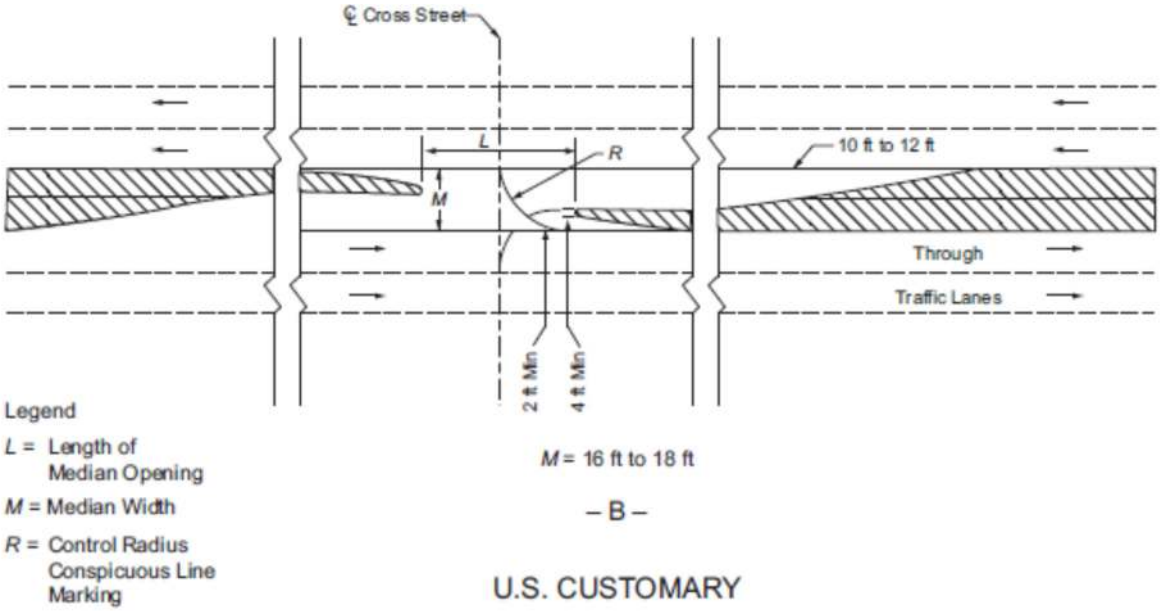


Figure 9-50. 4.2- to 5.4-m [14- to 18-ft] Median Width Left-Turn Design (U.S. Customary) (Continued)

The type of median end treatment adjacent to opposing traffic is dependent on available width. Narrowed medians can be used to: s*eparate opposing traffic; protect pedestrians; provide space for safety measures; and highlight lane edges.*

Minimum Narrowed Median Width*

4 ft (recommended)

6 to 8 ft (preferable)

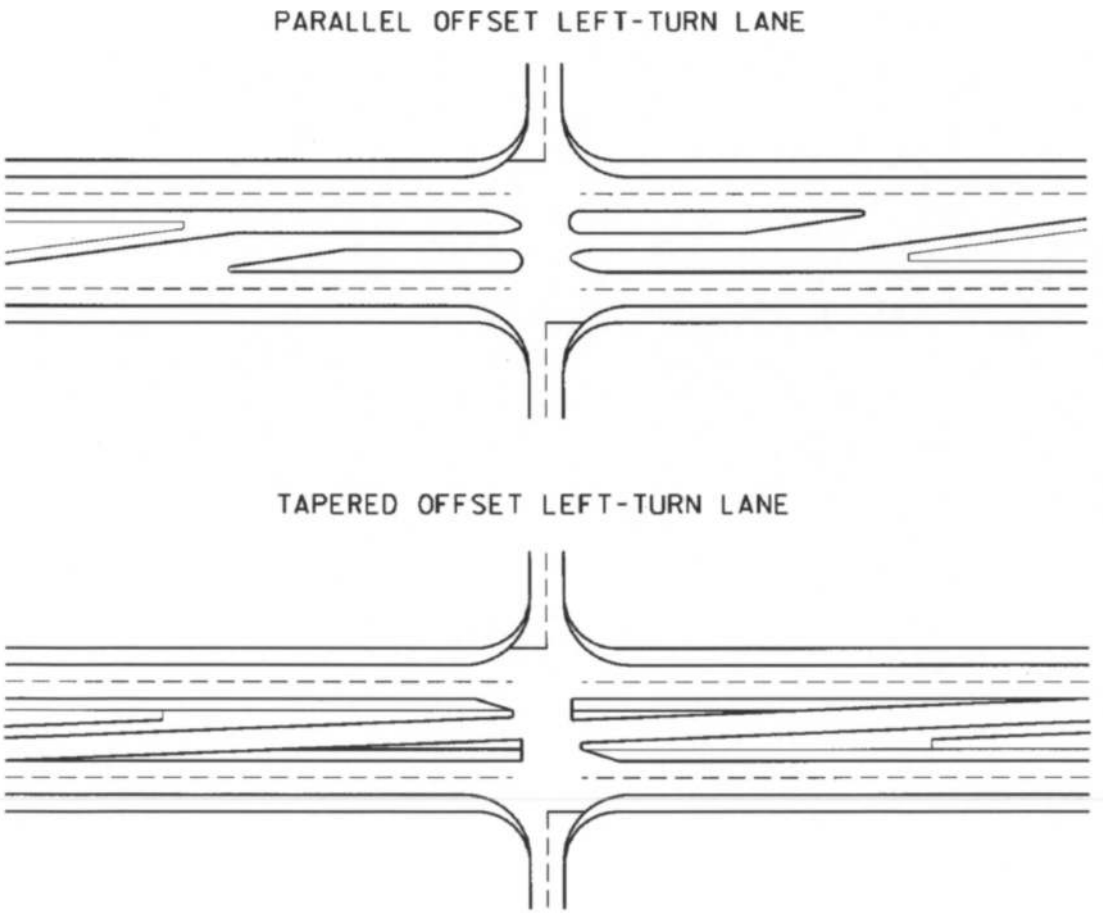
*For medians 16 to 18 ft wide with a 12 ft turning lane

It is preferable to offset left-turn lanes for medians wider than 18 feet. This will reduce the divider width to 6 to 8 feet prior to the intersection and prevent lane alignments parallel or adjacent to the through lanes.

Advantages of Offset Left-turn Lanes

- Better sight distance
- Decreased turning conflict possibility
- Increased left-turn traffic efficiency

The two main types of offset left-turn lane configurations used are **parallel** and **tapered**.



Parallel offset lanes are parallel but offset to the roadway's through lanes while **tapered** offset lanes diverge from the through lanes and cross the median at a slight angle. These offset lanes should be used in conjunction with painted or raised channelization. While both configurations are used for signalized intersections, parallel offset left-turn lanes may also be suitable for unsignalized ones.

Double and triple turn lanes should only be used for signalized intersection locations with separate turning phases. It is recommended that the receiving intersection leg be able to accommodate two lanes of turning vehicles (typically 30 feet). A 90-ft turning radius is preferable for accommodating design vehicles (P through WB-40) within a swept path width of 12 feet. Pavement markings may be used throughout the intersection to provide visual cues.

MEDIAN OPENINGS

Median openings should be consistent with site characteristics, through/turning traffic volumes, type of turning vehicles, and signal spacing criteria. For locations with low traffic volumes where the majority of vehicles travel on the divided roadway - the simplest and most economic design may be adequate. However, at locations with high speed/high volume through traffic or sites with considerable cross and

turning movements, the median opening should allow little or no traffic interference or lane encroachment.

Median Opening Design Steps

Consider traffic to be accommodated

Choose a design vehicle

Determine large vehicle turns without encroachment

Check for capacity

The design of any median opening should consider the simultaneous occurrences of all traffic movements (volume, composition). Traffic control devices (signs, signals, etc.) can help regulate vehicle movements and improve operational efficiency.

A crucial design consideration for median openings is the path of design vehicles making a minimum 10 to 15 mph left turn. If the type and volume of the turning vehicles require higher than minimum speeds – the appropriate corresponding radius should be used. Low-speed minimum turning paths are needed for minimum designs and larger design vehicles.

Typical intersections for divided highways have guides for the driver at the beginning and end of the left-turn:

- *Centerline of an undivided crossroad* OR *Median edge of a divided crossroad*
- *Curved median end*

The turn's central part is an open intersection area for maneuvers.

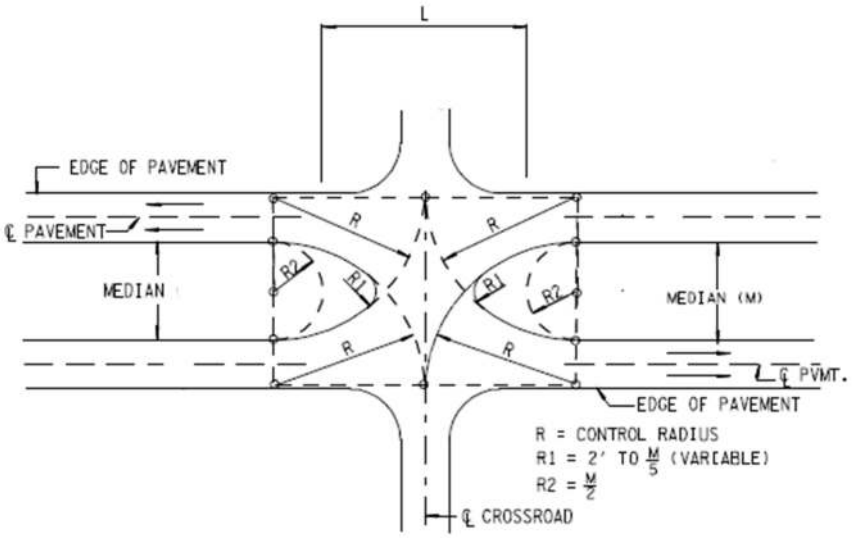
Sufficient pavement is needed for the turning path of occasional large vehicles, as well as appropriate edge markings for desired turning paths (passenger cars) to produce effective sizing for intersections.

The following control radii can be used for minimum practical median end design:

Control Radius	Design Vehicle	
40 feet	P	SU-30 (occasional)
50 feet	SU-30	SU-40/WB-40 (occasional)
75 feet	SU-40, WB-40, WB-62	
130 feet	WB-62	WB-67 (occasional)

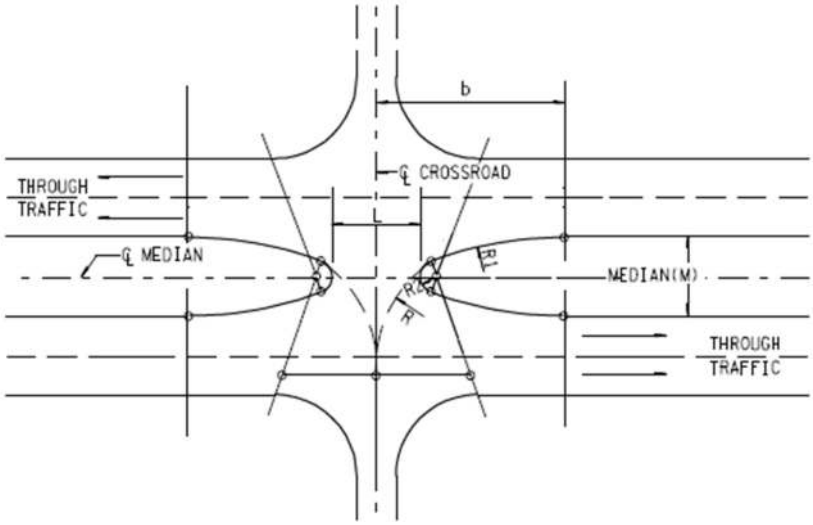
AASHTO "Green Book" Tables 9-25 through 9-27 and Figures 9-55 to 9-58 show these relationships.

Semicircle median opening designs are simple for narrow medians. More desirable shapes are typically used for median widths greater than 10 feet.



(Ref: TDOT, Standard Roadway Drawings)

The **bullet nose** design contains two parts of the control radius arcs with a small radius to round the nose. This form fits the inner rear wheel path with less pavement and shorter opening lengths. The bullet nose is preferable for median widths greater than 10 feet. This design positions left-turning vehicles to or from the crossroad centerline – semicircular forms direct left off movements into the crossroad's opposing traffic lane.



(Ref: TDOT, Standard Roadway Drawings)

The minimum length of median opening for three or four-leg intersections on divided roadways should be equivalent to the cross road width plus shoulders. The minimum opening length should equal the crossroad widths plus the median for divided roadway crossroads.

Do not use minimum opening length without regard to median width or control radius – except for very minor cross roads. Median openings do not need to be longer than required for rural unsignalized intersections.

Using control radii for minimum design of median openings produces lengths that increase with the intersection skew angle. This skew may introduce alternate designs – depending on median width, skew angle, and control radius.

Semicircular ends *: very long openings*

: minor left turn channelizing control (< 90° turning angle)

Bullet nose *: determined by control radius and point of tangency*

: little channelizing control from divided highway

Do not use median opening lengths longer than 80 feet – regardless of skew. These types of lengths may require special channelization, left-turn lanes, or skew adjustment to produce an above-minimum design.

Normally, **asymmetrical bullet nose ends** are the preferable type of skewed median end.

Median openings that allow vehicles to use minimum paths at 10 to 15 mph are suitable for intersections with a majority of through traffic. Locations with high speeds and through volumes plus important left-turns should have median openings that do not create adjacent lane encroachment. The general minimum design procedure can be used with larger dimensions to enable turns at greater speeds and provide adequate space for vehicle protection.

Various median opening designs may be used – depending on control dimensions and design vehicle size. Median opening length is governed by the radii.

INDIRECT LEFT TURNS & U-TURNS

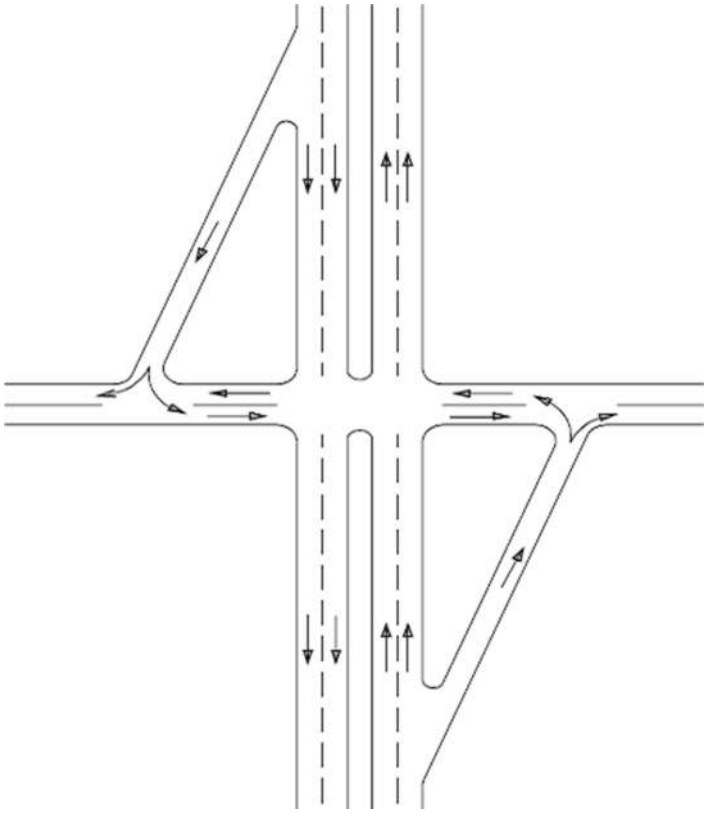
Median openings provide access for crossing traffic plus left-turns and U-turns. Since conventional intersection designs may not be appropriate for all intersections, innovative and unconventional treatments are being explored. These strategies share many of the following principles:

- Design and operations emphasis on through-traffic movements along the arterial corridor
- Reduction in the number of signal phases at major cross street intersections and increased green time for arterial through movements
- Reduction in the number of intersection conflict points and separation of the conflict points that remain

The product of these is to furnish an indirect path for left-turns.

Jughandles

Jughandles are one-way roadways used in different quadrants of intersections to separate left-turning vehicles from through traffic by forcing all turns to be made from the right side (right turns, left turns, U-turns). Road users wanting to turn left must first exit right from the major road and then turn left onto the minor roadway. Although less right-of-way may be required along the road due to no left-turn lanes, more land may be needed at the intersection for the jughandles.



Jughandle Considerations

Intersections with high major street movements

Locations with low-to-median left turns from the major street

Sites with low-to-median left turns from the minor street

Any amount of minor street through volumes

Intersections with too narrow medians for left turns

Jughandles can improve safety and operationability by reducing left-turn collisions and providing more green time for through movements.

Displaced Left-Turn Intersections

[Continuous-Flow Intersection (CFI) or Crossover-Displaced Left-Turn Intersection (XDL)]

Displace left-turn intersections use left-turn bays on the left of oncoming traffic to remove the potential hazard between left-turning and oncoming vehicles at main roadway intersections. These left-turn bays may be accessed at a midblock signalized intersection approach where continuous flow is wanted. Stops for left turns may occur for the following instances:

1) Midblock signal on approach
2) Main intersection on departure

Signals need to be coordinated to minimize the number of stops – especially at main intersections.

Two-Phase Signal Operation for Displaced Left-Turn Intersection

Signal Phase 1 *Serves cross street traffic*

Traffic permitted to enter left-turn by crossing oncoming traffic lanes

Signal Phase 2 *Serves through traffic*

Protects left-turn movements

Displaced left-turn intersections are suitable for locations with high through and left-turn volumes. Adjacent right-of-way may be required for the proposed left-turn roadways.

Median U-Turn Crossover Roadways

Median U-Turn crossovers move left-turning traffic to median crossover roadways beyond intersections. For major road crossovers, drivers pass through the intersection and turn left to make a U-turn at the crossover, and veer right at the cross road. For minor road median crossovers, major road traffic turns right on the minor road, and then left through the crossover roadway. Roundabouts may be considered to be a variation of U-turn crossovers.

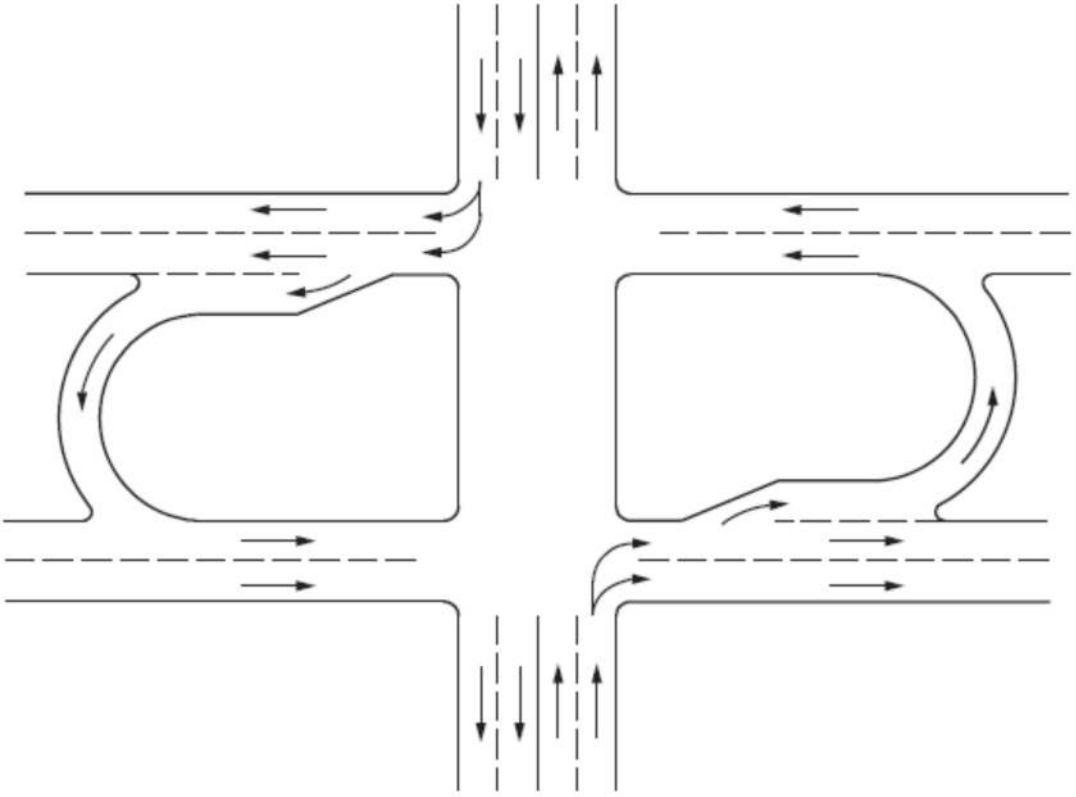


Figure 9-65. Typical Arrangement of U-Turn Roadways for Indirect Left Turns on Arterials with Wide Medians

Median U-Turn crossovers require a wide median due to their design. These roadways are more suitable for intersections with high major-street through movements, low-to-medium left turns from the major street, low-to-medium left turns from the minor street, and any amount of minor street through volumes. Locations with high left-turn volumes should be avoided.

Key Design Features

- Must accommodate design vehicle
- Deceleration/storage lengths should be based on design volume and traffic control
- Optimum location is 660 feet from the main intersection
- Four-lane arterial medians should be 60 feet wide to accommodate tractor-semitrailer combination truck design vehicle

ROUNDABOUT DESIGN

The “modern roundabout” was a British solution to the problems associated with rotary intersections. The resulting design is a one-way, circular intersection with traffic flow around a central island. The U.K. adopted a mandatory “give-way” rule for entering traffic at all circular intersections to yield to circulating traffic. This rule greatly reduced the number and severity of vehicle crashes.

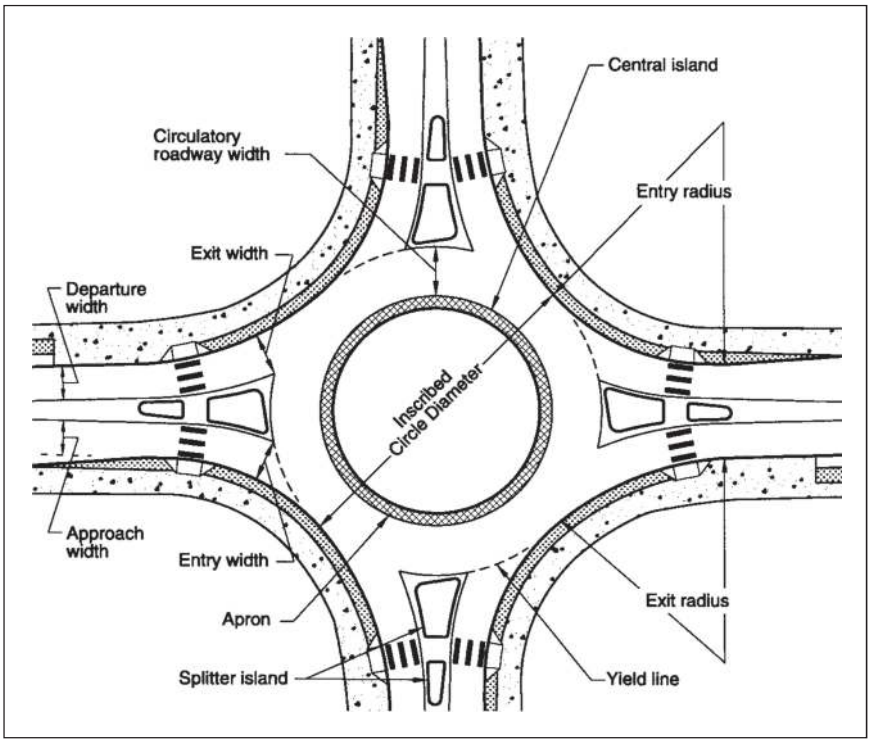
Basic Principles for Modern Roundabouts

1) **Yield control at all entry points** – All approaching traffic is required to yield to vehicles on the roundabout’s circulatory roadway before entering the circle. Yield signs are used primarily as entry control.
2) **Traffic deflection** – Entering vehicles are directed to the right (in the U.S.) by channelization or splitter islands onto the roundabout’s circulating roadway avoiding the central island.
3) **Geometric curvature** – Entry design and the radius of the roundabout’s circulating roadway can be designed to slow the speeds for entering and circulating traffic.

Roundabout geometric design is a combination of balancing operational and capacity performances with the safety enhancements. Roundabouts operate best when approaching vehicles enter and circulate at slow speeds. By using low-speed design elements (horizontal curvature and narrow pavement widths for slower speeds) the capacity of the roundabout may be negatively affected. Many of the geometric criteria used in design of roundabouts are also governed by the accommodation of over-sized vehicles expected to travel through the intersection.

Roundabout design is a creative process that is specific for each individual intersection. No standard template or “cookie-cutter” method exists for all locations. Geometric designs can range from easy (mini-roundabouts) to moderate (single lane roundabouts) to very complex (multi-lane roundabouts). How the intersection functions as a single traffic control unit is more important than the actual values of the individual design components. It is crucial that these individual geometric parts interact with each other within acceptable ranges in order to succeed.

Exhibit 6-1. Basic Geometric Elements of a Roundabout.



(Ref: FHWA. Roundabouts: An Informational Guide. 2000)

Roundabout Geometric Elements

Central Island *Raised area (not necessarily circular) in the center of the roundabout which is bordered by circulating traffic.*

Splitter Island *Raised or painted approach area for delineating, deflecting and slowing traffic. It also permits non-motorist crossings.*

Circulatory Roadway *Curved vehicle path for counterclockwise travel around the central island.*

Apron *Optional mountable part of the central island for accommodating larger vehicle wheel tracking.*

Yield Line *Pavement marking for entry point to the circulatory roadway. Entry vehicles must yield to circulating traffic before crossing the yield line onto the circulatory path.*

Accessible Pedestrian Crossings *Non-motorist access that is setback from the entrance line and cut through the splitter island.*

Landscape Strip *Optional areas for separating vehicle/non-motorist traffic, designating crossing locations, and providing aesthetic improvements.*

CAPACITY

A roundabout's capacity and size depends on the number of lanes required to handle future traffic. Exhibit 3-12 illustrates a simple, conservative way to estimate roundabout lane requirements. It is applicable for the following conditions:

Ratio of peak-hour to daily traffic (K)	*0.09 to 0.10*
Acceptable volume-to-capacity ratio	*0.85 to 1.00*
Ratio of minor street to total entering traffic	*0.33 to 0.50*
Direction distribution of traffic (D)	*0.52 to 0.58*

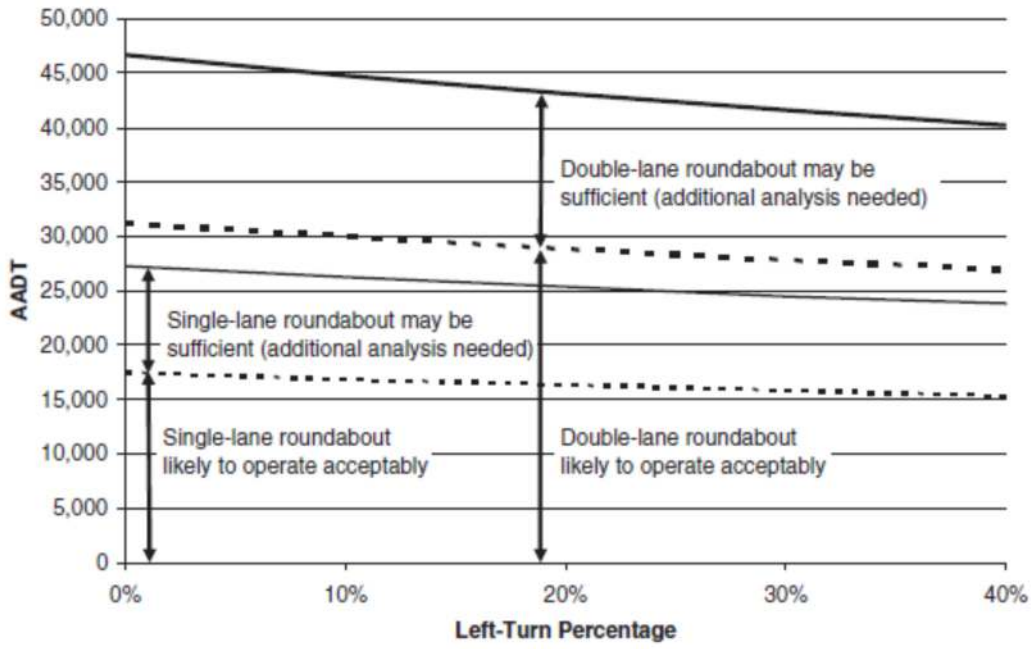


Exhibit 3-12. Planning-Level Daily Intersection Volumes

(Ref: FHWA. Roundabouts: An Informational Guide. 2000)

FRONTAGE ROADS

Frontage roads preserve the character of the highway and prevent impacts of road development. These roads are used most frequently on freeways to distribute and collect roadway traffic between local

streets and freeway interchanges. Frontage roads are typically used adjacent to arterials/freeways where property owners are denied direct access.

A minimum spacing of **150 feet** between arterial and frontage roads is recommended in urban areas to lengthen the spacing between successive intersections along the crossroads.

This dimension is based on the following criteria:

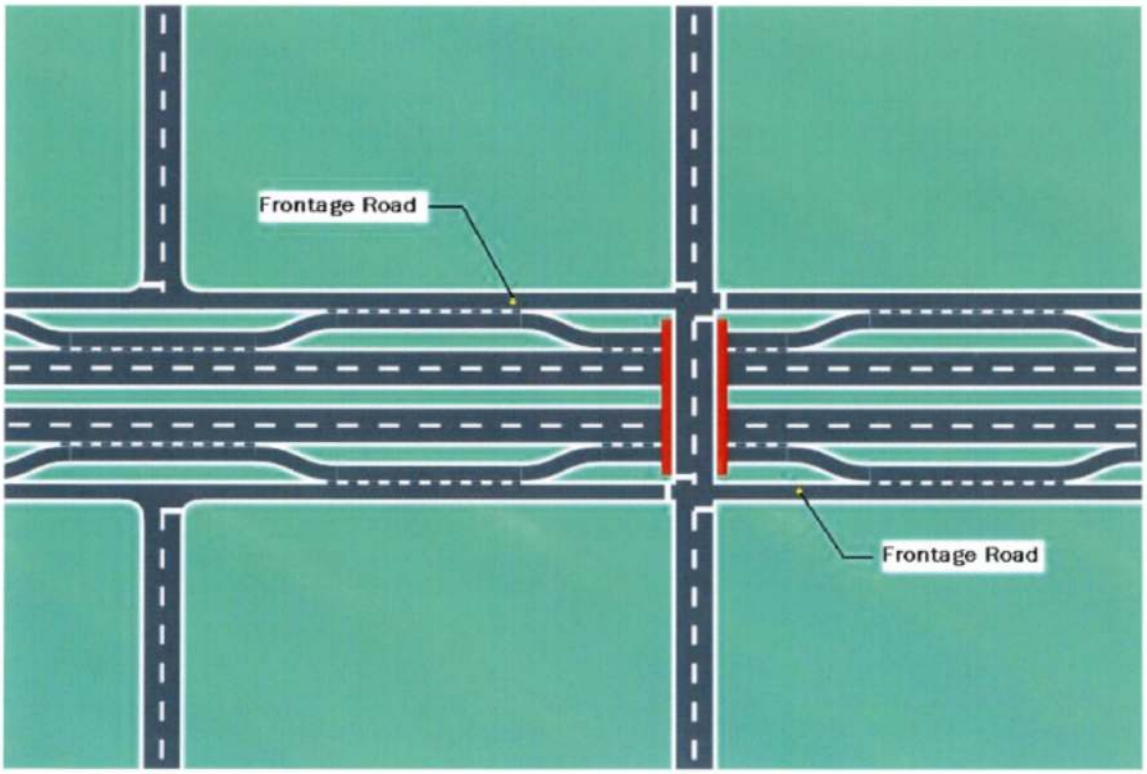
- Shortest acceptable length needed for signs and traffic control devices
- Acceptable storage space on crossroad in advance of main intersection
- Enables turning movements from the main road onto frontage road
- Facilitates U-turns between main lanes and two-way frontage roads
- Alleviates potential wrong-way entry onto highway

Frontage roads are typically parallel to the freeway

- *Either one or both sides*
- *Continuous or non-continuous*

Arterial and frontage road connections are a crucial element of design. For slow-moving traffic and one-way frontage roads, simple openings may be adequate. On high-speed roadways, ramps should be designed for speed changes and storage.

Frontage road design is also impacted by its intended type of service – it can assume the character of a major route or a local street.



Typical Frontage Road Example

Outer Separations

The "outer separation" is the buffer area between through traffic on a roadway and local traffic on a frontage road. The wider the separation → the lesser the influence on through traffic. Wide separations are particularly advantageous at intersections with cross streets to minimize vehicular and pedestrian conflicts. Separations of 300 feet allow for minimal vehicle storage and overlapping left-turn lanes.

The cross-section of an outer separation is dependent on:

width *type of arterial* *frontage road type*

PEDESTRIAN FACILITIES

Sidewalks

The safe and efficient accommodation of pedestrians along the traveled way is equally important as the provisions for vehicles. By separating pedestrians and vehicles, sidewalks increase pedestrian safety and help vehicular capacity. Sidewalks are typically an integral part of the transportation system

in central business districts. Data suggests that providing sidewalks along highways in rural and suburban areas results in a reduction in pedestrian accidents.

Early consideration of pedestrian needs during the project development process may also streamline compliance with accessibility requirements of the *Americans with Disabilities Act Accessibility Guidelines (ADAAG)*. Intersections designed with proper curb ramps, sidewalks, pedestrian signals, and refuge islands can also aid in furnishing a pedestrian-friendly environment.

Sidewalks are typically placed along roadways without shoulders – even at locations with light pedestrian traffic. For sidewalk locations along high-speed roads, buffer areas may be utilized to distance the sidewalk from the traveled way.

Sidewalks should be wide enough for the volume and type of expected pedestrian traffic. Typical residential sidewalks vary in width from 4 to 8 feet. The *Americans with Disabilities Act Accessibility Guidelines (ADAAG)* require passing sections for sidewalks with widths less than 5 feet spaced every 200 feet. An optional planted strip may be provided between the sidewalk and the curb (2 ft minimum width) to allow for maintenance activities. At locations with sidewalks adjacent to the curb, the width should be 2 feet wider than the minimum width required.

Advantages of Buffer Areas

Increased pedestrian distance from moving

Aesthetics of the facility

Reduced width of hard surface space

Space for snow storage

A major disadvantage of buffers or plant strips is the possibility of requiring additional right-of-way.

The wider the sidewalk, the more room there is for street furniture, trees, utilities, and pedestrians plus easier maneuvering around these fixed objects. It is important not to overlook the need to maintain as unobstructed a pathway as possible.

Grade-Separated Pedestrian Crossings

A grade-separated pedestrian facility (either over or under the roadway) permits pedestrian and vehicle crossings at different levels without interference. These structures may be used at locations where pedestrian/traffic volumes, intersection capacity, etc. encourage their construction. Governmental regulations and codes can provide additional design guidance when considering these facilities. The *AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities* provides more specific information for these structures.

Pedestrian walkways should be a minimum of 8 feet wide. Wider walkways may be used for tunnels, high pedestrian traffic areas, and overpasses with a tunnel effect (from screens).

Vandalism is a legitimate concern for pedestrian/vehicle overpass structures – where individuals drop objects onto oncoming traffic. While there is no universal deterrent, options have been developed to deal with this problem, including: *solid plastic enclosures* and *screens.*

Possible Overpass Locations (with screens)

- Schools, playgrounds, etc. – where children may be unaccompanied
- Large urban pedestrian overpasses – not under police surveillance
- Where history indicates a need

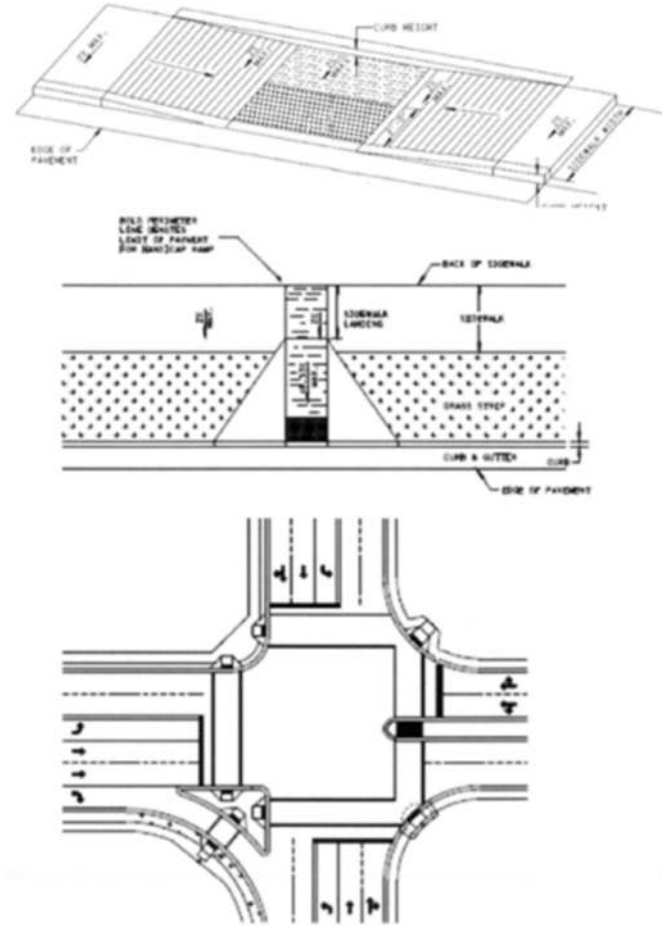
Curb Ramps

Curb ramps provide access between sidewalks and streets at pedestrian crossings. Basic curve types have been developed for use according to intersection geometric characteristics. Design considerations should include: *sidewalk width; sidewalk location; curb height & width; turning radius & curve length; street intersection angle; sign & signal locations; drainage inlets; utilities; sight obstructions; street width;* and *border width.*

The *Public Rights-of-Way Accessibility Guidelines* provide the following guidance for curb ramps:

Minimum curb ramp width	4 feet
Maximum curb ramp grade	8.33%
Sidewalk cross slopes	2% maximum
Top level landing area	4 ft x 4 ft (no obstructions, 2% max. cross slope)

Curb ramp locations should be closely integrated with the pedestrian crosswalk by having the curb ramp bottom within the crosswalk's parallel boundaries, and perpendicular to the curb face. These ramps are typically placed within the corner radius or beyond the radius on the tangent section.



Curb Ramp Examples

(Ref: TDOT, Standard Roadway Drawings)

BICYCLE FACILITIES

Due to the bicycle's popularity as a mode of transportation, their needs should be considered when designing roadways. The main factors to consider for accommodating bicycles include: *type of bicyclist being served by the route (experienced, novice, children); type of roadway project (widening, new construction, resurfacing); and traffic operations & design characteristics (traffic volume, sight distance, development).*

The basic types of bicycle facilities include:

Shared lane: typical travel lane shared by both bicycles and vehicles

Wide outside lane: outside travel lane (14 ft minimum) for both bicycles & vehicles

Bicycle lane: part of roadway exclusively designated (striping or signing) for bicycles, etc.

Shoulder: roadway paving to the right of traveled way for usage

Multiuse path: physically separated facility for bicycles, etc.

Transportation planners and designers list these factors that have a great impact on bicycle lanes – *traffic volume, average operating speed, traffic mix, on-street parking, sight distance, and number of intersections.*

RAILROAD-HIGHWAY GRADE CROSSINGS

The geometric roadway design for a railroad crossing should draw motorists' attention to roadway conditions. The major consideration is to enable highway traffic to move more efficiently.

Horizontal Alignment Guidelines

Intersect tracks at right angles and avoid nearby intersections or ramps

- Enhances sight distance
- Reduces conflicting vehicle movements
- Preferable for cyclists

Avoid locating crossings on highway or railroad curves

- Curvature inhibits driver's perception and sight distance
- Causes poor rideability and maintenance challenges (superelevation)

Where possible, the vertical alignment for a railroad-highway crossing should be as level as practical to enhance rideability, sight distance, acceleration, and braking. Limitations for the roadway surface include:

Being on the same plane as the rail tops for a minimum of 2 ft outside the rails

Limited to 3 in higher or lower than the top of the nearest rail at 30 ft from the rail

Grade crossing geometric design consists of utilizing alignments (horizontal and vertical), sight distance, and cross-sections. This design may change with the type of warning devices used.

Railroad-highway grade crossing traffic control devices may consist of passive warning devices (signs, pavement markings) and/or active warning devices (flashing light signals, automatic gates). Guidelines regarding these devices are covered fully in the MUTCD.

At railroad-highway grade crossings without train-activated warning devices, the following two scenarios are typically used to determine sight distances:

- *Vehicle can see the approaching train with a sight line adequate to pass the crossing prior to the train's arrival (GO)*
- *Vehicle can see the approaching train with a sight line adequate to stop prior to crossing (STOP)*

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Note: All figures, illustrations, tables, etc. contained within this course are from this text unless noted otherwise.

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