CHAPTER 400
INTERSECTIONS AT GRADE

Intersections are planned points of conflict where two or more roadways join or cross. At-grade intersections are among the most complicated elements on the highway system, and control the efficiency, capacity, and safety for motorized and non-motorized users of the facility. The type and operation of an intersection is important to the adjacent property owners, motorists, bicyclists, pedestrians, transit operators, the trucking industry, and the local community.

There are two basic types of at grade intersections: crossing and circular. It is not recommended that intersections have more than four legs. Occasionally, local development and land uses create the need for a more complex intersection design. Such intersections may require a specialized intersection design to handle the specify traffic demands at that location. In addition to the guidance in this manual, see Traffic Operations Policy Directive (TOPD) Number 13-02: Intersection Control Evaluation (ICE) for direction and procedures on the evaluation, comparison and selection of the intersection types and control strategies identified in Index 401.5. Also refer to the Complete Streets Intersection Guide for further information.

Topic 401 - Factors Affecting Design

Index 401.1 - General

At-grade intersections must handle a variety of conflicts among users, which includes truck, transit, pedestrians, and bicycles. These recurring conflicts play a major role in the preparation of design standards and guidelines. Arriving, departing, merging, turning, and crossing paths of moving pedestrians, bicycles, truck, and vehicular traffic have to be accommodated within a relatively small area. The objective of designing an intersection is to effectively balance the convenience, ease, and comfort of the users, as well as the human factors, with moving traffic (automobiles, trucks, motorcycles, transit vehicles, bicycles, pedestrians, etc.).The safety and mobility needs of motorist, bicyclist and pedestrians as well as their movement patterns in intersections must be analyzed early in the planning phase and then followed through appropriately during the design phase of all intersections on the State highway. It is Departmental policy to develop integrated multimodal projects in balance with community goals, plans, and values.

The Complete Intersections: A Guide to Reconstructing Intersections and Interchanges for Bicyclists and Pedestrians contains a primer on the factors to consider when designing intersections. It is published by the California Division of Traffic Operations.

401.2 Human Factors

(1) *The Driver.* An appreciation of driver performance is essential to proper highway design and operation. The suitability of a design rests as much on how safely and efficiently drivers are able to use the highway as on any other criterion.

Motorist's perception and reaction time set the standards for sight distance and length of transitions. The driver's ability to understand and interpret the movements and crossing times of the other vehicle drivers, bicyclists, and pedestrians using the intersection is equally important when making decisions and their associated reactions. The designer needs to keep in mind the user's limitations and therefore design intersections so that they meet user expectation.

(2) *The Bicyclist.* Bicyclist experience, skills and physical capabilities are factors in intersection design. Intersections are to be designed to help bicyclists understand how to traverse the intersection. Chapter 1000 provides intersection guidance for Class I and Class III bikeways that intersect the State highway system. The guidance in this chapter specifically relates to bicyclists that operate within intersections on the State highway system.

(3) *The Pedestrian.* Understanding how pedestrians will use an intersection is critical because pedestrian volumes, their age ranges, physical ability, etc. all factor in to their startup time and the time it takes them to cross an intersection and thus, dictates how to design

the intersection to avoid potential conflicts with bicyclists and motor vehicles. The guidance in this chapter specifically relates to pedestrian travel within intersections on the State highway system. See Topic 105, Pedestrian Facilities, Design Information Bulletin 82 - "Pedestrian Accessibility Guidelines for Highway Projects," the AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities, and the California Manual on Uniform Traffic Control Devices (California MUTCD) for additional guidance.

401.3 Traffic Considerations

Good intersection design clearly indicates to bicyclists and motorists how to traverse the intersection (see Figure 403.6A). Designs that encourage merging traffic to yield to through bicycle and motor vehicle traffic are desirable.

The size, maneuverability, and other characteristics of bicycles and motorized vehicles (automobiles, trucks, transit vehicles, farm equipment, etc.) are all factors that influence the design of an intersection. The differences in operating characteristics between bicycles and motor vehicles should be considered early in design.

Table 401.3 compares vehicle characteristics to intersection design elements.

A design vehicle is a convenient means of representing a particular segment of the vehicle population. See Topic 404 for a further discussion of the uses of design vehicles.

Transit vehicles and how their stops interrelate with an intersection, pedestrian desired walking patterns and potential transfers to other transit facilities are another critical factor to understand when designing an intersection. Transit stops and their placement needs to take into account the required maintenance operations that will be needed and usually supplied by the Transit Operator.

401.4 The Physical Environment

In highly developed urban areas, where right of way is usually limited, the volume of vehicular traffic, pedestrians, and bicyclists may be large, street parking exists, and transit stops (for both buses and light rail) are available. All interact in a variety of movements that contribute to and add to the complexity of a State highway and can result in busy intersections.

Industrial development may require special attention to the movement of large trucks.

Rural areas where farming occurs may require special attention for specialized farm equipment. In addition, rural cities or town centers (rural main streets) also require special attention.

Rural intersections in farm areas with low traffic volumes may have special visibility problems or require shadowing of left-turn vehicles from high speed approach traffic.

Table 401.3

Vehicle Characteristics	Intersection Design Element Affected
Length	Length of storage lane
Width	Lane width
Height	Clearance to overhead signs and signals
Wheel base	Corner radius and width of turning lanes
Acceleration	Tapers and length of acceleration lane
Deceleration	Tapers and length of deceleration lane

There are many factors to be considered in the design of intersections, with the goal to achieve a functional, safe and efficient intersection for all users of the facility. The location and level of use by various modes will have an impact on intersection design, and therefore should be considered early in the design process. In addition to current levels of use, it is important to consider future travel patterns for vehicles, including trucks; pedestrian and bicycle demand and the future expansion of transit.

401.5 Intersection Type

Intersection types are characterized by their basic geometric configuration, and the form of intersection traffic control that is employed:

(1) Geometric Configurations

(a) Crossing-Type Intersections - "Tee" and 4-legged intersections

(b) Circular Intersections –roundabouts, traffic circles, rotaries; however, only roundabouts are acceptable for State highways.

(c) Alternative Intersection Designs – various effective geometric alternatives to traditional designs that can reduce crashes and their severity, improve operations, reduce congestion and delay typically by reducing or altering the number of conflict points; these alternatives include geometric design features such as intersections with displaced left-turns or variations on U-turns.

(2) Intersection Control strategies, See California MUTCD and Traffic Operations Policy Directive (TOPD) Number 13-02, Intersection Control Evaluation for procedures and guidance on how to evaluate, compare and select from among the following intersection control strategies:

(a) Two-Way Stop Controlled - for minor road traffic

(b) All-Way Stop Control

(c) Signal Control

(d) Yield Control (Roundabout)

Historically, crossing-type intersections with signal or "STOP"-control have been used on the State highway system. However, other intersection types, given the appropriate circumstances may enhance intersection performance through fewer or less severe crashes and improve operations by reducing overall delay. Alternative intersection geometric designs should be considered and evaluated early in the project scoping, planning and decision-making stages, as they may be more efficient, economical and safer solutions than traditional designs. Alternative intersection designs can effectively balance the safety and mobility needs of the motor vehicle drivers, transit riders, bicyclists and pedestrians using the intersection.

401.6 Transit

Transit use may range from periodic buses, handled as part of the normal mix of vehicular traffic, to Bus Rapid Transit (BRT) or light rail facilities which can have a large impact on other users of the intersection. Consideration of these modes should be part of the early planning and design of intersections.

Topic 402 - Operational Features Affecting Design

402.1 Capacity

Adequate capacity to handle peak period traffic demands is a basic goal of intersection design.

(1) Unsignalized Intersections. The "Highway Capacity Manual", provides methodology for capacity analysis of unsignalized intersections controlled by "STOP" or "YIELD" signs. The assumption is made that major street traffic is not affected by the minor street movement. Unsignalized intersections generally become candidates for signalization when traffic backups begin to develop on the cross street or when gaps in traffic are insufficient for drivers to yield to crossing pedestrians. See the California MUTCD, for signal warrants. Changes to intersection controls must be coordinated with District Traffic Branch.

(2) Signalized Intersections. See Topic 406 for analysis of simple signalized intersections, including ramps. The analysis of complex and alternative intersections should be referred to the District Traffic Branch; also see Traffic Operations Policy Directive (TOPD) Number 13-02.

(3) Roundabout Intersections. See TOPD Number 13-02 for screening process and the Intersection Control Evaluation(ICE) Process Informational Guide for operational analysis methods and tools.

402.2 Collisions

(1) General. Intersections have a higher potential for conflict compared to other sections of the highway because travel is interrupted, traffic streams cross, and many types of turning movements occur.

The type of traffic control affects the type of collisions. Signalized intersections tend to have more rear end and same-direction

sideswipes than intersections with "STOP"-control on minor legs. Roundabouts experience few angle or crossing collisions. Roundabouts reduce the frequency and severity of collisions, especially when compared to the performance of signalized intersections in high speed environments. Other alternative intersection types are configurations to consider for minimizing the number of conflict points.

(2) Undesirable Geometric Features.

- Inadequate approach sight distance.
- Inadequate corner sight distance.
- Steep grades.
- Five or more approaches.
- Presence of curves within intersections(unless at roundabouts).
- Inappropriately large curb radii.
- Long pedestrian crossing distances.
- Intersection Angle <75 degrees (see Topic 403).

402.3 On-Street Parking

On-street parking generally decreases through-traffic capacity, impedes traffic flow, and increases crash potential. Where the primary service of the arterial is the movement of vehicles, it may be desirable to prohibit on-street parking on State highways in urban and suburban expressways and rural arterial sections. However, within urban and suburban areas and in rural communities located on State highways, on-street parking should be considered in order to accommodate existing land uses. Where adequate off-street parking facilities are not available, the designer should consider on-street parking, so that the proposed highway improvement will be compatible with the land use. On-street parking as well as off-street parking needs to comply with DIB82. See AASHTO, A Policy on Geometric Design of Highways and Streets for additional guidance related to on-street parking.

402.4 Consider All Users

Intersections should accommodate all users of the facility, including vehicles, bicyclists, pedestrians and transit. Bicycles have all the rights and responsibilities as motorist per the California Vehicle Code, but should have separate consideration of their needs, even separate facilities if volumes warrant. Pedestrians should not be prohibited from crossing one or more legs of an intersection, unless no other safe alternative exists. Pedestrians can be prohibited from crossing one or more legs of an intersection if a reasonable alternate route exists and there is a demonstrated need to do so. All pedestrian facilities shall be ADA compliant as outlined in DIB 82. Transit needs should be determined early in the planning and design phase as their needs can have a large impact on the performance of an intersection. Transit stops in the vicinity of intersections should be evaluated for their effect on the safety and operation of the intersection(s) under study. See Topic 108 for additional information.

402.5 Speed-Change Areas

Speed-change areas for vehicles entering or leaving main streams of traffic are beneficial to the safety and efficiency of an intersection. Entering traffic merges most efficiently with through traffic when the merging angle is less than 15 degrees and when speed differentials are at a minimum.

Topic 403 - Principles of Channelization

403.1 Preference to Major Movements

The provision of direct free-flowing high-standard alignment to give preference to major movements is good channelization practice. This may require some degree of control of the minor movements such as stopping, funneling, or even eliminating them. These controlling measures should conform to natural paths of movement and should be introduced gradually to promote smooth and efficient operation.

403.2 Areas of Conflict

Large multilane undivided intersection areas are undesirable. The hazards of conflicting movements are magnified when motorists, bicyclists, and pedestrians are unable to anticipate movements of other users within these areas. Channelization reduces areas of conflict by separating or regulating traffic movements into definite paths of travel by the use of pavement markings or traffic islands.

Multilane undivided intersections, even with signalization, are more difficult for pedestrians to cross. Providing pedestrian refuge islands enable pedestrians to cross fewer lanes at a time.

See Index 403.7 for traffic island guidance when used as pedestrian refuge. Curb extensions shorten crossing distance and increase visibility. See Index 303.4 for curb extensions.

403.3 Angle of Intersection

A right angle (90°) intersection provides the most favorable conditions for intersecting and turning traffic movements. Specifically, a right angle provides:

- The shortest crossing distance for motor vehicles, bicycles, and pedestrians.
- Sight lines which optimize corner sight distance and the ability of motorists to judge the relative position and speed of approach traffic.
- Intersection geometry that can reduce vehicle turning speeds so collisions are more easily avoided and the severity of collisions are minimized.
- Intersection geometry that sends a message to turning bicyclists and motorists that they are making a turning movement and should yield as appropriate to through traffic on the roadway they are leaving, to traffic on the receiving roadway, and to pedestrians crossing the intersection.

Minor deviations from right angles are generally acceptable provided that the potentially detrimental impact on visibility and turning movements for large trucks (see Topic 404) can be mitigated. However, large deviations from right angles may decrease visibility, hamper certain turning operations, and will increase the size of the intersection and therefore crossing distances for bicyclists and pedestrians, may encourage high speed turns, and may reduce yielding by turning traffic. When a right angle cannot be provided due to physical constraints, the interior angle should be designed as close to 90 degrees as is practical, but should not be less than 75 degrees. Mitigation should be considered for the affected intersection design features. (See Figure 403.3A). A 75 degree angle does not unreasonably increase the crossing distance or generally decrease visibility. Class II bikeway crossings at railroads follow similar guidance to Class I bikeway crossings at railroads, see Index 1003.5(3), and Figure 403.3B.

A characteristic of skewed intersection angles is that they result in larger intersections.

When existing intersection angles are less than 75 degrees, the following retrofit improvement strategies should be considered:

- Realign the subordinate intersection legs if the new alignment and intersection location(s) can be designed without introducing new geometric or operational deficiencies.
- Provide acceleration lanes for difficult turning movements due to radius or limited visibility.
- Restrict problematic turning movements; e.g. for minor road left turns with potentially limited visibility.
- Provide refuge areas for pedestrians at very long crossings.

For additional guidance on the above and other improvement strategies, consult with the District Design Liaison or HQ Traffic Liaison.

Particular attention should be given to skewed angles on curved alignment with regards to sight distance and visibility. Crossroads skewed to the left have more restricted visibility for drivers of vans and trucks than crossroads skewed to the right. In addition, severely skewed intersection angles, coupled with steep downgrades (generally over 4 percent) can increase the potential for high centered vehicles to overturn where the vehicle is on a downgrade and must make a turn greater than 90 degrees onto a crossroad. These factors should be considered in the design of skewed intersections.

403.4 Points of Conflict

Channelization separates and clearly defines points of conflict within the intersection. Bicyclists, pedestrians and motorists should be exposed to only one conflict or confronted with one decision at a time.

Speed-change areas for diverging traffic should provide adequate length clear of the through lanes to permit vehicles to decelerate after leaving the through lanes.

See AASHTO, A Policy on Geometric Design of Highways and Streets for additional guidance on speed-change lanes.

Figure 403.3A
Angle of Intersection
(Minor Leg Skewed to the Right)

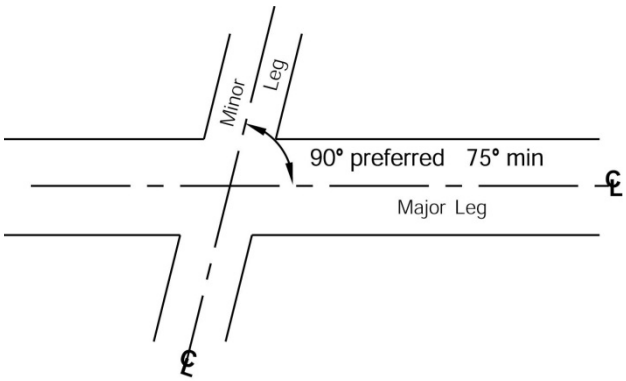
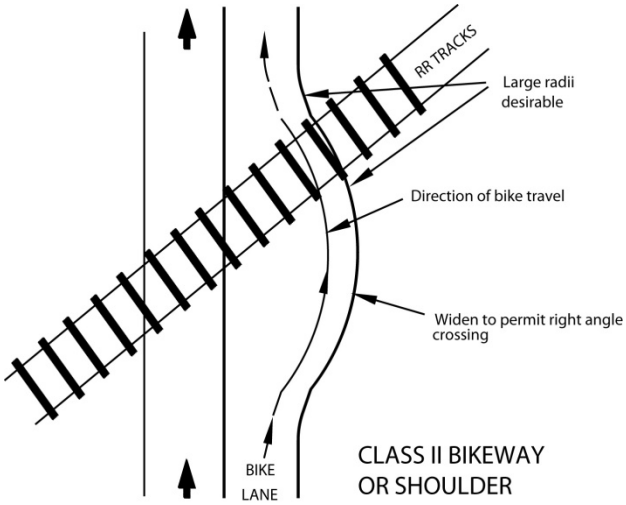


Figure 403.3.B
Class II Bikeway
Crossing Railroad



403.5 (Currently Not In Use)

403.6 Turning Traffic

A separate turning lane removes turning movements from the intersection area. Abrupt changes in alignment or sight distance should be avoided, particularly where traffic turns into a separate turning lane from a high-standard through facility.

For wide medians, consider the use of offset left-turn lanes at both signalized and unsignalized intersections. Opposing left-turn lanes are offset or shifted as far to the left as practical by reducing the width of separation immediately before the intersection. Rather than aligning the left-turn lane exactly parallel with and adjacent to the through lane, the offset left-turn lane is separated from the adjacent through lane. Offset left-turn lanes provide improved visibility of opposing through traffic. For further guidance on offset left-turn lanes, see AASHTO, A Policy on Geometric Design of Highways and Streets.

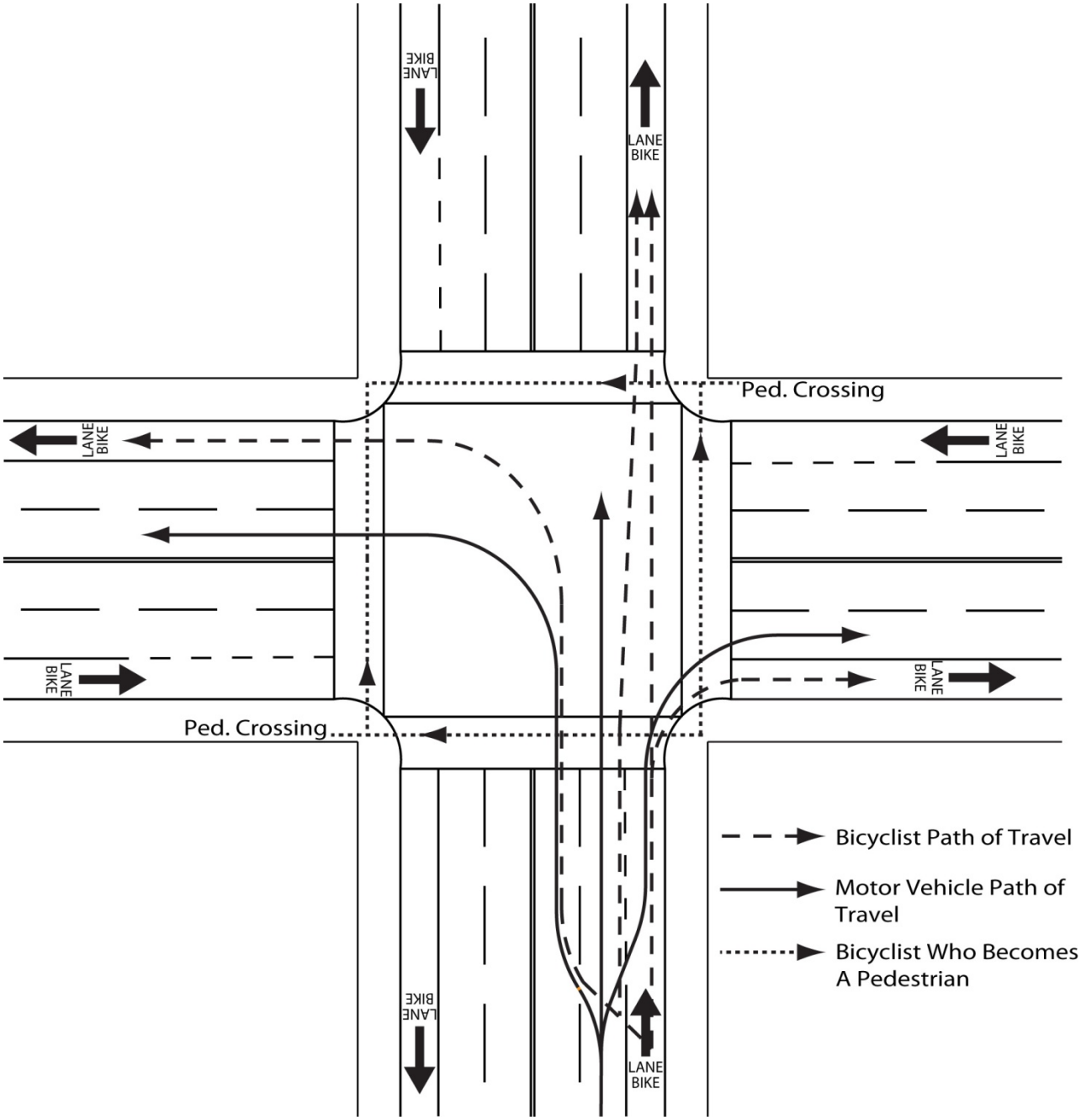
(1) *Treatment of Intersections with Right-Turn-Only Lanes.* Most motor vehicle/bicycle collisions occur at intersections. For this reason, intersection design should be accomplished in a manner that will minimize confusion by motorists and bicyclists, eliminate ambiguity and induce all road users to operate in accordance with the statutory rules of the road in the California Vehicle Code. Right-turn-only lanes should be designed to meet user expectations and reduce conflicts between vehicles and bicyclists.

Figure 403.6A illustrates a typical at-grade intersection of multilane streets without right-turn-only lanes. Bike lanes or shoulders are included on all approaches. Some common movements of motor vehicles and bicycles are shown. A prevalent crash type is between straight-through bicyclists and right-turning motorists, who do not yield to through bicyclists.

<u>Optional right-turn lanes should not be used in combination with right-turn-only lanes on roads where bicycle travel is permitted.</u> The use of optional right-turn lanes in combination with right-turn-only lanes is not recommended in any case where a Class II bike lane is present. This may increase the need for dual or triple right-turn-only lanes, which have

Figure 403.6A

Typical Bicycle and Motor Vehicle Movements at Intersections of Multilane Streets without Right-Turn-Only Lanes

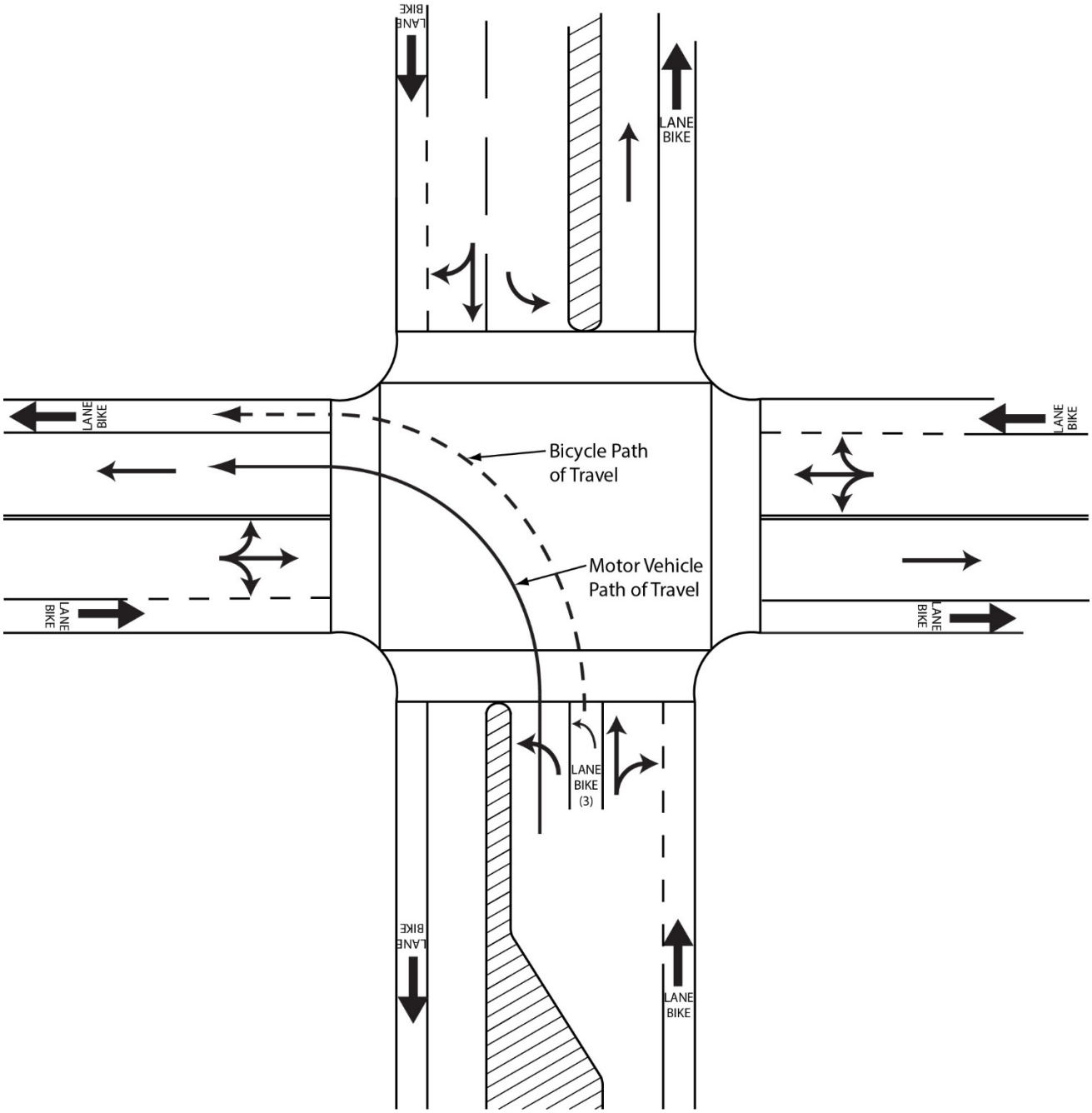


NOTE:

Only one direction is shown for clarity.

Figure 403.6B

Bicycle Left-Turn-Only Lane



NOTES:

(1) For bicycle lane markings, see the California MUTCD.

(2) Bicycle detectors are necessary for signalized intersections.

(3) Left-turn bicycle lane should have receiving bike lane or shoulder.

challenges with visibility between turning vehicles and pedestrians. Multiple right-turn-only lanes should not be free right-turns when there is a pedestrian crossing. If there is a pedestrian crossing on the receiving leg of multiple right-turn-only lanes, the intersection should be controlled by a pedestrian signal head, or geometrically designed such that pedestrians cross only one turning lane at a time.

Locations with right-turn-only lanes should provide a minimum 4-foot width for bicycle use between the right-turn and through lane when bikes are permitted, except where posted speed is greater than 40 miles per hour, the minimum width should be 6 feet. Configurations that create a weaving area without defined lanes should not be used.

For signing and delineation of bicycle lanes at intersections, consult District Traffic Operations.

Figure 403.6B depicts an intersection with a left-turn-only bicycle lane, which should be considered when bicycle left-turns are common. A left-turn-only bicycle lane may be considered at any intersection and should always be considered as a tool to provide mobility for bicyclists. Signing and delineation options for bicycle left-turn-only lanes are shown in the California MUTCD.

(2) *Design of Intersections at Interchanges.* The design of at-grade intersections at interchanges should be accomplished in a manner that will minimize confusion of motorists, bicyclists, and pedestrians. Higher speed, uncontrolled entries and exits from freeway ramps should not be used at the intersection of the ramps with the local road. The smallest curb return radius should be used that accommodates the design vehicle. Intersections with interior angles close to 90 degrees reduce speeds at conflict points between motorists, bicyclists, and pedestrians. The intersection skew guidance in Index 403.3 applies to all ramp termini at the local road.

403.7 Refuge Areas

Traffic islands should be used to provide refuge areas for bicyclists and pedestrians. See Index 405.4 for further guidance.

403.8 Prohibited Turns

Traffic islands may be used to direct bicycle and motorized vehicle traffic streams in desired directions and prevent undesirable movements. Care should be taken so that islands used for this purpose accommodate convenient and safe pedestrian and bicycle crossings, drainage, and striping options. See Topic 303.

403.9 Effective Signal Control

At intersections with complex turning movements, channelization is required for effective signal control. Channelization permits the sorting of approaching bicycles and motorized vehicles which may move through the intersection during separate signal phases. Pedestrians may also have their own signal phase. This requirement is of particular importance when traffic-actuated signal controls are employed.

The California MUTCD has warrants for the placement of signals to control vehicular, bicycle and pedestrian traffic. Pedestrian activated devices, signals or beacons are not required, but must be evaluated where directional, multilane, pedestrian crossings occur. These locations may include:

- Mid-block street crossings;
- Channelized turn lanes;
- Ramp entries and exits; and
- Roundabouts.

The evaluation, selection, programming and use of a chosen device should be done with guidance from District Traffic Operations.

403.10 Installation of Traffic Control Devices

Channelization may provide locations for the installation of essential traffic control devices, such as “STOP” and directional signs. See Index 405.4 for information about the design of traffic islands.

403.11 Summary

- Give preference to the major move(s).

- Reduce areas of conflict.
- Reduce the duration of conflicts.
- Cross traffic at right angles or skew no more than 75 degrees. (90 degrees preferred.)
- Separate points of conflict.
- Provide speed-change areas and separate turning lanes where appropriate.
- Provide adequate width to shadow turning traffic.
- Restrict undesirable moves with traffic islands.
- Coordinate channelization with effective signal control.
- Install signs in traffic islands when necessary but avoid building conflicts one or more modes of travel.
- Consider all users.

403.12 Other Considerations

- An advantage of curbed islands is they can serve as pedestrian refuge. Where curbing is appropriate, consideration should be given to mountable curbs. See Topic 303 for more guidance.
- Avoid complex intersections that present multiple choices of movement to the motorist and bicyclist.
- Traffic safety should be considered. Collision records provide a valuable guide to the type of channelization needed.

Topic 404 - Design Vehicles

404.1 General

Any vehicle, whether car, bus, truck, or recreational vehicle, while turning a curve, covers a wider path than the width of the vehicle. The outer front tire can generally follow a circular curve, but the inner rear tire will swing in toward the center of the curve.

Some terminology is vital to understanding the engineering concepts related to design vehicles. See Index 62.4 Interchanges and Intersection at Grade for terminology.

404.2 Design Considerations

It may not be necessary to provide for design vehicle turning movements at all intersections along the State route if the design vehicle's route is restricted or it is not expected to use the cross street frequently. Discuss with Traffic Operations and the local agency before a turning movement is not provided. The goal is to minimize possible conflicts between vehicles, bicycles, pedestrians, and other users of the roadway, while providing the minimum curb radii appropriate for the given situation.

Both the tracking width and swept width should be considered in the design of roadways for use of the roadway by design vehicles.

Tracking width lines delineate the path of the vehicle tires as the vehicle moves through the turn.

Swept width lines delineate the path of the vehicle body as the vehicle moves through the turn and will therefore always exceed the tracking width. The following list of criteria is to be used to determine whether the roadway can accommodate the design vehicle.

(1) Traveled way.

(a) To accommodate turn movements(e.g., at intersections, driveways, alleys, etc.),the travel way width and intersection design should be such that tracking width and swept width lines for the design vehicle do not cross into any portion of the lane for opposing traffic. Encroachment into the shoulder and bike lane is permitted.

(b) Along the portion of roadway where there are no turning options, vehicles are required to stay within the lane lines. **The tracking and swept widths lines for the design vehicle shall stay within the lane as defined in Index 301.1 and Table 504.3A.** This includes no encroachment into Class II bike lanes.

(2) Shoulders. Both tracking width and swept width lines may encroach onto paved shoulders to accommodate turning. For design projects where the tracking width lines are shown to encroach onto paved shoulders, the shoulder pavement structure should be engineered to sustain the weight of the design vehicle. See Index 613 for general traffic loading

considerations and Index 626 for tied rigid shoulder guidance. At corners where no sidewalks are provided and pedestrians are using the shoulder, a paved refuge area may be provided outside the swept width of turning vehicle.

(3) *Curbs and Gutters*. Tires may not mount curbs. If curb and gutter are present and any portion of the gutter pan is likewise encroached, the gutter pan must be engineered to match the adjacent shoulder pavement structure. See Index 613.5(2)(c) for gutter pan design guidance.

(4) *Edge of Pavement*. To accommodate a turn, the swept width lines may cross the edge of pavement provided there are no obstructions. The tracking width lines must remain on the pavement structure, including the shoulder, provided that the shoulder is designed to support vehicular traffic. If truck volumes are high, consideration of a wider shoulder is encouraged in order to preserve the pavement edge.

(5) *Bicycle Lanes.* Where bicycle lanes are considered, the design guidance noted above applies. Vehicles are permitted to cross a bicycle lane to initiate or complete a turning movement or for emergency parking on the shoulder. See the California MUTCD for Class II bike lane markings.

To accommodate turn movements (e.g., intersections, driveways, alleys, etc. are present), both tracking width and swept width lines may cross the broken white painted bicycle lane striping in advance of the right-turn, entering the bicycle lane when clear to do so.

(6) *Sidewalks.* Tracking width and swept width lines must not encroach onto sidewalks or pedestrian refuge areas, without exception.

(7) *Obstacles.* Swept width lines may not encroach upon obstacles including, but not limited to, curbs, islands, sign structures, traffic delineators/channelizers, traffic signals, lighting poles, guardrails, trees, cut slopes, and rock outcrops.

(8) *Appurtenances.* Swept width lines do not include side mirrors or other appurtenances allowed by the California Vehicle Code, thus, accommodation to non-motorized users of the facility and appurtenances should be considered.

If both the tracking width and swept width lines meet the design guidance listed above, then the geometry is adequate for that design vehicle. Consideration should be given to pedestrian crossing distance, motor vehicle speeds, truck volumes, alignment, bicycle lane width, sight distance, and the presence of on-street parking.

Note that the STAA Design Vehicle has a template with a 56-foot (minimum) and a 67-foot (longer) radius and the California Legal Design Vehicle has a template with 50-foot (minimum) and 60-foot (longer) radii. The longer radius templates are more conservative. The longer radius templates develop less swept width and leave a margin of error for the truck driver. The longer radius templates should be used for conditions where the vehicle may not be required to stop before entering the intersection.

The minimum radius template can be used if the longer radius template does not clear all obstacles. The minimum radius templates demonstrate the tightest turn that the vehicles can navigate, assuming a speed of less than 10 miles per hour.

For offtracking lane width requirements on freeway ramps, see Topic 504.

404.3 Design Tools

District Truck Managers should be consulted early in the project to ensure compliance with the design vehicle guidance contained in Topic 404. Consult local agencies to verify the location of local truck routes. Essentially, two options are available – templates or computer software.

- The turning templates in Figures 404.5A through G are a design aid for determining the swept width and/or tracking width of large vehicles as they maneuver through a turn. The templates can be used as overlays to evaluate the adequacy of the geometric layout of a curve or intersection when reproduced on clear film and scaled to match the highway drawings. These templates assume a vehicle speed of less than 10 miles per hour.
- Computer software such as AutoTURN or AutoTrak can draw the swept width and/or tracking width along any design curve within a CADD drawing program such as MicroStation

or AutoCAD. Dimensions taken from the vehicle diagrams in Figures 404.5A through G may be inputted into the computer program by creating a custom vehicle if the vehicle is not already included in the software library. The software can also create a vehicle turn template that conforms to any degree curve desired.

404.4 Design Vehicles and Related Definitions

(1) The Surface Transportation Assistance Act of 1982 (STAA).

(a) STAA Routes. STAA allows certain longer trucks called STAA trucks to operate on the National Network. After STAA was enacted, the Department evaluated State routes for STAA truck access and created Terminal Access and Service Access routes which, together with the National Network, are called the STAA Network. Terminal Access routes allow STAA access to terminals and facilities. Service Access routes allow STAA trucks one-mile access off the National Network, but only at identified exits and only for designated services. Service Access routes are primarily local roads. A "Truck Route Map," indicating the National Network routes and the Terminal Access routes is posted on the Department's Office of Commercial Vehicle Operations website and is also available in printed form.

(b) STAA Design Vehicle. The STAA design vehicle is a truck tractor-semitrailer combination with a 48-foot semitrailer, a 43-foot kingpin-to-rear-axle (KPRA) distance, an 8.5-foot body and axle width, and a 23-foot truck tractor wheelbase. Note, a truck tractor is a non-load-carrying vehicle. There is also a STAA double (truck tractor-semitrailer-trailer); however, the double is not used as the design vehicle due to its shorter turning radius. The STAA Design Vehicle is shown in Figures 404.5A and B.

<u>The STAA Design Vehicle in Figures 404.5A or B should be used on the National Network, Terminal Access, California Legal, and Advisory routes.</u>

(c) STAA Vehicle – 53-Foot Trailer. Another category of vehicle allowed only on STAA routes has a maximum 53-foot trailer, a maximum 40-foot KPRA for two or more axles, a maximum 38-foot KPRA for a single axle, and unlimited overall length. This vehicle is not to be used as the design vehicle as it is not the worst case for offtracking due to its shorter KPRA. The STAA Design Vehicle should be used instead.

(2) California Legal.

(a) California Legal Routes. Virtually all State routes off the STAA Network are California Legal routes. There are two types of California Legal routes, the regular California Legal routes and the KPRA Advisory Routes. Advisory routes have signs posted that state the maximum KPRA length that the route can accommodate without the vehicle offtracking outside the lane. KPRA advisories range from 30 feet to 38 feet, in 2-foot increments. California Legal vehicles are allowed to use both types of California Legal routes. California Legal vehicles can also use the STAA Network. However, STAA trucks are not allowed on any California Legal routes. The Truck Route Map indicating the California Legal routes is posted on the Department's Office of Commercial Vehicle Operations website.

(b) California Legal Design Vehicle. The California Legal vehicle is a truck tractor-semitrailer with the following dimensions: the maximum overall length is 65 feet; the maximum KPRA distance is 40 feet for semitrailers with two or more axles, and 38 feet for semitrailers with a single axle; the maximum width is 8.5 feet. There are also two categories of California Legal doubles (truck tractor-semitrailer-trailer); however, the doubles are not used as the design vehicle due to their shorter turning radii. The California Legal Design Vehicle is shown in Figures 404.5C and D.

<u>The California Legal Design Vehicle in Figures 404.5C and D should only be used</u>

when the STAA design vehicle is not feasible and with concurrence from the District Truck Manager.

(3) 40-Foot Bus.

(a) 40-Foot Bus Routes. All single-unit vehicles, including buses and motor trucks up to 40 feet in length, are allowed on virtually every route in California.

(b) 40-Foot Bus Design Vehicle. The 40-Foot Bus Design Vehicle shown in Figure 404.5E is an AASHTO standard. Its 25-foot wheelbase and 40-foot length are typical of city transit buses and some intercity buses. At intersections where truck volumes are light or where the predominate truck traffic consists of mostly 3-axle units, the 40-foot bus may be used. Its wheel path sweeps a greater width than 3-axle delivery trucks, as well as smaller buses such as school buses.

(4) 45-Foot Bus & Motorhome.

(a) 45-Foot Bus & Motorhome Routes. The "45-foot bus and motorhome" refers to bus and motorhomes over 40 feet in length, up to and including 45 feet in length. These longer buses and motorhomes are allowed in California, but only on certain routes.

The 45-foot tour bus became legal on the National Network in 1991 and later allowed on some State routes in 1995. The 45-foot motorhome became legal in California in 2001, but only on those routes where the 45-foot bus was already allowed. A Bus and Motorhome Map indicating where these longer buses and motorhomes are allowed and where they are not allowed is posted on the Department's Office of Commercial Vehicle Operations website.

(b) 45-Foot Bus and Motorhome Design Vehicle. The 45-Foot Bus & Motorhome Design Vehicle shown in Figure 404.5F is used by Caltrans for the longest allowable bus and motorhome. Its wheelbase is 28.5 feet. It is also similar to the AASHTO standard 45-foot bus. Typically this should be the smallest design vehicle used on a State highway. It may be used where the State highway intersects local streets without commercial or industrial traffic.

The 45-Foot Bus and Motorhome Design Vehicle shown in Figure 404.5F should be used in the design of all interchanges and intersections on all green routes indicated on the Bus and Motorhome Map for both new construction and rehabilitation projects. Check also the longer standard design vehicles on these routes as required – the STAA Design Vehicle and the California Legal Design Vehicle in Indexes 404.4(1) and (2).

(5) 60-Foot Articulated Bus.

(a) 60-Foot Articulated Bus Routes. The articulated bus is allowed a length of up to 60 feet per CVC 35400(b)(3)(A). This bus is used primarily by local transit agencies for public transportation. There is no master listing of such routes. Local transit agencies should be contacted to determine possible routes within the proposed project.

(b) 60-Foot Articulated Bus Design Vehicle. The 60-Foot Articulated Bus Design Vehicle shown in Figure 404.5G is an AASHTO standard. The routes served by these buses should be designed to accommodate the 60-Foot Articulated Bus Design Vehicle.

404.5 Turning Templates & Vehicle Diagrams

Figures 404.5A through G are computer-generated turning templates at an approximate scale of 1"=50' and their associated vehicle diagrams for the design vehicles described in Index 404.3. The radius of the template is measured to the outside front wheel path at the beginning of the curve. Figures 404.5A through G contain the terms defined as follows:

(1) Tractor Width - Width of tractor body.

(2) Trailer Width - Width of semitrailer body.

(3) Tractor Track - Tractor axle width, measured from outside face of tires.

(4) Trailer Track – Semitrailer axle width, measured from outside face of tires.

(5) Lock To Lock Time - The time in seconds that an average driver would take under normal driving conditions to turn the steering wheel of a vehicle from the lock position on one side to the lock position on the other side. The default in AutoTurn software is 6 seconds.

(6) Steering Lock Angle - The maximum angle that the steering wheels can be turned. It is further defined as the average of the maximum angles made by the left and right steering wheels with the longitudinal axis of the vehicle.

(7) Articulating Angle - The maximum angle between the tractor and semitrailer.

Topic 405 - Intersection Design Standards

405.1 Sight Distance

(1) Stopping Sight Distance. See Index 201.1 for minimum stopping sight distance requirements.

(2) *Corner Sight Distance.*

(a) General--At unsignalized intersections a substantially clear line of sight should be maintained between the driver of a vehicle, bicyclist or pedestrian waiting at the crossroad and the driver of an approaching vehicle. Line of sight for all users should be included in right of way, in order to preserve sight lines.

Adequate time must be provided for the waiting user to either cross all lanes of through traffic, cross the near lanes and turn left, or turn right, without requiring through traffic to radically alter their speed.

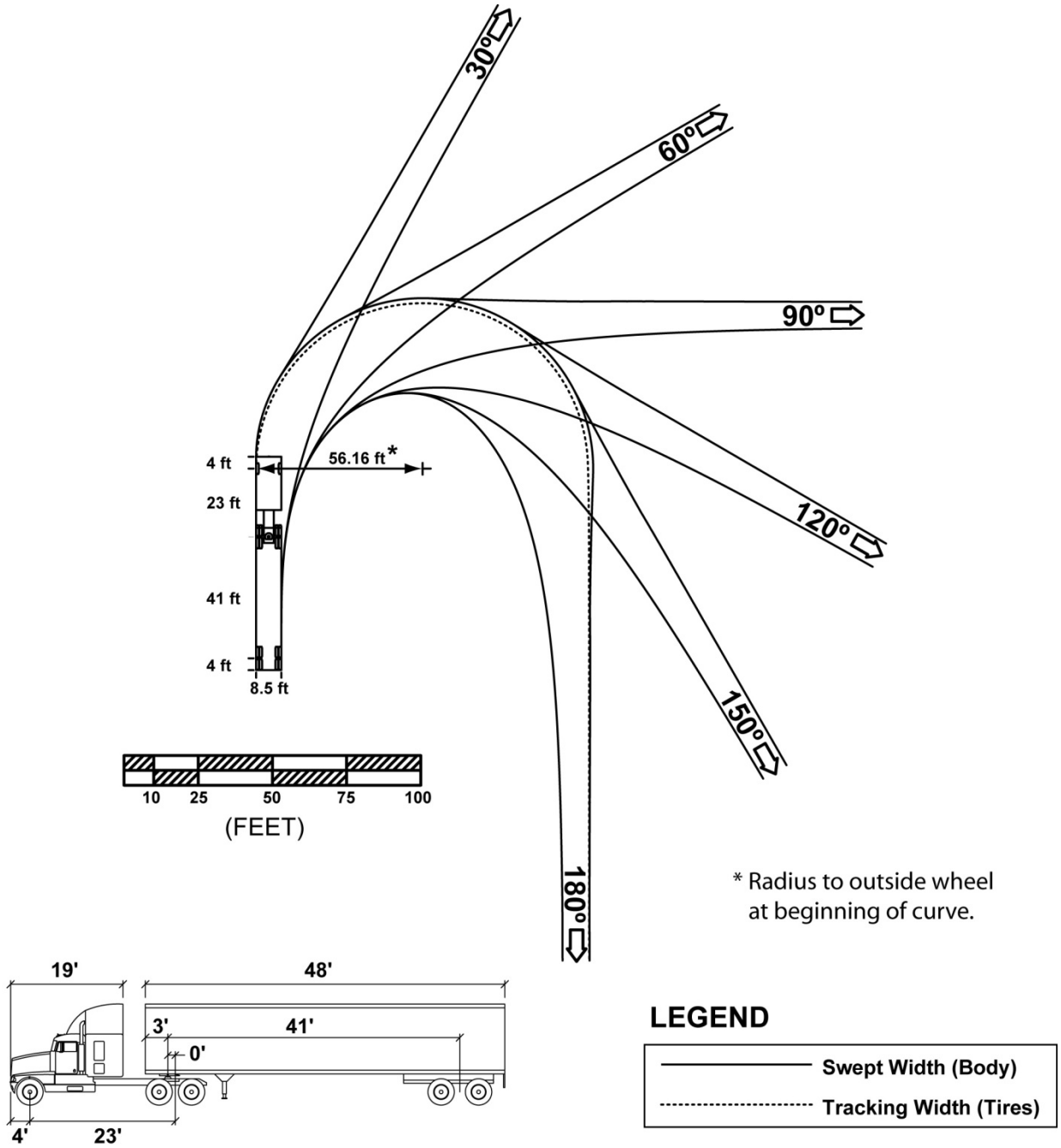
The values given in Table 405.1A provide 7-1/2 seconds for the driver on the crossroad to complete the necessary maneuver while the approaching vehicle travels at the assumed design speed of the main highway. The 7-1/2 second criterion is normally applied to all lanes of through traffic in order to cover all possible maneuvers by the vehicle at the crossroad. However, by providing the standard corner sight distance to the lane nearest to and farthest from the waiting vehicle, adequate time should be obtained to make the necessary movement. On multilane highways a 7-1/2 second criterion for the outside lane, in both directions of travel, normally will provide increased sight distance to the inside lanes. Consideration should be given to increasing these values on downgrades steeper than 3 percent and longer than 1 mile (see Index 201.3), where there are high truck volumes on the crossroad, or where the skew of the intersection substantially increases the distance traveled by the crossing vehicle.

In determining corner sight distance, a set back distance for the vehicle waiting at the crossroad must be assumed. **Set back for the driver of the vehicle on the crossroad shall be a minimum of 10 feet plus the shoulder width of the major road but not less than 15 feet.** Line of sight for corner sight distance is to be determined from a 3 and 1/2-foot height at the location of the driver of the vehicle on the minor road to a 4 and 1/4-foot object height in the center of the approaching lane of the major road as illustrated in Figure 504.3I. If the major road has a median barrier, a 2-foot object height should be used to determine the median barrier set back.

In some cases the cost to obtain 7-1/2 seconds of corner sight distances may be excessive. High costs may be attributable to right of way acquisition, building removal, extensive excavation, or immitigable environmental impacts. In such cases a lesser value of corner sight distance, as described under the following headings, may be used.

(b) Public Road Intersections (Refer to Topic 205)--<u>At unsignalized public road intersections (see Index 405.7) corner sight distance values given in Table 405.1A should be provided.</u>

Figure 404.5A
STAA Design Vehicle
56-Foot Radius



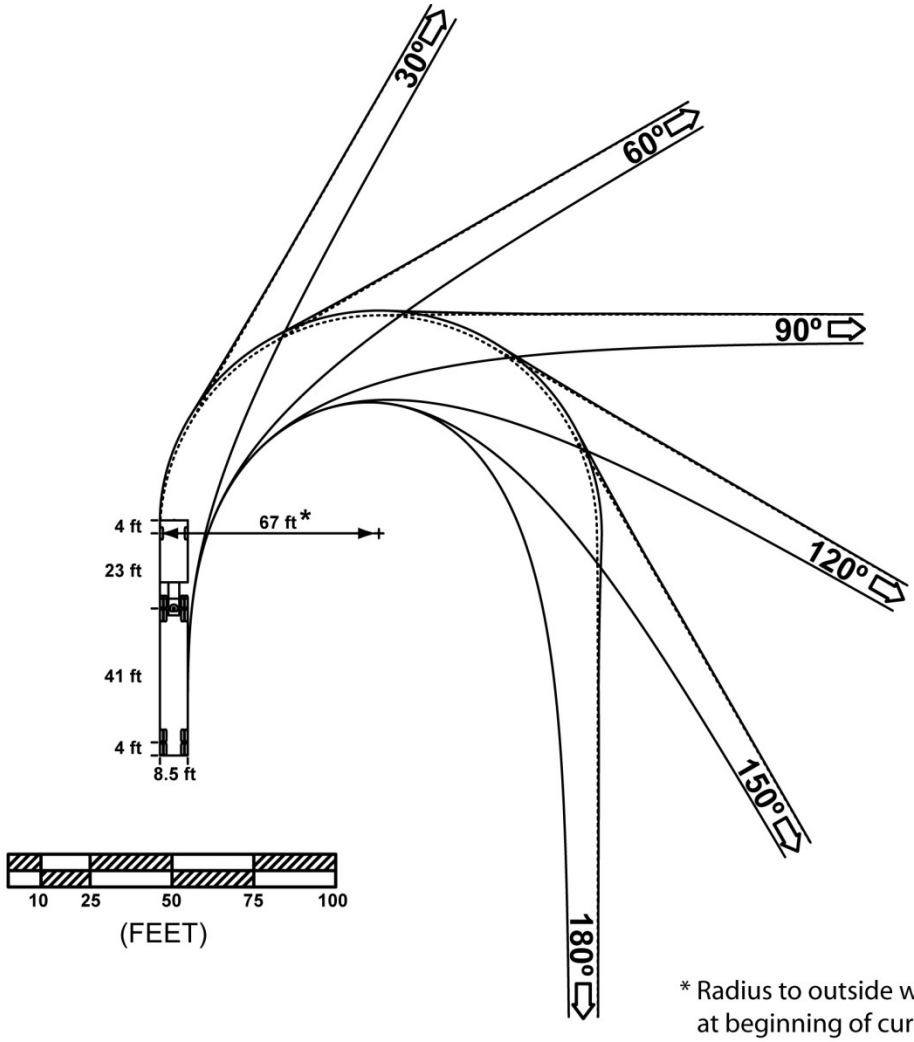
STAA - STANDARD

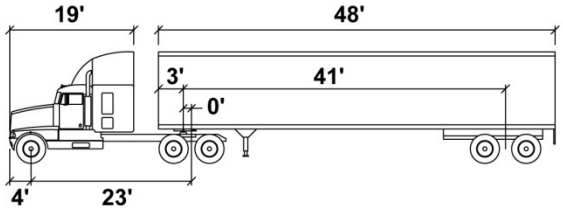
Tractor Width	: 8.5'	Lock to Lock Time	: 6 seconds
Trailer Width	: 8.5'	Steering Lock Angle	: 26.3 degrees
Tractor Track	: 8.5'	Articulating Angle	: 70 degrees
Trailer Track	: 8.5'		

Note: For definitions, see Indexes 404.1 and 404.5.

Figure 404.5B

STAA Design Vehicle
67-Foot Radius





LEGEND

———	Swept Width (Body)
- - - -	Tracking Width (Tires)

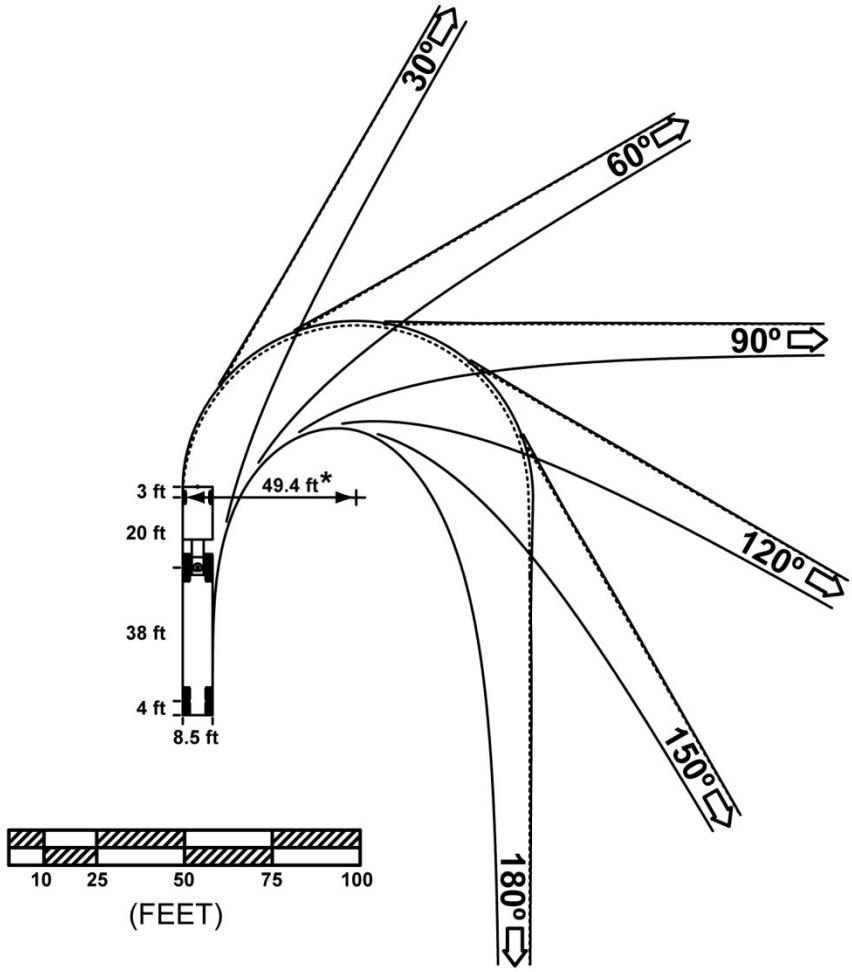
STAA - STANDARD

Tractor Width	: 8.5'	Lock to Lock Time	: 6 seconds
Trailer Width	: 8.5'	Steering Lock Angle	: 26.3 degrees
Tractor Track	: 8.5'	Articulating Angle	: 70 degrees
Trailer Track	: 8.5'		

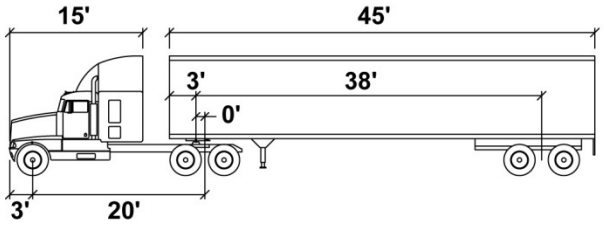
Note: For definitions, see Indexes 404.1 and 404.5.

Figure 404.5C

California Legal Design Vehicle
50-Foot Radius



* Radius to outside wheel at beginning of curve.



LEGEND

————	Swept Width (Body)
- - - - -	Tracking Width (Tires)

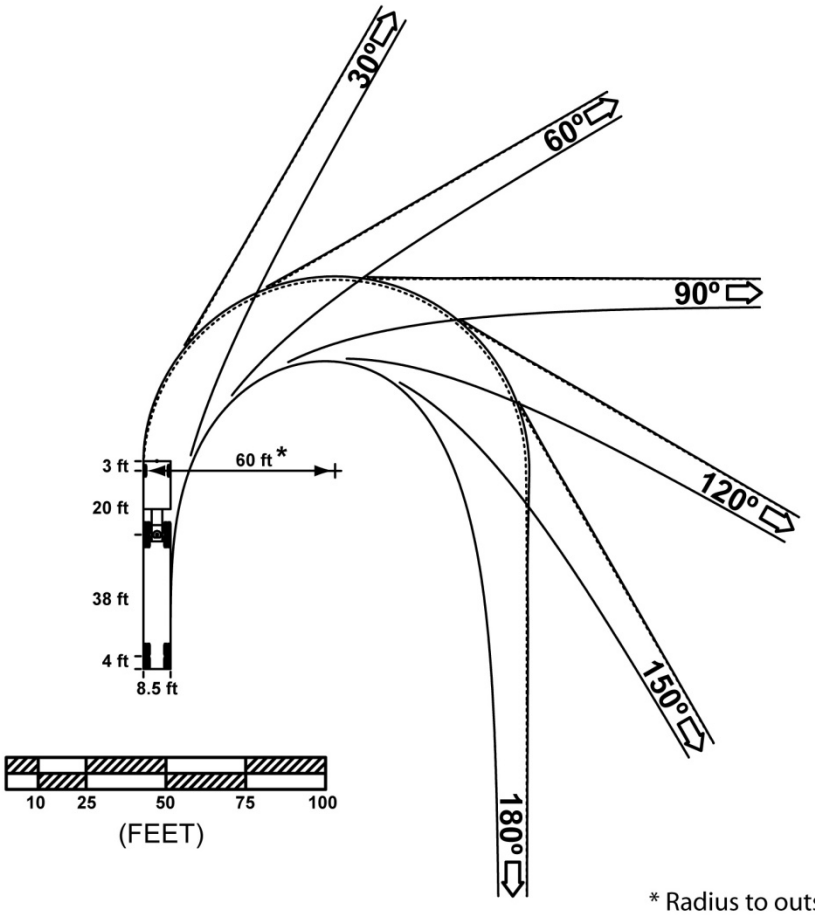
CA LEGAL - 65 FT

Tractor Width	: 8.5'	Lock to Lock Time	: 6 seconds
Trailer Width	: 8.5'	Steering Lock Angle	: 26.3 degrees
Tractor Track	: 8.5'	Articulating Angle	: 70 degrees
Trailer Track	: 8.5'		

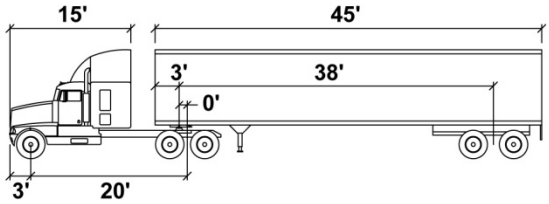
Note: For definitions, see Indexes 404.1 and 404.5.

Figure 404.5D

California Legal Design Vehicle
60-Foot Radius



* Radius to outside wheel at beginning of curve.



LEGEND

————	Swept Width (Body)
- - - - - -	Tracking Width (Tires)

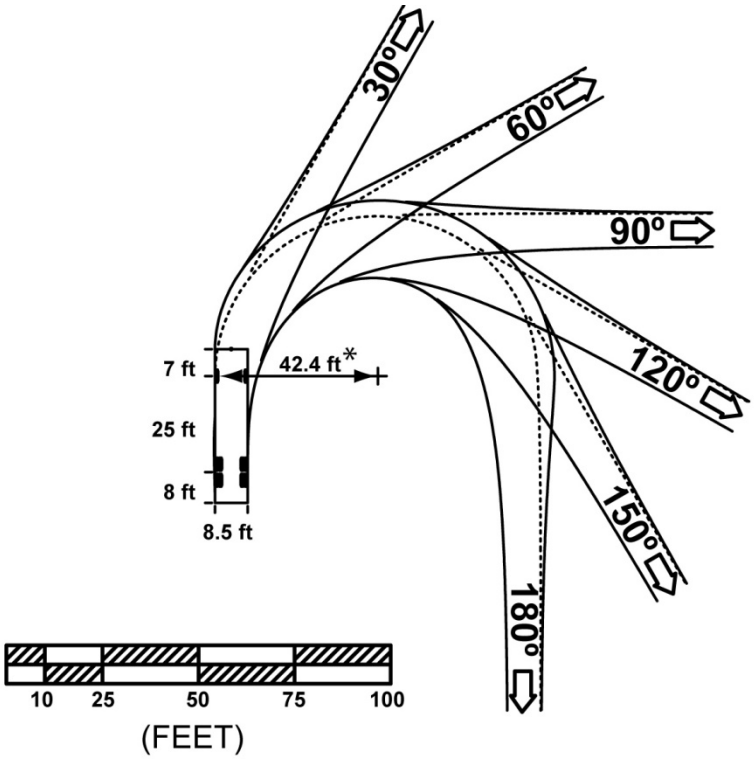
CA LEGAL - 65 FT

Tractor Width	: 8.5'	Lock to Lock Time	: 6 seconds
Trailer Width	: 8.5'	Steering Lock Angle	: 26.3 degrees
Tractor Track	: 8.5'	Articulating Angle	: 70 degrees
Trailer Track	: 8.5'		

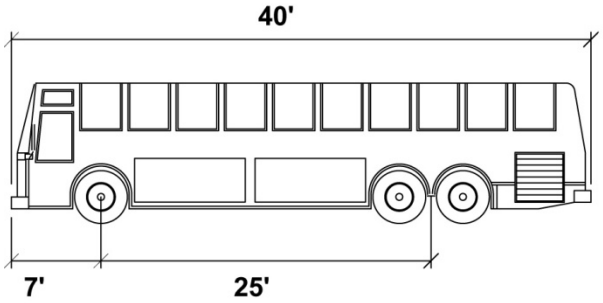
Note: For definitions, see Indexes 404.1 and 404.5.

Figure 404.5E

40-Foot Bus Design Vehicle



* Radius to outside wheel at beginning of curve.



LEGEND

————	Swept Width (Body)
- - - - -	Tracking Width (Tires)

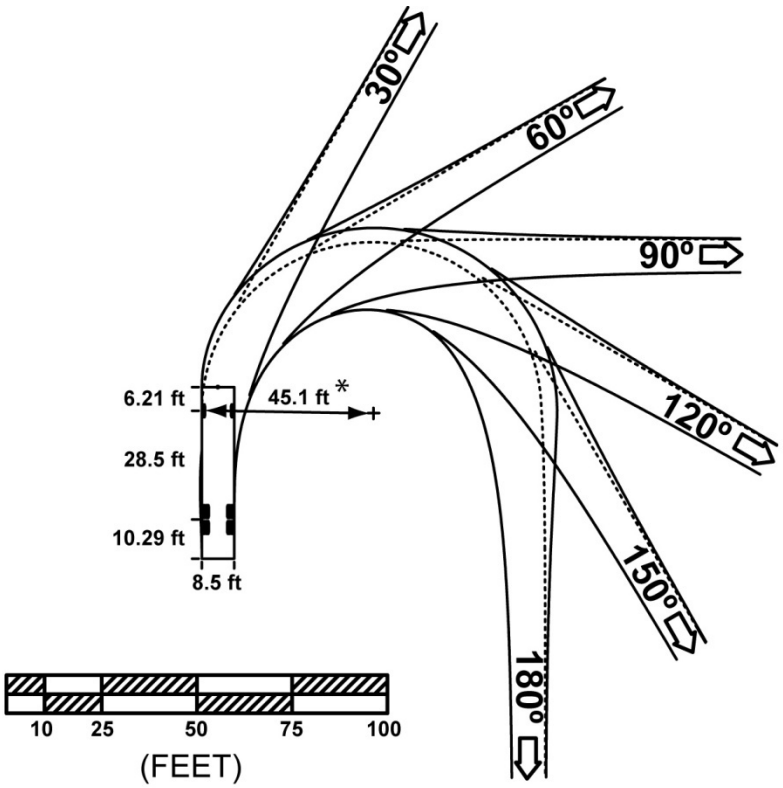
40' BUS

Width	: 8.5'
Track	: 8.5'
Lock to Lock Time	: 6 seconds
Steering Lock Angle	: 41.0 degrees

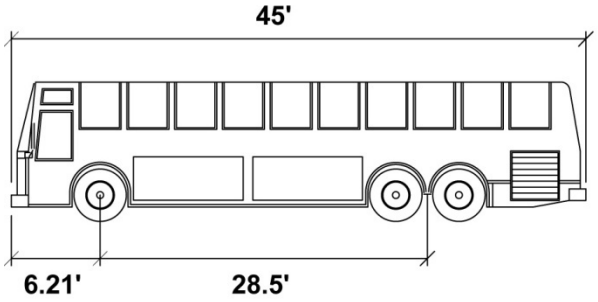
Note: For definitions, see Indexes 404.1 and 404.5.

Figure 404.5F

45-Foot Bus & Motorhome Design Vehicle



* Radius to outside wheel at beginning of curve.



LEGEND

———	Swept Width (Body)
- - - -	Tracking Width (Tires)

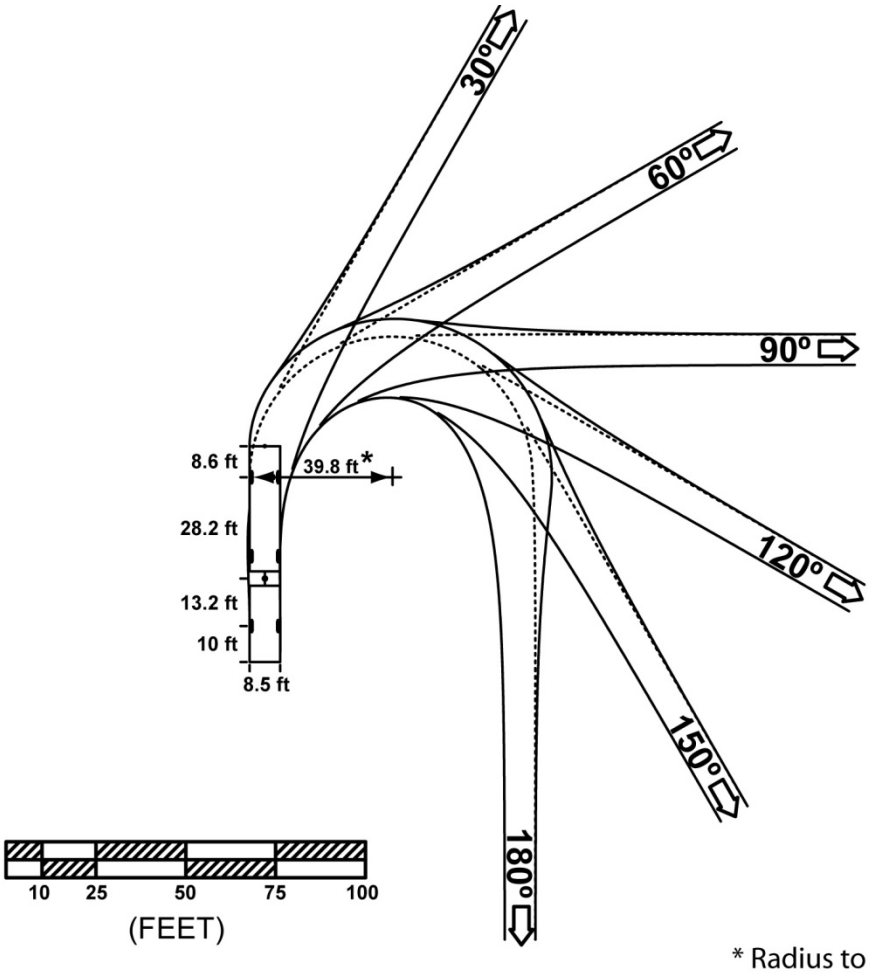
45' BUS

Width	: 8.5'
Track	: 8.5'
Lock to Lock Time	: 6 seconds
Steering Lock Angle	: 44.3 degrees

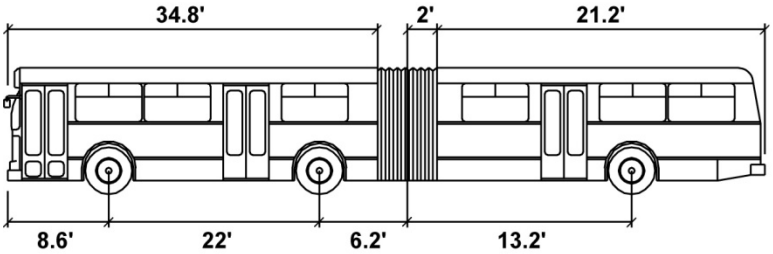
Note: For definitions, see Indexes 404.1, and 404.5.

Figure 404.5G

60-Foot Articulated Bus Design Vehicle



* Radius to outside wheel at beginning of curve.



LEGEND

———	Swept Width (Body)
- - - -	Tracking Width (Tires)

ARTICULATED BUS

Width	: 8.5'
Track	: 8.5'
Lock to Lock Time	: 6 seconds
Steering Lock Angle	: 38.3 degrees
Articulating Angle	: 50.0 degrees

Note: For definitions, see Indexes 404.1 and 404.5.

At signalized intersections the values for corner sight distances given in Table 405.1A should also be applied whenever possible. Even though traffic flows are designed to move at separate times, unanticipated conflicts can occur due to violation of signal, right turns on red, malfunction of the signal, or use of flashing red/yellow mode.

Table 405.1A
Corner Sight Distance
(7-1/2 Second Criteria)

Design Speed (mph)	Corner Sight Distance (ft)
25	275
30	330
35	385
40	440
45	495
50	550
55	605
60	660
65	715
70	770

Where restrictive conditions exist, similar to those listed in Index 405.1(2)(a), the minimum value for corner sight distance at both signalized and unsignalized intersections shall be equal to the stopping sight distance as given in Table 201.1, measured as previously described.

(c) Private Road Intersections (Refer to Index 205.2) and Rural Driveways (Refer to Index 205.4)--**The minimum corner sight distance shall be equal to the stopping sight distance as given in Table 201.1, measured as previously described.**

(d) Urban Driveways (Refer to Index 205.3)--Corner sight distance requirements as described above are not applied to urban driveways.

(3) *Decision Sight Distance.* At intersections where the State route turns or crosses another State route, the decision sight distance values given in Table 201.7 should be used. In computing and measuring decision sight distance, the 3.5-foot eye height and the 0.5-foot object height should be used, the object being located on the side of the intersection nearest the approaching driver.

The application of the various sight distance requirements for the different types of intersections is summarized in Table 405.1B.

Table 405.1B
Application of Sight Distance Requirements

Intersection Types	Sight Distance		
	Stopping	Corner	Decision
Private Roads	X	X(1)	
Public Streets and Roads	X	X	
Signalized Intersections	X	(2)	
State Route Inter-sections & Route Direction Changes, with or without Signals	X	X	X

NOTES:

(1) Per Index 405.1(2)(c), the minimum corner sight distance shall be equal to the stopping sight distance as given in Table 201.1. See Index 405.1(2)(a) for setback requirements.

(2) Apply corner sight distance requirements at signalized intersections whenever possible due to unanticipated violations of the signals or malfunctions of the signals. See Index 405.1(2)(b).

(4) *Acceleration Lanes for Turning Moves onto State Highways.* At rural intersections, with "STOP" control on the local cross road, acceleration lanes for left and right turns onto the State facility should be considered. At a minimum, the following features should be evaluated for both the major highway and the cross road:

- divided versus undivided

- number of lanes
- design speed
- gradient
- lane, shoulder and median width
- traffic volume and composition of highway users, including trucks and transit vehicles
- turning volumes
- horizontal curve radii
- sight distance
- proximity of adjacent intersections
- types of adjacent intersections

For additional information and guidance, refer to AASHTO, A Policy on Geometric Design of Highways and Streets, the Headquarters Traffic Liaison, the District Design Liaison, and the Project Delivery Coordinator.

405.2 Left-turn Channelization

(1) General. The purpose of a left-turn lane is to expedite the movement of through traffic by, controlling the movement of turning traffic, increasing the capacity of the intersection, and improving safety characteristics.

The District Traffic Branch normally establishes the need for left-turn lanes.

(2) Design Elements.

(a) Lane Width – **The lane width for both single and double left-turn lanes on State highways shall be 12 feet.**

For conventional State highways with posted speeds less than or equal to 40 miles per hour and AADTT (truck volume) less than 250 per lane that are in urban, city or town centers (rural main streets), the minimum lane width shall be 11 feet.

When considering lane width reductions adjacent to curbed medians, refer to Index 303.5 for guidance on effective roadway width, which may vary depending on drivers' lateral positioning and shy distance from raised curbs.

(b) Approach Taper -- On conventional highways without a median, an approach taper provides space for a left-turn lane by moving traffic laterally to the right. The approach taper is unnecessary where a median is available for the full width of the left-turn lane. Length of the approach taper is given by the formula on Figures 405.2A, B and C.

Figure 405.2A shows a standard left-turn channelization design in which all widening is to the right of approaching traffic and the deceleration lane (see below) begins at the end of the approach taper. This design should be used in all situations where space is available, usually in rural and semi-rural areas or in urban areas with high traffic speeds and/or volumes.

Figures 405.2B and 405.2C show alternate designs foreshortened with the deceleration lane beginning at the 2/3 point of the approach taper so that part of the deceleration takes place in the through traffic lane. Figure 405.2C is shortened further by widening half (or other appropriate fraction) on each side. These designs may be used in urban areas where constraints exist, speeds are moderate and traffic volumes are relatively low.

(c) Bay Taper -- A reversing curve along the left edge of the traveled way directs traffic into the left-turn lane. The length of this bay taper should be short to clearly delineate the left-turn move and to discourage through traffic from drifting into the left-turn lane. Table 405.2A gives offset data for design of bay tapers. In urban areas, lengths of 60 feet and 90 feet are normally used. Where space is restricted and speeds are low, a 60-foot bay taper is appropriate. On rural high-speed highways, a 120-foot length is considered appropriate.

(d) Deceleration Lane Length -- Design speed of the roadway approaching the intersection should be the basis for determining deceleration lane length. It is desirable that deceleration take place entirely off the through traffic lanes.

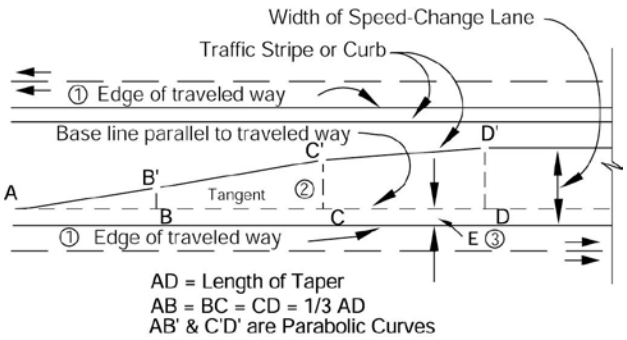
Deceleration lane lengths are given in Table 405.2B; the bay taper length is included. Where partial deceleration is permitted on the through lanes, as in Figures 405.2B and 405.2C, design speeds in Table 405.2B may be reduced 10 miles per hour to 20 miles per hour for a lower entry speed. In urban areas where cross streets are closely spaced and deceleration lengths cannot be achieved, the District Traffic branch should be consulted for guidance.

(e) Storage Length -- At unsignalized intersections, storage length may be based on the number of turning vehicles likely to arrive in an average 2-minute period during the peak hour. At a minimum, space for 2 vehicles should be provided at 25 feet per vehicle. If the peak hour truck traffic is 10 percent or more, space for at least one passenger car and one truck should be provided. Bus usage may require a longer storage length and should be evaluated if their use is anticipated.

At signalized intersections, the storage length may be based on one and one-half to two times the average number of vehicles that would store per signal cycle depending on cycle length, signal phasing, and arrival and departure rates. At a minimum, storage length should be calculated in the same manner as unsignalized intersection. The District Traffic Branch should be consulted for this information.

When determining storage length, the end of the left-turn lane is typically placed at least 3 feet, but not more than 30 feet, from the nearest edge of shoulder of the intersecting roadway. Although often set by the placement of a crosswalk line or limit line, the end of the storage lane should always be located so that the appropriate turning template can be accommodated.

Table 405.2A
Bay Taper for Median Speed-change Lanes



	LENGTH OF TAPER - feet			OFFSET DISTANCE			
	60	90	120	DD' = 10'	DD' = 11'	DD' = 12'	
	Distance From Point "A"						
	-	-	-	0.00	0.00	0.00	
	5	7.5	10.0	0.16	0.17	0.19	
	10	15.0	20.0	0.62	0.69	0.75	
	15	22.5	30.0	1.41	1.55	1.69	
B'	20	30.0	40.0	2.50	2.75	3.00	B'
	30	45.0	60.0	5.00	5.50	6.00	
C'	40	60.0	80.0	7.50	8.25	9.00	C'
	45	67.5	90.0	8.59	9.45	10.31	
	50	75.0	100.0	9.38	10.31	11.25	
	55	82.5	110.0	9.84	10.83	11.81	
	60	90.0	120.0	10.00	11.00	12.00	

NOTES:

(1) The table gives offsets from a base line parallel to the edge of traveled way at intervals measured from point "A". Add "E" for measurements from edge of traveled way.
(2) Where edge of traveled way is a curve, neither base line nor taper between B & C will be a tangent. Use proportional offsets from B to C.
(3) The offset "E" is usually 2 ft along edge of traveled way for curbed medians; Use "E" = 0 ft. for striped medians.

Table 405.2B
Deceleration Lane Length

Design Speed (mph)	Length to Stop (ft)
30	235
40	315
50	435
60	530

(3) *Double Left-turn Lanes.* At signalized intersections on multilane conventional highways and on multilane ramp terminals, double left-turn lanes should be considered if the left-turn demand is 300 vehicles per hour or more. The lane widths and other design elements of left-turn lanes given under Index 405.2(2) applies to double as well as single left-turn lanes.

The design of double left-turn lanes can be accomplished by adding one or two lanes in the median. See "Guidelines for Reconstruction of Intersections", published by Headquarters, Division of Traffic Operations, for the various treatments of double left-turn lanes.

(4) *Two-way Left-turn Lane (TWLTL).* The TWLTL consists of a striped lane in the median of an arterial and is devised to address the special capacity and safety problems associated with high-density strip development. It can be used on 2-lane highways as well as multilane highways. Normally, the District Traffic Operations Branch should determine the need for a TWLTL.

The minimum width for a TWLTL shall be 12 feet (see Index 301.1). The preferred width is 14 feet. Wider TWLTL's are occasionally provided to conform with local agency standards. However, TWLTL's wider than 14 feet are not recommended, and in no case should the width of a TWLTL exceed 16 feet. Additional width may encourage drivers in opposite directions to use the TWLTL simultaneously.

405.3 Right-turn Channelization

(1) *General.* For right-turning traffic, delays are less critical and conflicts less severe than for left-turning traffic. Nevertheless, right-turn lanes can be justified on the basis of capacity, analysis, and crash experience.

In rural areas a history of high speed rear-end collisions may warrant the addition of a right-turn lane.

In urban areas other factors may contribute to the need such as:

- High volumes of right-turning traffic causing backup and delay on the through lanes.
- Conflicts between crossing pedestrians and right-turning vehicles and bicycles.
- Frequent rear-end and sideswipe collisions involving right-turning vehicles.

Where right-turn channelization is proposed, lower speed right-turn lanes should be provided to reduce the likelihood of conflicts between vehicles, pedestrians, and bicyclists.

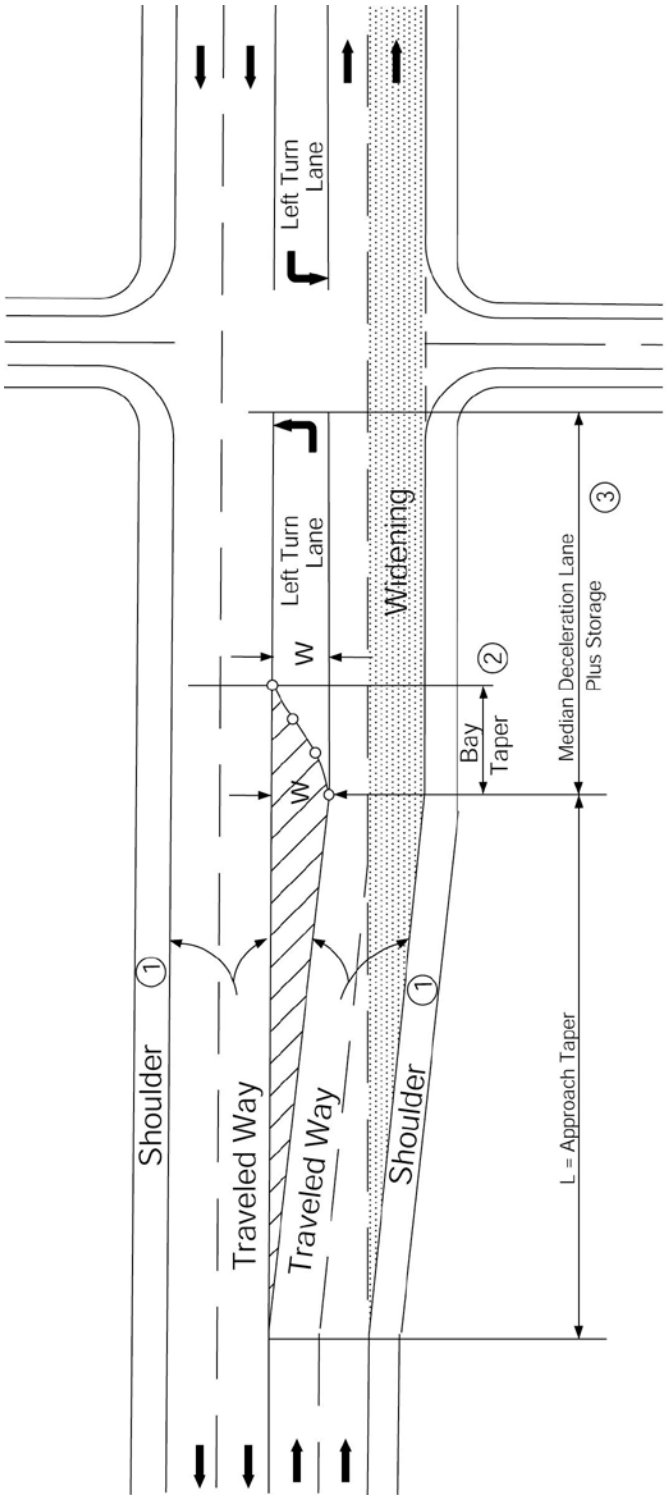
(2) *Design Elements.*

(a) Lane and Shoulder Width--**Index 301.1 shall be used for right-turn lane width requirements. Shoulder width shall be a minimum of 4 feet.** Although not desirable, lane and shoulder widths less than those given above can be considered for right-turn lanes under the following conditions pursuant to Index 82.2:

- In urban, city or town centers (rural main streets) with posted speeds less than 40 miles per hour in severely constrained situations, if truck or bus use is low, consideration may be given to reducing the right-turn lane width to 10 feet.
- Shoulder widths may also be considered for reduction under constricted situations. Whenever possible, at least a 2-foot shoulder should be provided where the right-turn lane is adjacent to a curb. Entire omission of the shoulder should only be considered in constrained situations and where an 11-foot lane can be constructed.

  Gutter pans can be included within a shoulder, but cannot be included as part of the travel lane width. Additional right of way for a future right-turn lane should be considered when an intersection is being designed.

Figure 405.2A
Standard Left-turn Channelization



EQUATION: L = Use WV, for V≥45mph 4
Or $WV^2/60$, for V<45mph

Where L = Length of Approach Taper - feet
V = Design Speed - mph
W = Width of Median Lane - feet

NOTES:

1. Where width is restricted, shoulder width may be reduced and parking restricted with an approved design exception pursuant to Index 82.2.
   For bicycle use, a minimum 4-foot shoulder is required (5-foot if gutter is present).
2. Bay taper length = 60 feet to 120 feet. (See Table 405.2A)
3. For deceleration lane length see Table 405.2B.
4. Where both sides of roadway are widened, use a fraction of "W" that is proportional to widening on each side.

Figure 405.2B
Minimum Median Left-turn Channelization
(Widening on one Side of Highway)

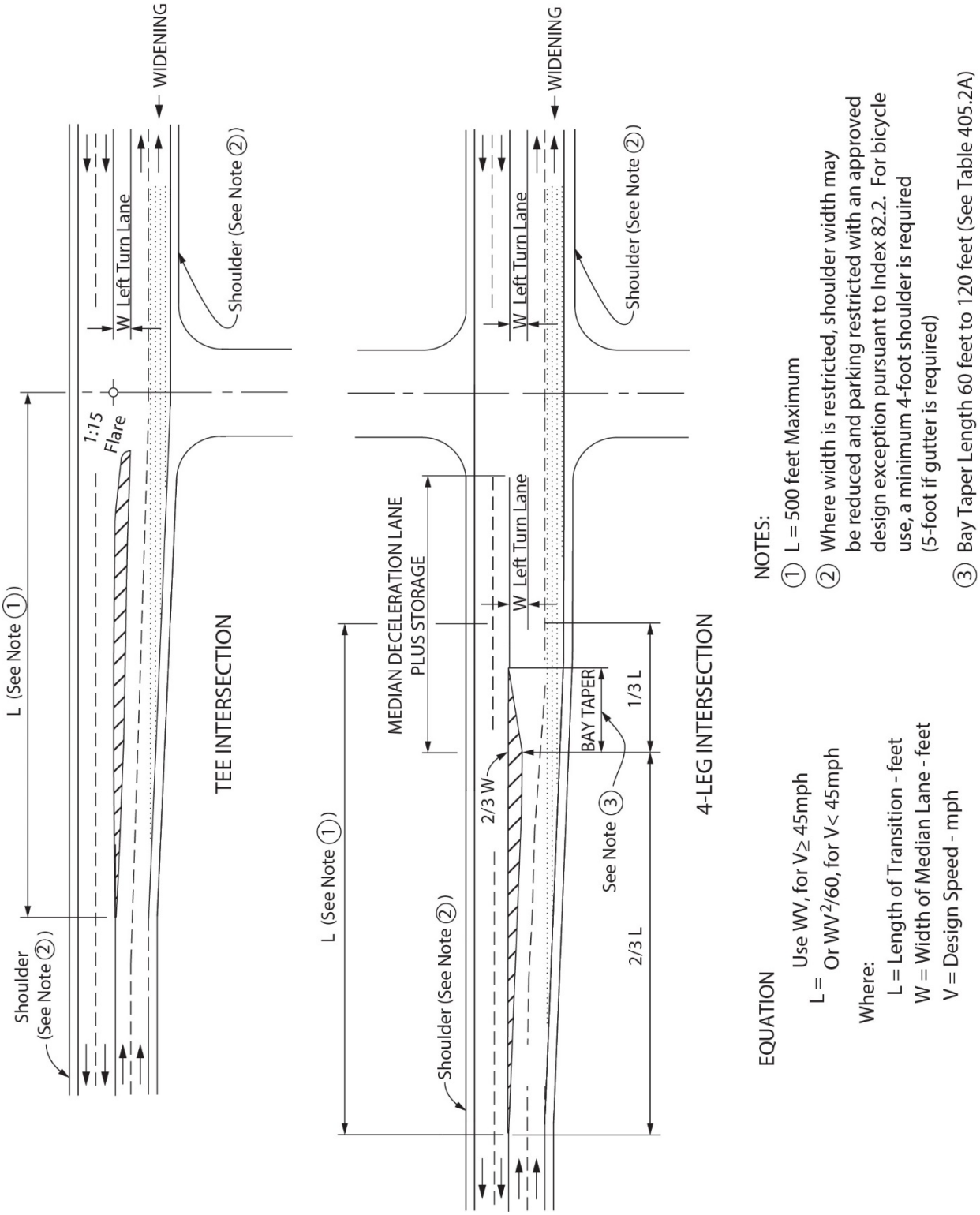
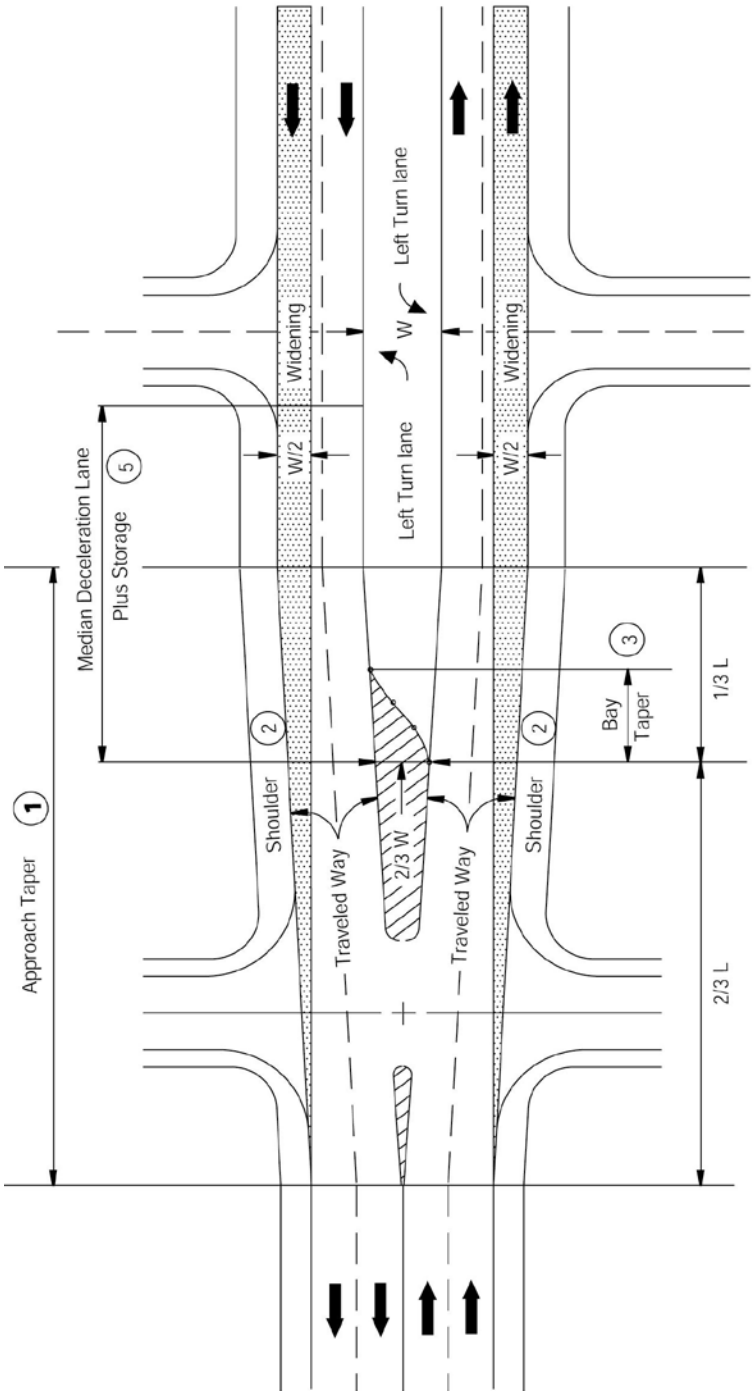


Figure 405.2C
Minimum Median Left-turn Channelization
(Widening on Both Sides in Urban Areas with Short Blocks)



NOTES:

1. L = 500 feet Maximum
2. Where width is restricted, shoulder width may be reduced and parking restricted with an approved design exception pursuant to Index 82.2. For bicycle use, a minimum 4 feet shoulder is required (5 feet if gutter is present).
3. Bay taper length = 60 feet to 120 feet. (See Table 405.2A)
4. Assumes equal widening each side. Where widening is unequal, use a fraction that is proportional to widening on each side.
5. For deceleration lane length see Table 405.2B.

EQUATION: 4

$L =$ Use $(1/2)WV$, for $V \geq 45$mph
Or $WV^2/120$, for $V < 45$mph

Where L = Length of Approach Taper - feet
W = Width of Median Lane - feet
V = Design Speed - mph

(b) Curve Radius--Where pedestrians are allowed to cross a free right-turning roadway, the curve radius should be such that the operating speed of vehicular traffic is no more than 20 miles per hour at the pedestrian crossing. See NCHRP Report 672, "Roundabouts: An Informational Guide" for guidance on the determination of design speed (fastest path) for turning vehicles. See Index 504.3(3) for additional information.

(c) Tapers--Approach tapers are usually unnecessary since main line traffic need not be shifted laterally to provide space for the right-turn lane. If, in some rare instances, a lateral shift were needed, the approach taper would use the same formula as for a left-turn lane.

Bay tapers are treated as a mirror image of the left-turn bay taper.

(d) Deceleration Lane Length--The conditions and principles of left-turn lane deceleration apply to right-turn deceleration. Where full deceleration is desired off the high-speed through lanes, the lengths in Table 405.2B should be used. Where partial deceleration is permitted on the through lanes because of limited right of way or other constraints, average running speeds in Table 405.2B may be reduced 10 miles per hour to 20 miles per hour for a lower entry speed. For example, if the main line speed is 50 miles per hour and a 10 miles per hour deceleration is permitted on the through lanes, the deceleration length may be that required for 40 miles per hour.

(e) Storage Length--Right-turn storage length is determined in the same manner as left-turn storage length. See Index 405.2(2)(e).

(3) Right-turn Lanes at Off-ramp Intersections. Diamond off-ramps with a free right-turn at the local street and separate right-turn off-ramps around the outside of a loop will likely cause conflict as traffic volumes increase. Serious conflicts occur when the right-turning vehicle must weave across multiple lanes on the local street in order to turn left at a major cross street close to the ramp terminal. Furthermore, free right-turns create sight distance issues for pedestrians and bicyclists crossing the off-ramp, or pedestrians crossing the local road. Also, rear-end collisions can occur as right-turning drivers slow down or stop waiting for a gap in local street traffic. Free right-turns usually end up with "YIELD", "STOP", or signal controls thus defeating their purpose of increasing intersection capacity.

405.4 Traffic Islands

A traffic island is an area between traffic lanes for channelization of bicycle and vehicle movements or for pedestrian refuge. An island may be defined by paint, raised pavement markers, curbs, pavement edge, or other devices. The California MUTCD should be referenced when considering the placement of traffic islands at signalized and unsignalized locations. For splitter island guidance at roundabouts, see Index 405.10(13).

Traffic islands usually serve more than one function. These functions may be:

(a) Channelization to confine specific traffic movements into definite channels;

(b) Divisional to separate traffic moving in the same or opposite direction; and

(c) Refuge, to aid users crossing the roadway.

Generally, islands should present the least potential conflict to approaching or crossing bicycles and vehicles, and yet perform their intended function.

(1) Design of Traffic Islands. Island sizes and shapes vary from one intersection to another. They should be large enough to command attention. Channelizing islands should not be less than 50 square feet in area, preferably 75 square feet. Curbed, elongated divisional median islands should not be less than 4 feet wide and 20 feet long. All traffic islands placed in the path of a pedestrian crossing must comply with DIB 82. See the Standard Plans for typical island passageway details.

The approach end of each island should be offset 3 feet to the left and 5 feet to the right of approaching traffic, using standard 1:15 parabolic flares, and clearly delineated so that it does not surprise the motorist or bicyclist. These offsets are in addition to the shoulder

widths shown in Table 302.1. Table 405.4 gives standard parabolic flares to be used in island design. On curved alignment, parabolic flares may be omitted for small triangular traffic islands whose sides are less than 25 feet long.

The approach nose of a divisional island should be highly visible day and night with appropriate use of signs (reflectorized or illuminated) and object markers. The approach nose should be offset 3 feet from the through traffic to minimize accidental impacts.

(2) Delineation of Traffic Islands. Generally, islands should present the least potential conflict to approaching traffic and yet perform their intended function. See Index 303.2 for appropriate curb type. Islands may be designated as follows:

(a) Raised paved areas outlined by curbs.

(b) Flush paved areas outlined by pavement markings.

(c) Unpaved areas (small unpaved areas should be avoided).

On facilities with posted speeds over 40 miles per hour, the use of any type of curb is discouraged. Where curbs are to be used, they should be located at or outside of the shoulder edge, as discussed in Index 303.5.

In rural areas, painted channelization supplemented with raised pavement markers may be more appropriate than a raised curbed channelization. This design is as forgiving as possible and decreases the consequence of a driver's or bicyclist's failure to detect or recognize the curbed island. Consideration for snow removal operations should be determined where appropriate.

In urban areas, posted speeds less than or equal to 40 miles per hour allow more frequent use of curbed islands. Local agency requirements and matching existing conditions are factors to consider.

(3) Pedestrian Refuge

Pedestrian refuge islands allow pedestrians to cross fewer lanes at a time while judging conflicts separately. They also provide a refuge so slower pedestrians can wait for a gap in traffic while reducing total crossing distance.

At unsignalized intersections in rural city/town centers (rural main streets), suburban, or urban areas, a pedestrian refuge should be provided between opposing traffic where pedestrians are allowed to cross 2 or more through traffic lanes in one direction of travel, at marked or unmarked crosswalks. Pedestrian islands at signalized crosswalks should be considered, taking into account crossing distance and pedestrian activity. Note that signalized pedestrian crossings must be timed to allow for pedestrians to cross. See the California MUTCD, Chapter 4E, for further guidance.

Traffic islands used as pedestrian refuge are to be large enough to provide a minimum of 6 feet in the direction of pedestrian travel, without exception.

All traffic islands placed in the path of a pedestrian crossing must be accessible, refer to DIB 82 and the Standard Plans for further guidance. An example of a traffic island that serves as a pedestrian refuge is shown on Figure 405.4.

405.5 Median Openings

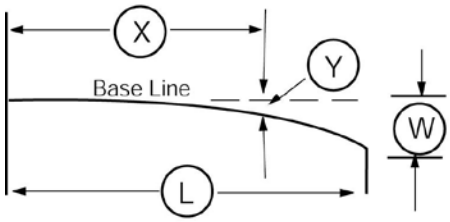
(1) General. Median openings, sometimes called crossovers, provide for crossings of the median at designated locations. Except for emergency passageways in a median barrier, median openings are not allowed on urban freeways.

Median openings on expressways or divided conventional highways should not be curbed except when the median between openings is curbed, or it is necessary for delineation of traffic signal standards and other necessary hardware, or for protection of pedestrians. In these special cases B4 curbs should be used. An example of a median opening design is shown on Figure 405.5.

(2) Spacing and Location. By a combination of interchange ramps and emergency passageways, provisions for access to the opposite side of a freeway may be provided for law enforcement, emergency, and maintenance vehicles to avoid extreme out-of-direction travel. Access should not be more frequent

Table 405.4

Parabolic Curb Flares Commonly Used



$$Y = \frac{W X^2}{L^2}$$

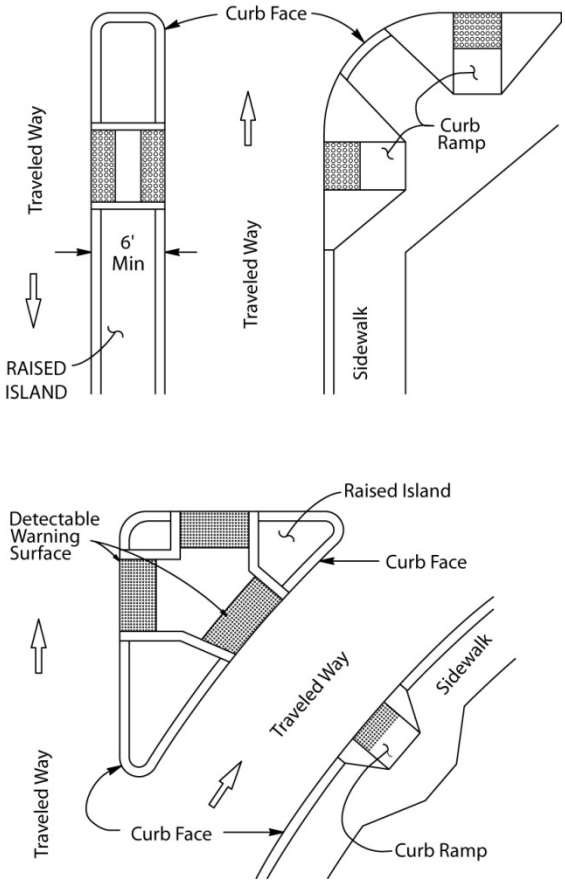
L = Length of flare in feet
W = Maximum offset in feet
X = Distance along base line in feet
Y = Offset from base line in feet

W is shown in table thus

OFFSET IN FEET FOR GIVEN "X" DISTANCE																
Distance X / Length of Flare L	10	15	20	25	30	40	45	50	60	70	75	80	90	100	110	120
1:5 FLARES																
25	0.80	1.80	3.20	5.00												
50	0.40		1.60		3.60	6.40		10.00								
1:10 FLARES																
50	0.20		0.80		1.80	3.20		5.00								
100	0.10		0.40		0.90	1.60		2.50	3.60	4.90		6.40	8.10	10.00		
1:15 FLARES																
45	0.15		0.59		1.33	2.37	3.00									
75	0.09		0.36		0.80	1.42		2.22	3.20	4.36	5.00					
90	0.07		0.30		0.67	1.19		1.85	2.67	3.63		4.74	6.00			
120	0.06		0.22		0.50	0.89		1.39	2.00	2.72		3.56	4.50	5.56	6.72	8.00

Figure 405.4

Pedestrian Refuge Island



than at three-mile intervals. See Chapter 7 of the Traffic Manual for additional information on the design of emergency passageways.

Emergency passageways should be located only where decision sight distance is available (see Table 201.7).

Median openings at close intervals on other types of highways create conflicts with high speed through traffic. Median openings should be spaced at intervals no closer than 1600 feet. If a median opening falls within 300 feet of an access opening, it should be placed opposite the access opening.

(3) *Length of Median Opening.* For any three or four-leg intersection on a divided highway, the length of the median opening should be at least as great as the width of the crossroads pavement, median width, and shoulders. An important factor in designing median openings is the path of the design vehicle making a minimum left turn at 5 miles per hour to 10 miles per hour. The length of median opening varies with width of median and angle of intersecting road.

Usually a median opening of 60 feet is adequate for 90 degree intersections with median widths of 22 feet or greater. When the median width is less than 22 feet, a median opening of 70 feet is needed. When the intersection angle is other than 90 degrees, the length of median opening should be established by using truck turn templates (see Index 404.3).

(4) *Cross Slope.* The cross slope in the median opening should be limited to 5 percent. Crossovers on curves with super elevation exceeding 5 percent should be avoided. This cross slope may be exceeded when an existing 2-lane roadbed is converted to a 4-lane divided highway. The elevation of the new construction should be based on the 5 percent cross slope requirement when the existing roadbed is raised to its ultimate elevation.

(5) *References.* For information related to the design of intersections and median openings, "A Policy on Geometric Design of Highways and Streets," AASHTO, should be consulted.

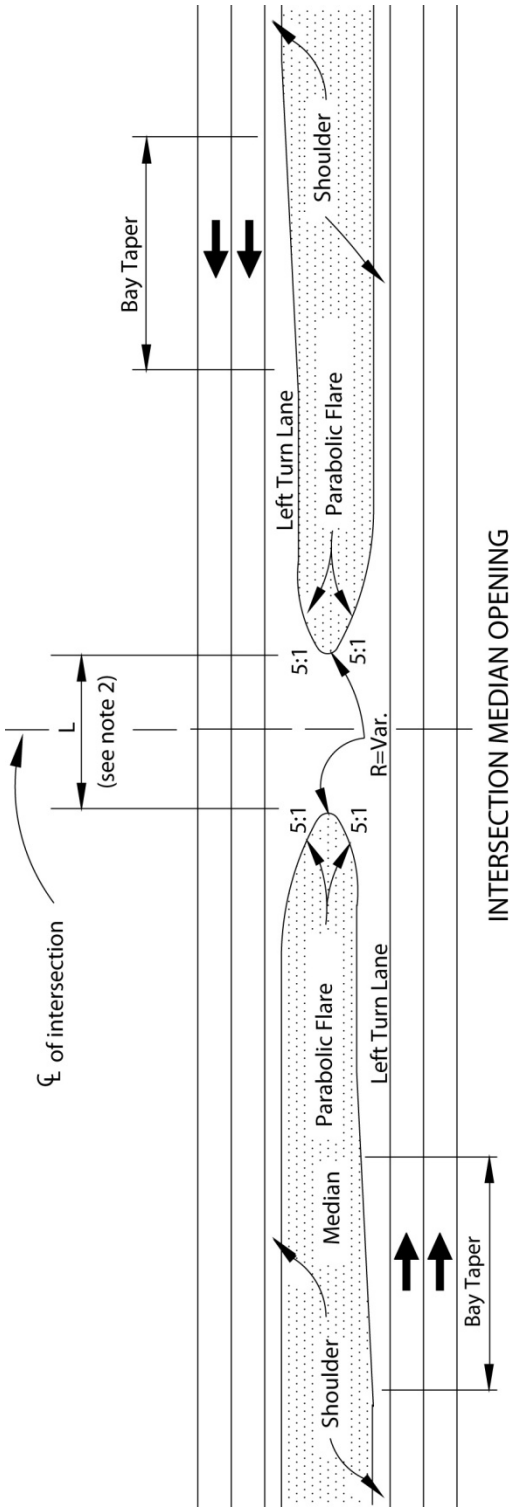
405.6 Access Control

The basic guidance which govern the extent to which access rights are to be acquired at interchanges (see Topic 104, Index 205.1 and 504.8 and the PDPM) also apply to intersections at grade on expressways. Cases of access control which frequently occur at intersections are shown in Figure 405.7. This illustration does not presume to cover all situations. Where required by traffic conditions, access should be extended in order to ensure proper operation of the expressway lanes. Reasonable variations which observe the basic principles referred to above are acceptable.

However, negative impacts on the mobility needs of pedestrians, bicyclists, equestrians, and transit users need to be assessed. Pedestrians and bicyclists are sensitive to additional out of direction travel.

Figure 405.5

Typical Design for Median Openings



NOTES:

① For length of bay taper, see Table 405.2A.

② L = Length of median opening: varies with width of median and angle of intersecting road. Usually for 90° intersection, L = 60 feet for median of 22 feet and wider. L = 70 feet for medians narrower than 22 feet.

③ See Index 405.2.

④ Pedeistrain and bicycle features are not shown on figure.

405.7 Public Road Intersections

The basic design to be used at right-angle public road intersections on the State Highway System is shown in Figure 405.7. The essential elements are sight distance (see Index 405.1) and the treatment of the right-turn on and off the main highway. Encroachment into opposing traffic lanes by the turning vehicle should be avoided or minimized.

(1) *Right-turn Onto the Main Highway.* The combination of a circular curve joined by a 2:1 taper on the crossroads and a 75-foot taper on the main highway is designed to fit the wheel paths of the appropriate turning template chosen by the designer.

It is desirable to keep the right-turn as tight as practical, so the "STOP" or "YIELD" sign on the minor leg can be placed close to the intersection.

(2) *Right-turn Off the Main Highway.* The combination of a circular curve joined by a 150-foot taper on the main highway and a 4:1 taper on the crossroads is designed to fit the wheel paths of the appropriate turning template and to move the rear of the vehicle off the main highway. Deceleration and storage lanes may be provided when necessary (see Index 405.3).

(3) *Alternate Designs.* Offsets are given in Figure 405.7 for right angle intersections. For skew angles, roadway curvature, and possibly other reasons, variations to the right-angle design are permitted, but the basic rule is still to approximate the wheel paths of the design vehicle.

A three-center curve is an alternate treatment that may be used at the discretion of the designer.

Intersections are major consideration in bicycle path design as well. See Indexes 403.6 and 1003.1(4) for general bicycle path intersection design guidance. Also see Section 5.3 of the AASHTO Guide for the Planning, Design, and Operation of Bicycle Facilities.

405.8 City Street Returns and Corner Radii

The pavement width and corner radius at city street intersections is determined by the type of vehicle to be accommodated and the mobility needs of pedestrians and bicyclists, taking into consideration the amount of available right of way, the types of adjoining land uses, the place types, the roadway width, and the number of lanes on the intersecting street.

At urban intersections, the California truck or the Bus Design Vehicle template may be used to determine the corner radius. Where STAA truck access is allowed, the STAA Design Vehicle template should be used giving consideration to factors mentioned above. See Index 404.3.

Smaller radii of 15 feet to 25 feet are appropriate at minor cross streets where few trucks or buses are turning. Local agency standards may be appropriate in urban and suburban areas.

Encroachment into opposing traffic lanes must be avoided.

405.9 Widening of 2-lane Roads at Signalized Intersections

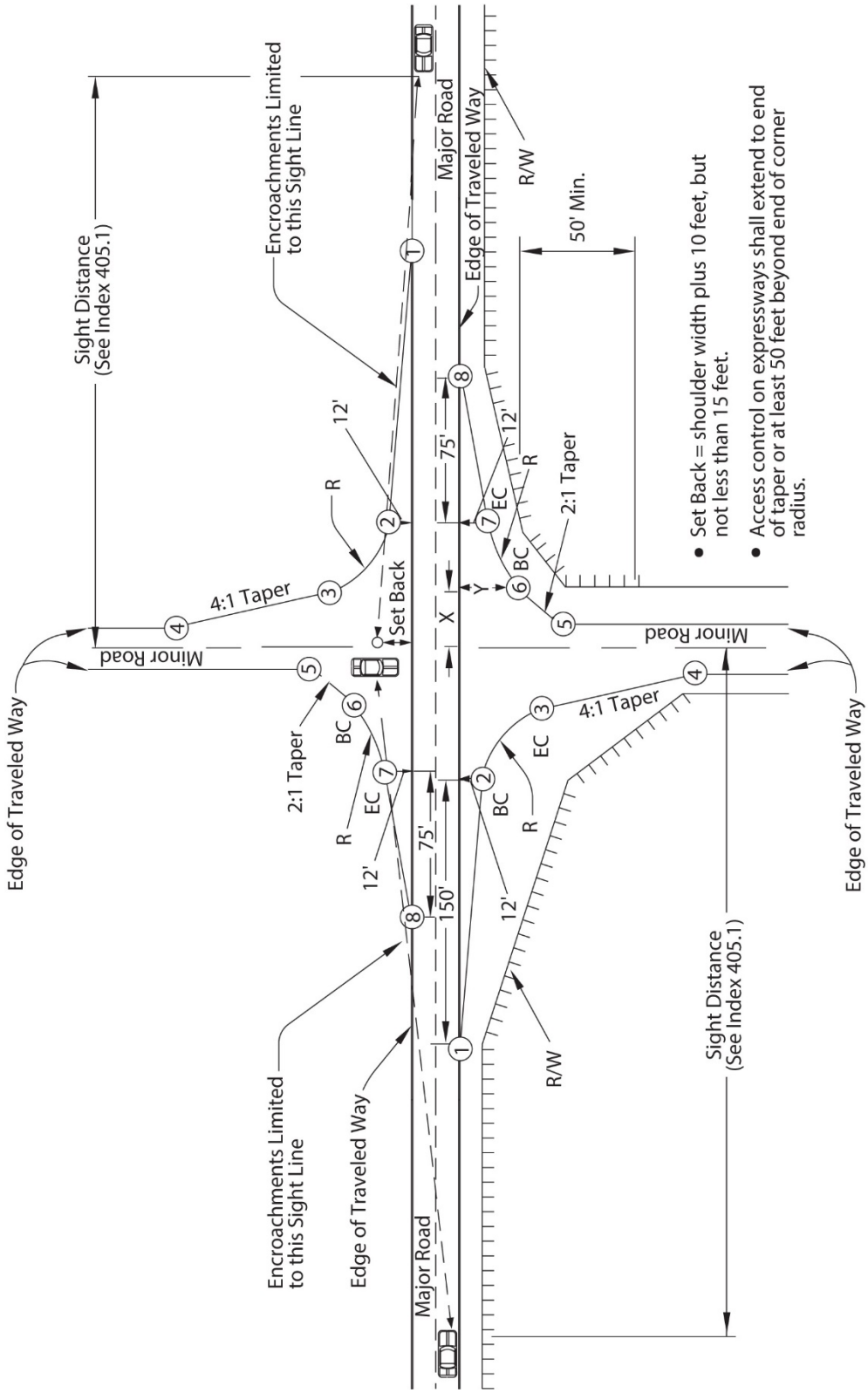
Two-lane State highways may be widened at intersections to 4-lanes whenever signals are installed. Sometimes it may be necessary to widen the intersecting road. The minimum design is shown in Figure 405.9. More elaborate treatment may be warranted by the volume and pattern of traffic movements. Unusual turning movement patterns may possibly call for a different shape of widening.

The impact on pedestrian and bicycle traffic mobility of larger intersections should be assessed before a decision is made to widen an intersection.

405.10 Roundabouts

Roundabout intersections on the State highway system must be developed and evaluated in accordance with National Cooperative Highway Research Program (NCHRP) Report 672 entitled "Roundabouts: An Informational Guide, 2nd ed." (NCHRP Guide 2) dated October 2010 and Traffic Operations Policy Directive (TOPD) Number 13-02. Also see Index 401.5 for general information and guidance. See Figure 405.10 Roundabout Geometric Elements for nomenclature associated with roundabouts. Signs, striping and markings at roundabouts are to comply with the California MUTCD.

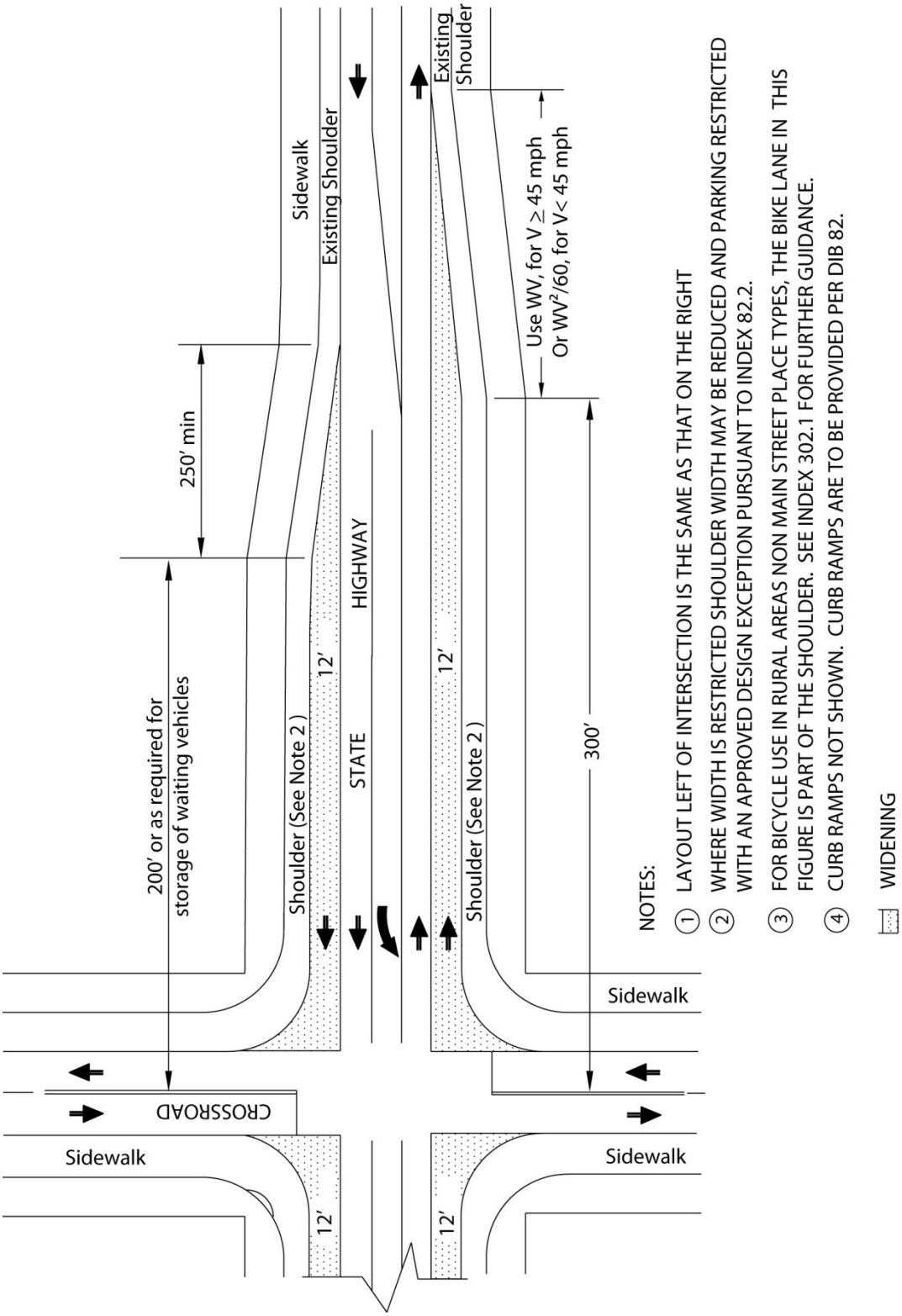
Figure 405.7
Public Road Intersections



X - Distance measured from centerline of minor road along major road - feet.
Y - Offset distance measured from edge of traveled way of major road to any given point - feet.

Radius of Curve	Design Vehicle	Pt ①		Pt ②		Pt ③		Pt ④		Pt ⑤		Pt ⑥		Pt ⑦		Pt ⑧	
		X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
30'	Bus	204.20	0.0	54.20	12.0	27.49	34.63	12.0	96.58	12.0	40.66	18.23	28.21	40.32	12.0	115.32	0.0
40'	California	215.08	0.0	65.08	12.0	29.46	42.17	12.0	112.03	12.0	53.35	21.87	33.61	51.33	12.0	126.33	0.0
50'	STAA	226.09	0.0	76.09	12.0	31.57	49.71	12.0	127.98	12.0	75.63	30.31	39.01	67.13	12.0	142.13	0.0

Figure 405.9
Widening of Two-lane Roads at Signalized Intersections



A roundabout is a form of circular intersection in which traffic travels counterclockwise around a central island and entering traffic must yield to the circulating traffic. Roundabouts feature, among other things, a central island, a circulatory roadway, and splitter islands on each approach. Roundabouts rely upon two basic and important operating principles:

(a) Speed reduction at the entry and through the intersection will be achieved through geometric design and,

(b) The yield-at-entry rule, which requires traffic entering the intersection to yield to traffic that is traveling in the circulatory roadway.

Benefits of roundabouts are:

- Fewer conflict points typically result in fewer collisions with less severity. Over half of vehicle to vehicle points of conflict associated with intersections are eliminated with the use of a roundabout. Additionally, a roundabout separates the points of conflict which eases the ability of the users to identify a conflict and helps prevent conflicts from becoming collisions.
- Roundabouts are designed to reduce the vehicular speeds at intersections. Lower speeds lessens the vehicular collision severity. Likewise, studies indicate that pedestrian and bicyclist collisions with motorized vehicles at lower speeds significantly reduce their severity.
- Roundabouts allow continuous free flow of vehicles and bicycles when no conflicts exist. This results in less noise and air pollution and reduces overall delays at roundabout intersections.

Except as indicated in this Index, the standards elsewhere in this manual do not apply to roundabouts. For the application of design standards, the approach ends of the splitter islands define the boundary of a roundabout intersection, see Figure 405.10. The design standards elsewhere in this manual apply to the approach legs beyond the approach ends of the splitter islands.

(1) Design Period.

First consider the design of a single lane roundabout per the design period guidance in Index 103.2. If a second lane is not needed until 10 or more years, it may be better to phase the improvements. Construct the first phase of the roundabout so at the 20-year design period, an additional lane can be easily added. In order to comply with the 20-year design period, the initial project must provide the right of way needed for utility relocations, a shared-use path designed for a Class I Bikeway, and all other features other than pavement, lighting, and striping in their ultimate locations.

In some locations, it may not be practical to build a single lane roundabout that will operate for 10 years. Geometric constraints and other conflicts may preclude widening to the ultimate configuration. In such cases, other intersection configurations or control strategies addressed in Index 401.5 may need to be considered.

When staging improvements, see NCHRP Guide 2, Section 6.12.

(2) Design Vehicles - See Topic 404.

The turning path for the design vehicle, see Index 404.5, dictates many of the roundabout dimensions. The design vehicle tracking and swept width are to be used when designing all the entries and exits, where design vehicles are unrestricted (see Index 404.2), and the circulatory roadway. The percentage of trucks and their lane utilization is an important consideration on multilane roundabouts when determining if the design will allow trucks to stay within their own lane or encroach into the adjacent lane. If permit vehicles larger than the design vehicle occasionally use the proposed roundabout, they can be accommodated by having removable signs or other removable features in the central island or around the circular path to ensure their swept path can negotiate the roundabout. Roundabouts should not be overdesigned for the occasional permit vehicle.

To accurately simulate the design vehicle swept width traveling through a roundabout, the minimum speed of the design vehicle used in computer simulation software (e.g., Auto

TURN) should be 10 miles per hour through the roundabout.

(3) Inscribed Circle Diameter.

At single lane roundabouts, the size of the inscribed circle is largely dependent upon the turning requirements of the design vehicle. The inscribed circle diameter (ICD) must be large enough to accommodate: (a) the STAA design vehicle for all roundabouts on the National Network and on Terminal Access routes; and, (b) the California Legal design vehicle on all non-STAA route intersections on California Legal routes and California Legal KPRA Advisory routes, while maintaining adequate deflection curvature to ensure appropriate travel speeds for smaller vehicles. The design vehicle is to navigate the roundabout with the front tractor wheels off the truck apron, if one is present. Transit vehicles, fire engines and single-unit delivery vehicles are also to be able to navigate the roundabout without using the truck apron, if one is present. The inscribed circle diameter for a single lane roundabout generally ranges between 105 feet to 150 feet to accommodate the California Legal design vehicle and 130 feet to 180 feet to accommodate the STAA design vehicle.

At multilane roundabouts, the inscribed circle diameter is to achieve adequate alignment of the natural vehicle path while maintaining deflection curvature to ensure appropriate travel speeds. To achieve both of these design objectives requires a slightly larger diameter than used for a single lane roundabout. The inscribed circle diameter for a multilane (2-lane) roundabout generally ranges between 150 feet to 220 feet to accommodate the California Legal design vehicle for non-STAA route intersections on California Legal routes and California Legal KPRA Advisory routes, and 165 feet to 220 feet to accommodate the STAA design vehicle for roundabouts on the National Network and on Terminal Access routes. Similar to a single lane roundabout, the design vehicle is to be able to navigate a multilane roundabout with the front tractor wheels staying off the truck apron, if one is present. Transit vehicles, fire engines and single-unit delivery vehicles are also to be able to navigate the roundabout without using the truck apron, if one is present.

The inscribed diameter ranges given above are typical values, design may be larger or smaller. Site location constraints and performance checks will determine if the diameter is appropriate for the location.

(4) Entry Speeds.

Lowering the speed of vehicles entering and traveling through the roundabout is a primary design objective that is achieved by approach alignment and entry geometry.

<u>The following entry speeds should not be exceeded</u>:

- <u>Single lane entry, 25 miles per hour.</u>
- <u>Multilane entry, 30 miles per hour.</u>

A bypass lane is not included in the number of entry lanes. A bypass prohibits entry into the circulatory roadway.

Entry speeds are to be determined through fastest path analysis. Fastest path is the smoothest, flattest path possible for a single vehicle in the absence of other traffic and ignoring all lane markings. The fastest path analysis should begin at least 165 feet from the inscribed circle diameter and should not bring the path closer than 3 feet from a stripe nor 5 feet from the face of a curb. These distances are minimums and the fastest path may occur further away from the curbs and striping depending on the roundabout configuration. For fastest path evaluation, see NCHRP Guide 2, Section 6.7.1.

(5) Exit Design.

Similar to entry design, exit design flexibility is required to achieve the optimal balance between competing design variables and project objectives to provide adequate capacity and, essentially, safety while minimizing excessive property impacts and costs. Thus, the selection of a curved versus tangential design is to be based upon the balance of each of these criteria. Exit design is influenced by the place type, pedestrian demand, bicyclist needs, the design vehicle

and physical constraints. The exit curb radii are usually larger than the entry curb radii in order to minimize the likelihood of congestion and crashes at the exits. However, the desire to minimize congestion at the exits needs to be balanced with the need to maintain an appropriate operating speed through the pedestrian crossing. Therefore, the exit path radius should not be significantly greater than the circulating path radius to ensure low speeds are maintained at the pedestrian crossing.

(6) Number of Legs Serving the Roundabout.

Intersections with more than four legs are often difficult to manage operationally. Roundabouts are a proven traffic control device in such situations. However, it is necessary to ensure that the design vehicle can maneuver through all unrestricted legs of the roundabout.

(7) Pedestrian Use.

Sidewalks around the circular roadway are to be designed as shared-use paths, see Index 405.10(8)(c). However, the guidance in Design Information Bulletin (DIB) 82 Pedestrian Accessibility Guidelines for Highway Projects must also be followed when designing these shared-use facilities around a roundabout. If there is a difference in the standards, the guidance in DIB 82 is to be followed. In addition,

(a) Pedestrian curb ramps need to be differentiated from bike ramps:

- The detectable warning surface (truncated domes) differentiates a pedestrian curb ramp from a bicycle ramp.
- Detectable warning surface is required on curb ramps. They are not to be used on a bike ramp.

(b) Truck aprons and mountable curbs are not to be placed in the pedestrian crossing areas.

(c) See the California MUTCD for the signs and markings used at roundabouts.

(d) At pedestrian crossing locations the accessibility design will be treated as a midblock pedestrian street crossing. See DIB 82 for more information.

(8) Bicyclist Use.

(a) General. Bicyclists may choose to travel in the circular roadway of a roundabout by taking a lane, while others may decide to travel using the shared-use path to bypass the circular roadway. Therefore, the approach and circular roadways, as well as the shared-use path all need to be designed for the mobility needs of bicyclists. See the California MUTCD for the signs and markings used at roundabouts.

(b) Bicyclist Use of the Circular Roadway. Single lane roundabouts do not require bicyclists to change lanes in the circular roadway to select the appropriate lane for their direction of travel, so they tend to be comfortable for bicyclists to use. Even two-lane roundabouts, which may have straighter paths of travel that can lead to faster vehicular traveling speeds, appear to be comfortable for bicyclists that prefer to travel like vehicles. Roundabouts that have more than two circular lanes can create complexities in signing and striping (see the California MUTCD for guidance), and their operating speed may cause some bicyclists to decide to bypass the circular roadway and use the bicycle ramp that provides access to the shared-use path around the roundabout.

(c) Bicyclists Use of the Shared-Use Path. The shared-use path is to be designed using the guidance in Index 1003.1 for Class I Bikeways and in NCHRP Guide 2 Section 6.8.2.2. However, the accessibility guidance in DIB 82 must also be followed when designing these shared-use facilities around a roundabout. If there is a difference in the standards, the accessibility guidance in DIB 82 is to be followed to ensure the facility is accessible to pedestrians with disabilities.

Bicycle ramps are to be located to avoid confusion as curb ramps for pedestrians. Also see Index 405.10(7) for guidance on how to differentiate the two types of ramps. The design details and width of the ramp are also important to the bicyclist. Bicyclists approaching the bicycle ramp need to be provided the choice of merging left into the lane or moving right to use the bicycle ramp. Bicycle ramps should be placed at a 35 to 45 degree angle to the departure roadway and the sidewalk to enable the bicyclists to use the ramp and discourage bicyclists from entering the shared-use path at a speed that is detrimental to the pedestrians. The shared-use path should be designated as Class I Bikeways; however, appropriate regulatory signs may need to be posted if the local jurisdiction has a law(s) that prohibit bicyclists from riding on a sidewalk.

A landscape buffer or strip between the shared-use/Class I Bikeway and the circular roadway of the roundabout is needed and should be a minimum of 2 feet wide.

Pedestrian crossings may also be used by bicyclists; thus, these shared-use crossings need to be designed for both bicyclist and pedestrian needs.

(9) Transit Use.

Transit vehicles and buses will not have difficulty negotiating a roundabout when it has been designed using the California Legal design vehicle or the STAA design vehicle. However, to minimize passenger discomfort, a roundabout should be designed such that the transit vehicle or bus does not use the truck apron, if one is present.

(10) Stopping Sight Distance and Visibility.

See Index 201.1 for stopping sight distance guidance at roundabouts.

A domed or mounded central island, between 3.5 to 6 feet high, is needed to focus attention on the approach and through roundabout alignment. A domed central island provides a visual screen from downstream alignment and other distractions and provides a visual cue for vehicles approaching the roundabout.

In high speed environments, additional lighting of, and vertical elements in the central island (i.e., landscaping and esthetic features) may be needed.

(11) Speed Consistency.

Consistency in operating speeds between the various movements within the roundabout can minimize collisions between traffic streams. The operating speeds between competing traffic streams and between consecutive geometric elements should be minimized such that the maximum speed differential between them is no more than 15 miles per hour; it is preferred that the operating speed differential be less than 10 miles per hour.

(12) Path Alignment (Natural Path).

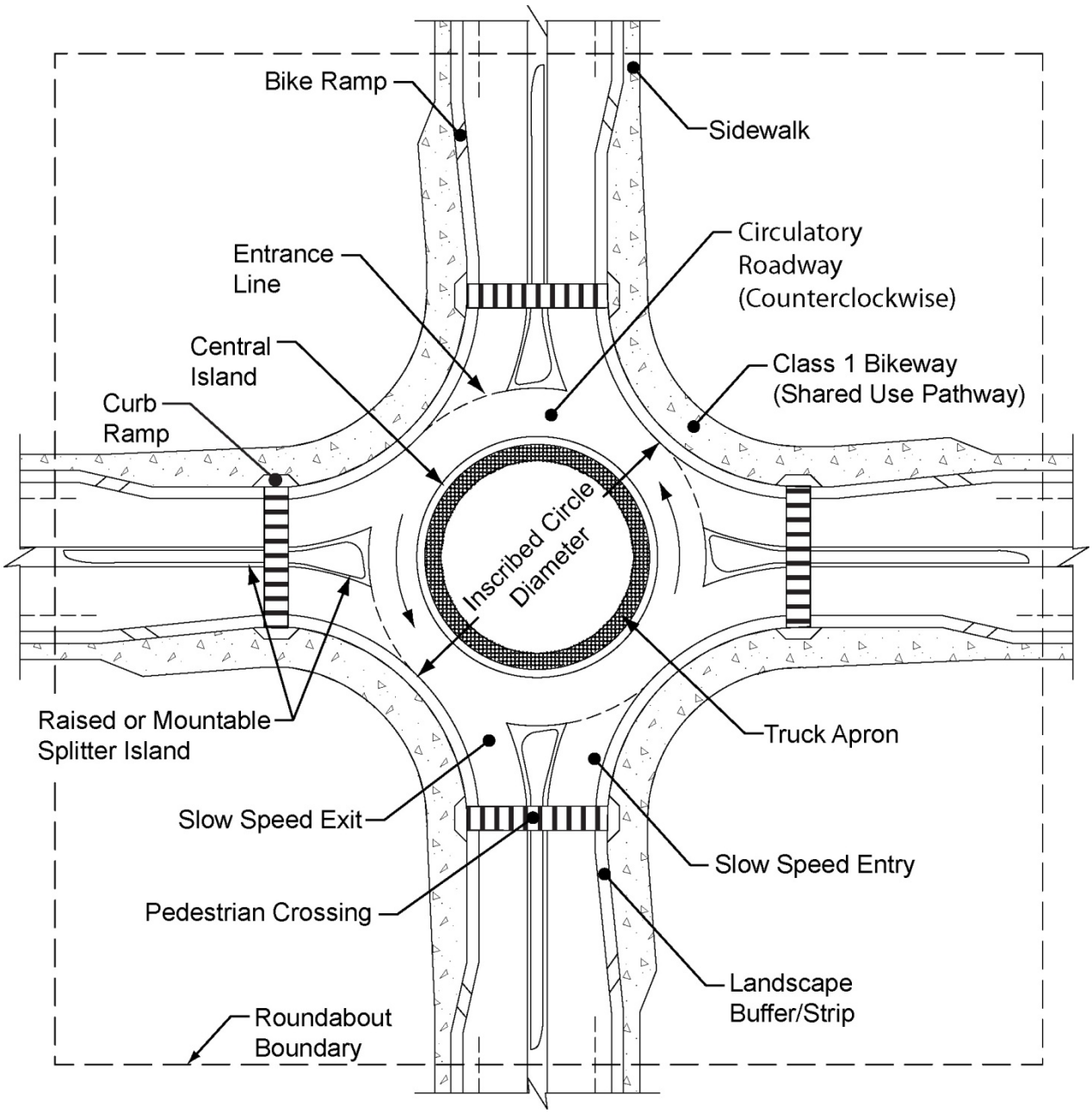
As two traffic streams approach the roundabout in adjacent lanes, drivers and bicyclists will be guided by lane markings up to the entrance line. At the yield point, they will continue along their natural trajectory into the circulatory roadway. The speed and orientation of the design vehicle at the entrance line determines what can be described as its natural path. The geometry of the exits also affects the natural path that the design vehicle travels. The natural path of two vehicles are not to overlap, see NCHRP Guide 2, Section 6.7.2.

(13) Splitter Islands.

Splitter islands (also called separator islands, divisional islands, or median islands) will be provided on all roundabouts. The purpose is to provide refuge for pedestrians, assist in controlling speeds, guide traffic into the roundabout, physically separate entering and exiting traffic streams, and deter wrongway movements.

The total length of the raised island should be at least 50 feet although 100 feet is desirable. On higher speed roadways, splitter island lengths of 150 feet or more is beneficial. Additionally, the splitter island should extend beyond the end of the exit curve to prevent

Figure 405.10
Roundabout Geometric Elements



NOTE:

This figure is provided to only show nomenclature and is not to be used for design details.

exiting traffic from crossing into the path of approaching traffic. The splitter island width should be a minimum of 6 feet at the pedestrian crossing to adequately provide refuge for pedestrians.

Posted speeds on the approach roadway greater than or equal to 45 miles per hour require the splitter island length, as measured from the inscribed circle diameter, to be 200 feet. In some instances, a longer splitter island may be desirable. Concrete curb is to be provided on the right side of the approach roadway equal to the length of the splitter island from the inscribed circle diameter.

(14) Access Control.

The access control standards in Index 504.3(3) and 504.8 apply to roundabouts at interchange ramp intersections. The dimensions shown in Index 504.8 are to be measured from the inscribed circle diameter.

Driveways should not be placed within 100 feet from the inscribed circle diameter.

(15) Lighting.

Lighting is required at all roundabouts. See NCHRP Report 672 Chapter 8, the Traffic Manual Chapter 9 as well as consult with the District Traffic Safety Engineer.

(16) Landscaping.

Landscaping should be designed such that drivers and bicyclists can observe the signing and shape of the roundabout as they approach, allowing adequate visibility for making decisions within the roundabout. The landscaping of the central island can enhance the intersection by making it a focal point, by promoting lower speeds and by breaking the headlight glare of oncoming vehicles or bicycles. It is desirable to create a domed or mounded central island, between 3.5 to 6 feet high, to increase the visibility of the intersection on the approach. Contact the District Landscape Architecture Unit to provide technical assistance in designing the roundabout landscaping.

(17) Vertical Clearance.

The vertical clearance guidance provided in Index 309.2 applies to roundabouts.

(18) Drainage Design.

See Chapter 800 to 890 for further guidance.

(19) Maintenance.

Contact the District Maintenance Engineer and appropriate Regional Manager for maintenance strategies and practices including seasonal operations, maintenance resources, and specialized equipment. Maintenance responsibilities may also include multiple state, county, and city agencies where coordination of maintenance efforts and funding is needed.

Consider maintenance of the central island. Provide a maintenance vehicle pullout within the central island beyond the truck apron, so maintenance vehicles will not conflict with circulating trucks.

(20) Snow Areas.

In climate regions where snowfall requires the use of snow removal equipment, consider the equipment to be used. Design ICD's as well as entrance and exit geometry to accommodate snow removal equipment and plow limitations. Check with District Maintenance for their requirements and limitations. Geometric elements to consider that facilitate snow removal are; mountable curb, tapering the ends of curbs down to allow plows to ride over curbs, plowing accommodation in both directions, providing snow storage space within the central island, and providing minimum entry/exit widths to accommodate the plow blade. Mountable curb may be used if sidewalk/shared use path is not contiguous to the curb. Provide a planter or textured pavement between the path and the roadway. Snow storage areas must be designed to prevent snow melt from entering the circulating lanes where it can freeze. Snow storage areas must not block pedestrian paths.

(21) Utilities.

Utility access openings (manholes) should not be located within the traveled way within the boundary of the roundabout. Roundabouts do not have shoulders to accommodate traffic while manholes are accessed. Manholes should not be allowed within the circulating roadway to avoid closing down the intersection during access. If a manhole is absolutely necessary within the boundary of the inscribed diameter, place it in the central island and off of the truck apron. Provide a maintenance vehicle pullout to allow access to the manhole without blocking truck traffic.

Topic 406 - Ramp Intersection Capacity Analysis

The following procedure for ramp intersection analysis may be used to estimate the capacity of any signalized intersection where the phasing is relatively simple. It is useful in analyzing the need for additional turning and through traffic lanes. For a more complete analysis refer to the Highway Capacity Manual.

(a) Ramp Intersection Analysis--For the typical local street interchange there is usually a critical intersection of a ramp and the crossroads that establishes the capacity of the interchange. The capacity of a point where lanes of traffic intersect is 1500 vehicles per hour. This is expressed as intersecting lane vehicles per hour (ILV/hr). Table 406 gives values of ILV/hr for various traffic flow conditions.

If a single-lane approach at a normal intersection has a demand volume of 1000 vph, for example, then the intersecting single-lane approach volume cannot exceed 500 vph without delay.

The three examples that follow illustrate the simplicity of analyzing ramp intersections using this 1500 ILV/hr concept.

(b) Diamond Interchange--The critical intersection of a diamond type interchange must accommodate demands of three conflicting travel paths. As traffic volumes approach capacity, signalization will be needed. For the spread diamond (Figure 406A), basic capacity analysis is made on the assumption that 3-phase signalization is employed. For the tight diamond (Figure 406B), it is assumed that 4-phase signal timing is used.

(c) 2 Quadrant Cloverleaf--Because this interchange design (Figure 406C) permits 2-phase signalization, it will have higher capacities on the approach roadways. The critical intersection is shared two ways instead of three ways as in the diamond case.

Table 406

Vehicle Traffic Flow Conditions at Intersections at Various Levels of Operation

ILV/hr	Description
< 1200:	Stable flow with slight, but acceptable delay. Occasional signal loading may develop. Free midblock operations.
1200-1500:	Unstable flow with considerable delays possible. Some vehicles occasionally wait two or more cycles to pass through the intersection. Continuous backup occurs on some approaches.
1500 (Capacity):	Stop-and-go operation with severe delay and heavy congestion(1). Traffic volume is limited by maximum discharge rates of each phase. Continuous backup in varying degrees occurs on all approaches. Where downstream capacity is restrictive, mainline congestion can impede orderly discharge through the intersection.

NOTE:

(1) The amount of congestion depends on how much the ILV/hr value exceeds 1500. Observed flow rates will normally not exceed 1500 ILV/hr, and the excess will be delayed in a queue.

Figure 406A
Spread Diamond

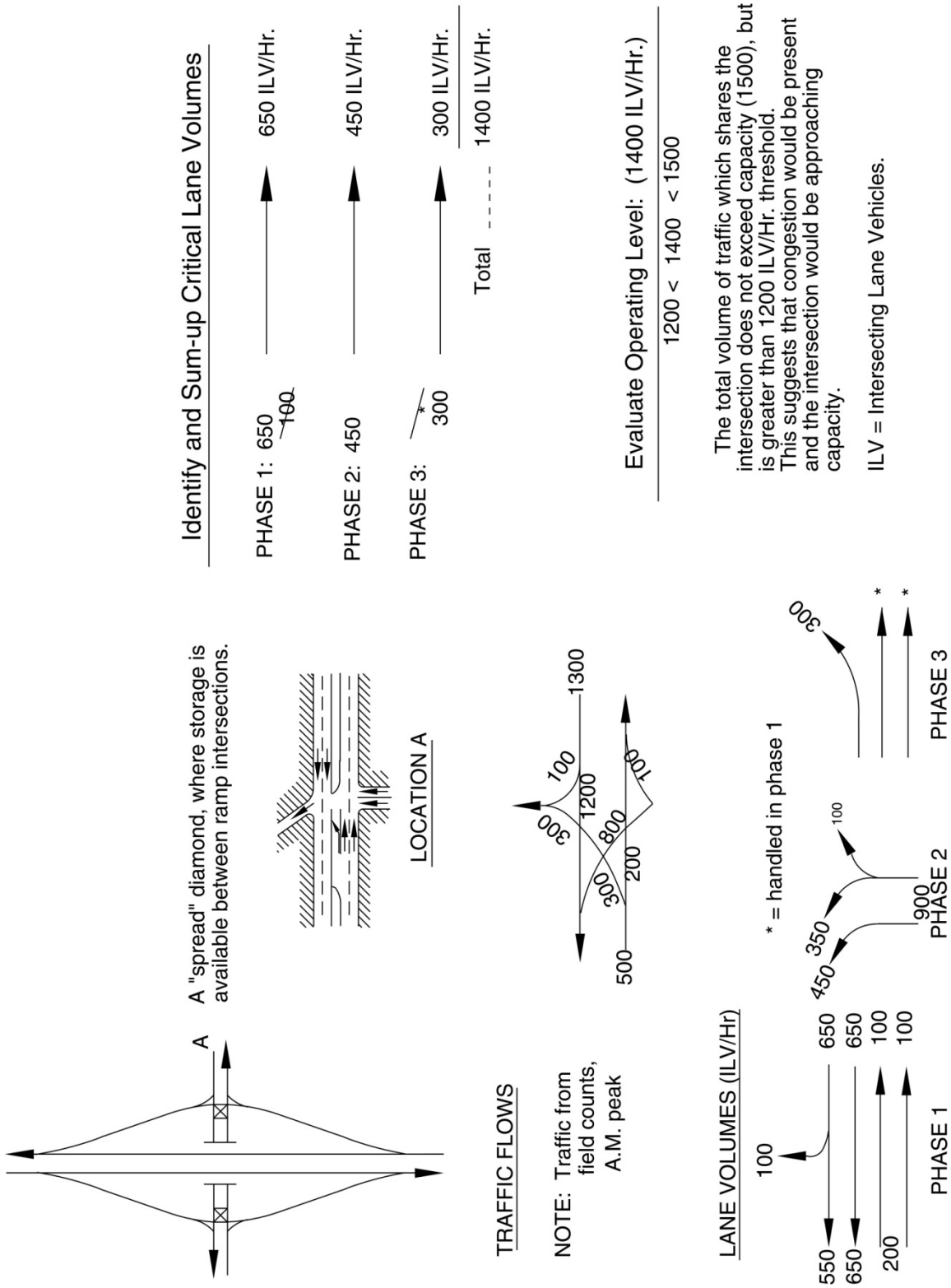
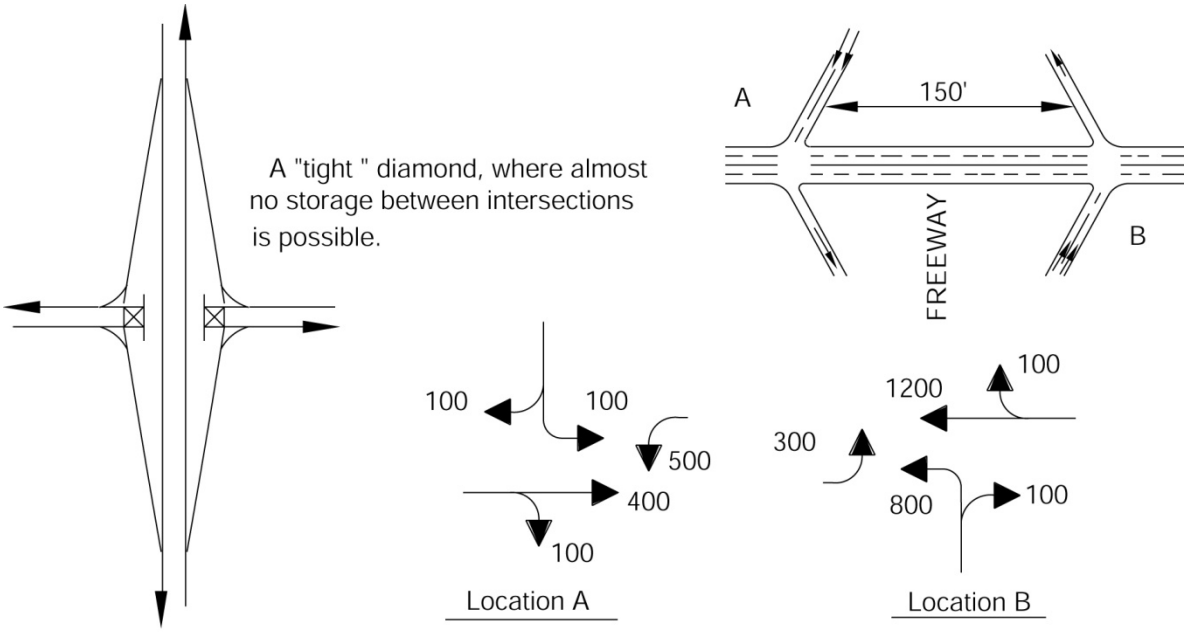
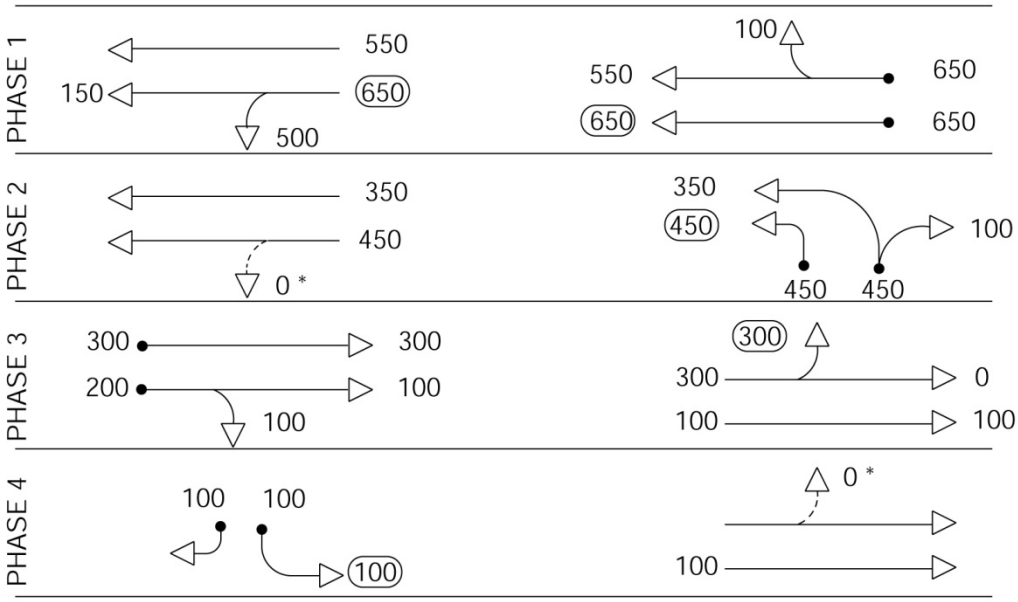


Figure 406B
Tight Diamond





*NOTE: When no storage at all is permitted, left-turn movement is cleared during this phase.

Critical Lane Volumes:	650
	450
	300
ILV=Intersecting Lane Vehicles.	100
	1500 ILV/Hr.

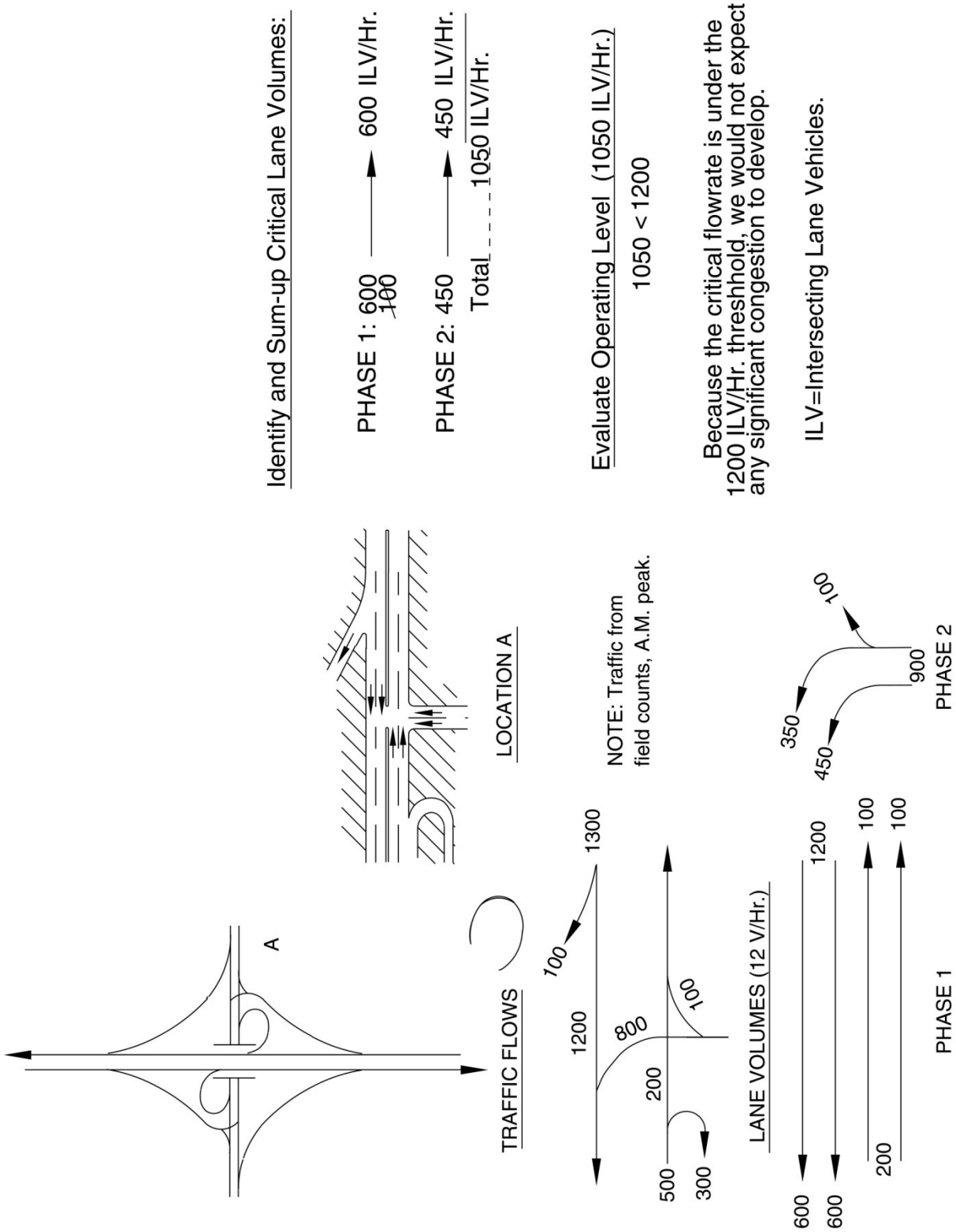



Figure 406C
Two-quadrant Cloverleaf