CHAPTER 400
INTERSECTIONS AT GRADE

Topic 401 - Factors Affecting Design

Index 401.1 - General

At-grade intersections must handle a variety of conflicts among vehicles, pedestrians, and bicycles. These recurring conflicts, a unique characteristic of intersections, play a major role in the preparation of design standards and guidelines. Arriving, departing, merging, turning, and crossing paths of moving traffic have to be accommodated within a relatively small area.

401.2 The Driver

The assumption of certain driver skills is a factor in intersection design. A driver's perception and reaction time set the standards for sight distance and length of transitions.

401.3 The Vehicle

Size and maneuverability of vehicles are factors that influence the design of an intersection.

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.

401.4 The Environment

In highly developed urban areas, street parking, pedestrians, and transit buses add to the complexity of a busy intersection.

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

Residential areas may have school children and bicycles to accommodate (see Indexes 105.1 and 1003.2).

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

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.

401.5 The Pedestrian

Pedestrian considerations are an integral part of intersection design because of their potential conflict with motor vehicles. Such factors include pedestrian volumes, their age and physical abilities, etc. Geometric features which may affect the pedestrian should be taken into account. See Topic 105 Pedestrian Facilities and Chapters 6 and 10 of the Traffic Manual.

401.6 The Bicyclist

The presence of bicyclists on State routes should be considered early in design. Chapter 1000 gives information on bikeway planning and design criteria.

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. Chapter 10 of the "Highway Capacity Manual", gives 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. See Chapter 9 of the Traffic Manual for signal warrants.

(2) Signalized Intersections. See Topic 406 for analysis of simple signalized intersections, including ramps. The analysis of complex signalized intersections should be referred to the District Traffic Branch.

402.2 Accidents

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

The type of traffic control affects the type of accidents. Signalized intersections tend to have more rear enders and same-direction sideswipes than stop-controlled intersections. The latter tend to have more angle or crossing accidents due to a lack of positive control.

(2) Undesirable Geometric Features.

- Inadequate approach sight distance.
- Inadequate corner sight distance.
- Steep grades.
- Inappropriate traffic control.
- Five or more approaches.
- Presence of curves within intersections.

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 intersectional areas are usually undesirable. The hazards of conflicting movements are magnified when drivers and bicyclists are unable to anticipate movements of other traffic 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.

Large areas of intersectional conflicts are characteristic of skewed intersection angles. Therefore, angles of intersection approaching 90° will aid in reducing conflict areas.

403.3 Angle of Intersection

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

- The shortest crossing distance for motor vehicles, bicycles, and pedestrians.
- Sight lines which optimize corner sight distance and the abilitiy of drivers to judge the relative position and speed of approach vehicles.

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. 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 403.3). A 75 degree angle does not unreasonably increase the crossing distance or generally decrease visibility.

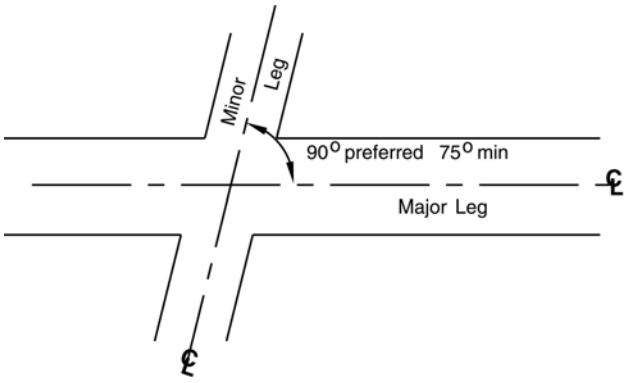
When existing intersection angles are less than 75 degrees, the following retrofit improvement strategies should be considered:

- 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.

For additional guidance on the above and other improvement strategies, consult the Design Reviewer or 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%) 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.

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



403.4 Points of Conflict

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

403.5 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.

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.

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.

403.7 Refuge Areas

The shadowing effect of traffic islands may be used to provide refuge areas for turning and crossing vehicles. Adequate shadowing provides refuge for a vehicle waiting to cross or enter an uncontrolled traffic stream. Similarly, channelization also may provide a safer crossing of two or more traffic streams by permitting drivers to select a time gap in one traffic stream at a time.

Traffic islands also may serve the same purposes for pedestrians and disabled persons.

403.8 Prohibited Turns

Traffic islands may be used to divert traffic streams in desired directions and prevent undesirable movements. Care should be taken that islands used for this purpose accommodate convenient and safe pedestrian 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 traffic which may move through the intersection during separate signal phases. This requirement is of particular importance when traffic-actuated signal controls are employed.

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.
- 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 built-in hazards.

403.12 Precautions

- Striping is usually preferable to curbed islands, especially adjacent to high-speed traffic where curbing can be an obstruction to out-of-control vehicles.
- Where curbing must be used, first consideration should be given to mountable curbs. Barrier curbs are usually justified only where protection of pedestrians is a primary consideration.
- Avoid complex intersections that present multiple choices of movement to the driver.
- Traffic safety should be considered. Accident records provide a valuable guide to the type of channelization needed.

Topic 404 - Design Vehicles

404.1 Offtracking

Any vehicle whether car, bus, truck, or combination tractor semi-trailer while turning a curve covers a wider path than the width of the vehicle. The front steering axle can generally follow a circular curve, but the following axles (and trailers) will swing inside toward the center of the curve. Some terminology is vital to understanding the engineering concepts. *Tracking width* is the distance measured along the curve radius from the outside front steering tire track to the inside rear tire track as they traverse around a curve. *Offtracking* is the difference between the tracking width and the vehicle axle width. *Swept width* is the total path width needed by the vehicle body to traverse a curve. Swept width always exceeds tracking width. Therefore a swept width is the preferred vehicle performance reference for design of tight curves on narrow mountainous roads and tight intersections with obstructions.

Computer software can determine the swept width at any point around a circular curve. An automated plotter can draw the swept width of vehicle body path for the preparation of a vehicle turn template.

Computer aided designs for truck turns plotted directly on geometric drawings must utilize curves with the same radii used to develop the truck turn templates included in Topic 407. Compound curves or multiple curves with intervening tangents should not be used.

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

404.2 Design Vehicles

(1) STAA. The Surface Transportation Assistance Act of 1982 (STAA), allows large trucks to operate on the Interstate and certain Federal Aid Primary System routes collectively called the National Network. For guidance refer to the current AASHTO publication, "A Policy on Geometric Design of Highway and Streets." Vehicle dimensions are spelled out in federal law on the maximum length of the semi-trailer (14.63 m for single and 8.69 m for double semi-trailers) and the maximum width (2.6 m). The truck shown in Figure 404.2 is representative of the large tractor semi-trailer combinations allowed on the National Network.

The STAA Design Vehicle is the model for truck-turn templates to be used on the National Network, Terminal Access Routes and Service Access Routes (STAA Network of Highways).

A current map titled "Truck Networks on California State Highways" is available through the Truck Size Branch of the Division of Traffic Operations in Headquarters, or through the District Traffic Engineer in each District. This map identifies the State highway routes on which defined trucks (STAA or California) can operate.

Consideration to widening the roadway width may be needed when encountering curved alignments. Depending on the severity of the curved alignment, trucks may off-track onto adjacent or opposing lanes. Some examples are in mountainous areas and construction areas. On curvilinear alignments, it is allowable to utilize the shoulders for off tracking. For further discussion and guidance refer to the current AASHTO publication, "A Policy on Geometric Design of Highway and Streets."

(2) California. California statutes limit the overall length of a tractor semi-trailer combination to 19.81 m for trucks operating on all highways in California unless National Network provisions apply. The law also limits the kingpin to rearmost axle dimension to 12.19 m for semi-trailers with two or more axles (11.58 m for single axle) and the width to 2.6 m.

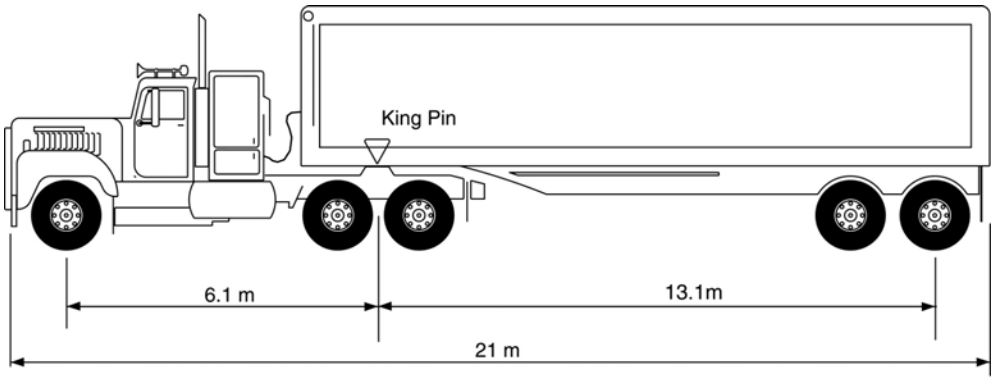
The California Legal Design Vehicle shown in Figure 404.2 is the model for truck-turn templates to be used on all routes off the National Network and the Terminal Access Routes.

(3) Bus. The AASHTO Bus Design Vehicle shown in Figure 404.2 is an AASHTO standard. Its 7.6 m wheel base and 12.2 m overall length are typical of transit and intercity buses. It is the model for the bus-turn template to be used under special circumstances.

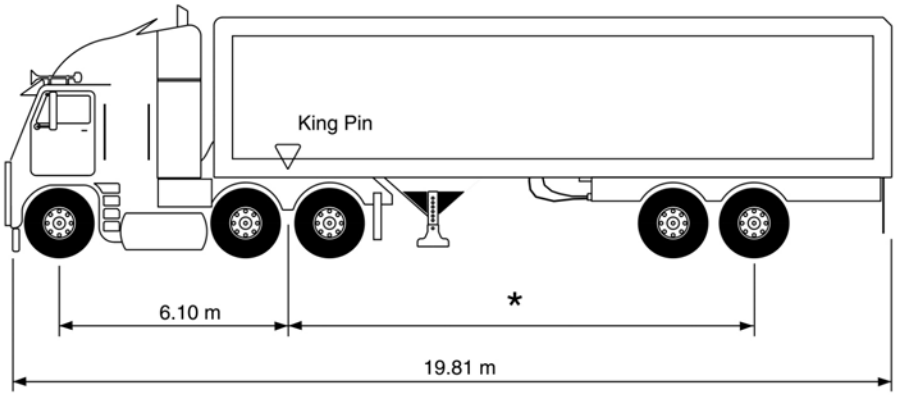
404.3 Turning Templates

(1) General. The truck-turn template is a design aid for locating the wheel paths of large vehicles as they turn through at-grade intersections. Consideration should be given to the overhang of the truck, where the body of the truck slightly extends (approximately 0.6 m) beyond the wheel path. The template is useful for determining corner radii, for positioning island noses, and for establishing clearance to bridge piers, signal poles, and other hardware at intersections. Templates can help determine the width of a channeled separate turning lane. Topic 407 illustrates scaled turning templates for the various design vehicles and turning radii.

Figure 404.2
Design Vehicles

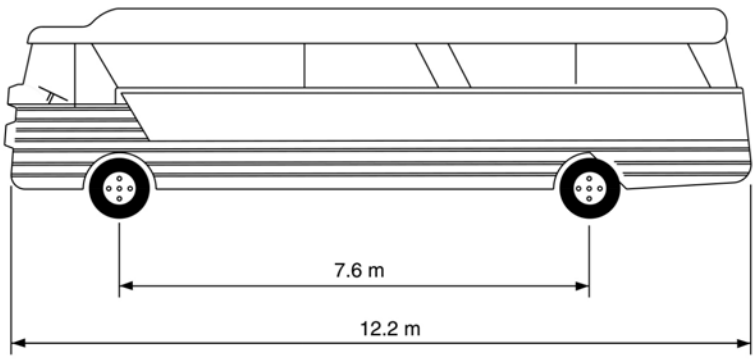


1 - STAA Design Vehicle



* 12.19 m two or more axles
11.58 m one axle

2 - California Design Vehicle



3 - Bus Design Vehicle

(2) *STAA Truck.* The STAA truck-turn templates should be used in the design of all new interchanges and intersections on the National Network and on routes leading from the National Network to designated service and terminal routes. On rehabilitation projects they should be used at interchanges and intersections proposed as service or terminal access routes. In some cases, factors such as cost, right of way, environmental issues, local agency desires, and the type of community being served may limit the use of the STAA templates. In those cases, other appropriate templates should be used.

The minimum practical turning radius is 15 m. However, the 18 m radius develops less swept width and may have an advantage. The 18 m radius should be used in most situations, but the 15 m radius is acceptable in restricted situations.

(3) *California Truck.* The California truck-turn template should be used in the design of highways not on the National Network. The minimum practical turning radius is 15 m.

(4) *Bus.* At intersections where truck volumes are light or where the predominate truck traffic consists of mostly 3-axle and 4-axle units, the bus turning template may be used. Its wheel paths sweep a greater width than 3-axle delivery trucks and the smaller buses such as school buses, but a slightly lesser width than a 4-axle truck.

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 waiting at the crossroad and the driver of an approaching vehicle. Adequate time must be provided for the waiting vehicle 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% and longer than 2 km (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 on the crossroad shall be a minimum of 3 m plus the shoulder width of the major road but not less than 4 m.** Corner sight distance is to be measured from a 1070 mm height at the location of the driver on the minor road to a 1300 mm object height in the center of the approaching lane of the major road. If the major road has a median barrier, a 600 mm 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 unmitigable 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)--At unsignalized public road intersections (see Index 405.7) corner sight distance values given in Table 405.1A should be provided.

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 vehicle conflicts can occur due to violation of signal, right turns on red, malfunction of the signal, or use of flashing red/yellow mode.

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 1070 mm eye height and the 150 mm 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.

(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
- turning volumes
- horizontal curve radii
- sight distance
- proximity of adjacent intersections
- types of adjacent intersections

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

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

Design Speed (km/h)	Corner Sight Distance (m)
40	90
50	110
60	130
70	150
80	170
90	190
100	210
110	230

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 Intersections & Route Direction Changes, with or without Signals	X	X	X

(1) Using stopping sight distance between an eye height of 1070 mm and an object height of 1300 mm. 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).

405.2 Left-turn Channelization

(1) General. The purpose of a left-turn lane is to expedite the movement of through traffic, control the movement of turning traffic, increase the capacity of the intersection, and improve safety characteristics.

The District Traffic Branch normally establishes the need for left-turn lanes. See "Guidelines for Reconstruction of Intersections," August 1985, published by the California Division of Transportation Operations.

(2) Design Elements.

(a) Lane Width -- **The lane width for both single and double left-turn lanes on State highways shall be 3.6 m.** Under certain circumstances (listed below), left-turn lane widths of 3.3 m or as narrow as 3.0 m may be used on RRR or other projects on existing State highways and on roads or streets under other jurisdictions when supported by an approved design exception pursuant to Index 82.2. 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.

- On high speed rural highways or moderate speed suburban highways where width is restricted, the minimum width of single or dual left-turn lanes may be reduced to 3.3 m.
- In severely constrained situations on low to moderate speed urban highways where large trucks are not expected, the minimum width of single left-turn lanes may be reduced to 3.0 m. When double left-turn lanes are warranted under these same circumstances the width of each lane shall be no less than 3.3 m. This added width is needed to assure adequate clearance between turning vehicles.

(b) Approach Taper -- On a conventional highway 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.

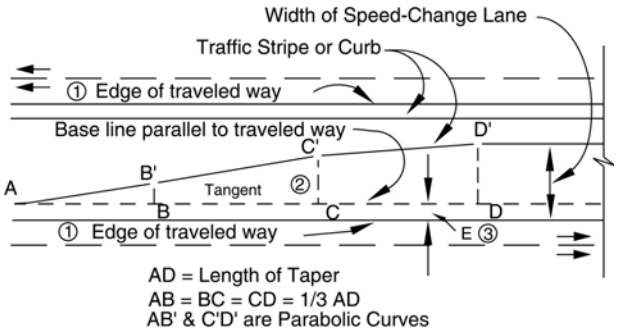
Figure 405.2A shows a standard left-turn channelization design in which all widening is to the right of approaching traffic and the deceleration lane (see below) begins at the end of the approach taper. This design should be used in all situations where space is available, usually in rural and semi-rural 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 18 m and 27 m are normally used. Where space is restricted and speeds are low, a 18 m bay taper is appropriate. On rural high-speed highways, a 36 m 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 15 to 30 km/h 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.

Table 405.2A
Bay Taper for Median Speed-change Lanes



	LENGTH OF TAPER - meters				OFFSET DISTANCE			
	18	27	36		DD' = 3.0 m	DD' = 3.3 m	DD' = 3.6 m	
	Distance From Point "A"							
	-	-	-		0	0	0	
	1.5	2.25	3.0		0.048	0.051	0.057	
	3.0	4.5	6.0		0.186	0.207	0.225	
	4.5	6.75	9.0		0.423	0.465	0.507	
B'	6	9	12	B'	0.75	0.825	0.90	B'
	9	13.5	18		1.50	1.65	1.80	
C'	12	18	24	C'	2.25	2.475	2.70	C'
	13.5	20.25	27		2.58	2.84	3.10	
	15	22.5	30		2.81	3.09	3.38	
	16.5	24.75	33		2.95	3.25	3.54	
	18	27	36		3.0	3.3	3.6	

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 0.6 m along edge of traveled way for curbed medians; Use "E" = 0 m for striped medians.

Table 405.2B
Deceleration Lane Length

Design Speed (km/h)	Length to Stop (m)
50	75
60	94
70	113
80	132
90	150
100	169

(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. As a minimum, space for 2 passenger cars should be provided at 7.5 m per car. If the peak hour truck traffic is 10 % or more, space for one passenger car and one truck should be provided.

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. As a minimum, storage length should be calculated 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 1 m, but not more than 10 m, from the nearest edge of shoulder of the intersecting roadway. Although often set by the placement of a crosswalk stripe or limit line, the end of the storage lane should always be located so that the appropriate turning template can be accommodated.

(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) apply 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 3.6 m (see Index 301.1). The preferred width is 4.2 m. Wider TWLTL's are occasionally provided to conform with local agency standards. However, TWLTL's wider than 4.2 m are not recommended, and in no case should the width of a TWLTL exceed 4.8 m. Additional width may encourage drivers in opposite directions to use the TWLTL simultaneously.

405.3 Right-turn Channelization

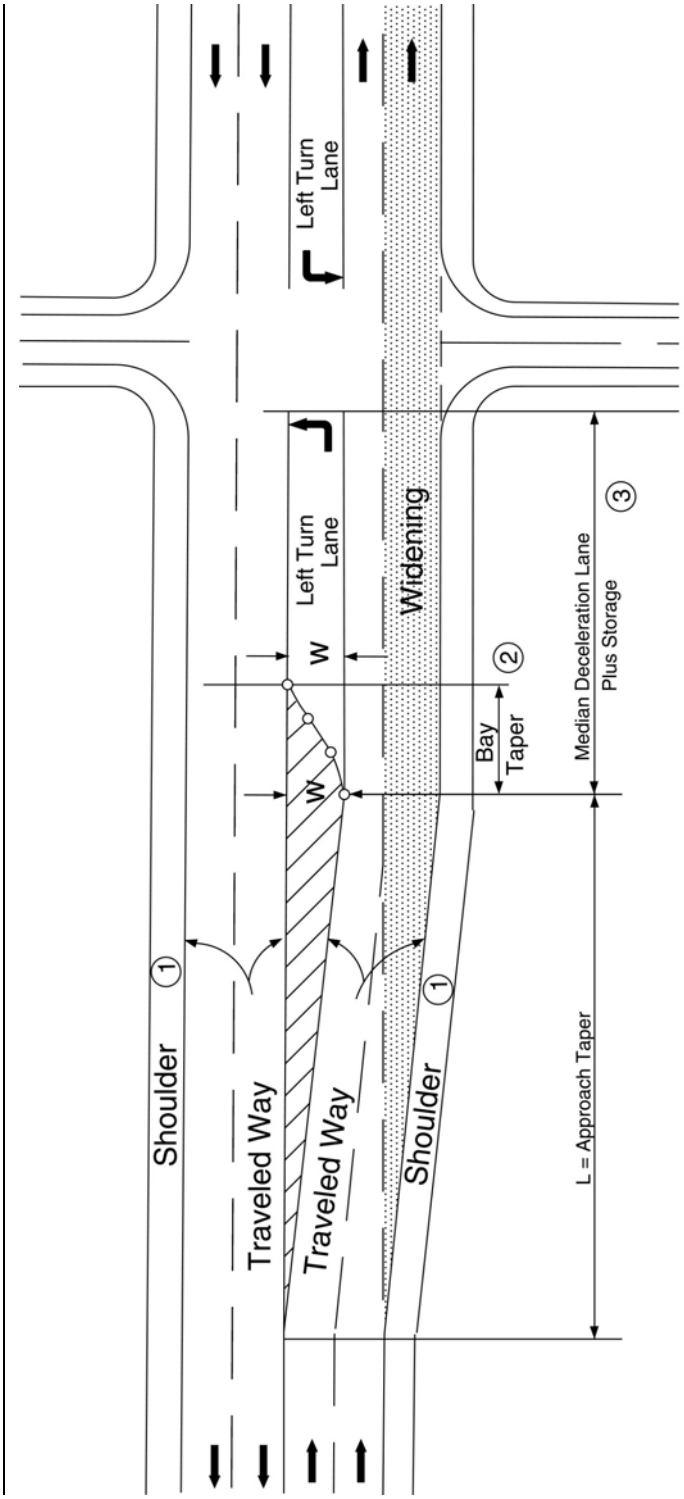
(1) General. For right-turning traffic, delays are less critical and conflicts less severe than for left-turning traffic. Nevertheless, right-turn lanes can be justified on the basis of capacity, analysis, and accident experience.

In rural areas a history of high speed rear-end accidents 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.
- Pedestrians conflicting with right turning vehicles.
- Frequent rear-end and sideswipe accidents involving right-turning vehicles.

Figure 405.2A
Standard Left-turn Channelization



EQUATION: L = Use (2/3)WV, for V≥70km/h④
Or $WV^2/150$, for V<70km/h

Where L = Length of Approach Taper - meters
V = Design Speed - km/h
W = Width of Median Lane - meters

NOTES:

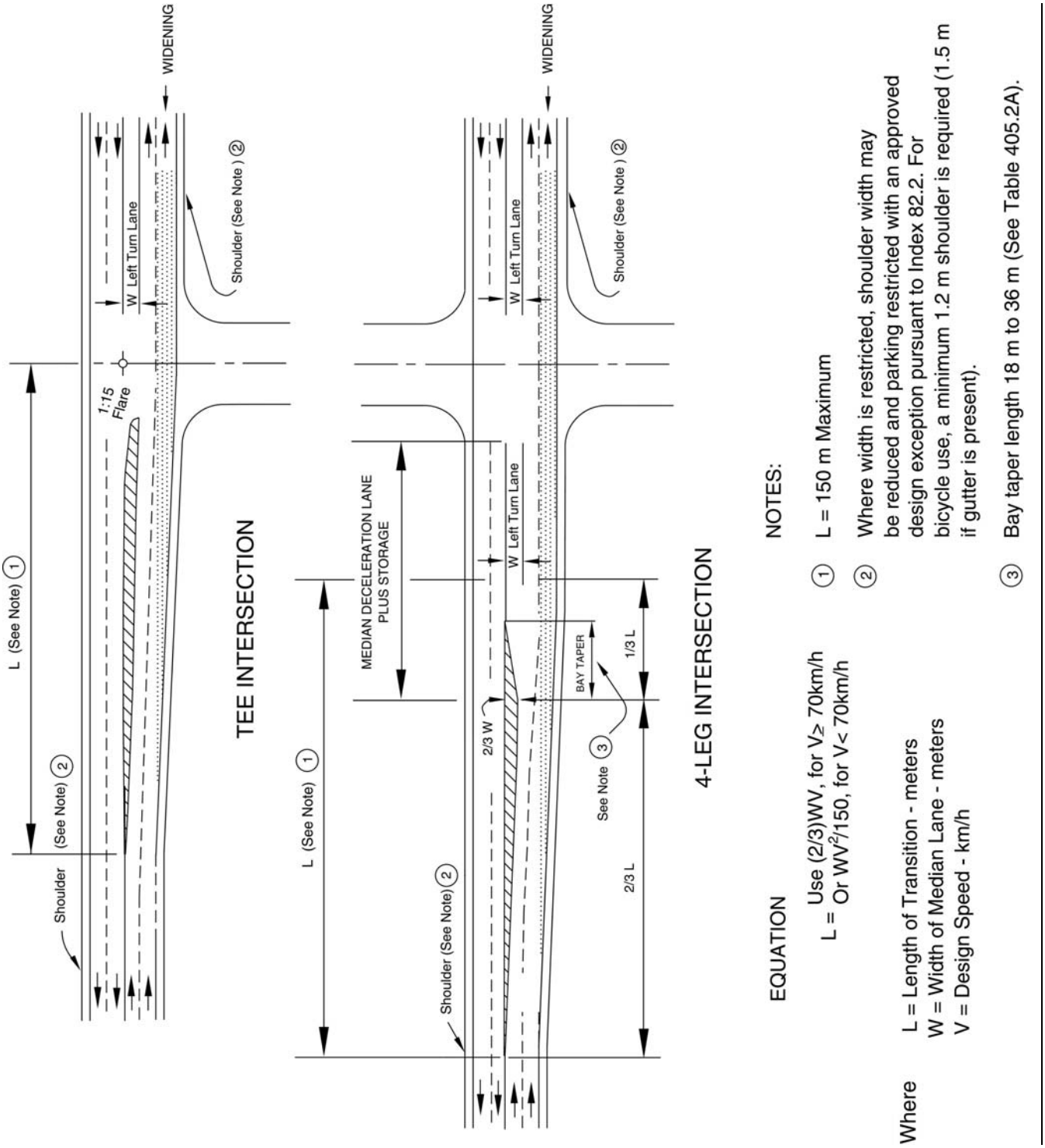
① Where width is restricted, shoulder width may be reduced and parking restricted with an approved design exception pursuant to Index 82.2.
For bicycle use, a minimum 1.2 m shoulder is required (1.5 m if gutter is present).

② Bay taper length = 18 m to 36 m. (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)



NOTES:

① L = 150 m 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 1.2 m shoulder is required (1.5 m if gutter is present).

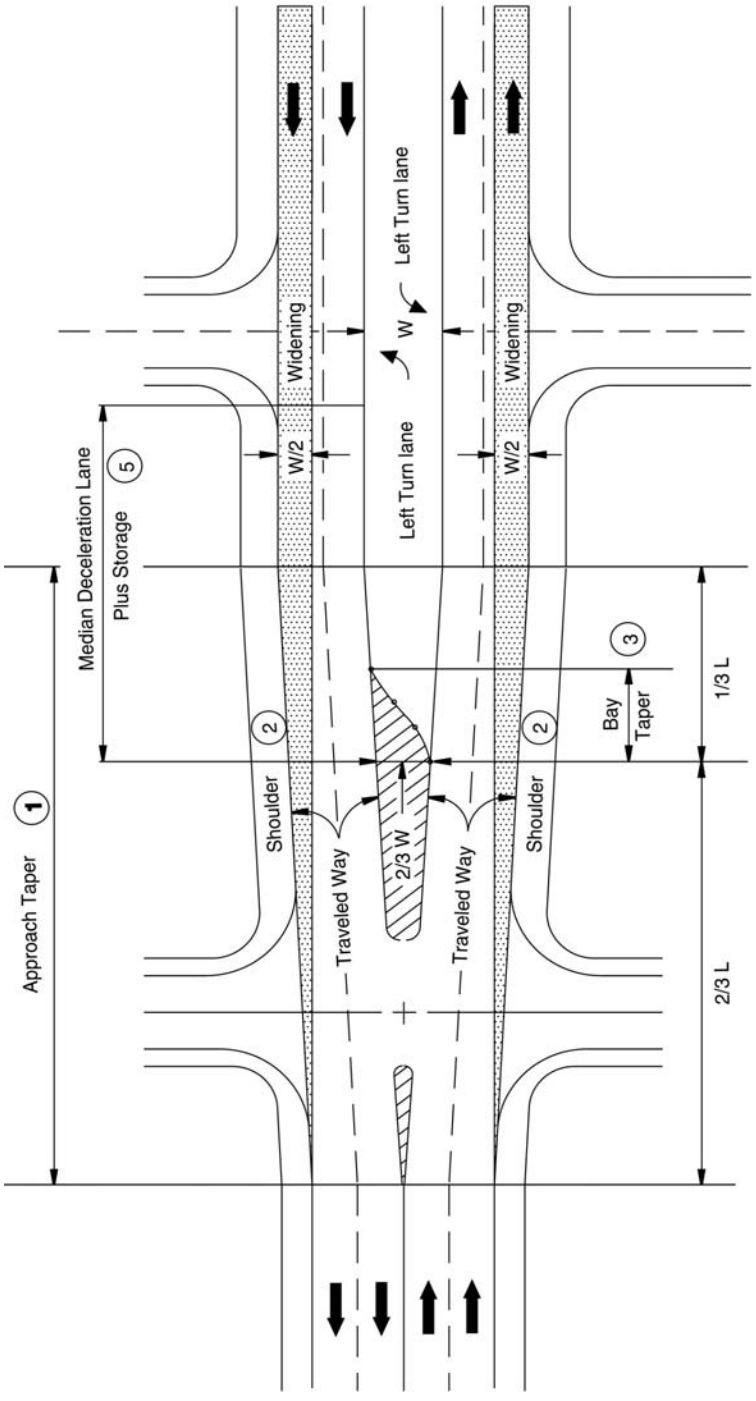
③ Bay taper length 18 m to 36 m (See Table 405.2A).

EQUATION

$$L = \begin{matrix}\text{Use } (2/3)WV, \text{ for } V \geq 70\text{km/h} \\ \text{Or } WV^2/150, \text{ for } V < 70\text{km/h}\end{matrix}$$

Where L = Length of Transition - meters
W = Width of Median Lane - meters
V = Design Speed - km/h

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



NOTES:

① L = 150 m 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 1.2 m shoulder is required (1.5 m if gutter is present).

③ Bay taper length = 18 m to 36 m. (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 $(1/3)WV$, for $V \geq 70$ km/h
Or $WV^2/300$, for $V < 70$ km/h

Where L = Length of Approach Taper - Meters
W = Width of Median Lane - Meters
V = Design Speed - km/h

(2) Design Elements.

(a) Lane and Shoulder Width--**The basic lane width for right turn lanes shall be 3.6 m. Shoulder width shall be a minimum of 1.2 m.** Whenever possible, consideration should be given to increasing the shoulder width to 2.4 m to facilitate the passage of bicycle traffic and provide space for vehicle breakdowns. Although not desirable, lane and shoulder widths less than those given above can be considered for right turn lanes under the following conditions and with the approval of a design exception pursuant to Index 82.2.

- On high speed rural highways or moderate speed suburban highways where width is restricted, consideration may be given to reducing the lane width to 3.3 m with approval of a design exception.
- On low to moderate speed roadways in severely constrained situations, consideration may be given to reducing the minimum lane width to 3.0 m with approval of a design exception.
- Shoulder widths may also be considered for reduction under constricted situations. Whenever possible, at least a 0.6 m offset should be provided where the right turn lane is adjacent to a curb. Entire omission of the shoulder should only be considered in the most severely constricted situations and where an 3.3 m lane can be constructed. Gutter pans can be included within a shoulder, but cannot be included as part of the lane width.

Additional right of way for a future right-turn lane should be considered when an intersection is being designed.

(b) 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.

(c) 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 15 to 30 km/h for a lower entry speed. For example, if the main line speed is 80 km/h and a 20 km/h deceleration is permitted on the through lanes, the deceleration length may be that required for 60 km/h.

(d) 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 cause problems 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. Also, rear-end accidents 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.

Free right turns should generally be avoided unless there is room for a generous acceleration lane or a lane addition on the local street. See Index 504.3(2) for additional information.

405.4 Traffic Islands

A traffic island is an area between traffic lanes for control of vehicle movements or for pedestrian refuge. An island may be designated by paint, raised pavement markers, curbs, pavement edge, or

other devices. Examples of traffic island designs are shown on Figure 405.4.

Traffic islands usually serve more than one function, but may be generally classified in three separate types:

(a) Channelizing islands which are designed to confine specific traffic movements into definite channels;

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

(c) Refuge islands to aid and protect pedestrians crossing the roadway. If a divisional island is located in an urban area where pedestrians are present, portions of each island can be considered a refuge island.

Traffic islands are also used to discourage or prohibit undesirable movements.

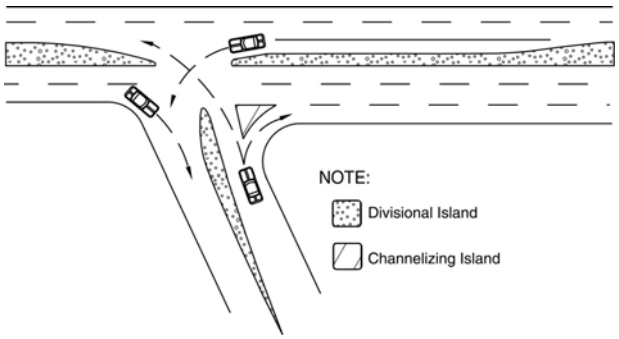
(1) Design of Traffic Islands. Island sizes and shapes vary from one intersection to another. They should be large enough to command attention. Channelizing islands should not be less than 5 m^2 in area, preferably 7 m^2. Curbed, elongated divisional islands should not be less than 1.2 m wide and 6 m long.

The approach end of each island should be offset 1 m to the left and 1.5 m to the right of approaching traffic, using standard 1:15 parabolic flares, and clearly delineated so that it does not surprise the motorist. These offsets are in addition to the normal 0.6 m left and 2.4 m right shoulder widths. 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 7.5 m 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 1 m from the through traffic to minimize accidental impacts.

Figure 405.4

Traffic Island Designs



(2) Delineation of Traffic Islands. Generally, islands should present the least potential conflict to approaching vehicles and yet perform their intended function. When curbs are used, Type B is preferable except where a Type A curb is needed for traffic control or pedestrian refuge (see Index 303.2). Islands may be designated as follows:

(a) Raised paved areas outlined by curbs.

(b) Flush paved areas outlined by pavement markings.

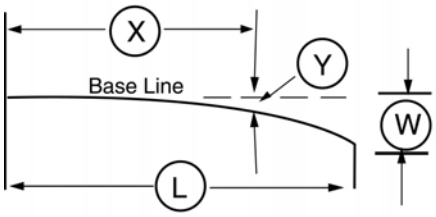
(c) Unpaved areas (small unpaved areas should be avoided).

On facilities with speeds over 75 km/h, 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 would be more appropriate than a raised curbed channelization. The design is as forgiving as possible and decreases the consequence of a driver's failure to detect or recognize the curbed island.

Table 405.4

Parabolic Curb Flares Commonly Used



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

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

(W) is shown in table thus

OFFSET IN METERS FOR GIVEN "X" DISTANCE																			
Distance (X) / Length of Flare (L)	2	4	5	8	10	12	15	16	18	20	22	24	26	28	30	32	34	36	45
1:5 FLARES																			
5	0.16	0.64	1.00																
10	0.08	0.32	0.50	1.28	2.00														
15	0.05	0.21	0.33	0.85	1.33	1.92	3.00												
1:10 FLARES																			
10	0.04	1.06	0.25	0.64	1.00														
20	0.02	0.08	0.13	0.32	0.50	0.72	1.13	1.28	1.62	2.00									
30	0.01	0.05	0.08	0.21	0.33	0.48	0.75	0.85	1.08	1.33	1.61	1.92	2.25	2.61	3.00				
1:15 FLARES																			
15	0.02	0.07	0.11	0.28	0.44	0.64	1.00												
30	0.01	0.04	0.06	0.14	0.22	0.32	0.50	0.57	0.72	0.89	1.08	1.28	1.50	1.74	2.00				
45	0.01	0.02	0.04	0.09	0.15	0.21	0.33	0.38	0.48	0.59	0.72	0.85	1.00	1.16	1.33	1.52	1.71	1.92	3.00

In urban areas, speeds less than 75 km/h allow more frequent use of curbed islands. Local agency requirements and matching existing conditions are factors to consider.

405.5 Median Openings

(1) General. Median openings, sometimes called crossovers, provide for vehicular 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 or for protection of traffic signal standards and other necessary hardware. 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 the freeway may be provided for law enforcement, emergency, and maintenance vehicles to avoid extreme out-of-direction travel. Access should not be more frequent than at 5 km intervals. See Chapter 7 of the Traffic Manual for additional information on the design of emergency passageways. Emergency passageways should be located where decision sight distance is available (see Table 201.7).

Median openings at close intervals on other types of highways create interference with fast through traffic. Median openings should be spaced at intervals no closer than 500 m. If a median opening falls within 100 m 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 8 to 15 km/h. The length of median opening varies with width of median and angle of intersecting road.

Usually a median opening of 18 m is adequate for 90 degree intersections with median widths of 6.6 m or greater. When the median width is less than 6.6 m, a median opening of 21 m 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%. Crossovers on curves with super elevation exceeding 5% 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% cross slope requirement when the existing roadbed is raised to its ultimate elevation.

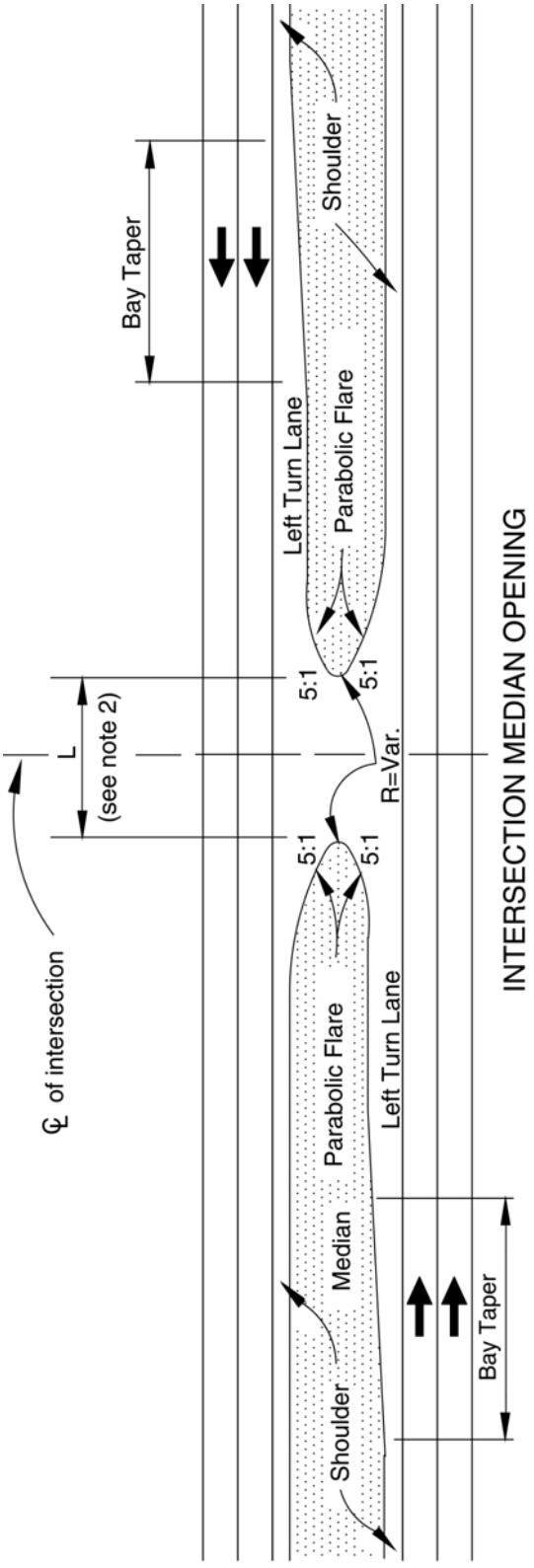
(5) References. For information related to the design of intersections and median openings, "A Policy on Geometric Design of Highways and Streets," AASHTO, should be consulted.

405.6 Access Control

The basic principles which govern the extent to which access rights are to be acquired at interchanges (see Index 205.1 and 504.8) 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 taking 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.

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=18 m for median of 6.6 m and wider. L=21 m for median narrower than 6.6 m

3 - See Index 405.2.

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 22.5 m 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 45 m 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.

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 taking into consideration the amount of available right of way, the roadway width, the number of lanes on the intersecting street, and the number of pedestrians.

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 anticipated, the STAA Design Vehicle template may be used giving consideration to factors mentioned above. (See Index 404.3.)

Smaller radii of 5 to 8 m are appropriate at minor cross streets where few trucks are turning. Local agency standards may be appropriate in urban and suburban areas.

Encroachment into opposing traffic lanes should be avoided.

405.9 Widening of 2-lane Roads at Signalized Intersections

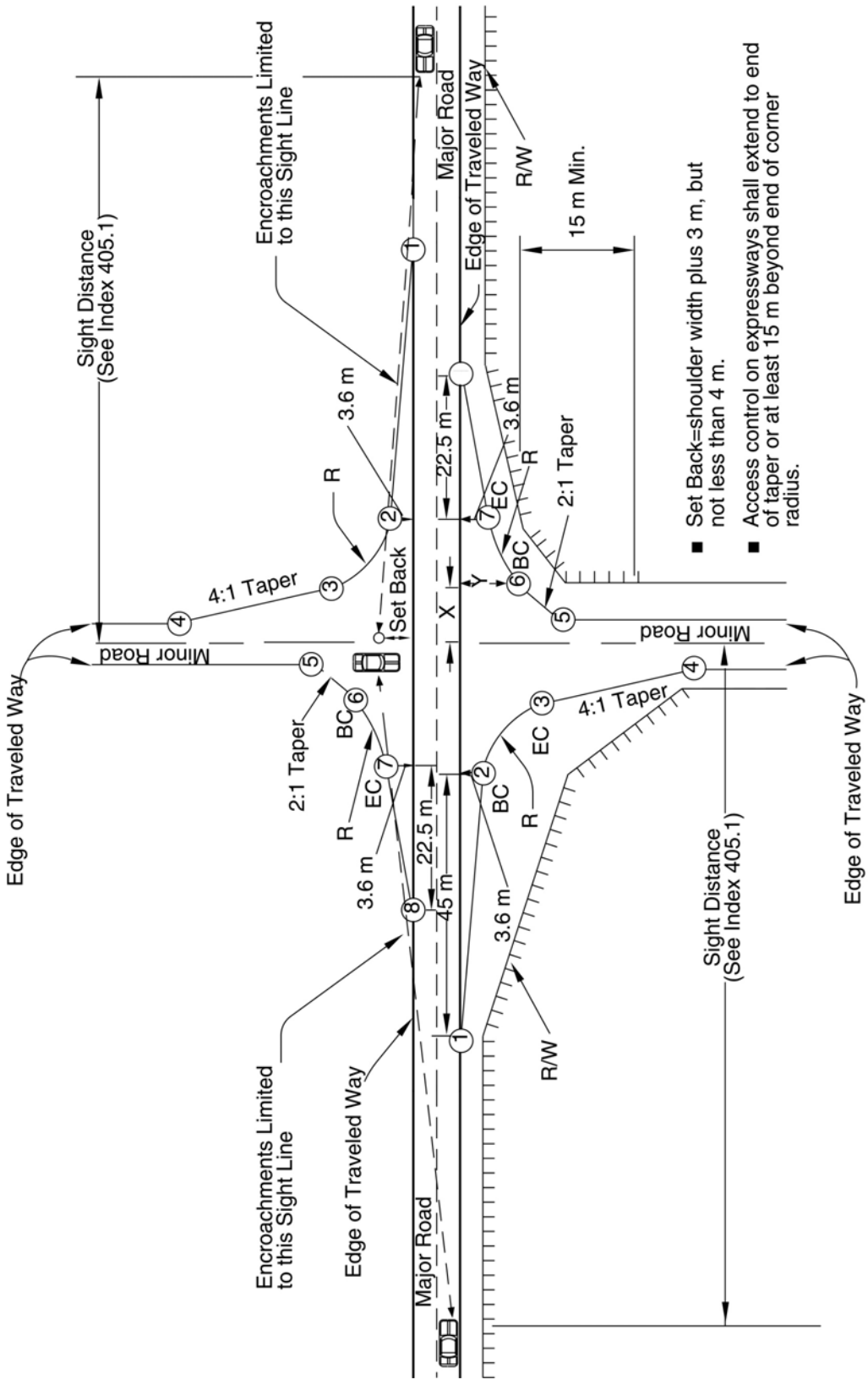
Two-lane state highways may be widened at intersections to 4-lanes whenever signals are installed. Sometimes it may be necessary to widen the intersecting road. The minimum design is shown in Figure 405.9. More elaborate treatment may be warranted by the volume and pattern of traffic movements. Unusual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

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.

(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.

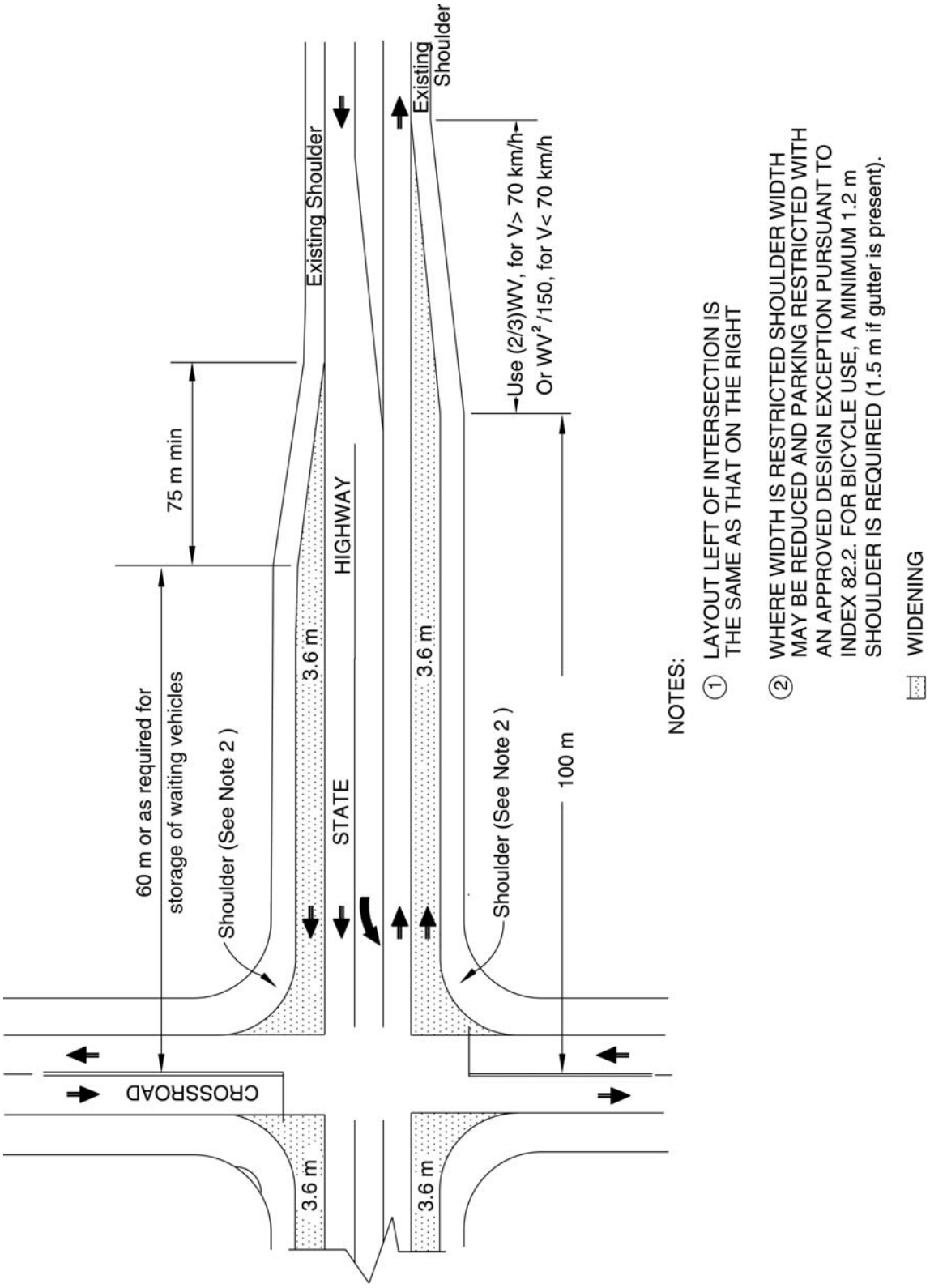
Figure 405.7
Public Road Intersections



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

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
9 m	Bus	61.26	0.0	16.26	3.6	8.25	10.39	3.6	28.97	3.6	12.20	5.47	8.46	12.10	3.6	34.60	0.0
12 m	California	64.52	0.0	19.52	3.6	8.84	12.65	3.6	33.61	3.6	16.01	6.56	10.08	15.40	3.6	37.90	0.0
15 m	STAA	67.85	0.0	22.83	3.6	9.47	14.91	3.6	38.39	3.6	22.69	9.09	11.70	20.14	3.6	42.64	0.0

Figure 405.9
Widening of Two-lane Roads at Signalized Intersections



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

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.

(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

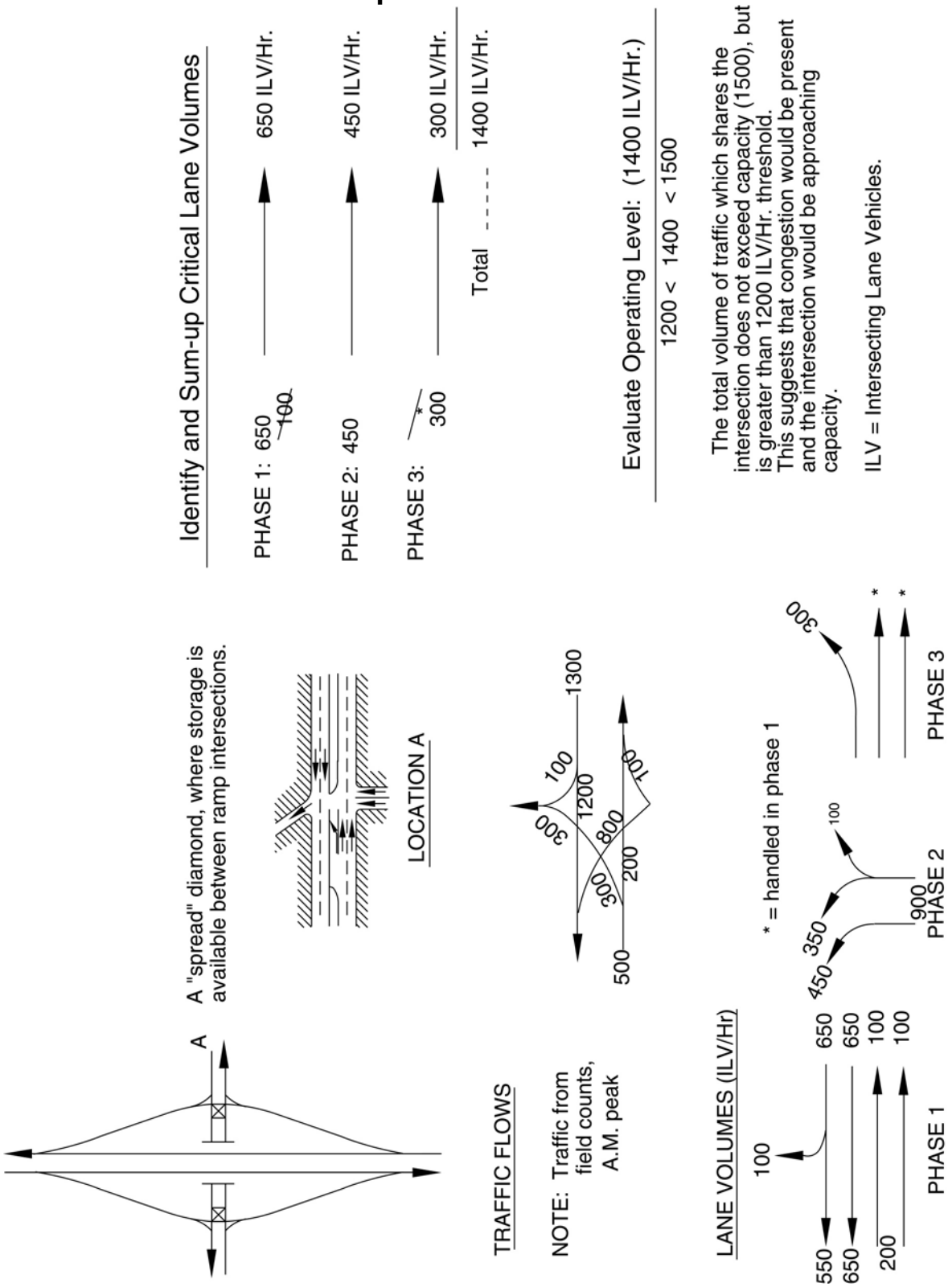
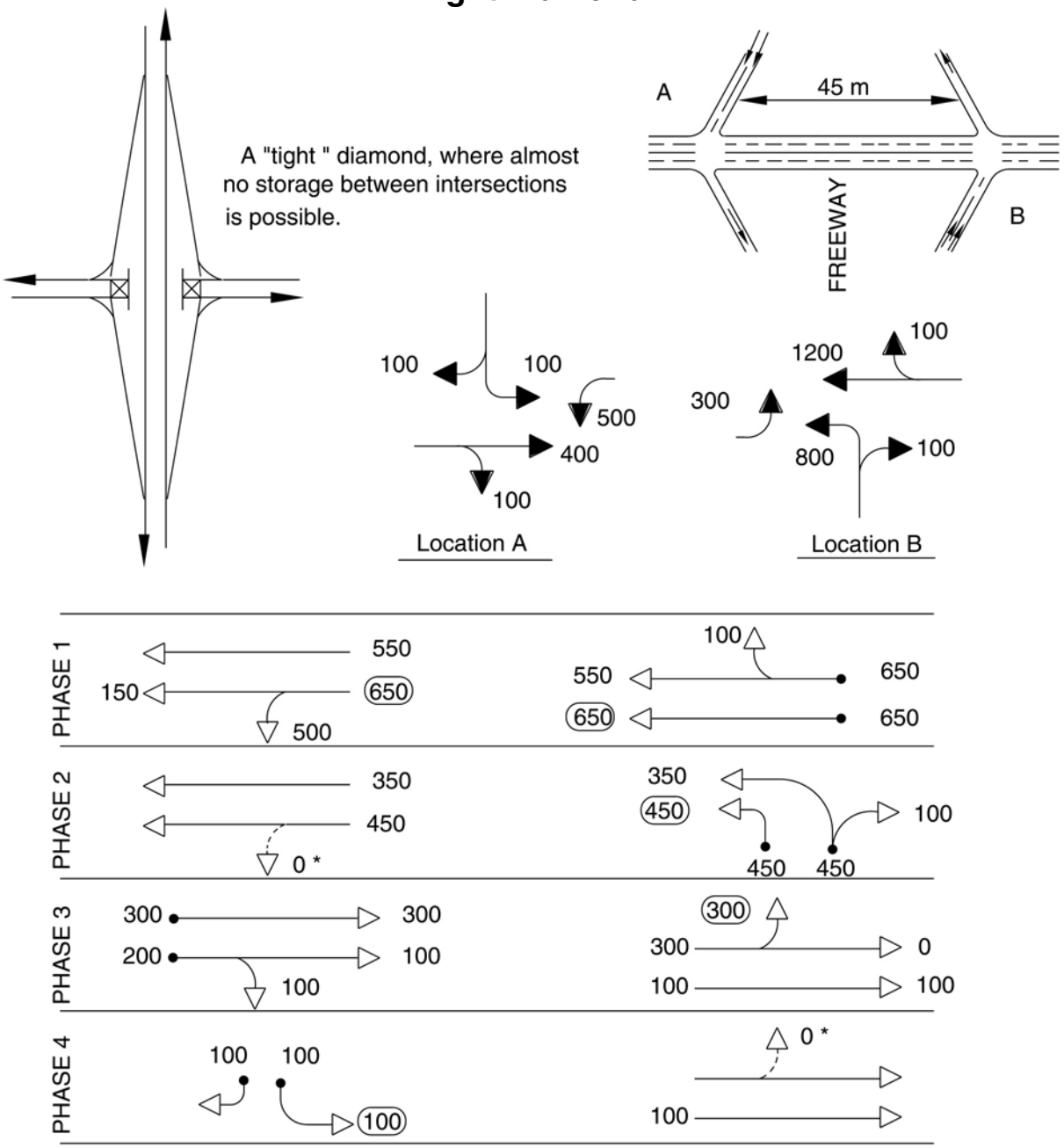


Figure 406B
Tight Diamond



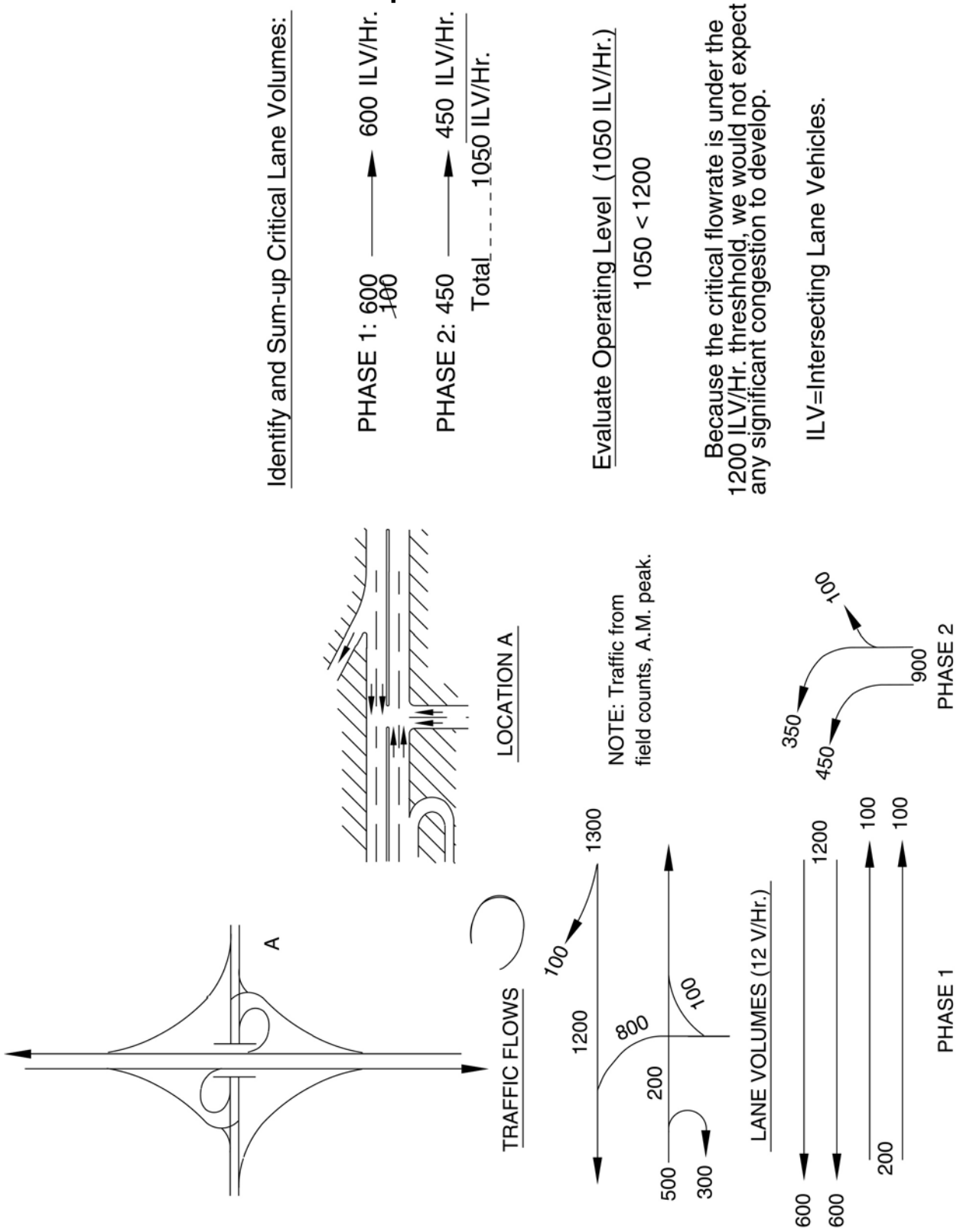
*NOTE: When no storage at all is permitted, left-turn movement is cleared during this phase.

Critical Lane Volumes:

650
450
300
100
1500 ILV/Hr.

ILV=Intersecting Lane Vehicles.

Figure 406C
Two-quadrant Cloverleaf



Topic 407 - Truck and Bus Turning Templates

Figures 407A through E are turning templates at an approximate scale of 1:500 for the three types of design vehicles described in Topic 404. A computer model of truck offtracking generated these "hard copy" templates. The printed templates can be used as overlays to evaluate the adequacy of the geometric layout of a curve when reproduced on clear film and scaled to match the highway drawings. The lines on the template delineate the path of the wheels and the body of the vehicle as the truck moves through the turn. These lines must clear any "obstacles" including curbs, islands, adjacent lanes, sign structures, traffic delineators, traffic signal and lighting poles, guardrails, trees and rock outcrops.

If any "obstacles" are encroached by the vehicle path on the template, then an alternative design is needed. If the wheel paths stay within the roadbed without "hitting" any obstacles, then the geometry is adequate for that design vehicle.

See Topic 404 for information on the design vehicles. A 15-meter and 18-meter radius template is given for each of the STAA and California Legal Design vehicles. The radius of the template is measured to the outside front wheel path through the curve. The 18-meter radius template is more conservative and is preferred. The 18-meter radius template requires less right of way on the inside of the curve, and it leaves a margin of error for the truck driver. The 18-meter radius template should be used for conditions where the vehicle may not be required to stop before entering the intersection. The 15-meter radius template can be used if the 18-meter radius template does not clear all obstacles. A 15-meter radius is the minimum radius that a STAA or California Design Vehicle can navigate.

- Figures 407A and B are templates for the STAA Design Vehicle turning on 15-meter and 18-meter radii, respectively.
- Figures 407C and D are templates for the California Design Vehicle turning on 15-meter and 18-meter radii, respectively.
- Figure 407E is the template for the AASHTO Bus Design Vehicle turning on a 12.8-meter radius.

Figure 407A

STAA Semitrailer Wheel Tracks
15 m Radius

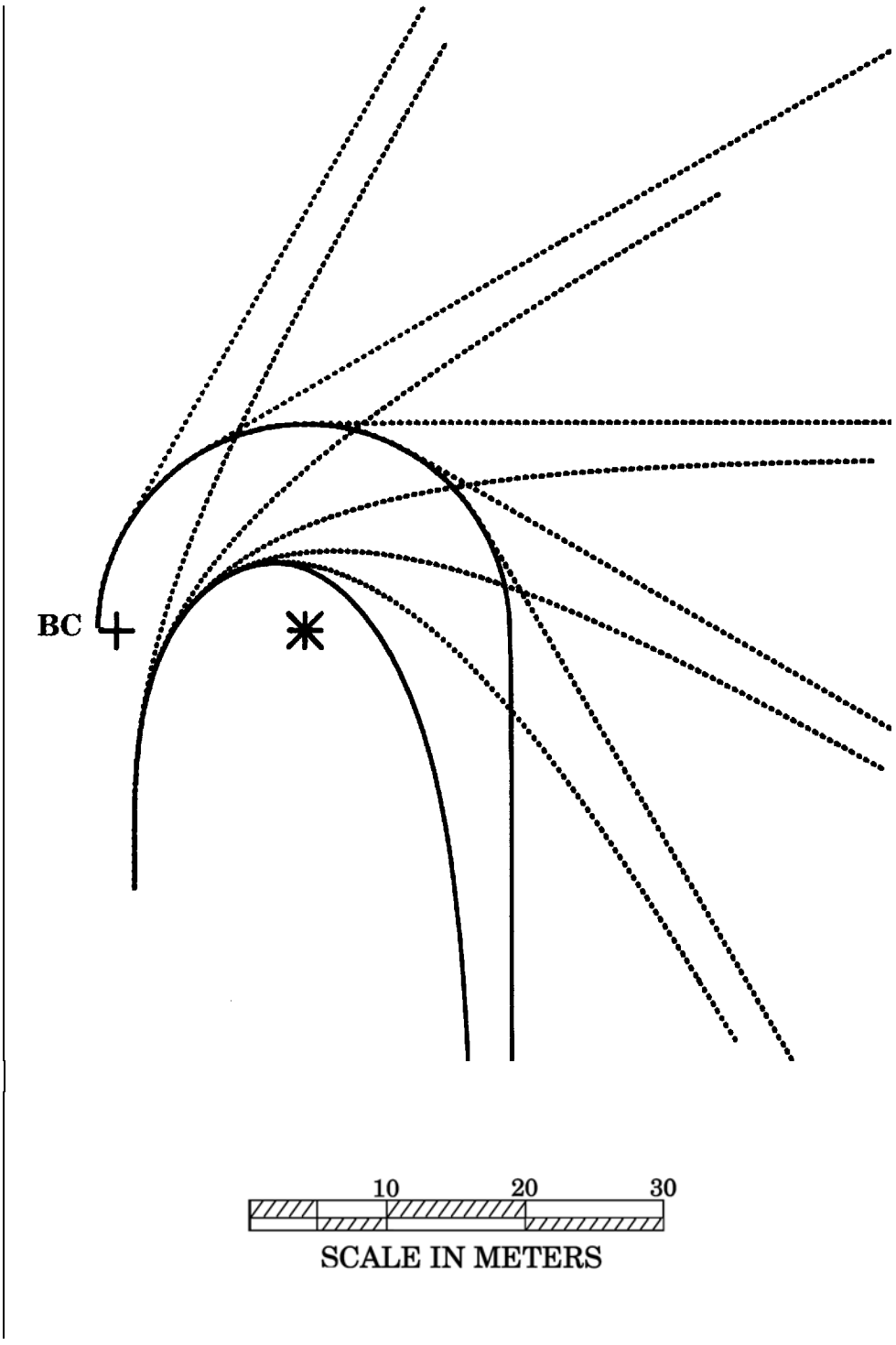


Figure 407B
STAA Semitrailer Wheel Tracks
18 m Radius

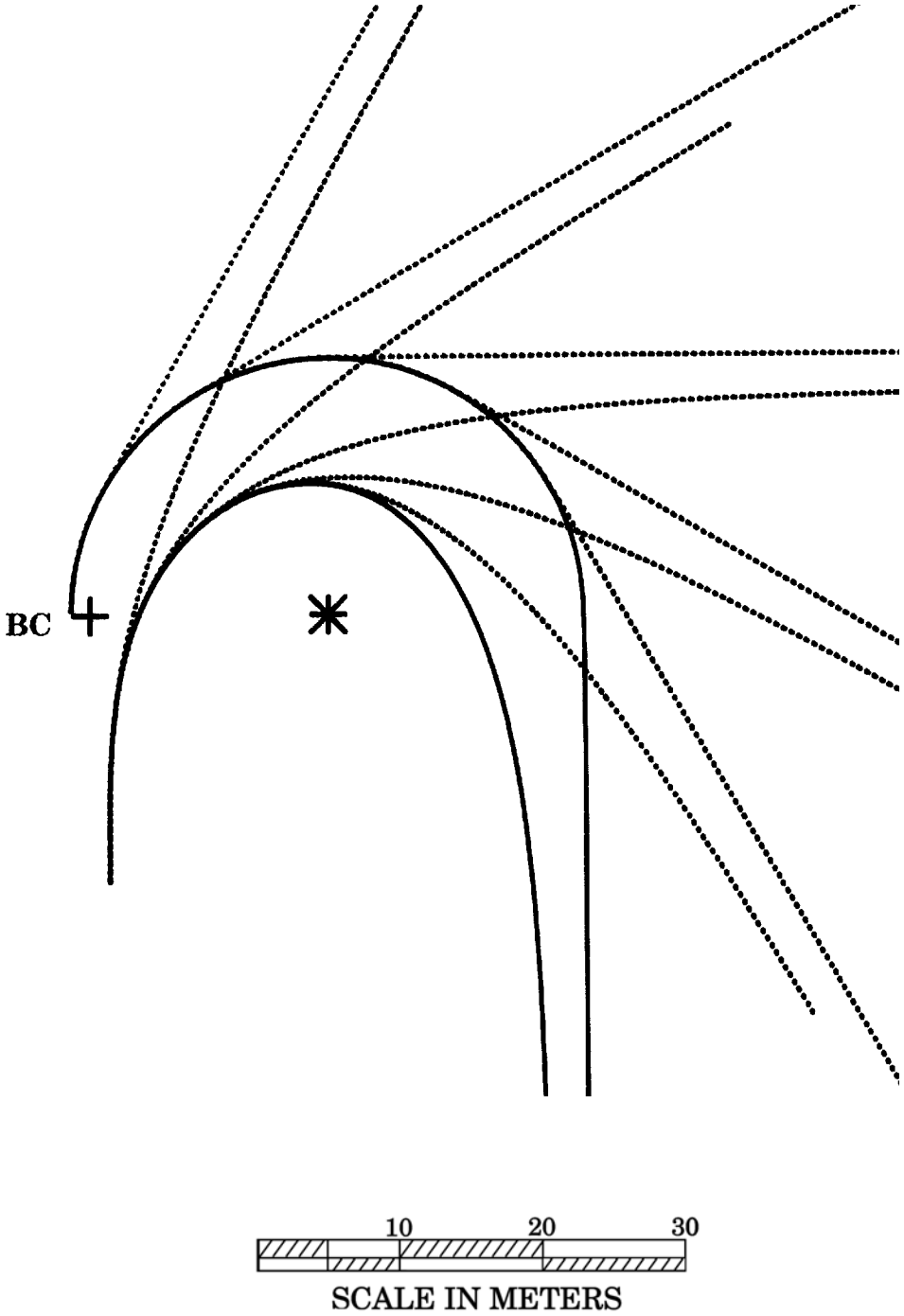


Figure 407C
California Semitrailer Wheel Tracks
15 m Radius

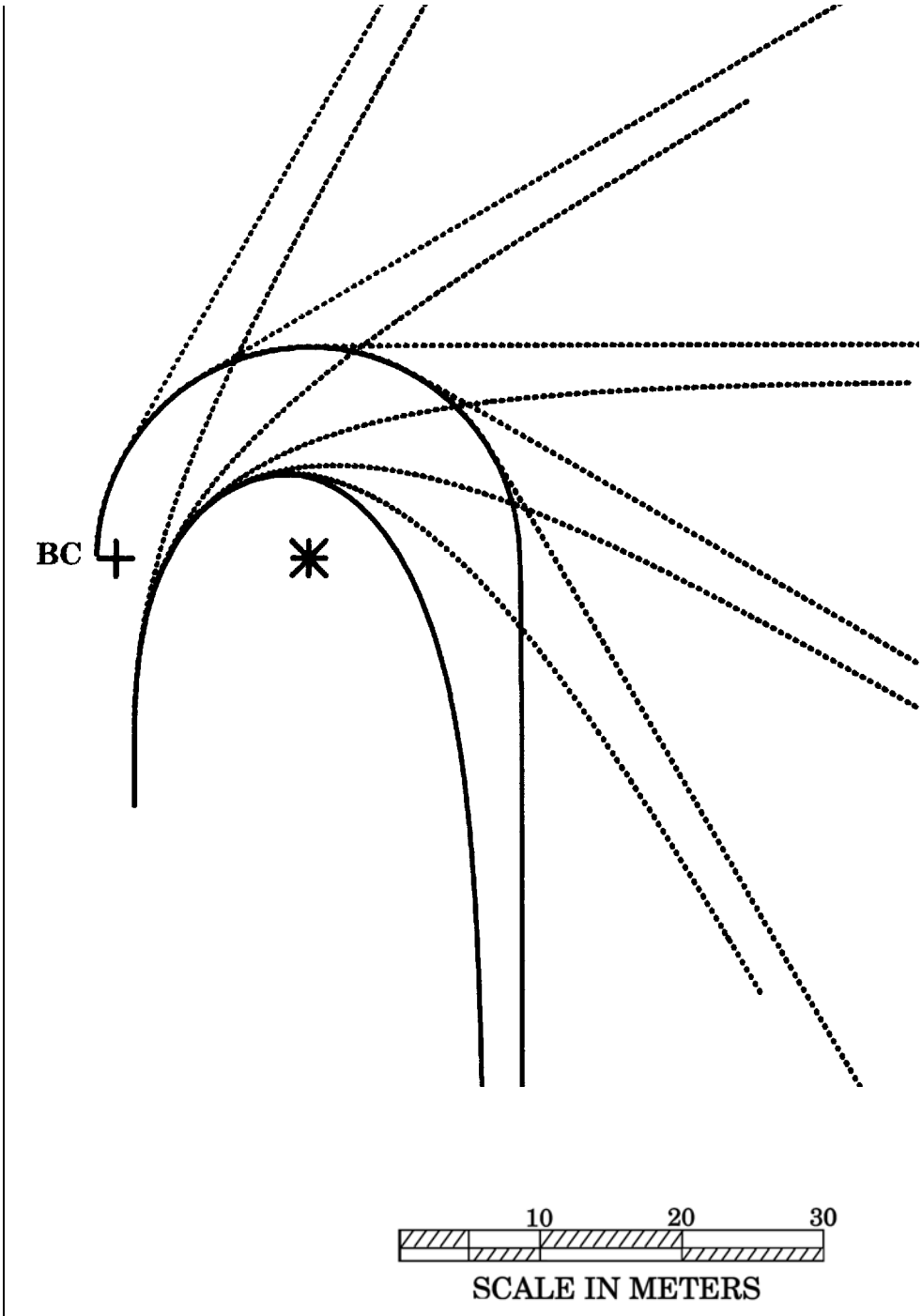


Figure 407D

California Semitrailer Wheel Tracks - 18 m Radius

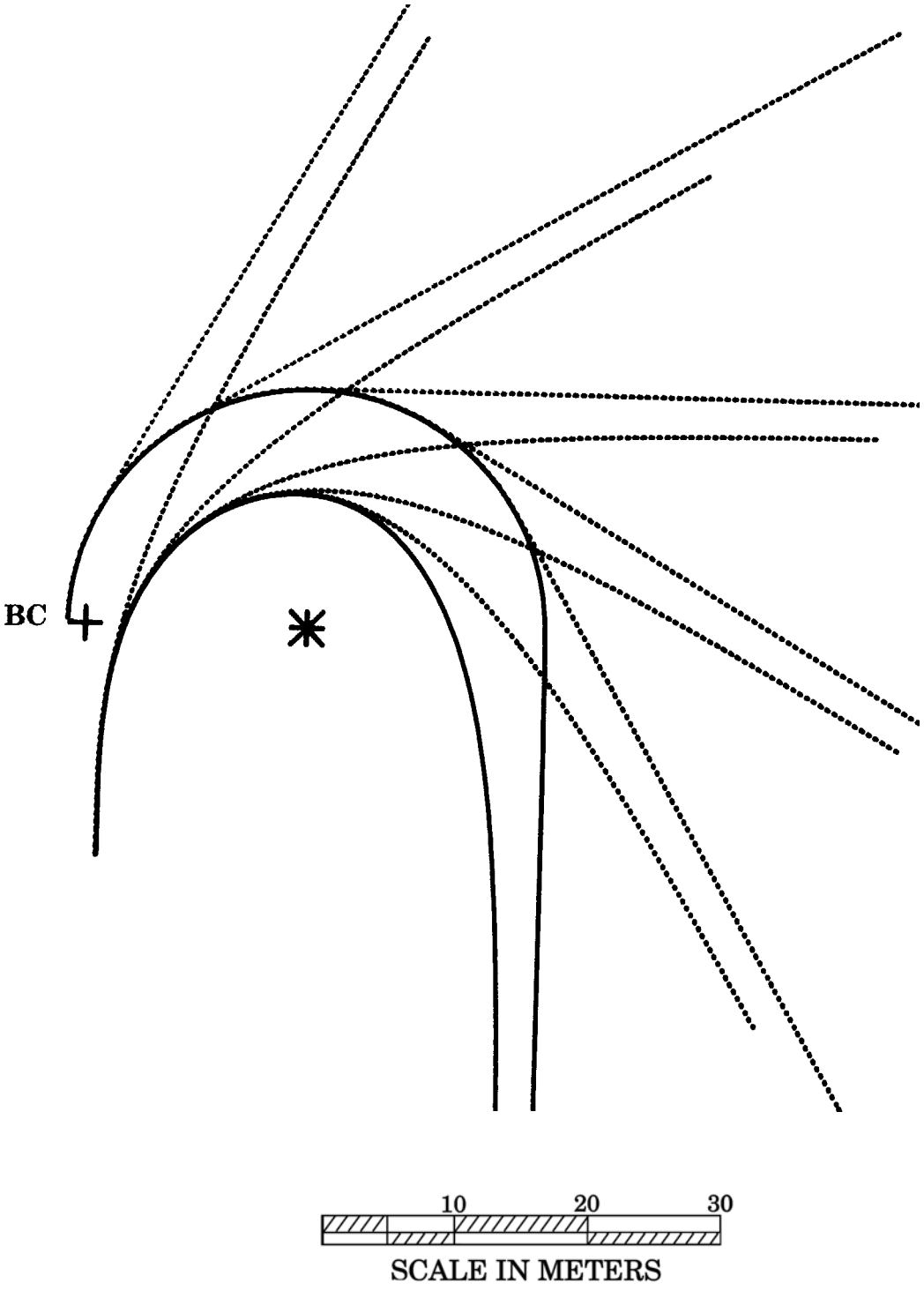


Figure 407E

Bus Wheel Tracks - 12.8 m Radius

