CHAPTER 5
AT-GRADE INTERSECTIONS

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5-1.0 INTRODUCTION

Vehicle crossing maneuvers can be accomplished in four ways: (a) uncontrolled crossing at grade, (b) traffic sign or signal-controlled crossing at grade, (c) weaving, and (d) grade separation. In general, both operational efficiency and construction costs increase in this order. The highest feasible type should be used in consideration of the ADT, type and speed of vehicles using the intersection. (a) and (b) are addressed in this chapter, (c) and (d) will be addressed in Chapter 6.

Intersections are significant points of conflict within the highway system. Their impact on safety, capacity, speed, and user costs is considerable. For this reason, intersections deserve special attention in their design.

5-1.01 Definition

An intersection is the area in which two or more roadways join or cross at the same grade.

5-1.02 Policy

Throughout this chapter, the Department policy is stated relative to the various design elements under consideration. The designer should make every effort to comply with the stated objectives. The policies are not absolute, but exceptions should be made only after all practical alternatives have been evaluated.

5-1.03 Design Considerations

The design of an intersection involves four basic elements: human, operational, physical and economic. This chapter will primarily discuss the physical geometric criteria incorporated into intersection design. Other intersection design criteria are:

1. desirable traffic controls (none, signs, signals, pavement markings);
2. capacity analysis (level of service, number of approach lanes, turning movements and turn lanes);
3. degree of access control for highway facility;
4. pedestrian traffic;
5. bicycle traffic; and
6. lighting warrants.

These criteria are addressed in the Mn/DOT Traffic Engineering Manual, MN MUTCD, Highway Capacity Manual, MN Bike Transportation Plan and Design Guidelines, elsewhere in this manual, and in AASHTO's A Policy on Geometric Design of Highways and Streets. The Highway Capacity Manual provides detailed methodologies for analyzing both signalized and unsignalized intersections. Section 2-5.08 of this manual further discusses the capacity analyses.

Usually, analyses and application of the listed criteria will precede and dictate the geometric layout of the intersection. An improper geometric design can partially negate the potential benefits from advanced signalization, approach roadway width and exclusive turn lanes. Each intersection requires an individual design within the basic criteria. The design should strike a reasonable balance among the several competing design criteria.

It is also beneficial to review the accident history and prepare a collision diagram while redesigning an intersection. Accident history is often the most accurate predictor of future accidents, and an analysis can offer valuable insights into any safety problems that may exist. It could also justify the inclusion of an element (e.g., signals, exclusive turn lanes, etc.) which would not be warranted by other criteria.

Individual vehicle (motorized and non-motorized) and pedestrian movements are the smallest units used for intersection design. They may be combined in various ways to produce alternate geometric designs for any intersection. To a considerable extent intersection design is governed by vehicle and pedestrian demands, topography, land use, and economic and environmental considerations; the proper compromise is a decision to be made by the designer. Intersection design should consider the following seven fundamental principles:

1. Reduce number of conflicts – The number of conflict points among vehicular movements increases significantly as the number of intersection legs increases. For example, an intersection with four 2-way legs has 32 conflict points, but an intersection with six 2-way legs has 172 conflict points. Intersections with more than four 2-way legs should be avoided wherever possible.
2. Reduce area of conflict - Excessive intersection area causes driver confusion and inefficient operations. Large areas are inherent in skewed and multiple approach intersections. When intersections have excessive areas of conflict, channelization such as free right islands, should be employed.
3. Segregate non-homogeneous flows - Separate lanes should be provided at intersections when there are appreciable volumes of traffic traveling at different speeds. Using turn lanes to separate the high-speed through-vehicle stream from the low-speed turning-vehicle stream has considerable safety and operational benefits. Where large numbers of pedestrians cross wide streets, refuge/median islands should be provided so that no more than three lanes have to be crossed at one time. Free right islands better define intersections, accommodate pedestrians and allow placement of signal poles.
4. Intersection Spacing - intersection hazards and delays increase greatly when intersections are too close together. Provide drivers sufficient time and distance to prepare for the next maneuver.
5. Control speed differentials – Speed differentials refer to the difference in speed between neighboring, same-direction traffic flows. Controlling speed differentials is especially important at merging locations. Speed differentials less than 25 km/h can (depending on geometry) allow entering traffic to merge with the through-vehicle stream without stopping. Acceleration lanes may be provided to assist entering traffic in merging. This uninterrupted flow minimizes delay. Speed differentials greater than 25 km/h force entering traffic to yield and seek gaps in the through-vehicle stream of traffic. The entering vehicle stream is interrupted. Traffic control devices may be used to aid entering vehicles. This is accomplished by stopping the through vehicle stream, which is undesirable but sometimes necessary.
6. Favor the heaviest and fastest flows - Intersections should be designed and operated (traffic control) to favor the heaviest and fastest flows to minimize delay and hazards.
7. Coordinate intersection design with the development of traffic control plans.

5-1.04 Vehicle Characteristics

The primary vehicle characteristics which affect intersection design are turning radii, off-tracking, braking distance and acceleration. Motor vehicle under clearance and rear bumper clearance often present problems at driveway entrances.

5-1.04.01 Turning Radii

The four design vehicles used for intersection design in Minnesota are: the passenger car (P), single unit truck (SU), bus (BUS) and interstate semi-trailer (WB-19). Because the wheel path of a double trailer truck combination (sometimes called a WB-21) falls inside that of a WB-19, the off-tracking of the latter shall be used in design. The minimum turning paths for each of the design vehicles are illustrated in Section 2-3.0.

To accommodate the turning movements of a design vehicle at 15 km/h or less the designer should use a taper offset with a simple curve, a 2-centered or a 3-centered symmetrical or asymmetrical compound curve. The details of the recommended curve layouts and how they accommodate the design vehicles are discussed in Sections 5-2.0 and 5-3.0 of this manual, and in Mn/DOT's Traffic Engineering Manual.

5-1.04.02 Approach

Vehicle deceleration and acceleration characteristics have a major impact on the approach design of an intersection. Stopping sight distance leads directly to the minimum sight triangle necessary in the intersection quadrants. The acceleration criteria for the selected design vehicle will yield the needed sight distance which will safely allow a stopped vehicle to cross or enter an intersecting highway. Both criteria also dictate the acceptable vertical grades on the approaches to intersections. Approaches for entering roadways should have a grade of 0.5% away from the roadway for 15 m (7.5 m minimum). Entrance approaches should have a grade of 0.5% away from the roadway for 7.5 m (4.5 m minimum). Stopping sight distance must be adjusted for negative grades, and a near flat storage platform is desirable for stopped vehicles. This is discussed in detail in Section 5-2.02, Intersection Sight Distance.

5-1.04.03 Maneuver Speeds

Vehicles are limited to how they can maneuver on the highway at intersections, and the design must reflect this. Larger vehicles cannot immediately turn to a given radius, but must gradually lead into it. This requires a combination of tapers and compound curves to properly accommodate the vehicle. If it is desirable to allow a vehicle to turn at speeds greater than 15 km/h, the turning radius templates cannot be used. This is discussed in Section 5-2.04, Minimum Turning Curve, and shown in Table 5-2.04A. The goal is to design the intersection within the practical extent of vehicle maneuverability.

5-1.04.04 Under and Edge Clearances

Vehicles must be able to negotiate the vertical profile at an intersection without dragging their underside or front and rear bumpers, preferably at speeds of at least 15 km/h. Although this is true of all intersections, this vehicle characteristic most often presents problems at driveway entrances and exits. A complete discussion of driveways appears in Section 5-3.04.

Since passenger vehicles generally have a much lower vertical clearance than most trucks, the dimensions of the typical automobile must be satisfied. The criteria presented in Section 5-3.04 will accomplish this. For an updated vehicle geometry the designer should refer to and use the dimensions and break-over angles of new vehicles which are published annually by the Motor Vehicle Manufacturers Association (MVMA) in Parking Dimension, (Year) Model Cars.

5-1.05 Intersection Types

At-grade intersections are usually the 3-leg (T-shape) or 4-leg design. Individual intersections vary greatly in size, shape and use of flares, channelization and free right turns. The primary factors which affect the selection of intersection type are the design speed, design-hour volume, turning movements, traffic composition, traffic control, and angle of intersection, many variations of which are possible. They are discussed in AASHTO's A Policy on Geometric Design of Highways and Streets and in NCHRP Report 279.

For railroad/highway intersection design, see Section 11-6.0.

5-1.06 Traffic Controls

The type and level of sophistication of traffic control will impact the geometric design of the intersection. At intersections with no traffic control, the full approach pavement width should be continued through the intersection. Stop control may sufficiently reduce capacity to warrant additional approach lanes. The presence of stop or signalization control requires the consideration of stopping sight distances for the approaching vehicles. Signalization will also impact the length of storage areas, location and position of turning roadways, and channelization. The intersection must also be designed to allow the physical placement of the traffic control devices in the safest location and out of the stream of pedestrian or bicycle traffic. Traffic control devices are discussed in the MN MUTCD and Mn/DOT's Traffic Engineering Manual. Their effect on capacity is discussed in AASHTO's Highway Capacity Manual.

5-1.07 Intersections on Horizontal Curves

Intersections on horizontal curves should be avoided. The curvature adds an extra element of complexity to the highway information that must be processed by the driver, thereby increasing the hazard. It also complicates the geometric design elements of sight distance, channelization and superelevation.

It may be impractical to provide the intersection on a tangent. In such cases, designers should consider realigning the minor highway to intersect the major highway perpendicular to a tangent at a point on the curve. However, this still has the disadvantage of difficult turning movements if the superelevation of the major highway is high.

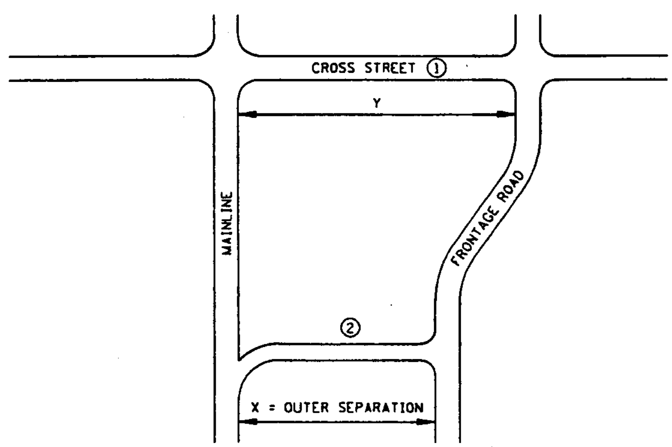
The general criteria for turning movements and sight distance are discussed later in this chapter. The same criteria applies to intersections on non-tangent highway sections. Due to the complexity of the driving task at intersections, additional construction and/or right-of-way costs may be justified to meet or exceed the minimum criteria. A detailed review of the accident history is useful in the evaluation of these intersection designs.

5-1.07.01 Superelevation and Roadway Crown

Crossing superelevated highways and crowned roadways can adversely affect vehicle control. This can be more of a problem at signalized intersections (and at stop controlled intersections that will be converted to signalized intersections) where higher speeds may be achieved. At some low volume crossings such as driveways and township roads, the rollover may be too large for some vehicles. A designer should analyze all vehicular paths relative to probable speeds when developing any intersection design. In some restricted areas, the beginning location of superelevation may be changed to adapt to field conditions. When this is done, Figure 3-3.03A should be used to determine if adequate superelevation is maintained at the P.C. or P.T. of the curve.

5-1.08 Frontage Roads to Arterials

1. For more details on frontage roads refer to Chapter 4, Section 4-7.0 and to AASHTO's A Policy On Geometric Design of Highways and Streets.
2. The separation between the mainline and the frontage road along the length of the facility, called the outer separation, is shown as distance X on Figure 5-1.08A.
3. For frontage roads on high speed arterials, the desirable minimum value of X is 9 m in addition to 1.2 m wide shoulders on the frontage road. In very restricted R/W areas, a concrete barrier may be used to separate the two roadways and the frontage road shoulder width may be reduced to 0.6 m (if the speed limit on the frontage road allows it). The barrier should be high enough to prevent headlight glare.
4. For frontage roads on low speed arterials, the desirable minimum value of X is 1.2 m in addition to 0.6 m wide shoulders on the frontage road.
5. The distance between the intersection of the mainline and the cross street, and the intersection of the cross street and frontage road has a great effect on the operation and safety of all three roadways. This distance is shown as distance Y on Figure 5-1.08A.
6. From the 1999 Traffic Engineering Handbook: A Y value of at least 75 m is desirable to reduce the interference of the two intersections. Such a separation also creates a buildable site suitable for a service station, fast food restaurant, or convenience store. A separation of 150 m will accommodate back-to-back left turn lanes between the mainline and the frontage road. Refer to Chapter 2, Section 2-3.06 and Contact Mn/DOT's Access Management Section for additional guidance.
7. For two-way frontage roads, Y should be wide enough to allow U-turns (by the appropriate design vehicle) between the frontage road and the arterial.



FRONTAGE ROAD TO ARTERIAL

① CROSS STREET PROVIDES INDIRECT ACCESS BETWEEN MAINLINE AND FRONTAGE ROAD.
② SLIP RAMP PROVIDES DIRECT ACCESS TO FRONTAGE ROAD.

FRONTAGE ROADS TO ARTERIALS
Figure 5-1.08A

5-2.0 INTERSECTIONS

Studies have demonstrated that the degree of access control is directly related to the accident rate on urban highways and streets. Restricting access on existing highways is usually not feasible because of the dependence of roadside development on direct access. Therefore, proper design of each intersection and driveway is necessary to minimize the safety hazard and increase the operational efficiency of the highway. Possible treatments include exclusive left-turn and right-turn lanes, improved sight distance, inclusion of free right turns, revised traffic controls, service roads and ease of ingress/egress, particularly at driveway entrances.

5-2.01 Design Vehicle Selection

A trunk highway in an urban area crosses many roads and streets having varying uses. In order to design safe and efficient intersections along its route, it is extremely important to select the design vehicle which will be using them. In addition to other guidelines given in this chapter and in Section 2-3.0, the following may be helpful to the designer in choosing the design vehicle:

Passenger Car (P)- when the main traffic generator is a parking lot or a series of parking lots.
Single Unit (SU)- at intersections with park roadways and residential streets.
BUS - at city streets which carry bus routes but have very few trucks and at park and ride facilities.
WB-19 truck - at intersections with other trunk highways, high volume CSAHs and County Roads, and highly industrialized streets.

5-2.02 Intersection Sight Distance

A vehicle operator approaching or entering an intersection needs adequate sight distance to safely conduct a turning maneuver. One research study concluded that of all intersection geometrics which may be related to accident experience, sight distance was most often the contributing factor. Providing sufficient sight distance deserves special attention, and the additional costs and impacts to remove sight obstructions generally are justified. An analysis of the intersection accident experience can also warrant the additional construction costs. Conversely it may be impractical or too costly to remove an obstruction even though inadequate sight distance and/or adverse accident history exists. The designer should then assess providing traffic controls, turn lanes, etc., that would not otherwise be warranted. This should be done in conjunction with the District Traffic and/or Right of Way Engineer as appropriate.

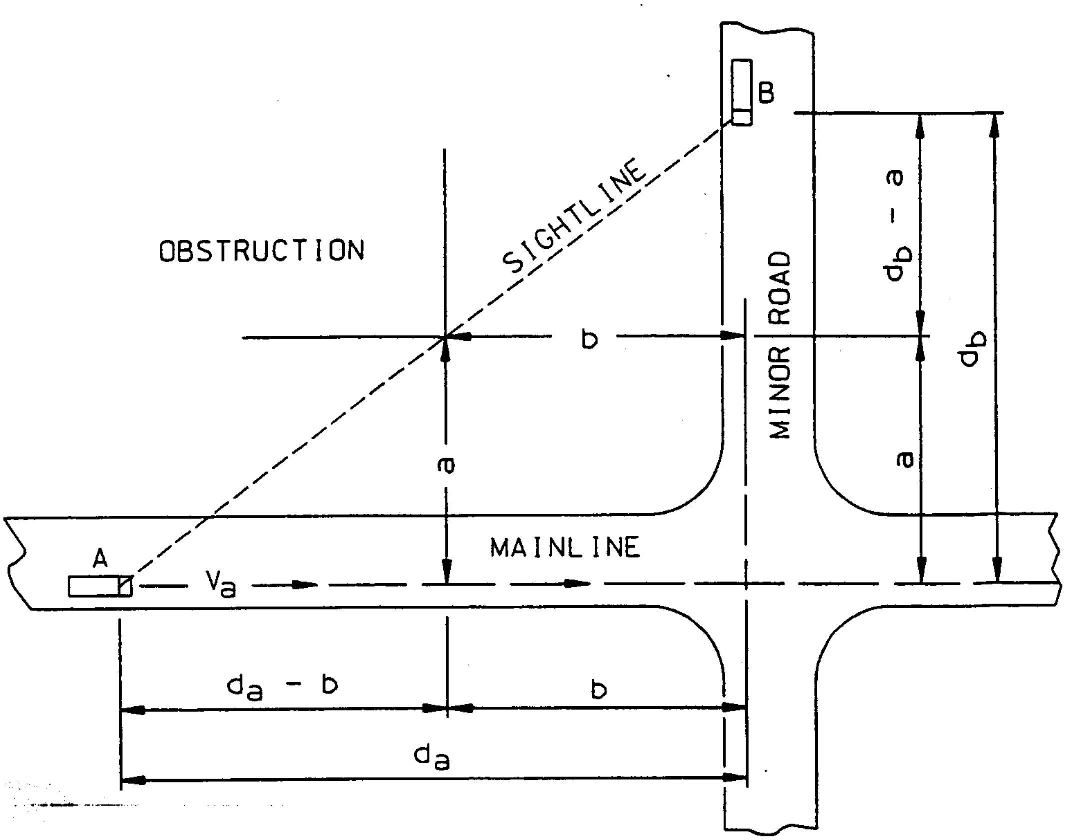
5-2.02.01 Sight Corners

Sight corners provide a line of sight between two vehicles approaching an intersection at right angles or nearly right angles. Availability of this line of sight may add to the safety of the intersection. In particular, on rural high speed roadways, sight corners provide an added comfort at relatively low cost. Sight corners provide mainline drivers (who have the right of way) the ability to see a sufficient distance along the minor road to make a speed adjustment or evasive maneuver should the crossroad vehicle fail to stop. Thus the installation of sight corners is justified even on very low volume crossroads.

In addition to intersection characteristics such as skew and grade (discussed later in this section), designers should consider the effects of parked cars, guardrail locations, snow storage, signs or any other roadside appurtenances that might restrict the line of sight. Figure 5-2.02A shows a graphical representation of the sight line.

The following criteria are used to develop the size of sight corners.

1. While crossroad traffic is required to stop, mainline traffic may not be.
2. Crossroad traffic will be slowing down in preparation of the stop.
3. The size of the sight corner depends on the amount of available right of way on each of the two intersecting roadways.



d_a = DISTANCE VEHICLE A TRAVELS IN APPROX. 3 SECONDS AT SPEED OF V_a.

d_b = STOPPING SIGHT DISTANCE FOR VEHICLE B.
USED FOR STOP CONDITION ON ALL INTERSECTING MINOR ROADS.

PERCEPTIONAL/REACTION DISTANCE AT INTERSECTIONS WITH MINOR HIGHWAYS
Figure 5-2.02A

Sight corners should provide sufficient sight line to give:

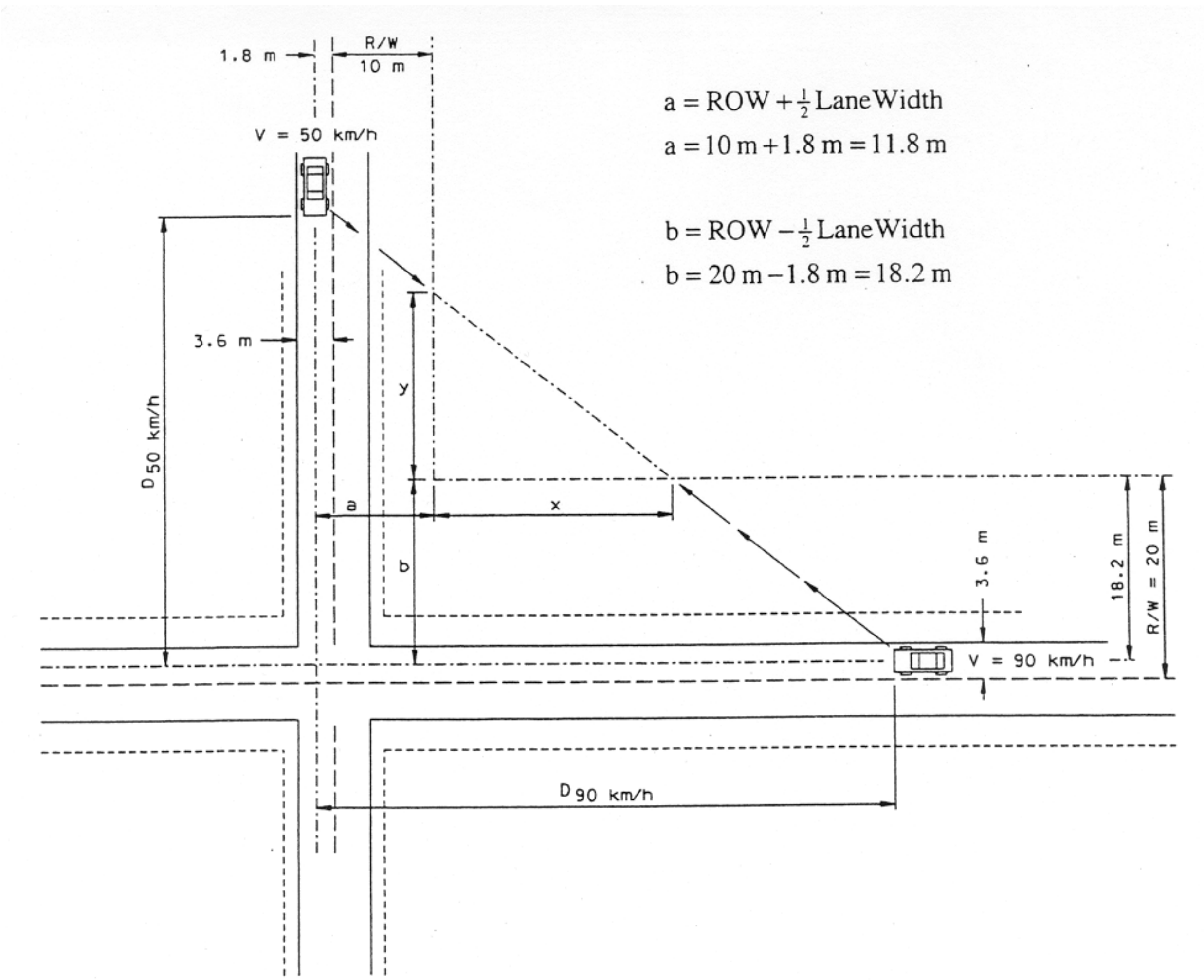
a) Stopping sight distance (SSD) to the vehicle traveling on the crossroad. The distance is measured from the center of the lane on which the mainline vehicle is traveling. SSD (section 2-5.09) corresponding to the design speed of the crossroad shall be the minimum sight distance provided along that road. Roads with design speeds less than 50 km/h shall provide sight distance equal to $SSD_{50\ km/h}$ = 65 m. And,

b) The vehicle traveling on the mainline 3 seconds to change speed (no stop) before reaching the cross street. Three (3) seconds is the average time needed for a driver to perceive (a vehicle traveling on the other roadway and approaching the same intersection) and react (by starting to reduce speed). The distance is measured from the center of the lane on which the crossroad vehicle is traveling. Table 5-2.02A shows the distance traveled by a vehicle during that 3 second interval.

Table 5-2.02A

DISTANCE traveled in 3 seconds, m								
DESIGN SPEED (V), km/h	50	60	70	80	90	100	110	120
DISTANCE (d), m	42	50	58	67	75	83	92	100

Example: Calculate the dimensions of the sight corner needed at the intersection of mainline (design speed = 90 km/h) and crossroad (design speed = 50 km/h). The mainline right of way is 20 m, the crossroad right of way is 10 m, and the two roadways are perpendicular to each other.



SOLUTION TO EXAMPLE
Figure 5-2.02B

Solution: The crossroad vehicle needs a distance ($D_{50\text{ km/h}} = SSD_{50\text{ km/h}}$ + ½ Lane Width = 65 m + 1.8 m = 66.8 m) measured to the center of the lane on which the mainline vehicle is traveling. The mainline vehicle needs a distance ($D_{90\text{ km/h}}$ = (90 km/h)(1 h/3600 s)(3 s) (1000 m/1 km) = 75 m) equal to the distance traveled in 3 seconds, measured to the center of the lane on which the crossroad vehicle is traveling.

Using similar triangles, the dimensions of the sight corner are then determined to be 42.8 m x 38.1 m. See Figure 5-2.02B.

Solving for x:

$$\frac{D_{90km/h}}{D_{50km/h}} = \frac{x + a}{D_{50km/h} - b}$$

$$\frac{75\ m}{66.8\ m} = \frac{x + 11.8\ m}{66.8\ m - 18.2\ m}$$

x = 42.8 m

Solving for y:

$$\frac{D_{90km/h}}{D_{50km/h}} = \frac{x}{y}$$

$$\frac{75\ m}{66.8\ m} = \frac{42.8\ m}{y}$$

y = 38.1 m

5-2.02.02 Policy

Mn/DOT's policy is to provide sufficient sight distance (for the intersection characteristics) at each intersection. AASHTO's A Policy on Geometric Design of Highways and Streets provides six sightline sight distance conditions (Cases I, II, IIIA, IIIB, IIIC, and IV) which apply to all types of roadway intersections. It is Mn/DOT's policy that only the four highest order conditions (Cases IIIA, IIIB, IIIC, and IV) be used in the design of intersections on the Trunk highway System.

The first three conditions (IIIA, IIIB, and IIIC) occur at intersections with a stop control on the minor road. The fourth condition, Case IV, occurs at signal controlled intersections.

5-2.02.03 Case IIIA- Crossing Maneuver, Enabling a Stopped Vehicle to Cross a Major Highway

At an intersection with stop control on the minor road, the operator of a stopped vehicle must have sufficient visibility to cross the major road without interfering with oncoming vehicles. The distance d, measured on the major highway, in Figure 5-2.02C is expressed as:

d = (velocity) (time) = $0.28V (J + t_a)$

where:

d	=	minimum sight distance along the major highway from the intersection, m
V	=	design speed on major highway, km/h
J	=	perception-reaction time, sec. Use 2.0 sec.
t_a	=	time (sec) required to traverse distance S to clear the major highway pavement.
S	=	D + W + L

where:

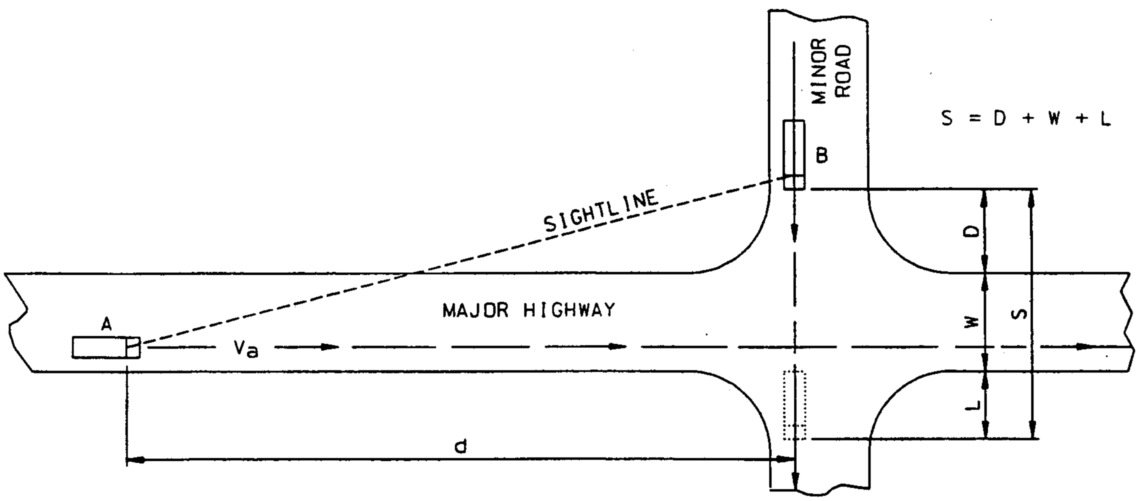
D	=	distance from the near edge of the pavement to the front of the stopped vehicle, m. Use 3.0 m
W	=	width of the pavement along the path of the crossing vehicle, m.
L	=	overall length of the vehicle, m. Use 6.0 m for P, 9.0 m for SU, 12 m for BUS, and 21 m for WB-19.

In this case, J refers to the average time taken by the driver of vehicle B to perceive the absence of any vehicles that can interfere with the crossing maneuver and then react by activating the clutch/automatic shift. Even though many drivers require only a fraction of a second, the value of J used in design should take slower drivers into account. Use J = 2.0 sec. Time t_a can be read from Figure 5-2.02D. For passenger cars it is appropriate to assume a slightly higher than normal acceleration (the lower solid-line curve). If an appreciable number of buses or trucks will be attempting the crossing maneuver, their corresponding acceleration curves should be used.

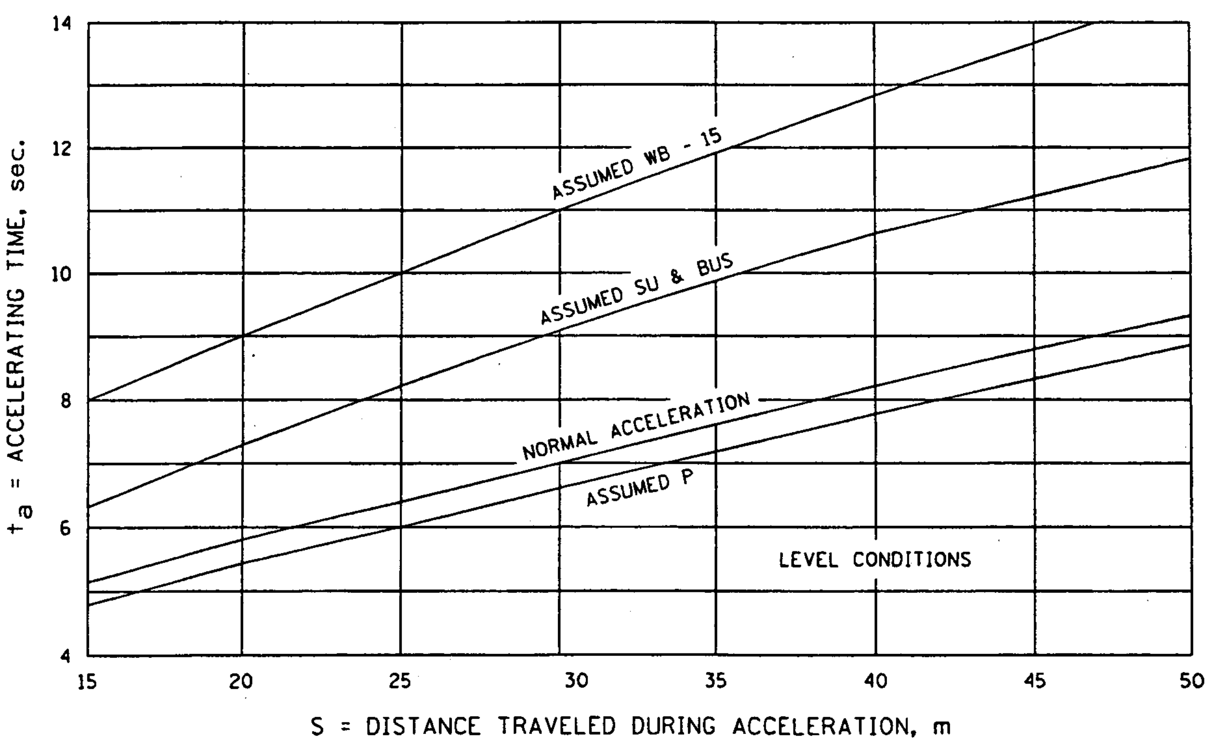
Figure 5-2.02E allows the designer to read the minimum sightline sight distances directly, assuming 3.6 m lanes, no median, approximately right-angle intersections, and level conditions (not to exceed ± 3 percent approach grades). For divided highways, if the median width is greater than the length of the design vehicle (L), the crossing maneuver can be considered a two-step process; if less than L, the median width should be part of the

W value. Mn/DOT's policy on testing for adequate sightline sight distance is to use a height-of-eye of 1070 mm and a height-of-object of 1300 mm.

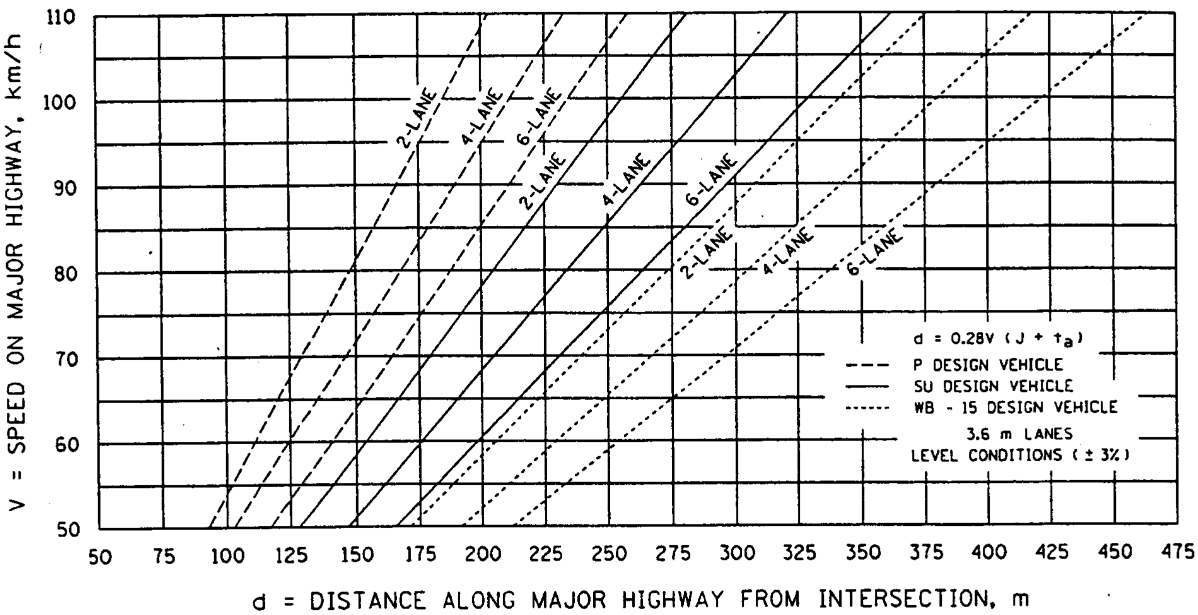
The Case IIIA condition should be used at intersections with traffic control when the predominant minor road movement is to cross the major highway. If the combination of vehicles turning from the minor road and major highway traffic volumes suggest a significant hazard, then either Case IIIB or Case IIIC should be used to determine the needed sightline sight distances at the intersection. The historical accident pattern may provide an indication of any sightline sight distance problems.



SIGHT DISTANCE AT INTERSECTIONS - Stop Control on Minor Road - Case IIIA
Figure 5-2.02C



SIGHT DISTANCE AT INTERSECTIONS - Case IIIA Data on Acceleration from Stop
Figure 5-2.02D



MINIMUM SIGHT DISTANCE AT INTERSECTIONS - Case IIIA
Figure 5-2.02E

5-2.02.04 Case IIIB - Turning Left onto a Major Highway, Enabling a Stopped Vehicle to Make a Left Turn

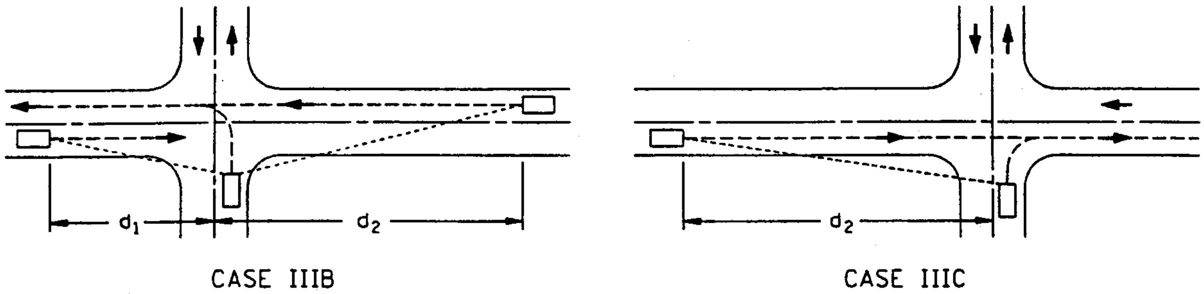
Case IIIB applies to a vehicle entering a major highway from a stopped position by clearing vehicles approaching from the left and then by turning left and clearing the traffic stream coming from the right. Figures 5-2.02F and G illustrate the requirements for passenger vehicles for the two turn conditions. The first turn condition applies when the critical movement is for a left-turning vehicle to safely clear a vehicle approaching from the left. The second turn condition applies to a left turning vehicle to safely turn in front of a vehicle approaching from the right.

In the case of undivided highways or divided highways where the median width is less than the length of the vehicle, both clearances are performed simultaneously as one operation. For divided highway with wide medians (the median is wider than the length of the design vehicle), maneuvers are performed as two operations. The stopped vehicle must first have the proper sight distance (sight distance d_1) to depart from a stopped position and cross traffic approaching from the left. The crossing vehicle may then stop and stay in the median prior to performing the second operation. This operation requires the necessary sight distance (sight distance d_2) for the vehicles approaching on the right to allow the crossing vehicle to depart from the median, to turn left into the highway and to accelerate without being overtaken by the vehicles approaching from the right.

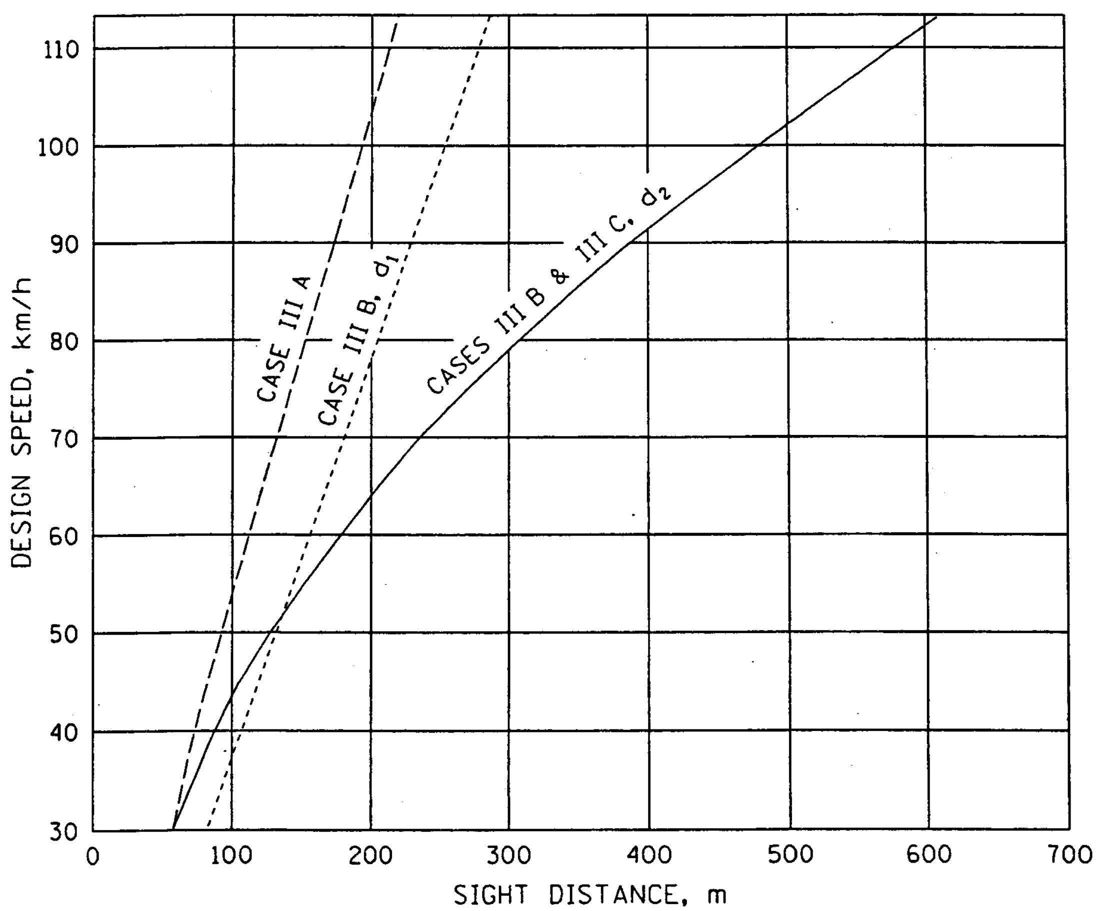
5-2.02.05 Case IIIC - Turning Right onto a Major Highway, Enabling a Stopped Vehicle to Make a Right Turn

Case IIIC applies to a vehicle departing from a stopped position, turning right and merging with traffic coming from the left. The right turning vehicle should have a sufficient sightline sight distance to clear vehicles approaching from the left, to complete its right turn and to accelerate to a predetermined speed without being overtaken by the vehicles approaching from the left at a predetermined speed. The sightline sight distance requirement for the right-turn maneuver is for all practical purposes the same as that required for the second operation of the left-turn maneuver outlined in Case IIIB, see Figures 5-2.02F and G to obtain required sight distances.

In designing for case IIIB or IIIC, figure 5-2.02G is used. The figure is based on a passenger car design vehicle. The intersection sight distance needed for trucks is considerably bigger than that for P. The required sight distances (d) may be computed using the formula $d = 0.28V(J+t_a)$. The time (t_a) required to accelerate and traverse the intersection (distance = S) may be obtained from figure 5-2.02D. Corrections for grades greater than $\pm$ 3% must be made using the truck acceleration charts shown in Chapter 3. Designers should use the curvilinear distance of S when applying cases IIIB and IIIC.



SIGHT DISTANCE AT INTERSECTIONS - Left and Right Turning Vehicles - Case IIIB and IIIC
Figure 5-2.02F



CASE IIIA - CROSSING MANEUVER.
CASE IIIB, d_1 - TURNING LEFT ONTO A MAJOR HIGHWAY ACROSS VEHICLE APPROACHING FROM LEFT.
CASE IIIB, d_2 - TURNING LEFT ONTO A MAJOR HIGHWAY AND ATTAINING AVERAGE RUNNING SPEED WITHOUT BEING OVERTAKEN BY VEHICLE APPROACHING FROM RIGHT WHICH REDUCES SPEED FROM DESIGN SPEED TO AVERAGE RUNNING SPEED.
CASE IIIC, d_2 - TURNING RIGHT ONTO A MAJOR HIGHWAY.

SAFE SIGHT DISTANCE ALONG MAJOR HIGHWAY FOR P TYPE DESIGN VEHICLES
Cases IIIA, IIIB and IIIC
Figure 5-2.02G

5-2.02.06 Case IV - Signal Control

Due to a variety of operational characteristics associated with intersections, sightline sight distance based on the Case III procedures should be available to the driver. This is due to the increased driver workload at intersections and the hazard involved when vehicles turn onto or cross the major highway. The hazard associated with unanticipated vehicle conflicts at signalized intersections, such as violation of the signal, right turns on red, malfunction of the sign or use of flashing red/yellow mode, further substantiate the need for incorporation of Case III sightline sight distances even at signal-controlled intersections. In addition, a sight corner consideration should be given as described in earlier in this section.

A basic requirement for all controlled intersections is that drivers must be able to see the control device soon enough to perform the action it indicates.

At intersections where right turns on red are permitted, the departure sight line for right-turning vehicles should be determined by the methods discussed in Case IIIC, Turning Right onto a Major Highway.

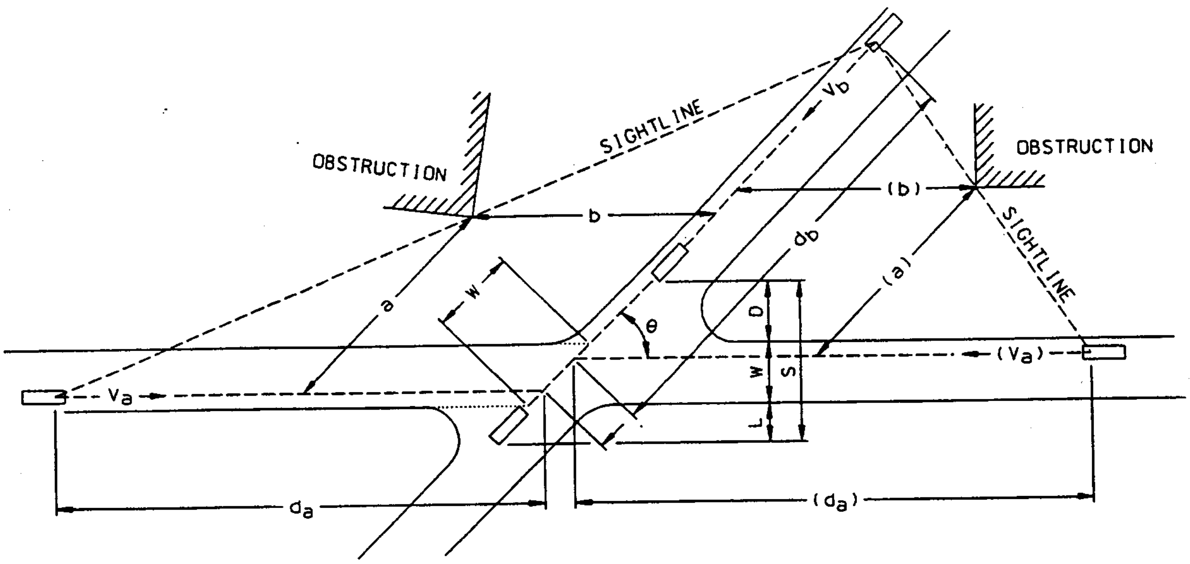
5-2.02.07 Effects of Skew

The alignment of intersecting highways should be as close to 90 deg as possible. Significant deviation can increase the hazard and decrease the efficiency of the intersection. Oblique angle intersections adversely affect sightline sight distance and turning movements. Sightline sight distance calculations must be adjusted when the angle of intersection is more than 30 deg from a right angle. Figure 5-2.02H shows the adjusted sightlines for oblique-angle intersections. The following alterations are necessary in the analysis:

1. Because of the difficulty of looking for approaching traffic, the intersection should not be left uncontrolled.
2. When the alignment is skewed, as shown in Figure 5-2.02H, the actual distance traversed, S_{skew} , shall be used in the calculation:

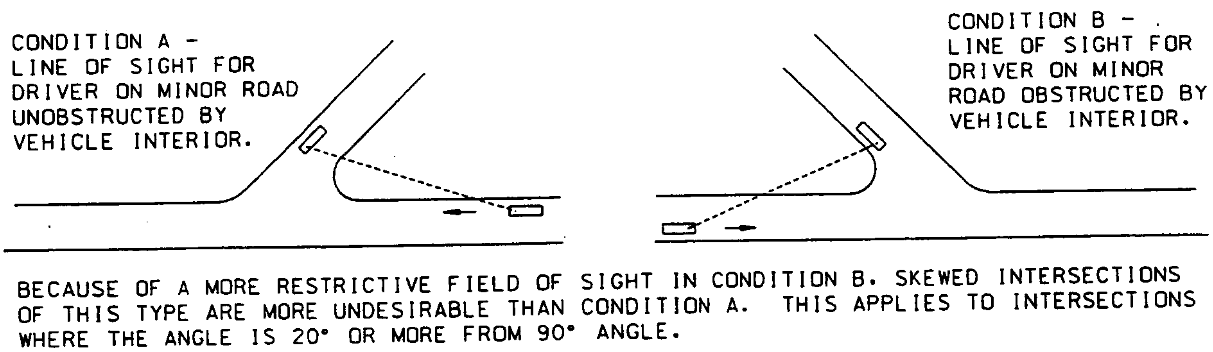
   $$S_{skew} = \frac{S}{\sin\theta} = \frac{D + W + L}{\sin\theta}$$
3. Figure 5-2.02E cannot be used to compute the required sight distance (d). It may be computed using the formula $d = 0.28V(J+t_a)$. The time (t_a) required to accelerate and traverse the skew distance (S_{skew}) may be obtained from Figure 5-2.02D.
4. Distances a, b, d_a and d_b from Figure 5-2.02H should be measured parallel to its corresponding highway as indicated.

Serious consideration should be given to realigning an intersection if its angle deviates by more than 20 deg from a right angle. Possible realignment designs include a reverse curve or a double intersection at right angles. The sightline sight distance restriction varies depending on which side the minor road intersects, as illustrated in Figure 5-2.02I. This factor should be considered when designing an intersection. An individual analysis, including review of the accident history, is necessary to evaluate the need for realignment and which alternative design is most cost-effective.



$$S_{skew} = \frac{S}{\sin\theta} = \frac{D+W+L}{\sin\theta}$$

SIGHT DISTANCE AT SKEWED INTERSECTION
Figure 5-2.02H



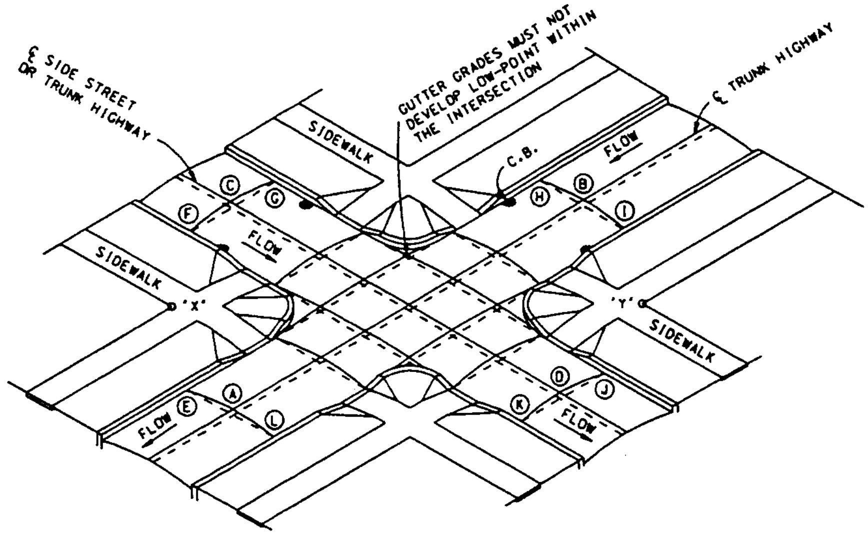
SKEWED INTERSECTION -LINE OF SIGHT
Figure 5-2.02I

5-2.03 Effect of Grades

The grades of intersecting highways should be as level as possible. Grades approaching an intersection affect the normal stopping and accelerating distances. Adjustments in these distances are needed if the grade exceeds +/- 3%. See chapter 9 of AASHTO's A Policy on Geometric Design of Highways and Streets for details. The gradient within the intersection should be +/-0.5% for the highway section needed for storage. Between 1.5 and 2.0% are acceptable to match cross slope of pavement.

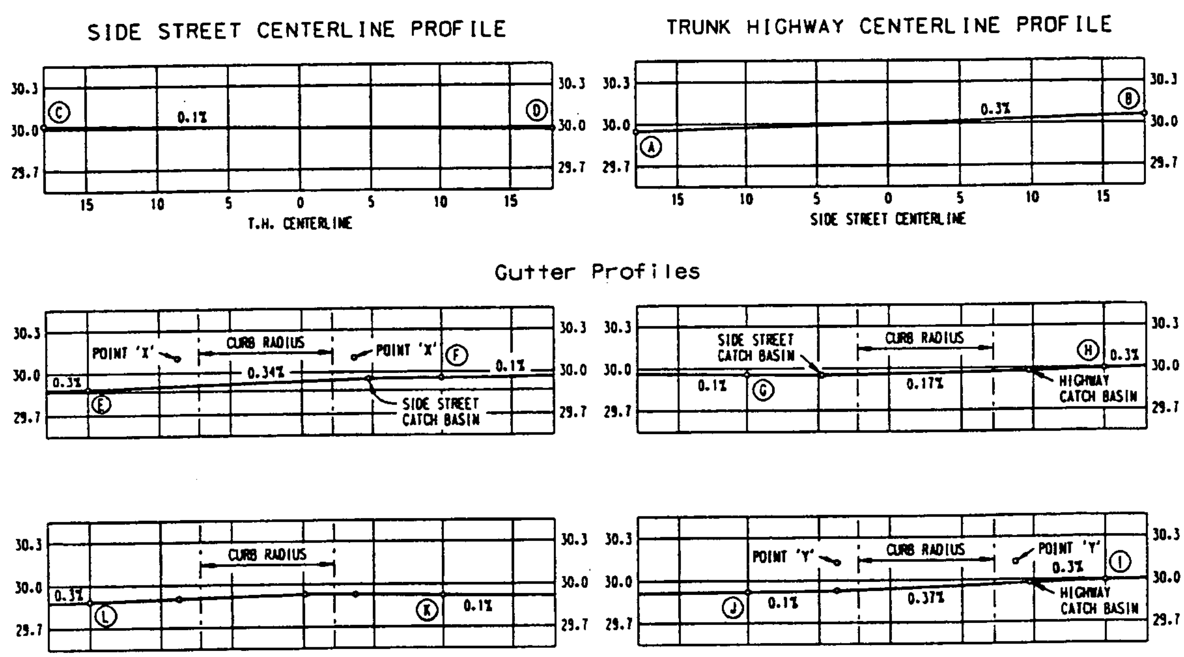
Attention must be given to adjusting the cross sections of the two intersecting highways to achieve a smooth crossing and proper drainage. Figures 5-2.03A, B, and C demonstrate three methods of accomplishing this for various combinations of closed and open drainage and the functional class of the intersecting highways.

Special attention should be given to signalized intersections where high speeds are possible on both crossing roadways. Figure 5-2.03A in combination with an appropriate superelevation rate of change (1:100 maximum slope), should be used as a guide when designing a signalized intersection. Design of more complicated intersections may require contouring the intersection at appropriate contour intervals to develop proper drainage and a smooth roadway crossing.



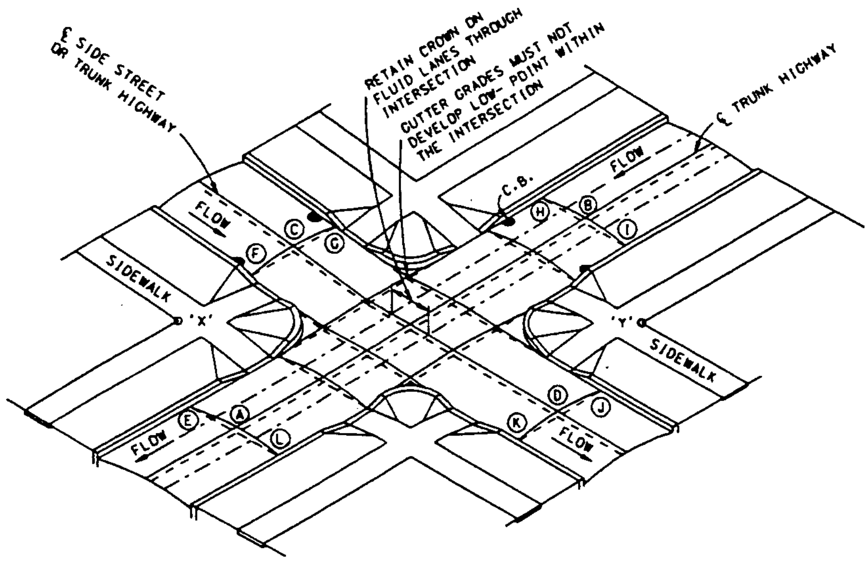
NOTES: IN ORDER TO AVOID EXCESSIVE SIDEWALK AND BOULEVARD GRADIENTS, POINTS X AND Y MUST BE CONSIDERED WHEN LAYING GUTTER GRADES. IF EXCESSIVE WALK GRADIENTS ARE ENCOUNTERED, ADJUST GUTTER GRADIENTS (E-F AND I-J) TO ALLEVIATE THE CONDITION IN PREFERENCE TO VARYING THE HEIGHT OF CURB.

AREAS BETWEEN DASHED AND SOLID LINE DO NOT REPRESENT THICKNESS OF PAVEMENT BUT INDICATE RELATIVE HEIGHTS OF CROWN.



* THE INTERSECTION OF SIDE STREET AND TRUNK HIGHWAY CENTERLINE PROFILES IS DESIGNATED AS ELEVATION 30.0 FOR ILLUSTRATIVE PURPOSES.
METHOD A: WARPING TRUNK HIGHWAY AND SIDE STREET CROWNS. UNDERGROUND DRAINAGE REQUIRED.

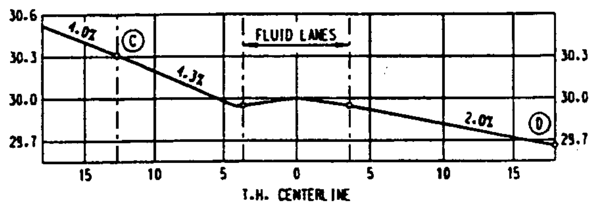
URBAN INTERSECTION - METHOD A
Figure 5-2.03A



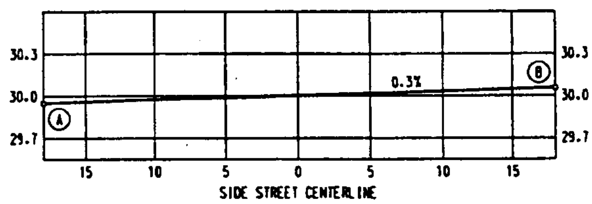
NOTES: IN ORDER TO AVOID EXCESSIVE SIDEWALK AND BOULEVARD GRADIENTS, POINTS X AND Y MUST BE CONSIDERED WHEN LAYING GUTTER GRADES. IF EXCESSIVE WALK GRADIENTS ARE ENCOUNTERED, ADJUST GUTTER GRADIENTS (E-F AND I-J) TO ALLEVIATE THE CONDITION IN PREFERENCE TO VARYING THE HEIGHT OF CURB.

AREAS BETWEEN DASHED AND SOLID LINE DO NOT REPRESENT THICKNESS OF PAVEMENT BUT INDICATE RELATIVE HEIGHTS OF CROWN.

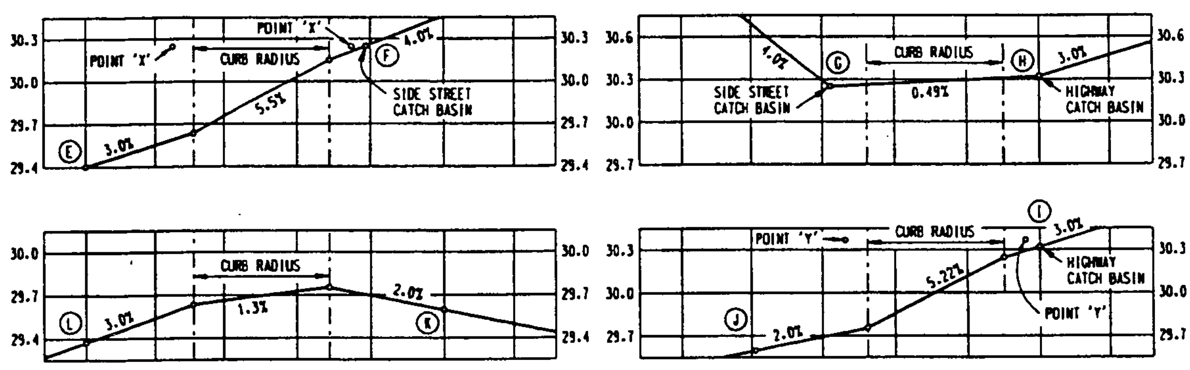
SIDE STREET CENTERLINE PROFILE



TRUNK HIGHWAY CENTERLINE PROFILE



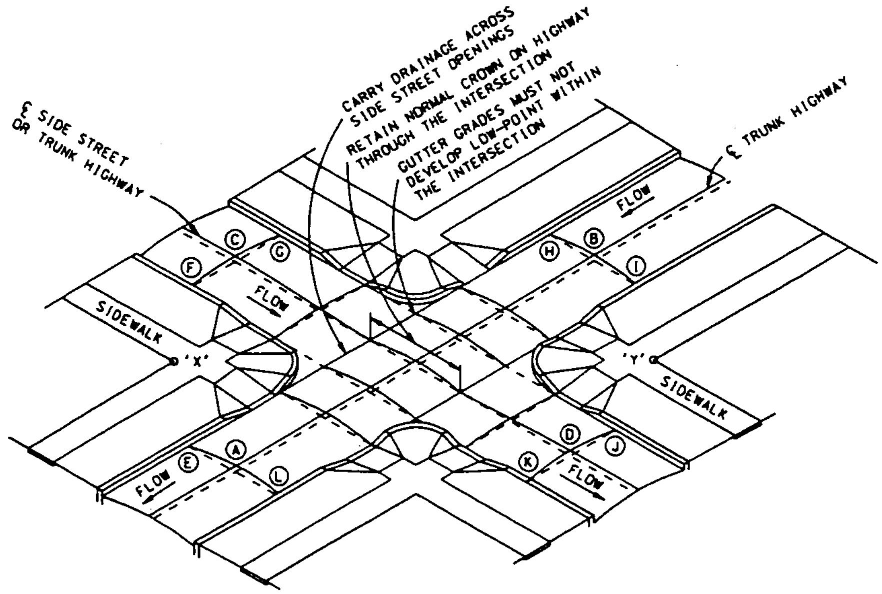
Gutter Profiles



* THE INTERSECTION OF SIDE STREET AND TRUNK HIGHWAY CENTERLINE PROFILES IS DESIGNATED AS ELEVATION 30.0 FOR ILLUSTRATIVE PURPOSES.

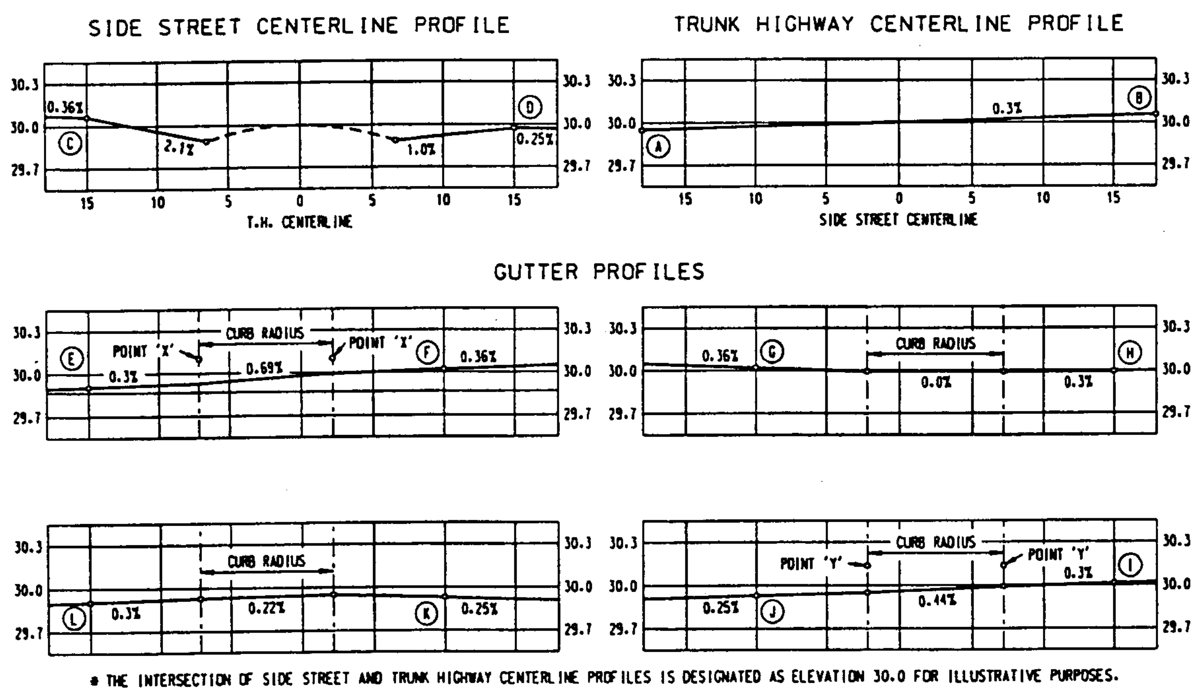
METHOD B: RETAINING NORMAL CROWN ON FLUID LANES OF TRUNK HIGHWAY. UNDERGROUND DRAINAGE REQUIRED.

URBAN INTERSECTION - METHOD B
Figure 5-2.03B



NOTES: IN ORDER TO AVOID EXCESSIVE SIDEWALK AND BOULEVARD GRADIENTS. POINTS X AND Y MUST BE CONSIDERED WHEN LAYING GUTTER GRADES. IF EXCESSIVE WALK GRADIENTS ARE ENCOUNTERED. ADJUST GUTTER GRADIENTS (E-F AND I-J) TO ALLEVIATE THE CONDITION IN PREFERENCE TO VARYING THE HEIGHT OF CURB.

AREAS BETWEEN DASHED AND SOLID LINE DO NOT REPRESENT THICKNESS OF PAVEMENT BUT INDICATE RELATIVE HEIGHTS OF CROWN.



* THE INTERSECTION OF SIDE STREET AND TRUNK HIGHWAY CENTERLINE PROFILES IS DESIGNATED AS ELEVATION 30.0 FOR ILLUSTRATIVE PURPOSES.

METHOD C: RETAINING NORMAL CROWN FULL WIDTH OF TRUNK HIGHWAY. SURFACE DRAINAGE.

URBAN INTERSECTION - METHOD C
Figure 5-2.03C

5-2.04 Design for Right-Turn Lanes

Intersections must be properly designed to accommodate the number and type of right-turning vehicles. This will significantly affect the geometric layout and operation of the intersection. The following must be considered:

1. Select the design vehicle based on the largest vehicle likely to make the turn with considerable frequency.
2. Select the speed at which the vehicle should be allowed to make the turn.
3. Determine the tolerable encroachment onto other lanes. This will vary with traffic volumes, lane width, 1-way or 2-way operation, and traffic control device.
4. Determine the need for a turn-lane.
5. Determine the availability of right-of-way.
6. Determine the required length of turn lane based on turning movement volume.
7. Evaluate the need to design for pedestrian traffic movements.
8. Determine the need and location of signal poles.
9. Select the appropriate channelization treatment.

5-2.04.01 Minimum Turning Curve

The edge of pavement or curb line for a right-turn can be designed by the following methods:

1. Simple curve radius,
2. Simple curve radius with taper offsets, or
3. Two-centered compound curve and a taper.

The compound curve arrangements most closely fit the natural turning path of vehicles. A simple curve with taper offsets is a close and reasonable approximation of a vehicular path that is easier to construct. It is appropriate to use simple curve radii with tapers, especially in rural conditions. Corner radius curves may be appropriate for intersections of the same character as the free right-turn Yield Condition intersection, but aligned at approximately right angles. The traffic control may be either stop or yield depending upon the intersection condition.

When selecting a specific curve arrangement, the designer should pay particular attention to where the regulatory signs will be placed per MN MUTCD. A general criteria for turning speeds along the corner radii is 15 km/h or less. Table 5-2.04A, Figure 5-2.04A, Figure 5-2.04B and Figure 5-2.04C provide a guide for at-grade intersection curb return designs. A computer generated vehicular wheel path or multiple turn templates are appropriate tools for use in the intersection design.

5-2.04.02 Free Right-Turns

Free right-turns are channelized roadways which allow the right-turn to be made away from the intersection. They may be warranted in the following situations:

1. When it is necessary to accommodate semi-trailers or large buses.
2. When intersections are skewed.
3. When it is desirable to allow right-turns at speeds of 20 km/h or more with an acceleration lane.
4. When it is necessary to accommodate traffic control signal installation.

Several right-turn designs from a crossroad to a main highway are shown in Figures 5-2.04A through 5-2.04C.

Numerical warrants for selecting the appropriate right turn design in Figures 5-2.04A through 5-2.04C cannot be meaningfully quantified. The primary warrant for the design is the need to define the conflict areas within the intersection. Other considerations are intersection capacity, accident experience, traffic volumes, frequency of intersections, pedestrian refuge, and accommodation of traffic control devices. The following are general guidelines for the design selection:

1. The Yield Condition is often used at skewed intersections where it is desired to reduce the amount of unused pavement area within the intersection. This is attained by introduction of the channelization or a raised island for development of a free right-turn. Figure 5-2.04A (1 and 2) shows the development of a minimum radius design. When there is a need to provide larger island areas for pedestrians, bicyclists and signal installation, the outside curb radius (O.C.R.)

should be increased. The traffic control for the right turning traffic may be either a stop or a yield depending upon the intersection characteristic. This condition applies to a rural minor highway which stops at a higher order roadway and which must have the stop sign visibly placed in the island, as well as to a signalized intersection requiring island space for signal placement. This condition requires the driver to wait for an opportunity to merge without disrupting through traffic.

2. The Acceleration Lane Condition is generally used at the intersection of a multi-lane divided highway and a major 2-lane county or trunk highway where the speeds and traffic volumes are high for one or both roadways. The acceleration lane enables the entering vehicle to increase its speed and merge more smoothly into the through-traffic openings which may be infrequent and short. The free right-turn lane should desirably have a horizontal curvature radius of 60 m or greater. For design and detail development, see Figures 5-2.04B through 5-2.04D.

   As a special case, the Acceleration Lane Condition may be modified at the intersection on lower speed roadways (70 km/h and less). The minimum acceleration taper or a flat curve, along the right edge of the pavement, should extend 100 m beyond the free right island nose to a point along the right edge of the through lane. Any other modification to the Acceleration Condition should be reviewed and justified on a case-by-case basis.

For the Acceleration Lane Condition, the curvature radius will depend upon the design speed which is appropriate for the right turning traffic. Table 5-2.04A provides the corresponding radii and superelevation rates for the selected design speed. For design speeds 65 km/h or higher, the criteria presented in Chapter Three on horizontal curvature and superelevation should be used to design the free right-turn lane. The horizontal curve for the inside edge of pavement should be designed either as a compound or a simple curve with approach and departure tapers in rural design. The entering and exiting curves and tapers provide the turning vehicles with transition for acceleration and deceleration during the turn. The superelevation transition should be designed according to the superelevation discussion in Chapter Three.

Table 5-2.04A
CURVATURE RADII FOR FREE RIGHT ACCELERATION LANE CONDITIONS

DESIGN SPEED (V), km/h	15	25	30	35	40	45	50	55	60
Side Friction Factor (f)	0.35	0.33	0.31	0.28	0.25	0.23	0.21	0.20	0.19
Assumed minimum superelevation (e), m/m	0.02	0.02	0.02	0.02	0.04	0.04	0.06	0.06	0.06
Total e & f	0.37	0.35	0.33	0.30	0.29	0.27	0.27	0.26	0.25
Radius, Minimum, m	0	15	22	33	44	60	73	92	114

Note: For design speeds of 65 km/h or higher, use criteria presented in Chapter 3.

For the Yield Condition, the edge of pavement horizontal curves should be designed as simple curves with taper offsets or two centered compound curves with tapers.

Lane width for channelized right turns is measured as follows:

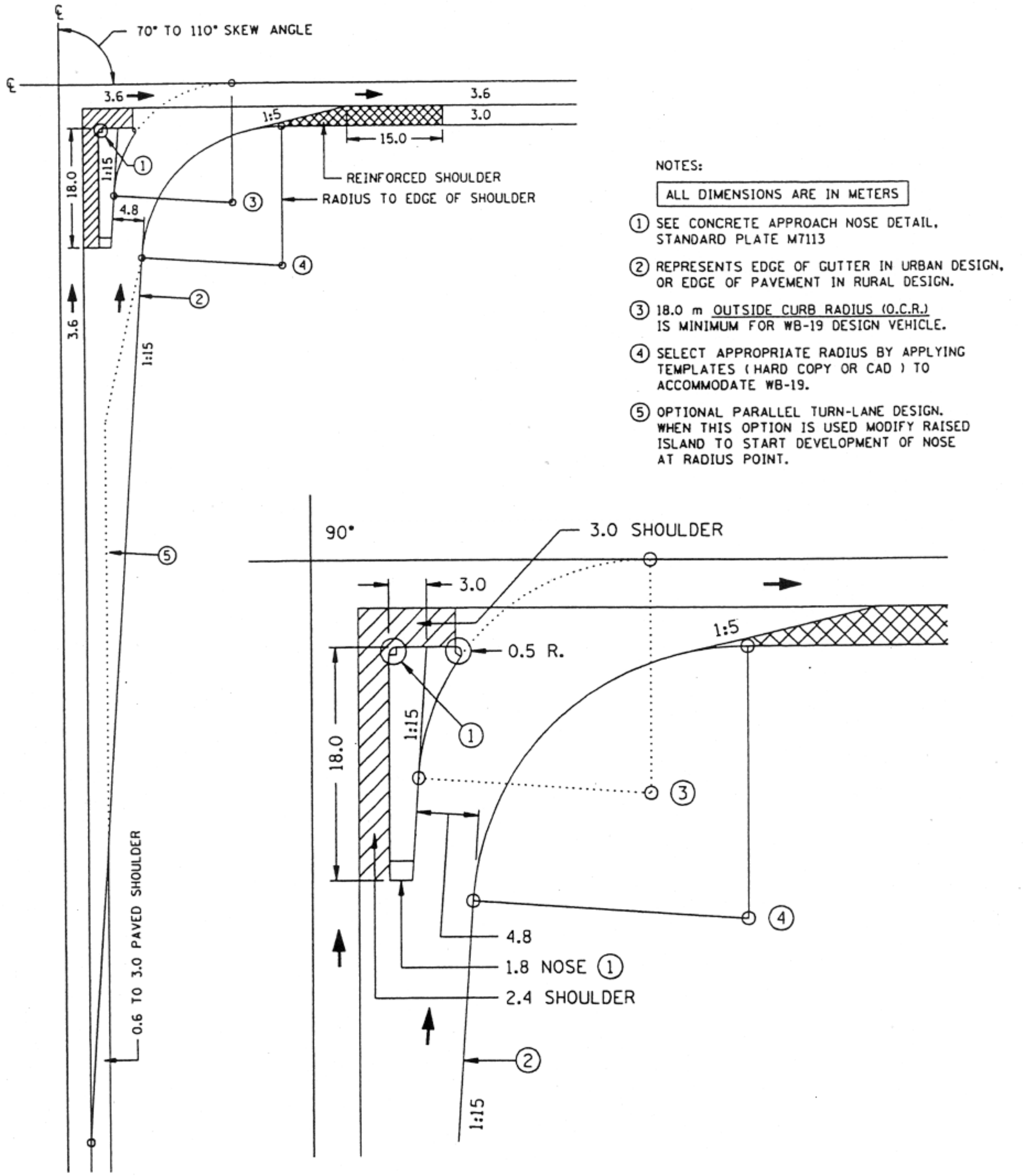
1. When no curbs are used, the lane width is the width of the traveled way exclusive of shoulders.
2. When curbs are used, the edge of the gutter is considered the edge of the traveled way.
3. Lane widths are variable for curve radii less than 60 m.

The determination of the lane width is as follows:

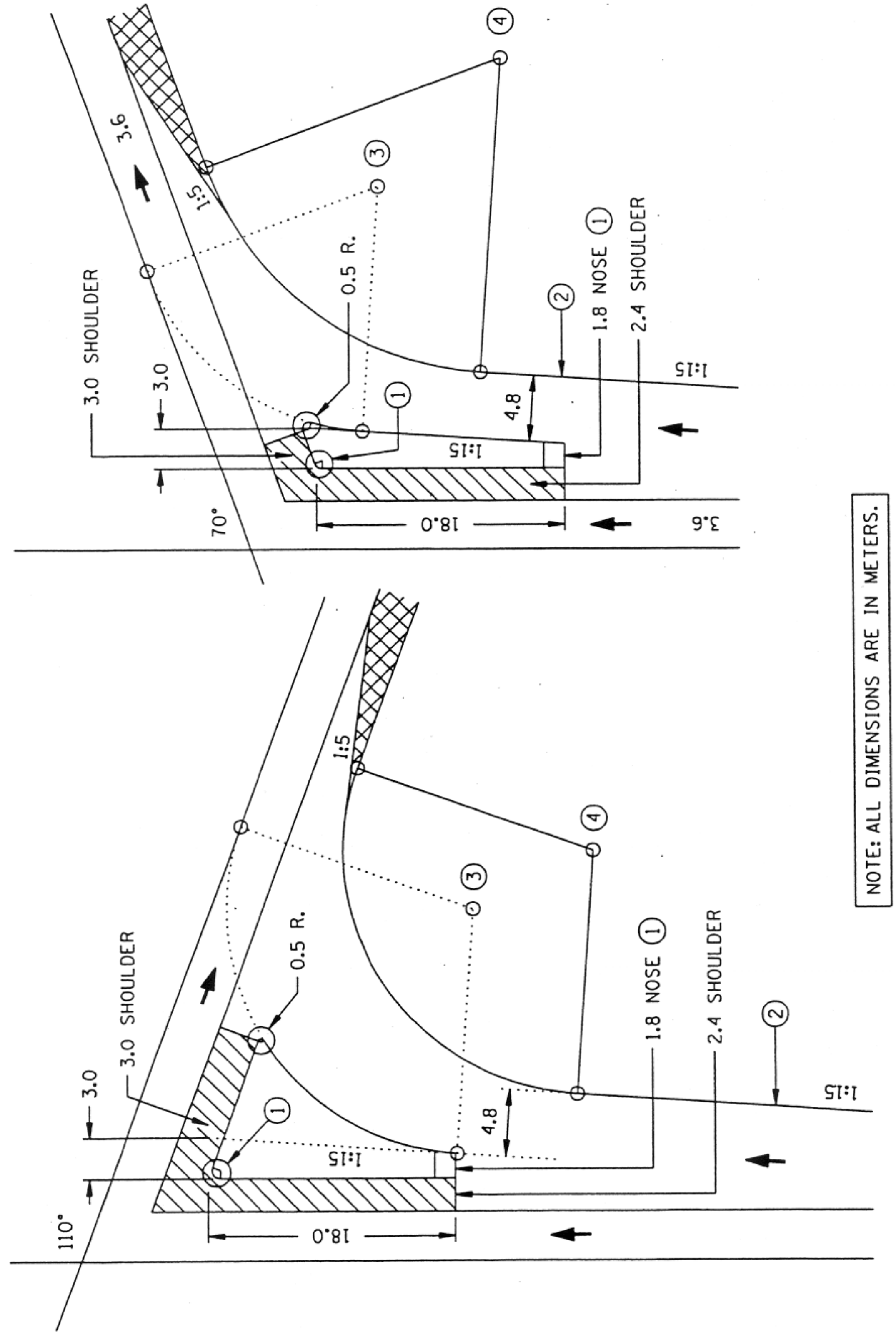
1. From Section 5-2.01 determine the design vehicle for the given intersection. In many cases the intersections along the trunk highways are designed to accommodate the WB-19 vehicle.
2. Pick an Outside Curb Radius (OCR) for the turn. Establish the wheel path for the selected vehicle following along the OCR, and use either turning movement software or the design templates to develop the path.
3. Add 0.5 m to each side of the swept path and 0.3 m to each curbed side.
4. Define the edges of the traveled way using curve radii and tapers as appropriate.
5. For the WB-19 design vehicle, in addition to the above, a chart shown in Figure 5-2.04D may be used to establish the Free Right Lane width, and Design Guides shown in Figures 5-2.04A through 5-2.04C may be used to develop minimum radius design.
6. Minimum width of any channelized lane is 4.2 m.

5-2.05 Design for Left-Turns

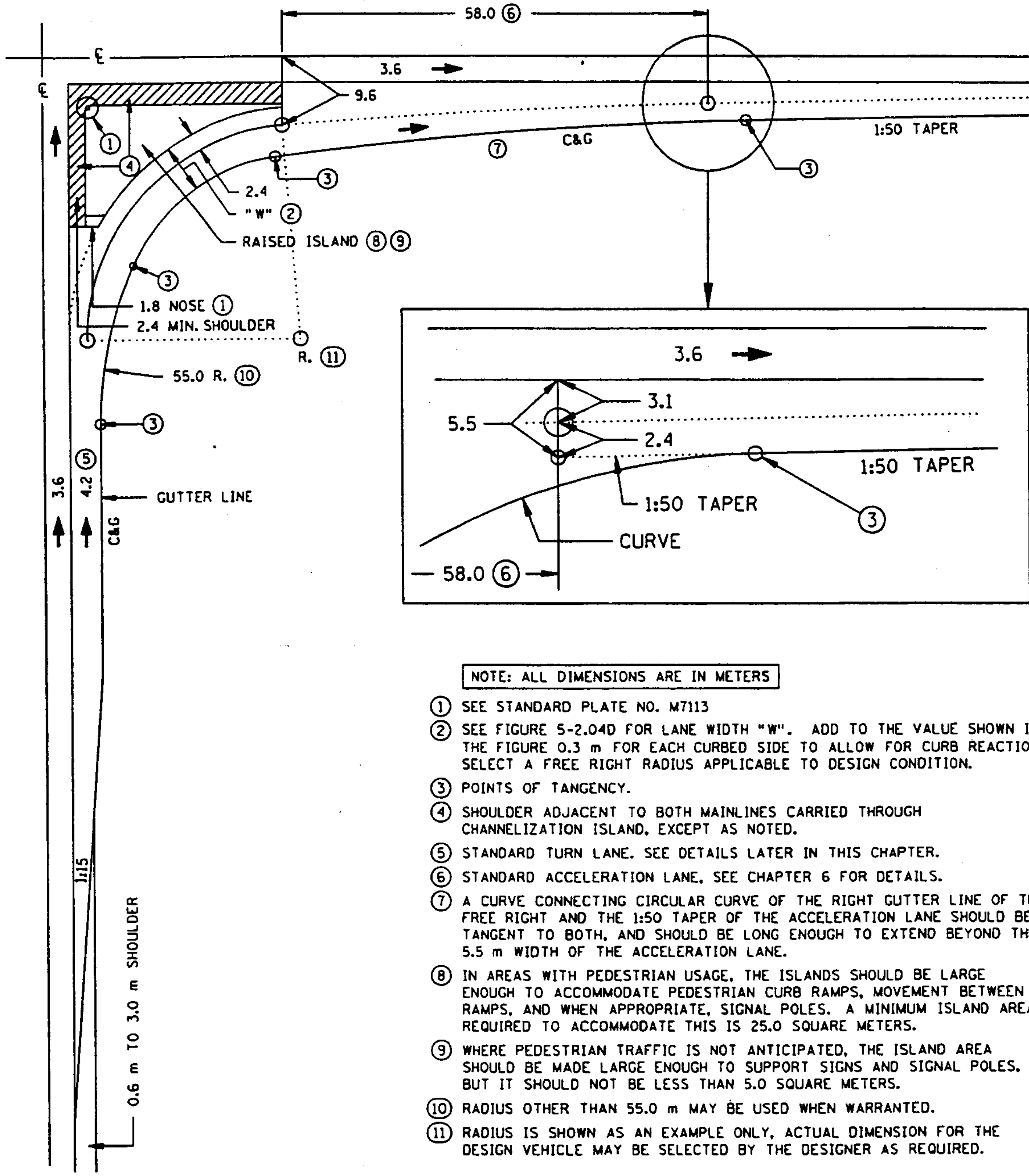
The same design decisions for right-turns also apply to left-turns. However, where the width of an undivided arterial is equivalent to four or more lanes for 2-way streets, there is usually enough intersection area to allow all left-turn movements without encroachment. Where the intersection width is less, there may be a problem with left-turning vehicles from the major road onto a narrow side street. If a vehicle is stopped on the side street, the left-turning vehicle from the major road may not be able to make the turn without encroaching beyond the curb line on the far side. Therefore, every intersection should be checked to determine if all left-turning movements can be made without encroachment or if it is warranted to widen the intersection to allow space to properly make all left-turns.



FREE RIGHT TURN - YIELD CONDITION - WB19 VEHICLE - 18.0 m RADIUS
Figure 5-2.04A (1 of 2)



FREE RIGHT TURN - YIELD CONDITION - WB19 VEHICLE - 18.0 m RADIUS
Figure 5-2.04A (2 of 2)



NOTE: ALL DIMENSIONS ARE IN METERS

① SEE STANDARD PLATE NO. M7113

② SEE FIGURE 5-2.04D FOR LANE WIDTH "W". ADD TO THE VALUE SHOWN IN THE FIGURE 0.3 m FOR EACH CURBED SIDE TO ALLOW FOR CURB REACTION. SELECT A FREE RIGHT RADIUS APPLICABLE TO DESIGN CONDITION.

③ POINTS OF TANGENCY.

④ SHOULDER ADJACENT TO BOTH MAINLINES CARRIED THROUGH CHANNELIZATION ISLAND, EXCEPT AS NOTED.

⑤ STANDARD TURN LANE. SEE DETAILS LATER IN THIS CHAPTER.

⑥ STANDARD ACCELERATION LANE. SEE CHAPTER 6 FOR DETAILS.

⑦ A CURVE CONNECTING CIRCULAR CURVE OF THE RIGHT GUTTER LINE OF THE FREE RIGHT AND THE 1:50 TAPER OF THE ACCELERATION LANE SHOULD BE TANGENT TO BOTH, AND SHOULD BE LONG ENOUGH TO EXTEND BEYOND THE 5.5 m WIDTH OF THE ACCELERATION LANE.

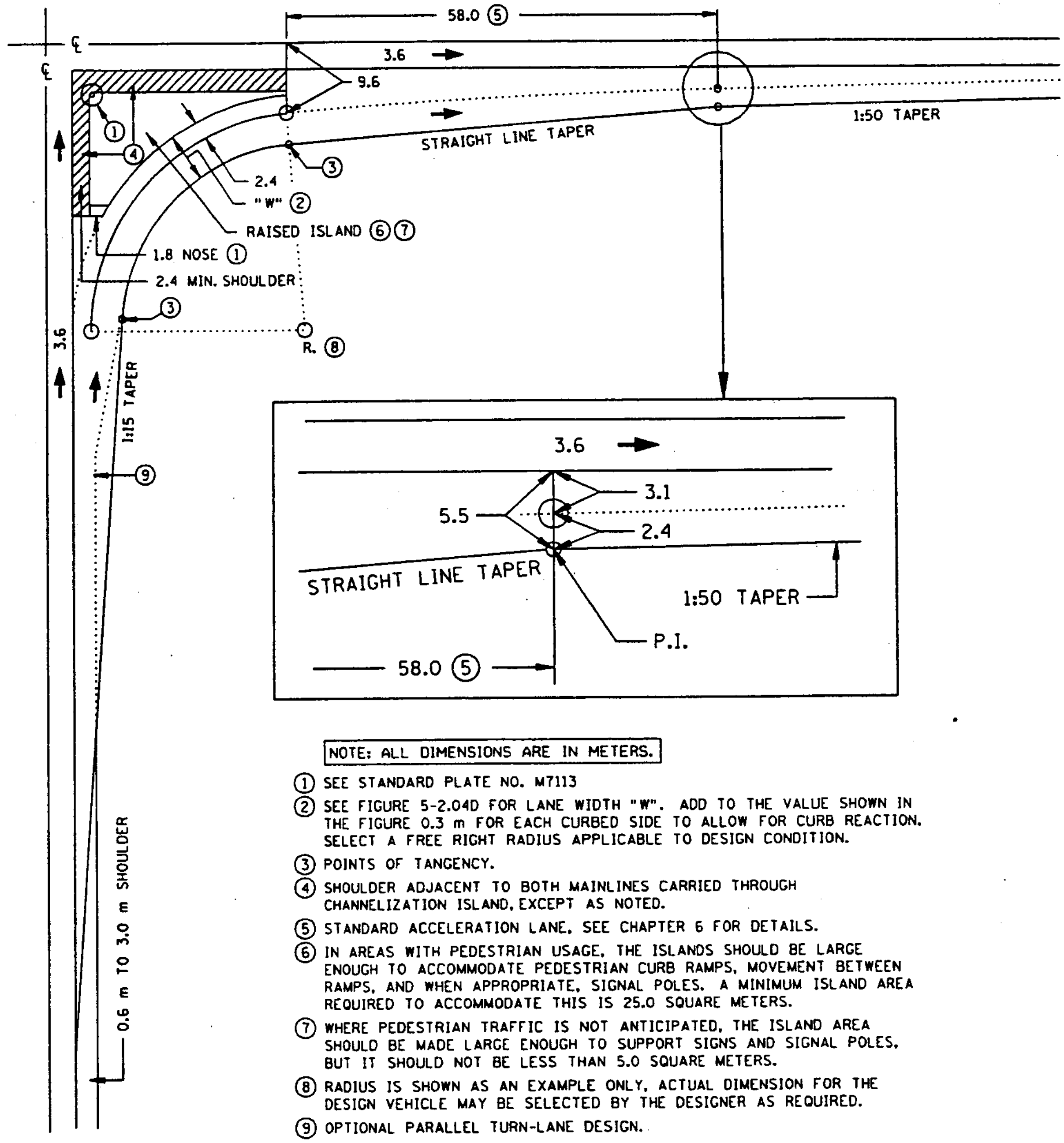
⑧ IN AREAS WITH PEDESTRIAN USAGE, THE ISLANDS SHOULD BE LARGE ENOUGH TO ACCOMMODATE PEDESTRIAN CURB RAMPS, MOVEMENT BETWEEN RAMPS, AND WHEN APPROPRIATE, SIGNAL POLES. A MINIMUM ISLAND AREA REQUIRED TO ACCOMMODATE THIS IS 25.0 SQUARE METERS.

⑨ WHERE PEDESTRIAN TRAFFIC IS NOT ANTICIPATED, THE ISLAND AREA SHOULD BE MADE LARGE ENOUGH TO SUPPORT SIGNS AND SIGNAL POLES, BUT IT SHOULD NOT BE LESS THAN 5.0 SQUARE METERS.

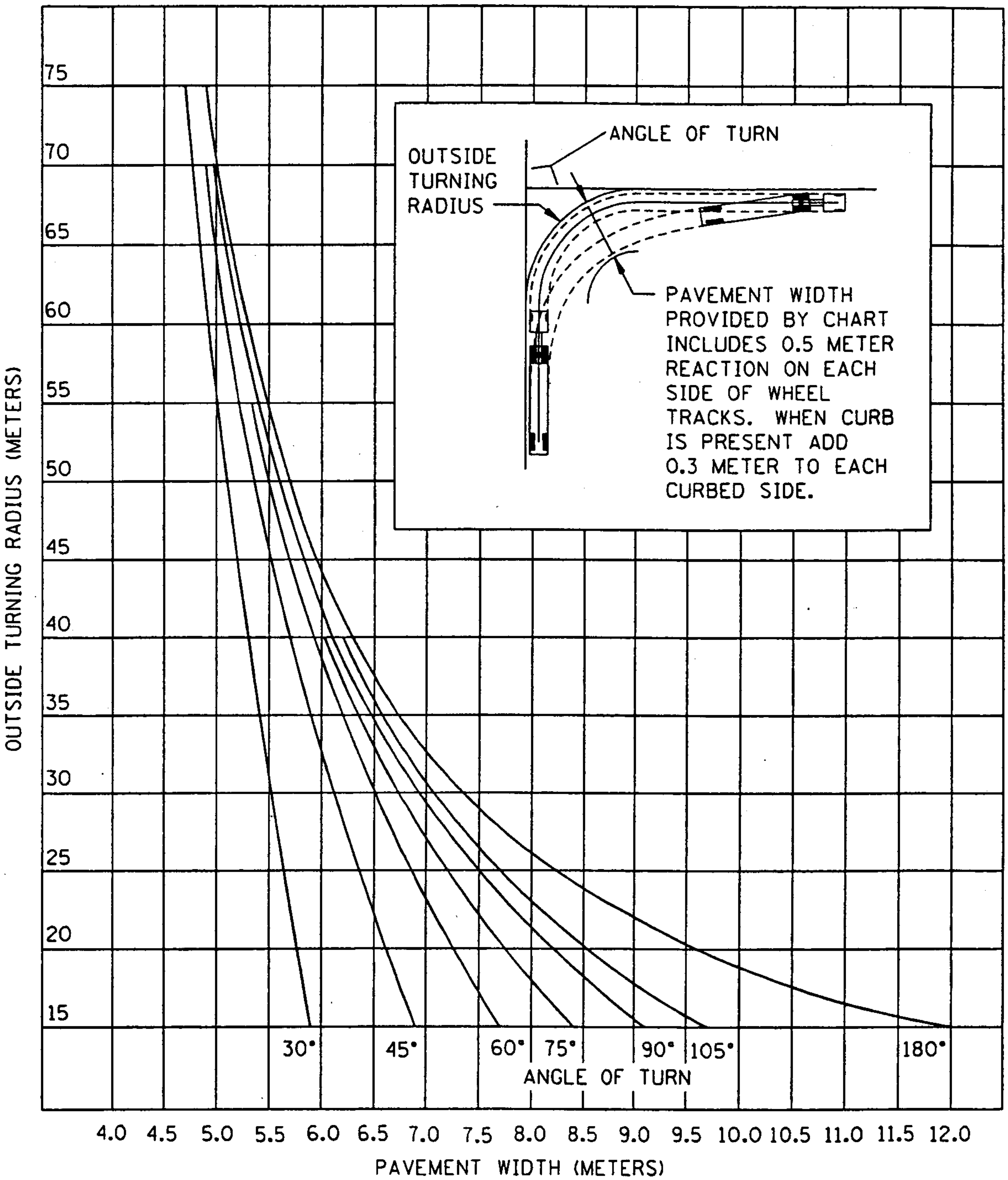
⑩ RADIUS OTHER THAN 55.0 m MAY BE USED WHEN WARRANTED.

⑪ RADIUS IS SHOWN AS AN EXAMPLE ONLY, ACTUAL DIMENSION FOR THE DESIGN VEHICLE MAY BE SELECTED BY THE DESIGNER AS REQUIRED.

FREE RIGHT TURN - ACCELERATION LANE CONDITION
URBAN DESIGN
Figure 5-2.04B



FREE RIGHT TURN - ACCELERATION LANE CONDITION
RURAL DESIGN
Figure 5-2.04C



LANE WIDTHS AND RADII - WB19 VEHICLE
Figure 5-2.04D

5-3.0 URBAN INTERSECTIONS

At urban intersections, all the modes of transportation which may be present should be considered. Pedestrian and bicycle traffic, in particular, are on the rise and are strongly supported and encouraged both at the Federal and State levels. They should be provided safe movement while traversing through intersections alongside motorized vehicles. Intersections near pedestrian and bicycle traffic generators (such as: major employment centers, schools, parks and shopping centers) should be carefully reviewed to identify existing and potential multi-modal travel needs.

5-3.01 Turn Lanes

Studies have demonstrated the accident-reducing potential of exclusive right-turn and left-turn lanes, particularly for left turns. They provide an area for deceleration and storage which reduces the conflict with through traffic. They also increase the capacity and improve the level of service of the intersection.

5-3.01.01 Turn Lane Policy at Urban Intersections

Because of the operational and safety benefits associated with right- and left-turn lanes, it is Mn/DOT's policy that, in urban areas, they be considered wherever construction is economically feasible taking into account the amount of right of way needed, type of terrain, and environmentally or culturally sensitive areas.

For new construction/reconstruction projects on divided highways, left-turn and right-turn lanes should be considered at all locations where a paved crossover will be constructed. Right-turn lanes may also be considered at some locations with no crossover as determined by the District Traffic Engineer in consideration of accidents, capacity and traffic volumes.

For preservation projects, left-turn lanes should, if feasible, be provided:

1. At all public road median crossovers.
2. At non-public access locations generating high traffic volumes.
3. At locations where accident records confirm the existence of an excessive hazard.
4. At locations determined by the District Traffic Engineer in consideration of accidents, capacity and traffic volumes.
5. Where a median opening is planned or exists, and its continued existence is justified, a left-turn lane may be added regardless of what the access point serves.

For preservation projects, right-turn lanes should, if feasible, be provided at all public road intersections, and at other locations as determined by the District Traffic Engineer in consideration of accidents, capacity and traffic volumes.

The principles of Access Management call for controlling the number of access points allowed on the higher classifications of roadways. Mn/DOT's policy on installing turn lanes in urban areas, as listed above, does not violate these principals; designers should try to close any unjustified or potentially dangerous access points. However, if an access point is to remain open, adding a turn lane will enhance the operation and safety.

5-3.01.02 Cross Section and Pavement Details

1. Turn lane widths should be 3.6 m with 0.5 m shoulders. Where curb and gutter is present, 0.6 m should be added to the lane width. See Figures 5-3.01A and B.
2. The cross section elements for the turn lane will vary depending on mainline construction and turning movement volumes. When the mainline is rigid, the turn lane may be either rigid or flexible design. When the mainline is flexible, the turn lane will be flexible. Contact the District Materials and/or Soils Engineer for design recommendations.
3. When the roadway is superelevated, a right-turn lane on the high side should have 0.02 m/m cross slope away from the travel lane except that the algebraic difference between cross slopes cannot exceed 0.07 m/m. A turn lane on the low side shall have the same slope as the adjacent traffic lane with a minimum slope of 0.02 m/m. The general design of superelevation transition as discussed in Chapter 3 should be used to develop superelevation on the turn lane. This is particularly important where the turn lane is diverging from the travel lane.

4. The cross slope on left-turn lanes when the roadway is superelevated should be designed the same as for right-turn lanes. On divided roadways where the roadway slopes away from the median, the left-turning lane would have the same cross slope as the adjacent traffic lane.
5. See Figures 5-3.01A, B, C and D for design details of turn lanes.

5-3.01.03 Typical Length of Turn Lanes (right-turn and left-turn)

The typical length of a turn lane is 90 m of full width lane plus additional length based on a 54 m taper section (1:15 taper from a 3.6 m wide lane), plus any additional length needed for down grades (see item 4 below). The total length of the turn lane can also be based on the sum of the taper length, deceleration length, storage length and downgrade. The turn lane length may be longer or shorter than the typical length as explained in Table 5-3.01A and later in this section.

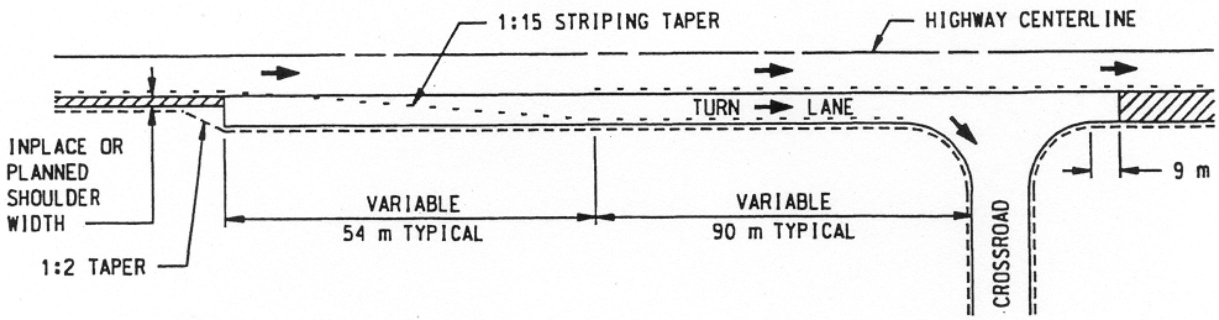
1. Taper - A divergence angle between 2 and 5 degrees is considered acceptable. Normally, the taper is 1:15 off tangent sections; which corresponds to a 3.8 degree angle. A shorter taper (as short as 1:5) may be used where a turn lane is on a curve or where greater storage length is needed.
2. Deceleration Length - It is accepted practice to consider that some deceleration (15 km/h) occurs in the through lane and to consider the taper as part of the deceleration length. On the other hand, heavy through traffic and high speeds justify an increase in the deceleration length of turn lanes. In these cases, it is desirable to provide for all the deceleration within the turn lane (ie not within the through-lane). The deceleration lengths, including the taper are shown in Table 5-3.01A. These lengths assume that no deceleration occurs until the vehicle enters the taper. Lengths are provided for combinations of highway design speed and turning speed, or for the stop condition. The table may be used if appropriate in the judgement of the designer or with the recommendation of the District Traffic Engineer.
3. Storage Length
   A. At Unsignalized Intersections
      1. The length should be based on the number of turning vehicles likely to arrive in an average 2-minute period within the peak hour.
      2. As a minimum, space for at least two passenger cars should be provided.
      3. If mainline traffic contains over 10% trucks, space for at least one car and one truck should be provided.
   B. At Signalized Intersections
      1. The length should be based on 1.5 to 2.0 times the average number of vehicles that would be stored per cycle.

   The designer should consult with the District Traffic Engineer to determine the storage length at both signalized and unsignalized intersections.
4. Downgrades - When designing a turn lane on a downgrade, additional length should be provided. See Chapter 2 Table 2-5.09B.

Table 5-3.01A
DECELERATION LENGTHS (INCLUDING TAPERS) FOR TURN LANES
FOR DESIGN SPEED OF EXIT CURVE - km/h (V)

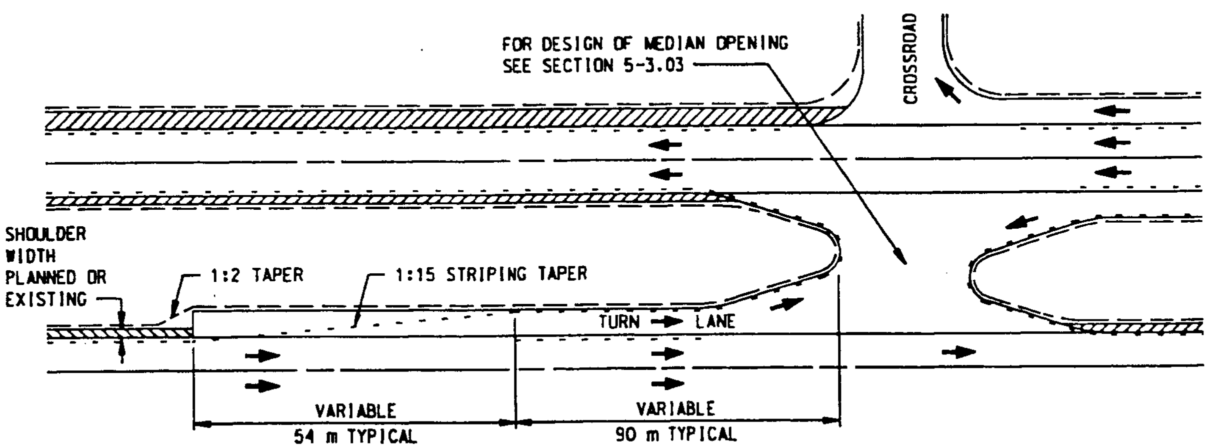
HIGHWAY DESIGN SPEED, km/h	AVERAGE RUNNING SPEED, km/h	STOP CONDITION	25	35	40	50	55	65	70	80
		FOR AVERAGE RUNNING SPEED ON EXIT - km/h - (1)								
		0	23	31	35	43	47	58	62	70
50	47	74	60	54	44	-	-	-	-	-
60	55	90	86	82	66	55	44	-	-	-
70	63	104	102	94	78	64	50	42	-	-
80	71	132	128	126	108	98	84	68	52	-
90	79	150	148	137	130	126	114	98	82	68

(1) Turning speeds for free right-turns



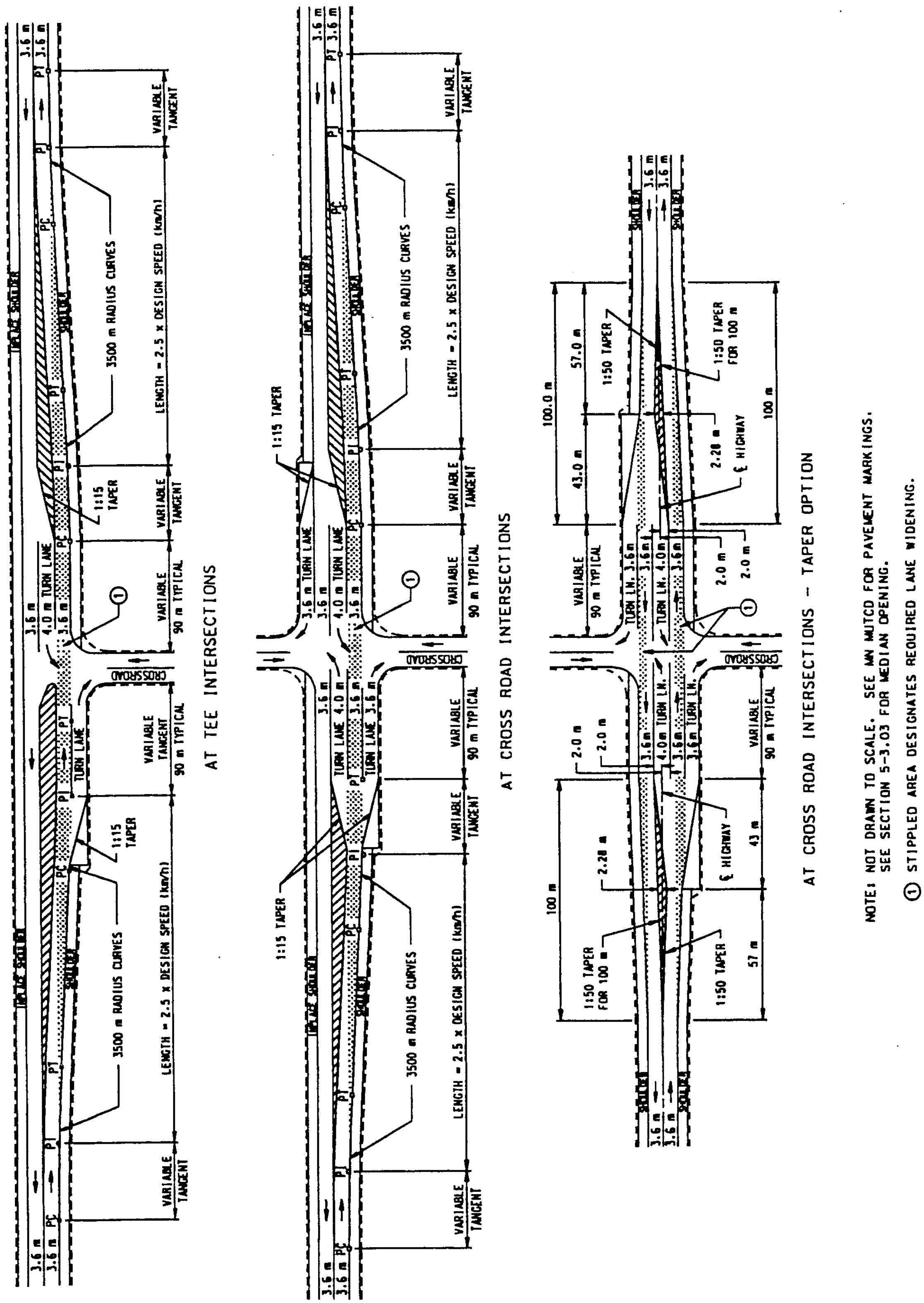
NOTES:
ON DOWNGRADES, THE TURN LANE MAY NEED TO BE EXTENDED. REFER TO SECTION 2-5.09.
TURN LANE WIDTH IS 4.2 m WHEN CURB AND GUTTER ARE PRESENT, 3.6 m OTHERWISE.

RIGHT-TURN LANE
Figure 5-3.01A

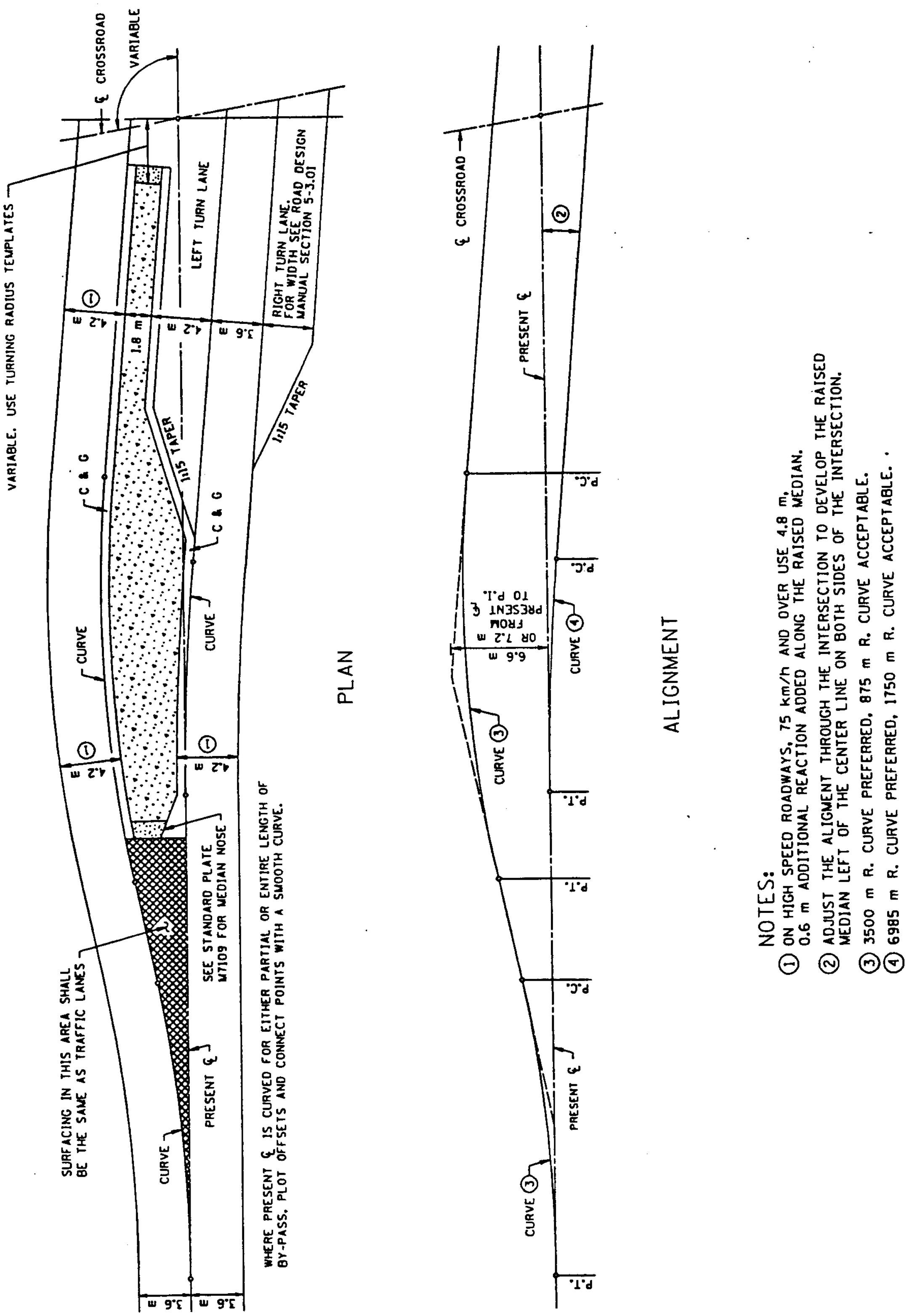


NOTES:
ON DOWNGRADES, THE TURN LANE MAY NEED TO BE EXTENDED. REFER TO SECTION 2-5.09.
TURN LANE WIDTH IS 4.2 m WHEN CURB AND GUTTER ARE PRESENT, 3.6 m OTHERWISE.

LEFT-TURN LANE
Figure 5-3.01B



PAINTED MEDIAN LEFT-TURN LANE ON EXISTING HIGHWAY
Figure 5-3.01C



CHANNELIZED LEFT-TURN LANE
Figure 5-3.01D

5-3.01.04 Exceptions to Turn Lane Lengths

Ideally the full deceleration length (including taper) and the storage length should be provided. However, conditions may justify a shorter turn lane. Such conditions include:

1. Urban facilities with closely spaced intersections and considerable roadside development, where full length turn lanes are physically unfeasible.
2. Low volume roads, where a full length turn lane is not needed or economically unfeasible to construct.

In such cases, designers may assume that most of the deceleration will be performed in the through-lane. This is a reasonable assumption that does not sacrifice safety.

If the first condition listed above is the one influencing turn lane lengths, designers are encouraged to consider alternative measures such as restricting turning movements, adjusting the signal cycle (done by the District Traffic Engineer), providing dual left-turn lanes (warranted at turning volumes greater than 300 VPH), or providing continuous one-way or two-way left-turn lanes.

When shorter turn lanes are being considered, the following factors should be taken into account:

1. Through-traffic volumes,
2. Traffic composition,
3. Future plans for signalizing a presently unsignalized intersection, and
4. Future land use changes which may alter traffic and turning volumes.

In contrast, it may be justified to provide a turn lane length greater than the typical lengths. Criteria for consideration include: traffic generated by adjacent land use, types of vehicles, deceleration, downgrades, and storage needs. At some sign or signal controlled intersections, heavy through-traffic blocks the entrance of the turning lane. In such cases, designers are encouraged to extend the length of the turning lane to allow turning vehicles to get into the turning lane without having to drive on the shoulder.

Before modifying the length of a turn lane, the District Traffic Engineer should review the specific location and the effect on traffic operation.

5-3.01.05 Continuous One-Way or Two-Way Left-Turn Lanes (COWLTL; CTWLTL)

COWLTL and CTWLTL increase safety and improve traffic operation on roadways with numerous and closely spaced roadside entrances and exits. Several studies have shown significant savings in time delays, number of stops, and reduction in rear-end, right-angle and sideswipe accidents without a corresponding increase in head-on accidents. Research shows that accident rates decrease by 20 percent or more after installing continuous left-turn lanes (CLTLs) on previously undivided highways. Furthermore, CLTLs can reduce some types of accidents, such as rear-end and sideswipe accidents by as much as 30 percent. CLTLs also increase driver comfort by providing a queuing spot (while waiting to make a left-turn) that is physically removed from the through-traffic stream. CLTLs have a traffic calming effect by causing drivers to reduce their speed. Having said that, it is important to note that even though CLTLs separate the two through streams of traffic, they are not as good (in providing separation) as divided highways. It is also important to note that three-lane sections may tempt some aggressive drivers to use the CLTL itself to pass slow-moving through vehicles.

No rigid design criteria have been established for CLTLs design, the following are general guidelines:

1. CLTLs are typically used in areas that shift from rural to suburban or urban (for example, when a rural trunk highway goes through a town).
2. Since roadside development is usually (or will be) evenly distributed on both sides of the highway, CTWLTLs are usually more appropriate than COWLTLs.
3. Early studies advised that CLTLs should only be used with low speeds. Since then, several states including California, Texas and Iowa have installed CLTLs on roads with 55 mph (88 km/h) posted speed limit. These states report that there are no safety problems resulting from constructing CLTLs on high speed roadways.
4. Early studies also advised that CLTLs should be used with relatively low ADTs. Since then, Iowa has installed a five-lane section with 10,000 vpd including over 1,000 trucks. The state

reports that there are no safety problems resulting from constructing CLTLs with high ADTs. Texas has installed several seven-lane sections.

5. The accepted lane width is 3.9 to 4.5 m with 4.2 m being the norm. 3.6 m wide CLTLs may be used if right-of-way is very restrictive and if approved by the Geometrics Engineer.
6. If the roadway is being reconstructed, realign opposite side driveway entrances to provide better safety and operation.
7. Pavement markings for CLTLs should be developed as directed by the District Traffic Engineer.

5-3.01.06 Double Left-Turn Lanes

Double left-turn lanes should be considered when the turning volume equals or exceeds 300 vehicles per hour (VPH), when the requirements for storage makes the turn lane extremely long, or when geometrically a required length for the single left-turn lane cannot be provided. Double left-turn lanes operate at approximately 1.8 times the capacity of a single left-turn lane. Because of high volumes associated with double left-turn lanes, fully protected signal phasing is required.

The following design guidelines for double left-turn lanes are from NCHRP 279, Intersection Channelization Design Guide:

1. The throat width for turning traffic is the most important design element. Drivers are most comfortable with extra space between the turning queues of traffic. Because of the off tracking characteristics of vehicles and the relative difficulty of two abreast turns, an 11 m throat width is desirable for two lanes of turning traffic. In very constrained situations, a 9 m throat width is an acceptable minimum.
2. Designers should check for possible conflicts involving left-turns opposing double left-turns. For proper design, use the swept path of semi-trailer and a 4.2 m strip placed alongside on the inside of the turn for a passenger vehicle. Turn templates should be used to check the design.
3. Consideration should be given to providing pavement markings to separate the turn lanes. The MN MUTCD recommends 0.6 m long dashed lines with 1.2 m gaps to channel turning traffic. These channelization lines should be carefully laid out to reflect off-tracking and driving characteristics.

5-3.01.07 Continuous Right-Turn lane (CRTL)

A continuous right-turn lane is essentially a combination of right-turn acceleration and deceleration lanes that are extended to accommodate closely spaced driveways. For proper operation, continuous right-turn lanes should not be longer than 0.4 kilometers. Continuous right-turn lanes are desirable where speeds are greater than 50 km/h, the roadway volumes heavy, and turning demands high.

1. The use of continuous turn lanes may reduce the frequency and severity of rear-end conflicts by removing turning vehicles from higher speed through lanes.
2. The need and application should be site-specific and should be based on analysis of rear-end accidents, turn volumes and operation.
3. The design of a typical section and tapers should be the same as that for a typical right-turn lane.

5-3.02 Channelization

Large all-paved intersections may cause the driver to make conflicting movements. Channelization separates and clearly defines points of conflict within the intersection. Channelized islands should be placed so that the proper course of travel is immediately obvious, easy to follow, and of unquestionable continuity. This can be achieved with painted, flush, or curbed islands. The islands also provide pedestrian refuge and a location for traffic control devices. The following is general guidance for channelized intersections:

1. There is a practical limit to how much channelization is appropriate for a given intersection before driver confusion results.
2. Curbed islands should only be used on multi-lane highways and the more important 2-lane facilities.

3. Curbed islands whose area is less than 5.0 sq m should not be constructed. The minimum width and length of median islands is 1.2 m and 8.0 m respectively. Where signs or ramp meters are to be used, the minimum width should be 2.4 m.
4. The approach nose should be squared and ramped on a 1:10 slope. The nose of the island should be on the left side of the centerline for approaching traffic.
5. Pavement markings should precede curbed islands for advance warnings.
6. Curbed islands may be covered with a concrete walk or a low-growing vegetative cover.
7. Snow-melt drainage from an island should be controlled to prevent re-freezing within a traveled lane. Controlling the drainage could be accomplished by sloping the island surface to a drainage structure within the island. An alternative would be to slope all the gutters surrounding the island to catch the drainage rather than sloping the gutters to match the superelevation, thus the drainage is held to the curb and can be routed to a drainage structure.

5-3.03 Median Openings

Although many of the design considerations have already been discussed, median openings introduce additional design elements which must be addressed.

5-3.03.01 Policy

Median openings that allow cross-street traffic to cross, or turn left onto the arterial should be provided at public street intersections only. However, they are not warranted at every public street intersection. An exception to the “public street” only policy may be at access points to large traffic generators which conform to the median opening spacing criteria, and at locations which accommodate U-turns when crossings are spaced far apart. Contact Mn/DOT’s Access Management Section for the appropriate spacing of median openings on different road classifications.

5-3.03.02 Geometrics

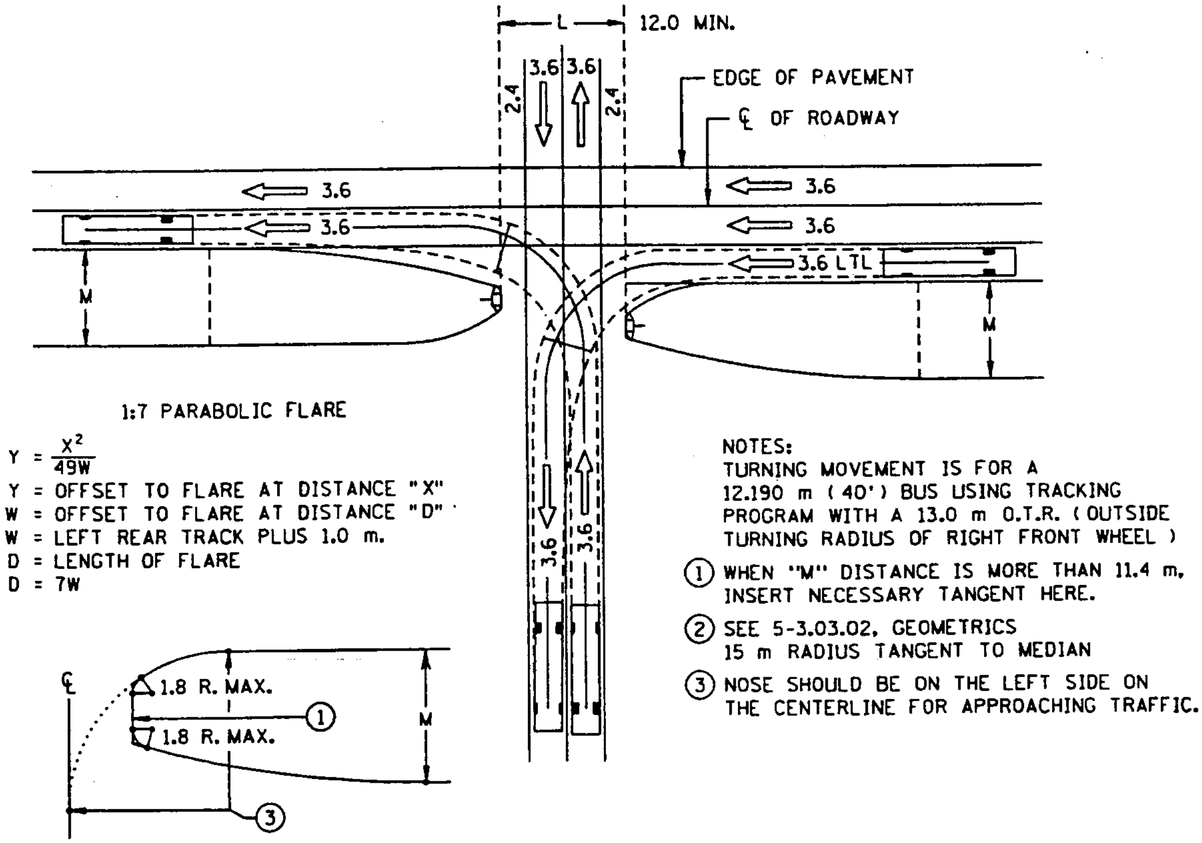
As with the design for right turns, a design vehicle and an acceptable encroachment must be selected. This will include a review of traffic volumes, turning movements, traffic composition, and traffic control. The left-turn paths of vehicles are essentially the same as the right-turn paths.

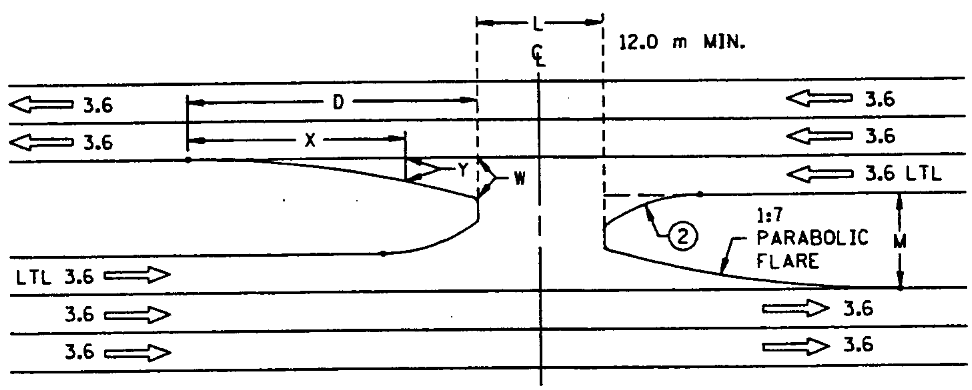
It is recommended that a school bus be the design vehicle for designing a median crossing at minor roadways with under 400 ADT. The same geometric design can be applied for median openings at crossroads with ADT up to 1000 if a traffic study shows that the presence of large trucks is only a rare occurrence (5 or less per day).

The width of a median plays an important part in how the median opening will be designed. Wide medians provide the design vehicle with an option of a one or two-stage crossing. The space between the two roadways with a wide median is used for refuge when a vehicle is either crossing to the other side or turning left into the far roadway. The left-turning vehicle may elect to turn into the far or the near lane. The design vehicle should be able to make the left-turn with little or no encroachment beyond the outer edge of the lane the vehicle is entering. Either the turning templates or a computer tracking program should be used to design the edge of pavement curve to accommodate the design vehicle path. A flat curve, a 1:7 parabolic flare, a bullet nose, and a blunt nose with 0.6 to 1.8 m corner radii all can be used individually or in combination for median crossing nose design. The minimum median opening at any crossing should be 12 m. Figure 5-3.03A provides guidance for median design. The median openings in Figure 5-3.03A are for bus design vehicles. Larger design vehicles should be used if appropriate, and the median opening that best fits the design vehicle turning movements should be used.

For new construction/reconstruction projects, 1:10 inslopes or flatter should be provided at all median crossovers and ditch blocks.

For preservation projects, when grading is involved; 1:10 inslopes should be considered on all median crossovers and ditch blocks to the extent practicable. Where no grading is involved, the existing slopes maybe left in place, provided accident history or other criteria do not indicate corrective action is needed. Grading is defined as any work done outside the shoulder to correct sideslopes and ditches.





M = MEDIAN WIDTH (m) *										
3.6	4.2	4.8	5.4	6.0	6.6	7.2	7.8	8.4	9.0	M = GREATER THAN 9.0
L = MINIMUM LENGTH OF MEDIUM OPENING (m)										
34.2	29.2	25.2	22.2	19.8	17.6	16.0	14.4	13.0	12.0	L = 12.0 MINIMUM

* WHEN A LEFT TURN LANE IS PROVIDED, THE CONTROLLING M (FOR PURPOSES OF DETERMINING L) IS THE ORIGINAL WIDTH MINUS THE TURN LANE WIDTH.

MINIMUM DESIGN OF MEDIAN OPENING FOR LOW VOLUME CROSSROADS
BUS Design Vehicle
Figure 5-3.03A

5-3.03.03 Median Opening Spacing on Low-Speed Multi-Lane Highways

A Low Speed Multi-Lane Highway generally serves the local transportation needs; it is usually classified as an arterial or a collector. Because of its function it inherently has many points of access and median openings which are difficult to eliminate. Nevertheless, the designer should try to reduce the number of median openings to an acceptable minimum. Contact Mn/DOT's Access Management Section for the appropriate median opening spacing on the different classifications of roadways.

5-3.04 Driveways

Driveways should be treated as low volume intersections in their design. Nationally, driveway accidents account for between 5 and 11 percent of all urban accidents. It is therefore warranted to closely examine their design and location.

Driveways that serve major traffic generators such as shopping centers, industrial complexes, large apartment complexes, office parks, etc., require special design considerations. The design for these types of developments can be complex. The Office of Technical Support, Geometrics Unit, and the Office of Traffic Engineering should review the proposed designs. These driveways should be treated as street intersections and in some cases major street intersections.

For urban design, Standard Plate M7035 should be used for private driveways that service low traffic generators, i.e., private homes, duplexes, small apartment complexes, small business establishments, etc. This means that the gutter should be continued across these entrances. Designers should use their discretion as to whether the flared entrance design or a radius design should be used on a project. In some instances, a municipality may have a preference. Refer to Table 5-3.04A and Figure 5-3.04A for driveway radii. Conflicting standards in entrance design between the state and a municipality should be resolved with the designer and the municipality. For rural design see Standard Plate M90009.

5-3.04.01 Policy

Minnesota Rules, Trunk Highway System, Chapters 8810.4100 through 8810.5600, and 8810.9920 and 8810.9921, describe the general rules and regulations governing the design and location of driveways. This section provides further guidance and design details which should be used for driveway design where chapters 8810.4100 through 8810.9921 do not provide this guidance. To reduce the risk of accident potential, it is imperative that driveway access be limited to a reasonable number. Contact Mn/DOT's Access Management Section for guidance on the appropriate number of direct access driveways on different functional classification roadways.

For new construction/reconstruction projects, 1:6 inslopes or flatter should be provided on all driveways, field entrances, and intersecting roadways.

For preservation projects, when grading is involved, 1:6 inslopes should be considered on driveways, field entrances, and intersecting roadways to the extent practicable within the existing right-of-way. Where no grading is involved, the existing entrance slopes may be left in place, provided accident history or other criteria do not indicate corrective action is needed. Grading is defined as any work done outside the shoulder to correct sideslopes and ditches.

5-3.04.02 Geometric Design Elements

The criteria presented are predicated on allowing a passenger vehicle to enter or exit a driveway at a minimum of 15 km/h. Studies have indicated that this yields an acceptable amount of vehicle delay on the main highway and significantly reduces the safety hazard compared to lower entrance speeds.

1. Turning Radii - See Table 5-3.04A and standard plates M7035 and M9000.
2. Sight Distance - The criteria for intersections also apply to driveways (Section 5-2.02).
3. Turn Lanes - A turn lane may be warranted at high volume generators. Its design would be as described earlier in this section.

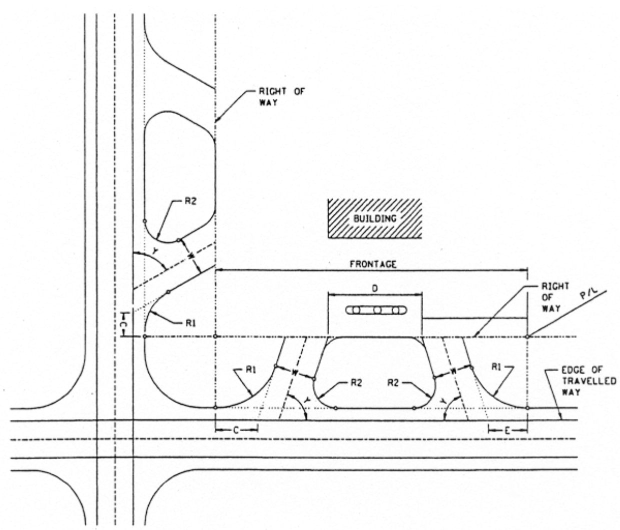
4. Skews - For 2-way operation, the angle should not deviate by more than 20 deg. from a right angle. For 1-way operation where only right-turns will be made, an angled driveway may be preferable to a perpendicular intersection since it will permit a higher entrance or exit speed. However, this is undesirable where pedestrian or bicycle traffic is appreciable.
5. Width - Excessive or restrictive driveway widths can detrimentally affect operations and safety. If the proper curb radius is provided for the design vehicle (Table 5-3.04A), then a lane width of 3.6 m (1-way) or 7.2 m (2-way) will theoretically work without encroachment. For design purposes, desirable widths of 4.8 m and 9.6 m should be used. If the desirable radii are impractical to provide, an individual assessment of each driveway must be conducted. For 1-way operation, the vehicle cannot be allowed to encroach beyond the far edge of pavement or curb. For 2-way operation, the designer must select the tolerable encroachment based on the likelihood that an entering and exiting vehicle will appear at the same time. These considerations will yield the desirable width for a given set of conditions.
6. Corner clearance - Driveways should not be located so close to intersections or other driveways that they interfere with the safety and operation of the highway. These general guidelines are also presented in Minnesota Rules, Trunk Highway System, Chapter 8810. It should be noted that dimensions may exceed the recommended values but should not exceed a 15 m maximum.
7. Vertical profile - To allow ingress and egress speeds of at least 15 km/h, the vertical profile cannot exceed certain limits without causing vehicle underside and edge clearance problems. Therefore, the criteria shown in Figure 5-3.04B should be followed. For these values, no vertical curves are needed; for more abrupt grade changes, vertical curves at least 3.0 m in length should connect the tangents. Maximum grades should be 15 percent for residential driveways and 8 percent for commercial and industrial driveways.

   Figure 5-3.04B shows vehicle clearance as the minimum design for the driveway vertical profile. Figure 5-3.04C illustrates the critical vehicle clearances as designated by Motor Vehicle Manufacturers Association (MVMA) of the United States, Inc. Each year MVMA publishes the detailed vehicle dimensions for all American made automobiles. The vertical profile should be designed to accommodate the vehicle with the most severe restrictions. An allowance for the dynamic condition of traversing the driveway should be provided, since the MVMA dimensions are for a fully loaded static condition. In very restrictive conditions it may be necessary to design the profile to accommodate only specific vehicles which will be using the driveway. One example is the lowboy semi-trailers which have a long wheel base and have problems with the conventional roll over of entrances. These entrances will have to be designed for the clearances of the lowboy. When the driveway profile includes a vertical crest, the H147 ramp breakover angle from Figure 5-3.04C is the critical vehicle dimension. For a sag condition, the H107 rear bumper angle is the critical vehicle dimension, although the H106 front bumper angle may sometimes determine the acceptability of the sag.
8. Additional information can be obtained from the Institute of Traffic Engineers Handbook, "Guidelines For Driveway Design and Location" and the MVMA.

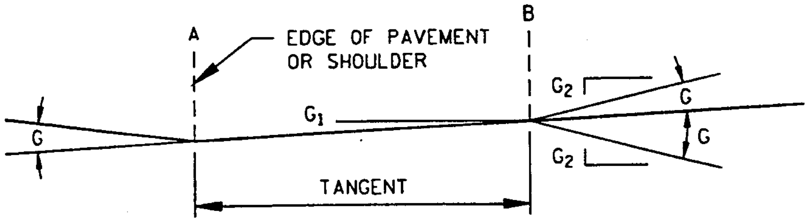
Table 5-3.04A
Driveway Dimensions

		RESIDENTIAL		COMMERCIAL - INDUSTRIAL -FARM			
		URBAN	RURAL	URBAN		RURAL	
Driveway Angle (degrees) (Y) **(1)**		70 - 90	70 - 90	70	90	70	90
Recommended Driveway Width (W) (m) **(2) (3)**		4.8	7.2	9.6	9.6	9.6	9.6
Radius of Curvature (R1) (m)	Min.	1.5	1.5	1.5	1.5	3	3
	Max.	4.5	7.5	9	9 **(4)**	12	12 **(4)**
Radius of Curvature (R2) (m)	Min.	1.5	1.5	1.5	1.5	1.5	1.5
	Max	4.5	4.5	4.5	4.5	4.5	4.5
Recommended Edge Clearance (E) (m)		N/A	N/A	1.5	1.5	3	3
Recommended Distance Between Double Driveways (D) (m) **(5)**		6	15	6	6	9	9
Recommended Corner Clearance From Major Street (C) (m) **(5)**		9	18	9	9	18	18
Recommended Corner Clearance From Minor Street (C) (m) **(5)**		6	18	6	6	18	18

1. A 90 degree driveway is desired. Driveway angle "Y" shall not be less than 70 degrees for two-way driveways.
2. Driveway widths, other than those recommended, up to 15 m will be permitted only by special permission of the Commissioner of Transportation or designee. The larger driveway dimensions are intended for those used nearly exclusively by tractor trailer combinations. Required widths are determined with vehicle wheel path templates.
3. One-way driveway dimensions may be reduced.
4. The recommended radius of a 90 degree driveway is 7.5 m.
5. Clearances other than those recommended may be needed due to varying circumstances.



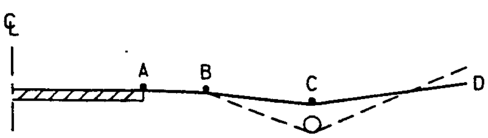
MINIMUM DRIVEWAY LOCATIONS AND DIMENSIONS
Figure 5-3.04A



SUGGESTED MAXIMUM GRADE CHANGE (G)

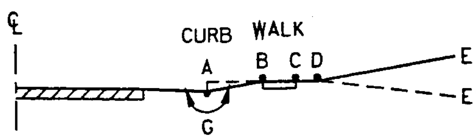
	DESIRABLE	MAXIMUM
HIGH VOLUME DRIVEWAY	0%	± 3%
LOW VOLUME DRIVEWAY ON MAJOR OR COLLECTOR STREETS	± 3%	± 6%
LOW VOLUME DRIVEWAY ON LOCAL STREETS	± 6%	CONTROLED BY VEHICLE CLEARANCE

NOTE: THE CHANGE IN VERTICAL ALIGNMENT AT POINTS "A" AND "B" SHOULD NOT EXCEED THE VALUE OF "G" IN THE ABOVE TABLE. DESIRABLY, "G" SHOULD NOT EXCEED 7%.



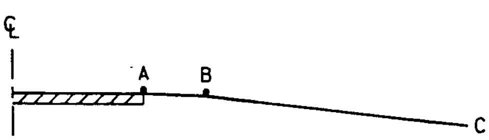
PROFILE IN CUT SECTION

A TO B = SAME PITCH AS SHOULDER SLOPE
B TO C = 8% MAX. (MIN. PITCH SAME AS SHOULDER SLOPE)
C TO D = 8% MAX. FOR COMMERCIAL AND INDUSTRIAL DRIVEWAYS. 15% FOR RESIDENTIAL.



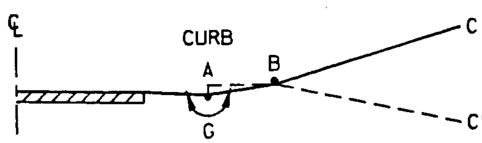
PROFILE WITH CURB AND SIDEWALK

A TO B = SLOPE FROM GUTTER TO MEET SIDEWALK
C TO D = VARIABLE DISTANCE
D TO E = ± 8% MAX. FOR COMMERCIAL AND INDUSTRIAL DRIVEWAYS. 15% FOR RESIDENTIAL.



PROFILE IN FILL SECTION

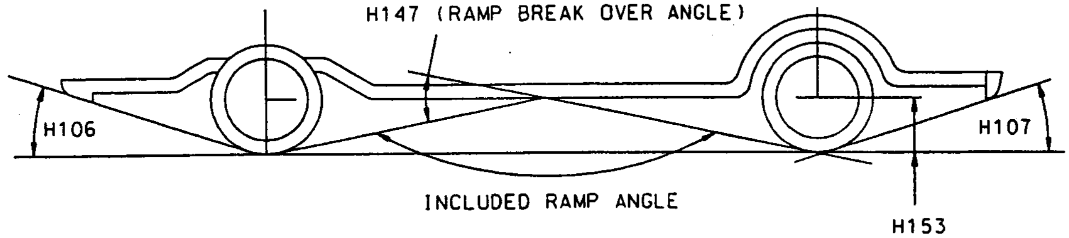
A TO B = SAME AS SHOULDER SLOPE
B TO C = 8% MAX. FOR COMMERCIAL AND INDUSTRIAL DRIVEWAYS. 15% FOR RESIDENTIAL.



PROFILE WITH CURB

A TO B = SLOPE UPWARD TO A MIN. HEIGHT EQUAL TO CURB HEIGHT
B TO C = ± 8% MAX. FOR COMMERCIAL AND INDUSTRIAL DRIVEWAYS. 15% FOR RESIDENTIAL.

DRIVEWAY PROFILES
Figure 5-3.04B



NOTE: DATA FOR INDIVIDUAL VEHICLES MAY BE OBTAINED FROM THE MOTOR VEHICLE MANUFACTURERS ASSOCIATION (MVMA) OF THE UNITED STATES, INC

VEHICLE CLEARANCE DIMENSIONS
Figure 5-3.04C

5-4.0 RURAL INTERSECTIONS

Most of the discussion in Section 5-3.0, “Urban Intersections” also applies to rural intersections. Therefore this section will only elaborate where appropriate for the design of rural intersections.

Some rural roadways in Minnesota see a dramatic increase in volume of traffic in different seasons, for example roads leading to lake cabins, etc. Designers should take seasonal/weekend variations in ADT into account when determining the appropriate design.

5-4.01 Turn Lanes

As with urban highways, the degree of access control greatly influences the accident rate and efficiency of traffic operation on rural highways. Therefore, designers should try to close any unjustified or potentially dangerous access points. However, if an access point is to remain open, adding a turn lane will enhance the operation and safety.

The following apply to rural multi-lane and 2-lane highways:

1. In addition to the policies listed below, left-turn and right-turn lanes should be constructed at locations determined by the District Traffic Engineer in consideration of accidents, capacity, and traffic volumes.
2. Where a median opening is planned, or already exists and its continued existence is justified, a left-turn lane may be added regardless of what the access point serves.
3. Turn lanes should be considered at every public road intersection along a stretch of highway if most intersections on the stretch meet the warrants. If most intersections have turn lanes, motorists will come to expect all intersections to have them.

5-4.01.01 Policy on Multi-Lane Rural Highways

1. Right-turn and left-turn lanes should be standard features at all public access points.
2. Right-turn and left-turn lanes are also warranted if the access point serves an industrial, commercial, or any substantial trip-generating land use, or if the access point serves more than three residential units.

5-4.01.02 Policy on 2-Lane Highways

1. Right-turn lanes should be considered when the projected ADT is over 1500, the design speed is higher than 70 km/h, and the following:
   a. At all public road access points.
   b. If industrial, commercial, or substantial trip generating land use is to be served, or
   c. If the access serves more than 10 residential units.
2. Left-turn lanes should be provided when the access is to a public road, an industrial tract or a commercial center.
3. The designer, in conjunction with the District Traffic Engineer may select either a channelized or a painted left-turn lane. The selection will be based on a number of factors including accident history, traffic volume, comparative costs, availability of right of way, environmental impacts, and physical features such as sight distance.

5-4.01.03 Length

The length of turn lanes should be determined as described in Section 5-3.01 for urban highways. However, the total length including taper, deceleration and storage should normally be 144 m.

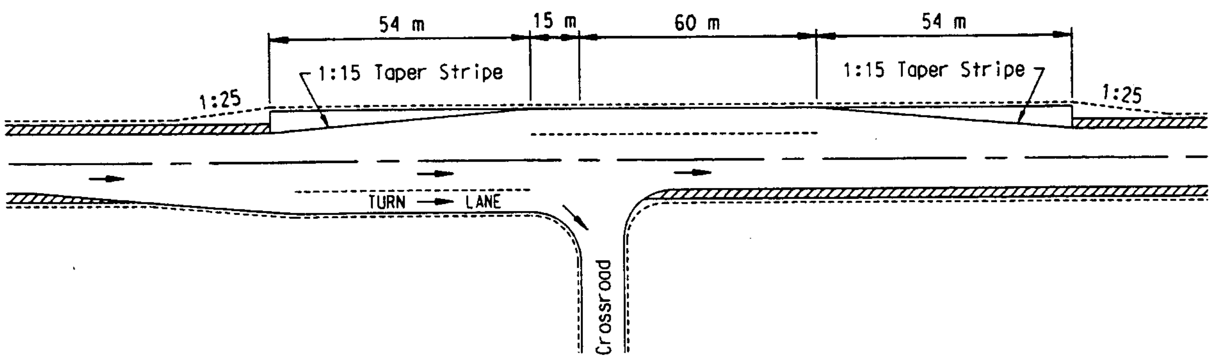
5-4.01.04 Left-Turn Bypass Lanes

If a left turn lane is not warranted, or if the construction of a left-turn lane is not practical (due to R/W, terrain, etc.), leaving no left-turn treatment as the only other alternative, designers should consider left-turn bypass lanes.

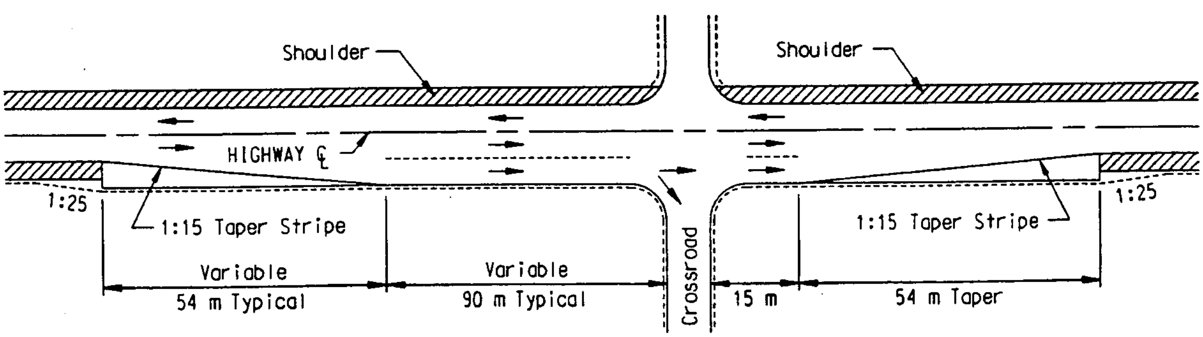
The bypass lane shown in figure 5-4.01A is for use at “T” intersections. The combination right-turn and bypass lane shown in figure 5-4.01B is for use at four-legged intersections. Because of the higher volumes associated with four-legged intersections, left-turn lanes are a more appropriate solution. Bypass lanes at four-legged intersections should only be used after all other solutions have been found impractical and where the cross street volume is low.

Exclusive left-turn lanes are the most effective and safe way to separate the left-turning from the through traffic streams. Bypass lanes are a convenience or an emergency measure, and are designed for lower speed maneuvering. If a left-turn is warranted <u>and</u> practical, then it should be built. Bypass lanes are a quick and inexpensive way to make intersections (that would otherwise have no left-turn treatment) more efficient for traffic operation.

Designers should take into account that pavement markings for bypass lanes will infringe on the availability of the passing zone.



BY-PASS LANE AT "T" INTERSECTION
Figure 5-4.01A



COMBINED BY-PASS LANE AND RIGHT-TURN LANE
(To be used only where cross street volume is low.)
Figure 5-4.01B

5-4.01.05 CTWLTL

A continuous Two Way Left-Turn Lane on rural 2-lane roadways may be considered on sections of roadway with numerous entrances and a high accident rate. For design of CTWLTL and additional information, see Section 5-3.01.

5-4.01.06 Median Acceleration Lane

Minnesota highways have a limited number of median acceleration lanes. Those which have been constructed thus far have favorable results. At unsignalized intersections with relatively heavy truck volumes, the median acceleration lane provides the left turning truck, entering the expressway, the opportunity to accelerate and reduce the speed differential before entering the traffic stream.

Median acceleration lanes should not be constructed indiscriminately. They may be used at locations where there is a high number of trucks turning left onto the mainline, where the existing median does not provide enough room for a truck to stop in the median when making a two-stage crossing, and where there is a history of high rate of truck accidents.

The basic design for a median acceleration lane is shown in Figure 5-4.01C, the applied design criteria are:

1. The entering throat should be wide enough so that a turning truck will be far enough from the through-lane not to have a negative impact on the through-lane traffic.
2. The lane width should be wide enough to provide the accelerating truck added buffer in the zone where the speed differential is the greatest.
3. There should be sufficient length for the truck to accelerate and reduce the speed differential before entering the through-lane.
4. When near a crossover, the acceleration lane taper shall end before the crossover left-turn lane is developed.

In 1997, the 87.5 percentile mass/power ratio for trucks was 117 kg/kw. The rate of acceleration from a stop for these trucks is 0.3 m/s^2 (ITE's 1999 Traffic Engineering Handbook). Designers may use the appropriate acceleration rate for their design truck.

The formula used to calculate speed is:

$$V_F{}^2 = V_I{}^2 + 2AS$$

Where

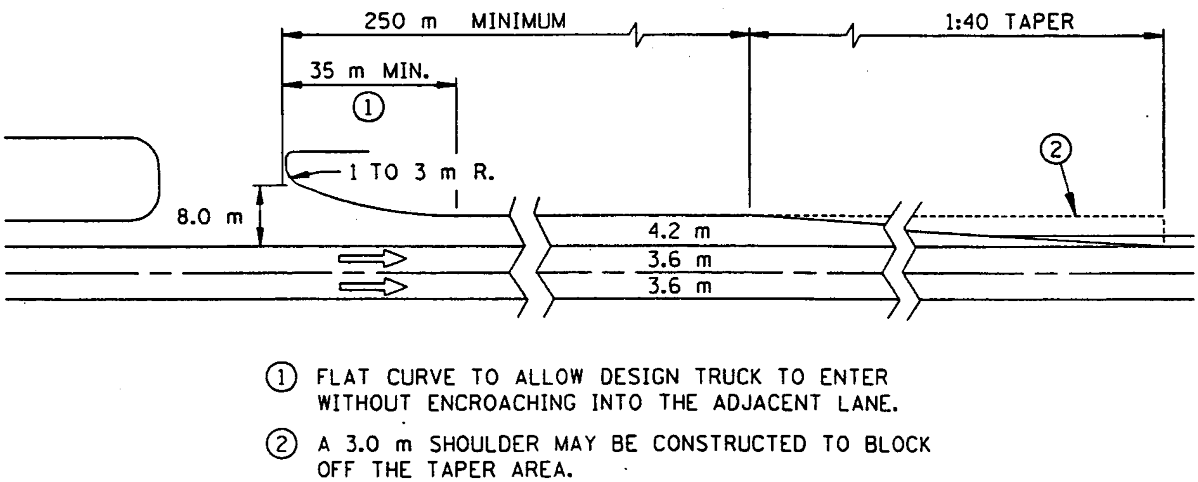
V_F = Speed achieved at the end of distance S, m/s.
V_I = Initial speed, m/s. In Table 5-4.01A, V_I = zero was used.
A = Acceleration, m/s^2.
S = Distance, m.

The minimum length of the full width median acceleration lane shall be 250 m which corresponds to V_F = 44 km/h. The desirable length of the full width median acceleration lane shall be the length which allows the design truck to reach 60 percent of the posted speed limit. If the posted speed limit is not known, use 60 percent of the design speed.

Table 5-4.01A
Desirable Length of Full Width Median Acceleration Lane

Posted Speed (km/h)	60% of Posted Speed (km/h)	Desirable Length of Full Width Median Acceleration Lane, Rounded (m)
70	42	250*
80	48	296
90	54	375
100	60	463
110	66	560

* Desirable length = minimum length = 250 m.



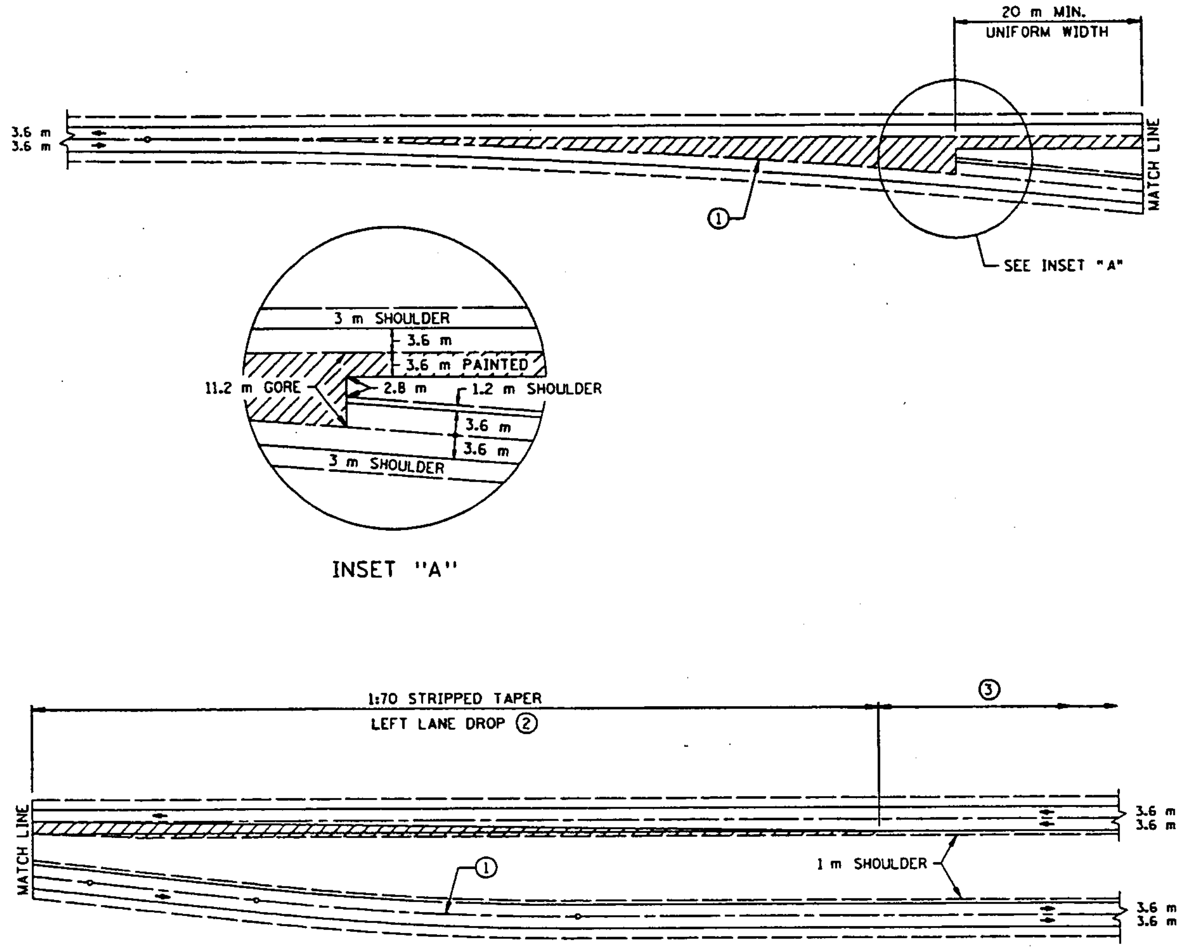
MEDIAN ACCELERATION LANE
Figure 5-4.01C

5-4.01.07 Transition from Divided to Single Highway

A divided highway transition to a single highway provides for terminating a 4-lane divided highway, or in reverse, starting one. It is important that this transition be made easy for the driver to understand and drive. Generally, the executed maneuvers done by the drivers in the transition section are done at normal highway speeds.

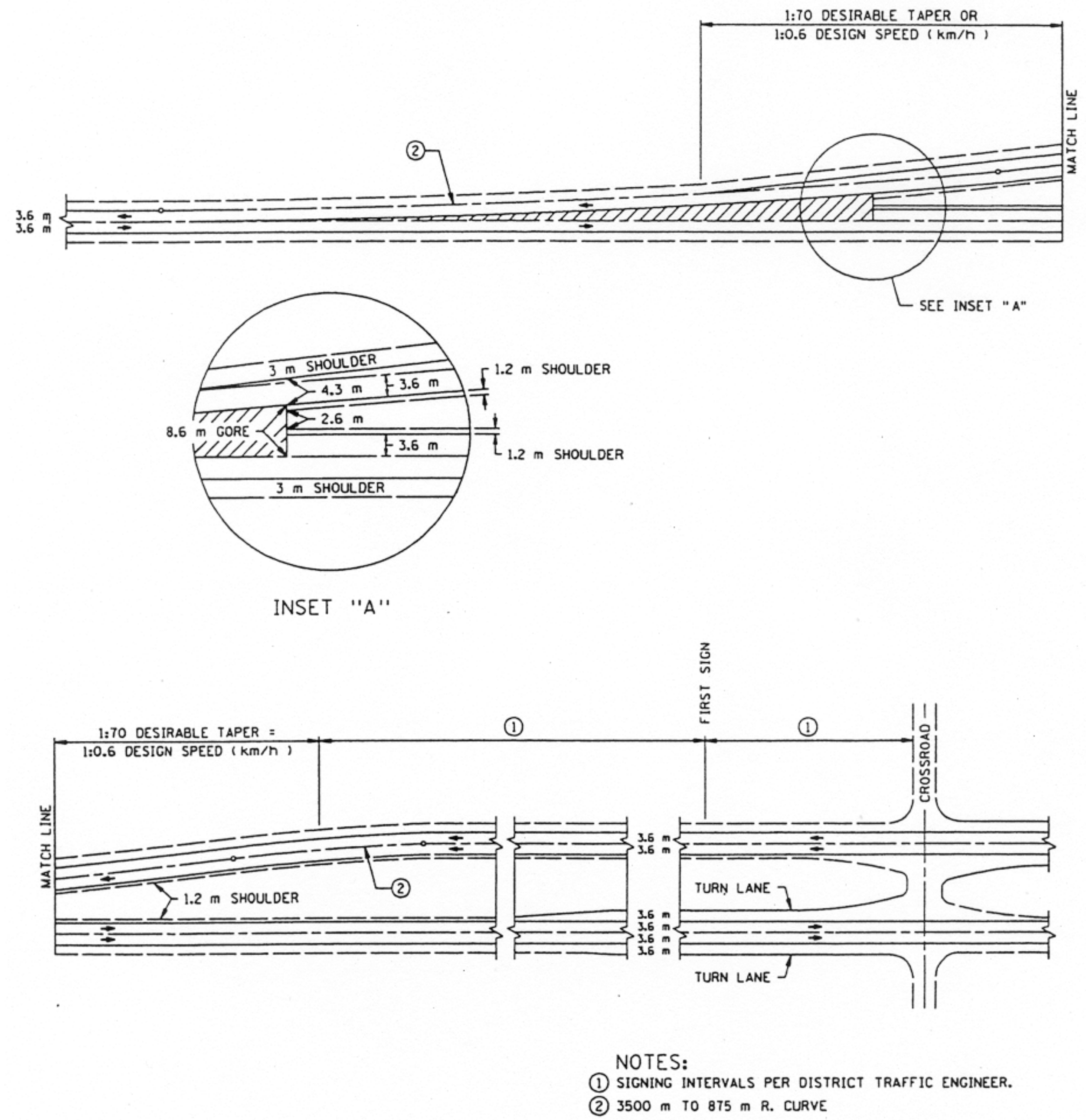
The two designs for the transition section shown in Figure 5-4.01D and Figure 5-4.01E are different in the sense that one is a left-lane drop and the other is a right-lane drop. Each design can be used as the situation may require in any one existing condition. However, in new construction or reconstruction projects, the right lane drop is preferred because, in case of emergency, cars in that lane can use the right shoulder as a refuge.

The location of the transition section should be some distance away from any major roadway. If a transition section must be constructed near a crossroad, then as a minimum, a distance as required by the Traffic Manual for proper signing should be provided. There should not be any entrances to adjoining properties in the tapered lane drop area, and in particular, not in an area 75 m upstream and downstream from the nose. It is also important to keep in mind that any crossroad in the two-lane section should be far enough from the gore to have the right-turn lane developed in the two-lane section beyond the gore.



NOTES:
① 3500 m TO 875 m RADIUS CURVE.
② RIGHT LANE DROP IS PREFERABLE.
③ SIGNING INTERVALS PER DISTRICT TRAFFIC ENGINEER.

RURAL DIVIDED HIGHWAY TO SINGLE HIGHWAY TRANSITION
Tangent Approach to Single Highway, Left-Lane Drop
Figure 5-4.01D



RURAL DIVIDED HIGHWAY TO SINGLE HIGHWAY TRANSITION
Curve Approach to Single Highway, Right-Lane Drop (Preferred)
Figure 5-4.01E

5-5 REFERENCES

1. A Policy on Geometric Design of Highways and Streets, AASHTO, 1994.
2. Geotechnical and Pavement Manual, MN/DOT, 1994.
3. Highway Capacity Manual, Special Report No. 209, Transportation Research Board.
4. Intersection Chanelization Design Guide - Report 279, transportation Research Board, 1985.
5. Roadside Design Guide, AASHTO, 1989.
6. Low-Cost Methods for Improving Traffic Operations on Two-Lane Roads, Report No. FHWA-IP-87-2, January 1987.
7. Safety Effectiveness of Highway Design Features, Publication No. FHWA-RD-91-044,045,046,047,048,049, November 1992.
8. Geometric Design and Operational Effects, Record No. 1122, Transportation Research Board, 1989.
9. Highway Sight Distance Design Issues, Record No. 1208, Transportation Research Board, 1989.
10. Operational Effects on Geometrics and Geometric Design, Record No. 1356, Transportation Research Board, 1992.
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12. Access Management Guidance for Activity Centers, Report No.348, Transportation Research Board, 1992
13. Transportation and Traffic Engineering Handbook, Institute of Traffic Engineering, 1982.
14. Volume Warrants for Left-Turn Storage Lanes at Unsignalized Grade Intersections, M.D. Harmelink, Highway Research Record 211, 1967.

Major Changes to Chapter 5

1. 5-1.0 Introduction, added language from old fundamental principle #4.
2. 5-1.03 Design Considerations, consolidated into seven fundamental principles.
3. 5-1.04.01 Turning Radii, rewrote first paragraph.
4. 5-1.07 Sight Corners, moved subsection to 5-2.02.01 (see #7 below)
5. 5-1.08 Frontage Roads to Arterials - new subsection.
6. 5-2.0 Renamed Section "Intersections", Section 5-3.0 is renamed "Urban Intersections", and Section 5-4.0 is renamed "Rural Intersections".
7. 5-2.02.02 Sight Corners, rewrote the subsection combining it with old section 5-1.08. Rewrote the example.
8. Table 5-2.02A, changed "d" to conform to 1994 AASHTO page 699.
9. 5-2.02.03 Case IIIA, NOT allow use of J less than 2 seconds (per AASHTO), added definition of J.
10. 5-2.02.03 Case IIIA, changed language to indicate that adjustment is also needed for -3% grade (old language only said +3%, figure 5-2.02D said + or - 3%).
11. New Figure 5-2.02E - deleted Bus curves and WB-19 curves, added WB-15 curves to conform to AASHTO.
12. 5-2.02.05 Case IIIC, rewrote second paragraph.
13. 5-2.02.07 Effect of Skew, rewrote # 2.
14. 5-2.02.07 Effect of Skew, # 3, added language to explain method of calculation.
15. 5-2.02.07 added language on skew from 5-2.02.08.
16. 5-2.02.08 removed language on skew, renamed subsection "Effect of Grade".
17. New Figure 5-2.02I is old Figure 5-2.03A. Figure is now part of subsection 5-2.02.07.
18. 5-2.04 Design for Right Turn Lanes, changed #1 to conform to language in 2-3.02
19. 5-2.04 Design for Right Turn Lanes, added language to # 3.
20. 5-2.04 Design for Right Turn Lanes, added # 6
21. 5-2.04.01 Minimum Turning Curve, deleted all references to 3-centered asymmetric compound curves.
22. 5-2.04.02 Free Right Turns* - #2 Acceleration Lane Condition, changed desirable horizontal radius to 60m.
23. Table 5-2.04A, redid table using the values of "f" (urban conditions) that were used in Chapter 3.
24. 5-2.04.02 Free Right Turns, # 2 is changed to "When curbs are used, the edge of gutter is considered the edge of the traveled way".
25. 5-2.04.02 Free Right Turns, #6 at the end of the subsection is changed to "Minimum width of any channelized lane is 4.2 m"
26. Figures 5-2.04 A, B and C were eliminated, Figures 5-2.04D (1&2), E, F and G remain and are renumbered accordingly. Those figures were modified to conform to the changes listed above.
27. New Section 5-3.0 Urban Intersection (see #6 above)
28. 5-3.01.01 Turn Lane Policy At Urban Intersections, rewrote subsection.
29. 5-3.01.02 Cross Section and Pavement Details, eliminated pavement details from #2.
30. 5-3.01.03 Typical Length of Turn Lanes, rewrote subsection.

31. Table 5-3.01A, eliminated entries for 100 and 110 km/h.
32. Figures 5-3.01 A, B, and D were modified per changes listed above.
33. Figure 5-3.01C, removed speed limit (for speeds of 70 km/h or less) from the taper option in developing left turn lanes, and reconfigured turn lane development.
34. 5-3.01.04 Exceptions to Turn-lane lengths, rewrote subsection, eliminated previously unnamed table Re: turn lane length including taper.
35. 5-3.01.05 COWLTL and CTWLTL, rewrote subsection. Changed allowable lane width.
36. 5-3.01.06 Double Left-Turn Lanes, eliminated 2nd paragraph (The need or desirability..).
37. 5-3.02 Channelization, rewrote curbed island dimensions (# 3).
38. 5-3.03.02 Geometrics, changed blunt nose corner radius to "0.6 to 1.8 m".
39. 5-3.03.01 Policy (previously named Guidelines), changed last two sentences.
40. 5-3.03.03 Median Opening Spacing On Low-Speed Multi-Lane highways, deleted numbers, added last sentence.
41. 5-3.04.01 Policy, updated references to Minnesota Rules.
42. Table 5-3.04A, changed to reflect latest standard.
43. 5-4.0 Rural Intersections, rewrote subsection.
44. 5-4.01 Turn Lanes, rewrote subsection.
45. 5-4.01.01 Policy on Multi-Lane Highways, rewrote subsection. Note that this policy now applies to both divided and undivided multi-lane highways.
46. 5-4.01.02 Policy on 2-lane Highways, rewrote subsection.
47. Old Figures 5-3.01A, B, C and D were eliminated, remaining figures were renumbered accordingly.
48. 5-4.01.03 Length, rewrote subsection.
49. 5-3.01.04 Left Turn Bypass Lanes, new subsection.
50. 5-4.01.06 Median Acceleration Lane, rewrote subsection, note new minimum and desirable lengths.
51. Figure 5-4.01C, revised per # 50 above.
52. 5-3.01.07 Divided Highway to Single Highway Transition, added words to last sentence in 2nd paragraph.

* (#22 above) The Geometrics Unit is creating new a new standard for free right turns. The final version should be available shortly.