CHESTERFIELD TWP BURLINGTON COUNTY, NJ.

FATAL SCHOOL BUS TRUCK COLLISION

THURSDAY, FEBRUARY 16, 2012; 8:15 A.M.

HWY-12-MH-007

ATTACHMENT 5, AASHTO EXCERPTS FROM GEOMETRIC DESIGN MANUAL 2011 EDITION

26 PAGES

Although desirable at higher volume intersections, approach sight triangles like those shown in Figure 9-15A are not needed for intersection approaches controlled by stop signs or traffic signals. In that case, the need for approaching vehicles to stop at the intersection is determined by the traffic control devices and not by the presence or absence of vehicles on the intersecting approaches.

Departure Sight Triangles

A second type of clear sight triangle provides sight distance sufficient for a stopped driver on a minor-road approach to depart from the intersection and enter or cross the major road. Figure 9-15B shows typical departure sight triangles to the left and to the right of the location of a stopped vehicle on the minor road. Departure sight triangles should be provided in each quadrant of each intersection approach controlled by stop or yield signs. Departure sight triangles should also be provided for some signalized intersection approaches (see Case D in Section 9.5.3 on "Intersection Control"). Distance a_2 in Figure 9-15B is equal to distance a_1 plus the width of the lane(s) departing from the intersection on the major road to the right. Distance a_2 should also include the width of any median present on the major road unless the median is wide enough to permit a vehicle to stop before entering or crossing the roadway beyond the median. The appropriate measurement of distances a_1 and a_2 for departure sight triangles depends on the placement of any marked stop line that may be present and, thus, may vary with site-specific conditions.

The recommended dimensions of the clear sight triangle for desirable traffic operations where stopped vehicles enter or cross a major road are based on assumptions derived from field observations of driver gap-acceptance behavior (*12*). The provision of clear sight triangles like those shown in Figure 9-15B also allows the drivers of vehicles on the major road to see any vehicles stopped on the minor-road approach and to be prepared to slow or stop, if needed.

Identification of Sight Obstructions within Sight Triangles

The profiles of the intersecting roadways should be designed to provide the recommended sight distances for drivers on the intersection approaches. Within a sight triangle, any object at a height above the elevation of the adjacent roadways that would obstruct the driver's view should be removed or lowered, if practical. Such objects may include buildings, parked vehicles, highway structures, roadside hardware, hedges, trees, bushes, unmowed grass, tall crops, walls, fences, and the terrain itself. Particular attention should be given to the evaluation of clear sight triangles at interchange ramp/crossroad intersections where features such as bridge railings, piers, and abutments are potential sight obstructions.

The determination of whether an object constitutes a sight obstruction should consider both the horizontal and vertical alignment of both intersecting roadways, as well as the height and position of the object. In making this determination, it should be assumed that the driver's eye is 1.08 m [3.50 ft] above the roadway surface and that the object to be seen is 1.08 m [3.50 ft] above the surface of the intersecting road.

This object height is based on a vehicle height of 1.33 m [4.35 ft], which represents the 15th percentile of vehicle heights in the current passenger car population less an allowance of 250 mm [10 in.]. This allowance represents a near-maximum value for the portion of a passenger car height that needs to be visible for another driver to recognize it as the object. The use of an object height equal to the driver eye height makes intersection sight distances reciprocal (i.e., if one driver can see another vehicle, then the driver of that vehicle can also see the first vehicle).

Where the sight-distance value used in design is based on a single-unit or combination truck as the design vehicle, it is also appropriate to use the eye height of a truck driver in checking sight obstructions. The recommended value of a truck driver's eye height is 2.33 m [7.6 ft] above the roadway surface.

9.5.3 Intersection Control

The recommended dimensions of the sight triangles vary with the type of traffic control used at an intersection because different types of control impose different legal constraints on drivers and, therefore, result in different driver behavior. Procedures to determine sight distances at intersections are presented below according to different types of traffic control, as follows:

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

Case A—Intersections with No Control

For intersections not controlled by yield signs, stop signs, or traffic signals, the driver of a vehicle approaching an intersection should be able to see potentially conflicting vehicles in sufficient time to stop before reaching the intersection. The location of the decision point (driver's eye) of the sight triangles on each approach is determined from a model that is analogous to the stopping sight distance model, with slightly different assumptions.

While some perceptual tasks at intersections may need substantially less time, the detection and recognition of a vehicle that is a substantial distance away on an intersecting approach, and is near the limits of the driver's peripheral vision, may take up to 2.5 s. The distance to brake to a stop can be determined from the same braking coefficients used to determine stopping sight distance in Table 3-1.

Field observations indicate that vehicles approaching uncontrolled intersections typically slow to approximately 50 percent of their midblock running speed. This occurs even when no potentially conflicting vehicles are present (*12*). This initial slowing typically occurs at deceleration rates up to 1.5 m/s^2 [5 ft/s^2]. Deceleration at this gradual rate has been observed to begin even before a potentially conflicting vehicle comes into view. Braking at greater deceleration rates, which can approach those assumed in stopping sight distance, can begin up to 2.5 s after a vehicle on the intersecting approach comes into view. Thus, approaching vehicles may be traveling at less than their midblock running speed during all or part of the perception-reaction time and can, therefore, where needed, brake to a stop from a speed less than the midblock running speed.

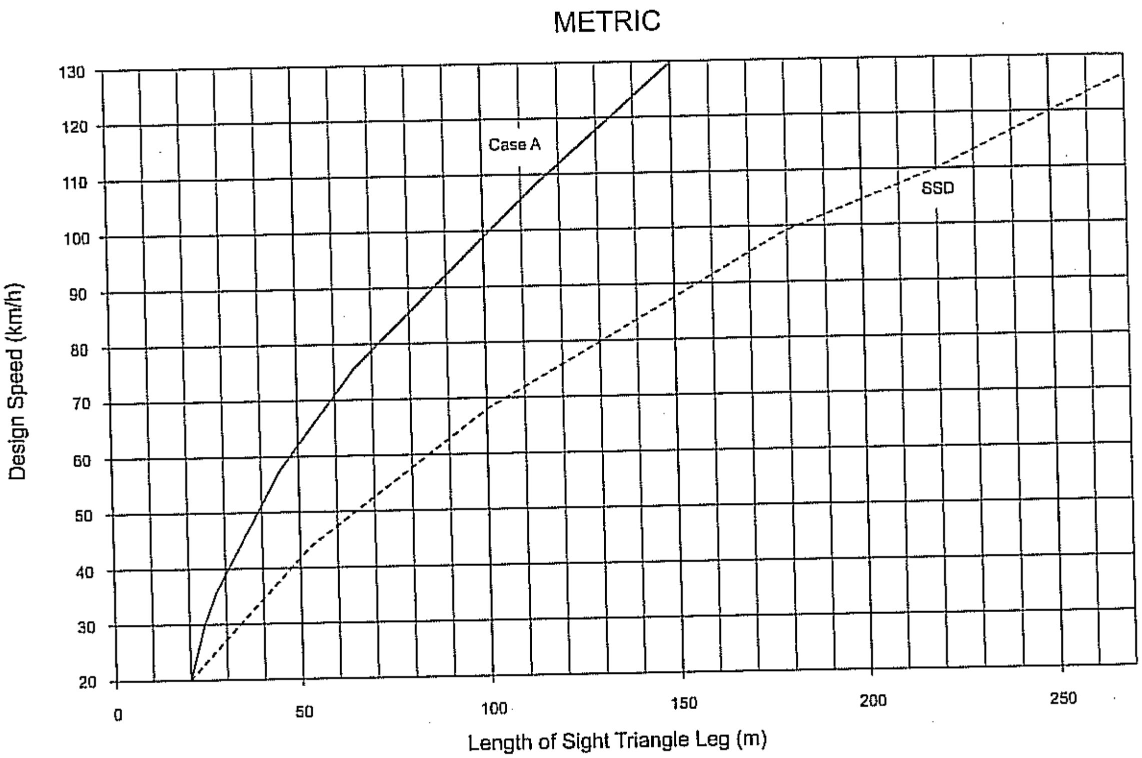
Table 9-3 shows the distance traveled by an approaching vehicle during perception-reaction and braking time as a function of the design speed of the roadway on which the intersection approach is located. These distances should be used as the legs of the sight triangles shown in Figure 9-15A as dimensions a_1 and b. Distance a_2 is longer than distance a_1, as defined in discussion of "Approach Sight Triangles" in Section 9.5.2. Referring to Figure 9-15A, highway A with an assumed design speed of 80 km/h [50 mph] and highway B with an assumed design speed of 50 km/h [30 mph] need a clear sight triangle with legs extending at least 75 m and 45 m [245 and 140 ft] along highways A and B, respectively. Figure 9-16 shows the length of the legs of the sight triangle from Table 9-3.

Table 9-3. Length of Sight Triangle Leg—Case A, No Traffic Control

Metric		U.S. Customary	
Design Speed (km/h)	**Length of Leg (m)**	**Design Speed (mph)**	**Length of Leg (ft)**
20	20	15	70
30	25	20	90
40	35	25	115
50	45	30	140
60	55	35	165
70	65	40	195
80	75	45	220
90	90	50	245
100	105	55	285
110	120	60	325
120	135	65	365
130	150	70	405
—	—	75	445
—	—	80	485

Note: For approach grades greater than 3%, multiply the sight distance values in this table by the appropriate adjustment factor from Table 9-4.

This clear triangular area will permit the vehicles on either road to stop, if needed, before reaching the intersection. If the design speed of any approach is not known, it can be estimated by using the 85th percentile of the midblock running speeds for that approach.



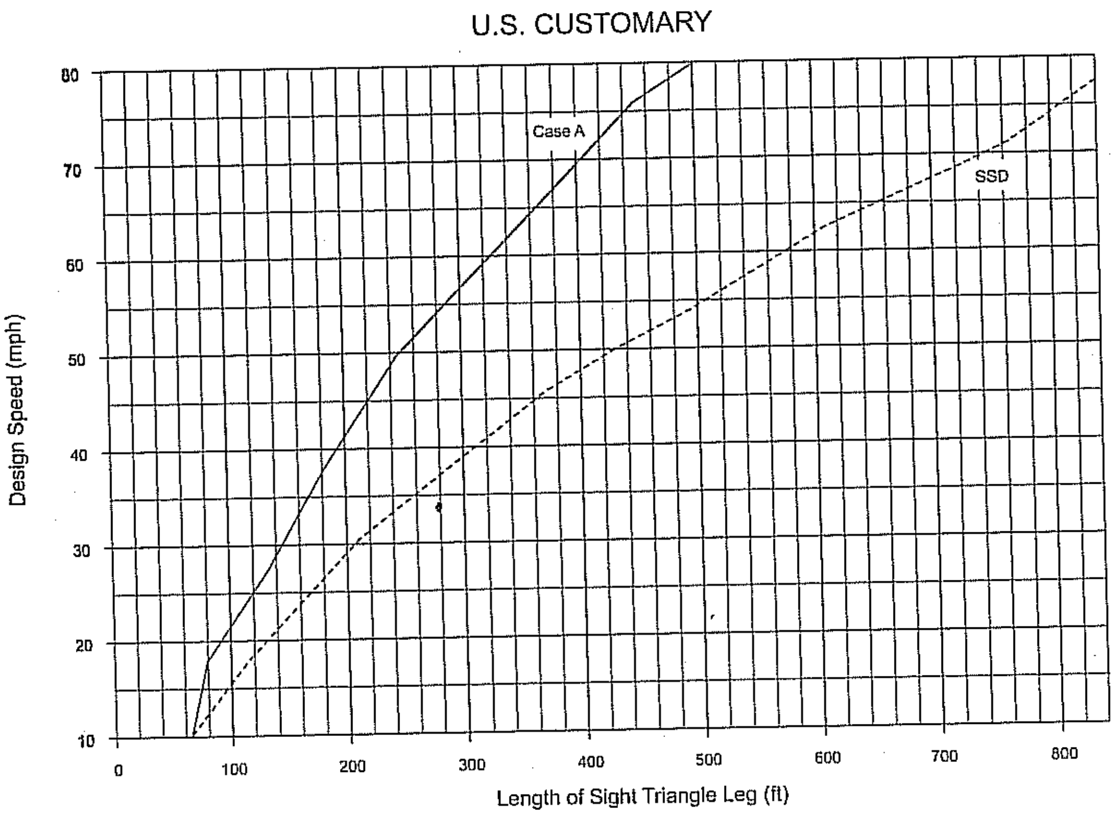


Figure 9-16. Length of Sight Triangle Leg—Case A, No Traffic Control

The distances shown in Table 9-3 are generally less than the corresponding values of stopping sight distance for the same design speed. This relationship is illustrated in Figure 9-16. Where a clear sight triangle has legs that correspond to the stopping sight distances on their respective approaches, an even greater margin of efficient operation is provided. However, since field observations show that motorists slow down to some extent on approaches to uncontrolled intersections, the provision of a clear sight triangle with legs equal to the full stopping sight distance is not essential.

Where the grade along an intersection approach exceeds 3 percent, the leg of the clear sight triangle along that approach should be adjusted by multiplying the appropriate sight distance from Table 9-3 by the appropriate adjustment factor from Table 9-4.

Table 9-4. Adjustment Factors for Sight Distance Based on Approach Grade

Metric														
Approach Grade (%)	Design Speed (mph)													
	20	30	40	50	60	70	80	90	100	110	120	130	—	—
−6	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	—	—
−5	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	—	—
−4	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	—	—
−3 to +3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	—	—
+4	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	—	—
+5	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	—	—
+6	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	—	—

U.S. Customary														
Approach Grade (%)	Design Speed (mph)													
	15	20	25	30	35	40	45	50	55	60	65	70	75	80
−6	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2
−5	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2
−4	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
−3 to +3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
+4	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
+5	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
+6	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

Note: Based on ratio of stopping sight distance on specified approach grade to stopping sight distance on level terrain.

If the sight distances given in Table 9-3, as adjusted for grades, cannot be provided, consideration should be given to installing regulatory speed signing to reduce speeds or installing stop signs on one or more approaches.

No departure sight triangle like that shown in Figure 9-15B is needed at an uncontrolled intersection because such intersections typically have very low traffic volumes. If a motorist needs to stop at an uncontrolled intersection because of the presence of a conflicting vehicle on an intersecting approach, it is very unlikely another potentially conflicting vehicle will be encountered as the first vehicle departs the intersection.

Case B—Intersections with Stop Control on the Minor Road

Departure sight triangles for intersections with stop control on the minor road should be considered for three situations:

- Case B1—Left turns from the minor road;
- Case B2—Right turns from the minor road; and
- Case B3—Crossing the major road from a minor-road approach.

Intersection sight distance criteria for stop-controlled intersections are longer than stopping sight distance to allow the intersection to operate smoothly. Minor-road vehicle operators can wait until they can proceed safely without forcing a major-road vehicle to stop.

Case B1—Left Turn from the Minor Road

Departure sight triangles for traffic approaching from either the right or the left, like those shown in Figure 9-15B, should be provided for left turns from the minor road onto the major road for all stop-controlled approaches. The length of the leg of the departure sight triangle along the major road in both directions, shown as distance b in Figure 9-15B, is the recommended intersection sight distance for Case B1.

The vertex (decision point) of the departure sight triangle on the minor road should be 4.4 m [14.5 ft] from the edge of the major-road traveled way. This represents the typical position of the minor-road driver's eye when a vehicle is stopped relatively close to the major road. Field observations of vehicle stopping positions found that, where needed, drivers will stop with the front of their vehicle 2.0 m [6.5 ft] or less from the edge of the major-road traveled way. Measurements of passenger cars indicate that the distance from the front of the vehicle to the driver's eye for the current U.S. passenger car population is nearly always 2.4 m [8 ft] or less (*12*). Where practical, it is desirable to increase the distance from the edge of the major-road traveled way to the vertex of the clear sight triangle from 4.4 m to 5.4 m [14.5 to 18 ft]. This increase allows 3.0 m [10 ft] from the edge of the major-road traveled way to the front of the stopped vehicle, providing a larger sight triangle. The length of the sight triangle along the minor road (distance *a* in Figure 9-15B) is the sum of the distance from the major road plus $^1/_2$ lane width for vehicles approaching from the left, or $1^1/_2$ lane widths for vehicles approaching from the right.

Field observations of the gaps in major-road traffic actually accepted by drivers turning onto the major road have shown that the values in Table 9-5 provide sufficient time for the minor-road vehicle to accelerate from a stop and complete a left turn without unduly interfering with major-road traffic operations. The time gap acceptance time does not vary with approach speed on the major road. Studies have indicated that a constant value of time gap, independent of approach speed, can be used as a basis for intersection sight distance determinations. Observations have also shown that major-road drivers will reduce their speed to some extent when minor-road vehicles turn onto the major road. Where the time gap acceptance values in Table 9-5 are used to determine the length of the leg of the departure sight triangle, most major-road drivers should not need to reduce speed to less than 70 percent of their initial speed (*12*).

The intersection sight distance in both directions should be equal to the distance traveled at the design speed of the major road during a period of time equal to the time gap. In applying Table 9-5, it can usually be assumed that the minor-road vehicle is a passenger car. However, where substantial volumes of heavy vehicles enter the major road, such as from a ramp terminal, the use of tabulated values for single-unit or combination trucks should be considered.

Table 9-5 includes appropriate adjustments to the gap times for the number of lanes on the major road and for the approach grade of the minor road. The adjustment for the grade of the minor-road approach is needed only if the rear wheels of the design vehicle would be on an upgrade that exceeds 3 percent when the vehicle is at the stop line of the minor-road approach.

Table 9-5. Time Gap for Case B1, Left Turn from Stop

Design Vehicle	Time Gap (t_g)(s) at Design Speed of Major Road
Passenger car	7.5
Single-unit truck	9.5
Combination truck	11.5

Note: Time gaps are for a stopped vehicle to turn left onto a two-lane highway with no median and with grades of 3 percent or less. The table values should be adjusted as follows:

For multilane highways—For left turns onto two-way highways with more than two lanes, add 0.5 s for passenger cars or 0.7 s for trucks for each additional lane, from the left, in excess of one, to be crossed by the turning vehicle.

For minor road approach grades—If the approach grade is an upgrade that exceeds 3 percent, add 0.2 s for each percent grade for left turns.

The intersection sight distance along the major road (distance *b* in Figure 9-15B) is determined by:

Metric	U.S. Customary
$ISD = 0.278\, V_{major}\, t_g$	$ISD = 1.47\, V_{major}\, t_g$ (9-1)
where:	where:
ISD = intersection sight distance (length of the leg of sight triangle along the major road) (m)	ISD = intersection sight distance (length of the leg of sight triangle along the major road) (ft)
V_{major} = design speed of major road (km/h)	V_{major} = design speed of major road (mph)
t_g = time gap for minor road vehicle to enter the major road (s)	t_g = time gap for minor road vehicle to enter the major road (s)

For example, a passenger car turning left onto a two-lane major road should be provided sight distance equivalent to a time gap of 7.5 s in major-road traffic. If the design speed of the major road is 100 km/h [60 mph], this corresponds to a sight distance of 0.278(100)(7.5) = 208.5 or 210 m [1.47(60)(7.5) = 661.5 or 665 ft], rounded for design.

A passenger car turning left onto a four-lane undivided roadway will need to cross two near lanes, rather than one. This increases the recommended gap in major-road traffic from 7.5 to 8.0 s. The corresponding value of sight distance for this example would be 223 m [706 ft]. If the minor-road approach to such an intersection is located on a 4 percent upgrade, then the time gap selected for intersection sight distance design for left turns should be increased from 8.0 to 8.8 s, equivalent to an increase of 0.2 s for each percent grade.

The design values for intersection sight distance for passenger cars are shown in Table 9-6. Figure 9-17 includes design values, based on the time gaps for the design vehicles included in Table 9-5.

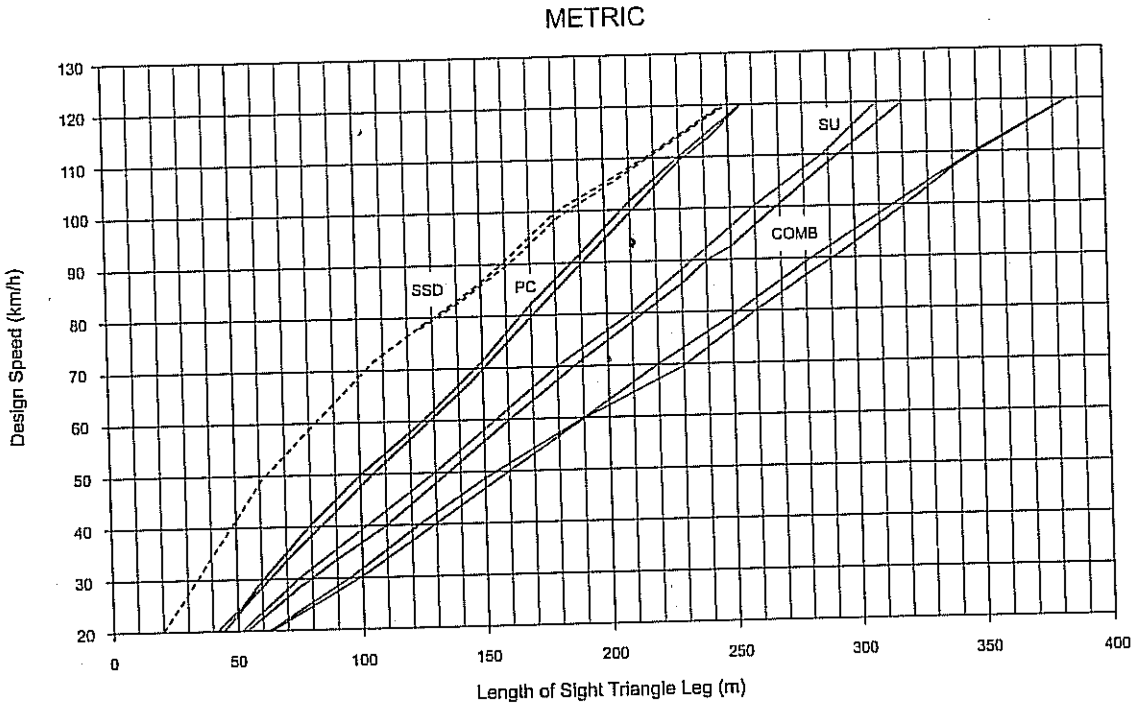
No adjustment of the recommended sight distance values for the major-road grade is generally needed because both the major- and minor-road vehicle will be on the same grade when departing from the intersection. However, if the minor-road design vehicle is a heavy truck and the intersection is located near a sag vertical curve with grades over 3 percent, then an adjustment to extend the recommended sight distance based on the major-road grade should be considered.

Table 9-6. Design Intersection Sight Distance—Case B1, Left Turn from Stop

Metric				U.S. Customary			
		Intersection Sight Distance for Passenger Cars				Intersection Sight Distance for Passenger Cars	
Design Speed (km/h)	Stopping Sight Distance (m)	Calculated (m)	Design (m)	Design Speed (mph)	Stopping Sight Distance (ft)	Calculated (ft)	Design (ft)
20	20	41.7	45	15	80	165.4	170
30	35	62.6	65	20	115	220.5	225
40	50	83.4	85	25	155	275.6	280
50	65	104.3	105	30	200	330.8	335
60	85	125.1	130	35	250	385.9	390
70	105	146.0	150	40	305	441.0	445
80	130	166.8	170	45	360	496.1	500
90	160	187.7	190	50	425	551.3	555
100	185	208.5	210	55	495	606.4	610
110	220	229.4	230	60	570	661.5	665
120	250	250.2	255	65	645	716.6	720
130	285	271.1	275	70	730	771.8	775
—	—	—	—	75	820	826.9	830
—	—	—	—	80	910	882.0	885

Note: Intersection sight distance shown is for a stopped passenger car to turn left onto a two-lane highway with no median and grades 3 percent or less. For other conditions, the time gap should be adjusted and the sight distance recalculated.

Sight distance design for left turns at divided-highway intersections should consider multiple design vehicles and median width. If the design vehicle used to determine sight distance for a divided-highway intersection is larger than a passenger car, then sight distance for left turns will need to be checked for that selected design vehicle and for smaller design vehicles as well. If the divided-highway median is wide enough to store the design vehicle with a clearance to the through lanes of approximately 1 m [3 ft] at both ends of the vehicle, no separate analysis for the departure sight triangle for left turns is needed on the minor-road approach for the near roadway to the left. In most cases, the departure sight triangle for right turns (Case B2) will provide sufficient sight distance for a passenger car to cross the near roadway to reach the median. Possible exceptions are addressed in the discussion of Case B3.



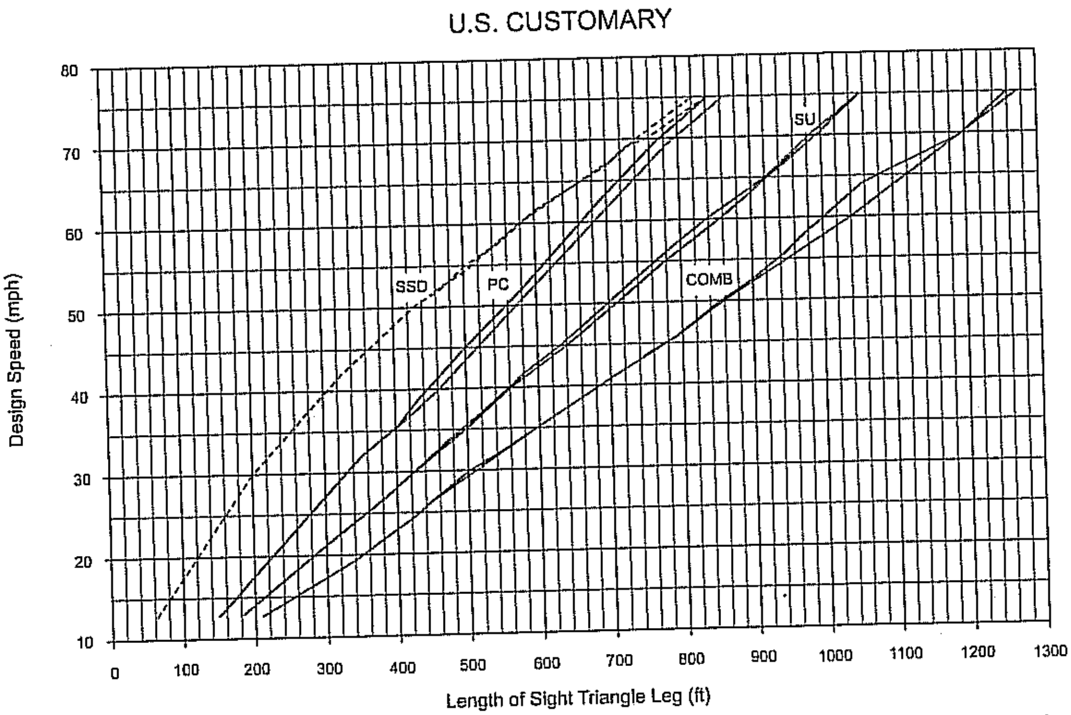


Figure 9-17. Intersection Sight Distance—Case B1, Left Turn from Stop

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If the design vehicle can be stored in the median with adequate clearance to the through lanes, a departure sight triangle to the right for left turns should be provided for that design vehicle turning left from the median roadway. Where the median is not wide enough to store the design vehicle, a departure sight triangle should be provided for that design vehicle to turn left from the minor-road approach.

The median width should be considered in determining the number of lanes to be crossed. The median width should be converted to equivalent lanes. For example, a 7.2-m [24-ft] median should be considered as two additional lanes to be crossed in applying the multilane highway adjustment for time gaps in Table 9-5. Furthermore, a departure sight triangle for left turns from the median roadway should be provided for the largest design vehicle that can be stored on the median roadway with adequate clearance to the through lanes. If a divided highway intersection has a 12-m [40-ft] median width and the design vehicle for sight distance is a 22-m [74-ft] combination truck, departure sight triangles should be provided for the combination truck turning left from the minor-road approach and through the median. In addition, a departure sight triangle should also be provided to the right for a 9-m [30-ft] single unit truck turning left from a stopped position in the median.

If the sight distance along the major road shown in Figure 9-38, including any appropriate adjustments, cannot be provided, then consideration should be given to installing regulatory speed signing on the major-road approaches.

Case B2—Right Turn from the Minor Road

A departure sight triangle for traffic approaching from the left like that shown in Figure 9-15B should be provided for right turns from the minor road onto the major road. The intersection sight distance for right turns is determined in the same manner as for Case B1, except that the time gaps (t_g) in Table 9-5 should be adjusted. Field observations indicate that, in making right turns, drivers generally accept gaps that are slightly shorter than those accepted in making left turns (*12*). The time gaps in Table 9-5 can be decreased by 1.0 s for right-turn maneuvers without undue interference with major-road traffic. These adjusted time gaps for the right turn from the minor road are shown in Table 9-7. Design values based on these adjusted time gaps are shown in Table 9-8 for passenger cars. Figure 9-18 includes the design values for the design vehicles for each of the time gaps in Table 9-7. When the minimum recommended sight distance for a right-turn maneuver cannot be provided, even with the reduction of 1.0 s from the values in Table 9-5, consideration should be given to installing regulatory speed signing or other traffic control devices on the major-road approaches.

Table 9-7. Time Gap for Case B2—Right Turn from Stop and Case B3—Crossing Maneuver

Design Vehicle	Time Gap (t_g)(s) at Design Speed of Major Road
Passenger car	6.5
Single-unit truck	8.5
Combination truck	10.5

Note: Time gaps are for a stopped vehicle to turn right onto or to cross a two-lane highway with no median and with grades of 3 percent or less. The table values should be adjusted as follows:

For multilane highways—For crossing a major road with more than two lanes, add 0.5 s for passenger cars and 0.7 s for trucks for each additional lane to be crossed and for narrow medians that cannot store the design vehicle.

For minor road approach grades—If the approach grade is an upgrade that exceeds 3 percent, add 0.1 s for each percent grade.

Table 9-8. Design Intersection Sight Distance—Case B2, Right Turn from Stop, and Case B3, Crossing Maneuver

Metric				U.S. Customary			
Design Speed (km/h)	Stopping Sight Distance (m)	Intersection Sight Distance for Passenger Cars Calculated (m)	Intersection Sight Distance for Passenger Cars Design (m)	Design Speed (mph)	Stopping Sight Distance (ft)	Intersection Sight Distance for Passenger Cars Calculated (ft)	Intersection Sight Distance for Passenger Cars Design (ft)
20	20	36.1	40	15	80	143.3	145
30	35	54.2	55	20	115	191.1	195
40	50	72.3	75	25	155	238.9	240
50	65	90.4	95	30	200	286.7	290
60	85	108.4	110	35	250	334.4	335
70	105	126.5	130	40	305	382.2	385
80	130	144.6	145	45	360	430.0	430
90	160	162.6	165	50	425	477.8	480
100	185	180.7	185	55	495	525.5	530
110	220	198.8	200	60	570	573.3	575
120	250	216.8	220	65	645	621.1	625
130	285	234.9	235	70	730	668.9	670
—	—	—	—	75	820	716.6	720
—	—	—	—	80	910	764.4	765

Note: Intersection sight distance shown is for a stopped passenger car to turn right onto or to cross a two-lane highway with no median and with grades of 3 percent or less. For other conditions, the time gap should be adjusted and the sight distance recalculated.

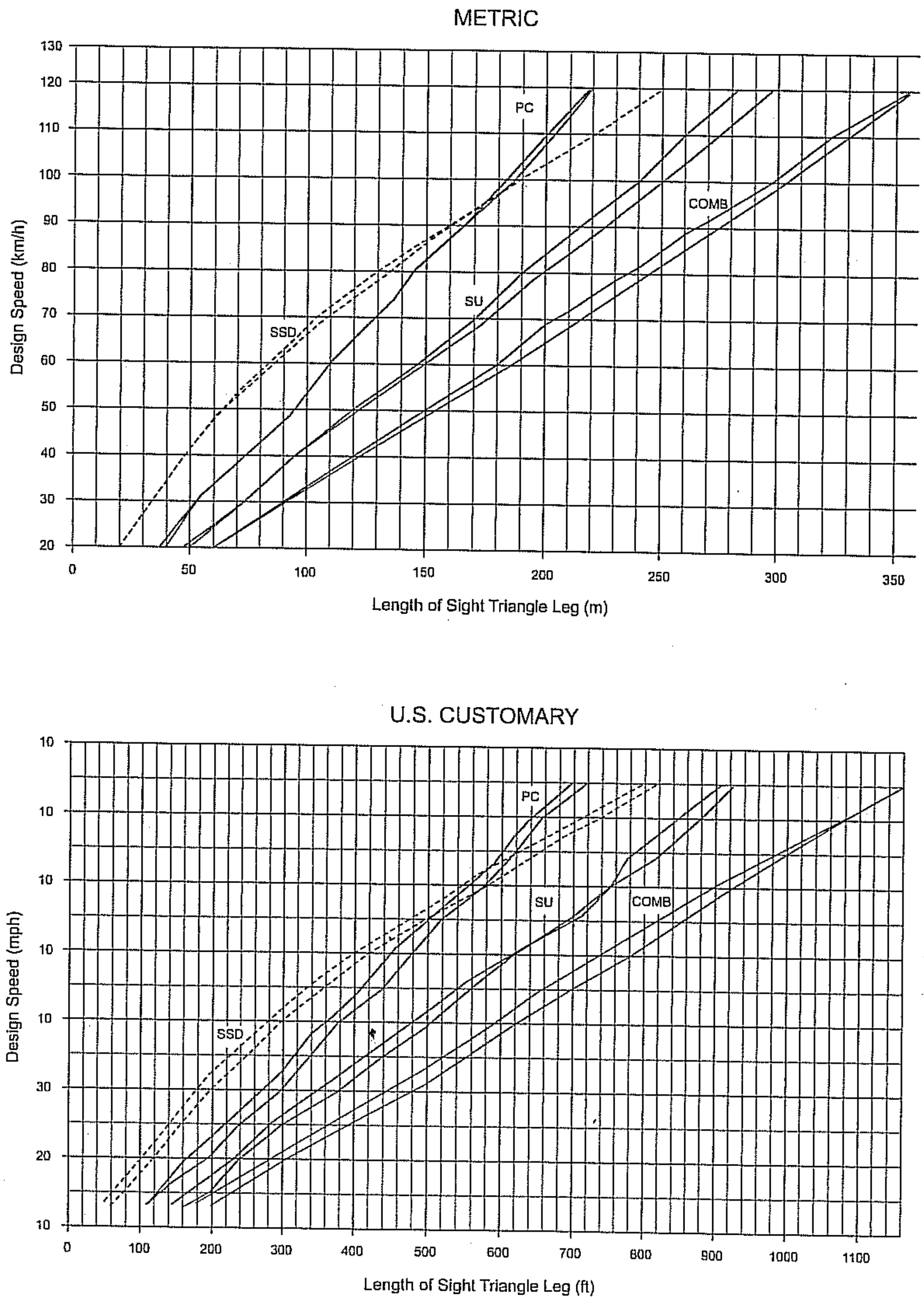


Figure 9-18. Intersection Sight Distance—Case B2, Right Turn from Stop, and Case B3, Crossing Maneuver

Case B3—Crossing Maneuver from the Minor Road

In most cases, the departure sight triangles for left and right turns onto the major road, as described for Cases B1 and B2, will also provide more than adequate sight distance for minor-road vehicles to cross the major road. However, in the following situations, it is advisable to check the availability of sight distance for crossing maneuvers:

- where left or right turns or both are not permitted from a particular approach and the crossing maneuver is the only legal maneuver;
- where the crossing vehicle would cross the equivalent width of more than six lanes; or
- where substantial volumes of heavy vehicles cross the highway and steep grades that might slow the vehicle while its back portion is still in the intersection are present on the departure roadway on the far side of the intersection.

The equation for intersection sight distance in Case B1 (see Equation 9-1) is used again for the crossing maneuver except that time gaps (t_g) are obtained from Table 9-7, which presents time gaps and appropriate adjustment factors to determine the intersection sight distance along the major road to accommodate crossing maneuvers. At divided highway intersections, depending on the relative magnitudes of the median width and the length of the design vehicle, intersection sight distance may need to be considered for crossing both roadways of the divided highway or for crossing the near roadway only and stopping in the median before proceeding. The application of adjustment factors for median width and grade is discussed under Case B1.

Table 9-8 shows the design values for passenger cars for the crossing maneuver based on the unadjusted time gaps in Table 9-7. Figure 9-18 includes the design values based on the time gaps for the design vehicles in Table 9-7.

Case C—Intersections with Yield Control on the Minor Road

Drivers approaching yield signs are permitted to enter or cross the major road without stopping, if there are no potentially conflicting vehicles on the major road. The sight distances needed by drivers on yield-controlled approaches exceed those for stop-controlled approaches.

For four-leg intersections with yield control on the minor road, two separate pairs of approach sight triangles like those shown in Figure 9-15A should be provided. One set of approach sight triangles is needed to accommodate crossing the major road and a separate set of sight triangles is needed to accommodate left and right turns onto the major road. Both sets of sight triangles should be checked for potential sight obstructions.

For three-leg intersections with yield control on the minor road, only the approach sight triangles to accommodate left- and right-turn maneuvers need be considered, because the crossing maneuver does not exist.

Case C1—Crossing Maneuver from the Minor Road

The length of the leg of the approach sight triangle along the minor road to accommodate the crossing maneuver from a yield-controlled approach (distance a_1 in Figure 9-15A) is given in Table 9-9. Distance a_2 is longer than distance a_l as defined in the discussion of "Approach Sight Triangles" in Section 9.5.2. The distances in Table 9-9 are based on the same assumptions as those for Case A except that, based on field observations, minor-road vehicles that do not stop are assumed to decelerate to 60 percent of the minor-road design speed rather than 50 percent.

Sufficient travel time for the major road vehicle should be provided to allow the minor-road vehicle: (1) to travel from the decision point to the intersection, while decelerating at the rate of 1.5 m/s² [5 ft/s²] to 60 percent of the minor-road design speed; and then (2) to cross and clear the intersection at that same speed. The intersection sight distance along the major road to accommodate the crossing maneuver (distance b in Figure 9-15A) should be computed with the following equations:

Metric	U.S. Customary	
$t_g = t_a + \dfrac{w+L_a}{0.167V_{minor}}$	$t_g = t_a + \dfrac{w+L_a}{0.88V_{minor}}$	(9-2)
$b = 0.278V_{major}t_g$	$b = 1.47V_{major}t_g$	
where:	where:	
t_g = travel time to reach and clear the major road (s)	t_g = travel time to reach and clear the major road (s)	
b = length of leg of sight triangle along the major road (m)	b = length of leg of sight triangle along the major road (ft)	
t_a = travel time to reach the major road from the decision point for a vehicle that does not stop (s) (use appropriate value for the minor-road design speed from Figure 9-43 adjusted for approach grade, where appropriate)	t_a = travel time to reach the major road from the decision point for a vehicle that does not stop (s) (use appropriate value for the minor-road design speed from Figure 9-43 adjusted for approach grade, where appropriate)	
w = width of intersection to be crossed (m)	w = width of intersection to be crossed (ft)	
L_a = length of design vehicle (m)	L_a = length of design vehicle (ft)	
V_{minor} = design speed of minor road (km/h)	V_{minor} = design speed of minor road (mph)	
V_{major} = design speed of major road (km/h)	V_{major} = design speed of major road (mph)	

Table 9-9. Case C1—Crossing Maneuvers from Yield-Controlled Approaches, Length of Minor Road Leg and Travel Times

Metric					U.S. Customary				
	Minor-Road Approach		Travel Time (t_g) (s)			Minor-Road Approach		Travel Time (t_g) (s)	
Design Speed (km/h)	Length of Leg[a] (m)	Travel Time t_a[a,b] (s)	Calculated Value	Design Value[c,d]	Design Speed (mph)	Length of Leg[a] (ft)	Travel Time t_a[a,b] (s)	Calculated Value	Design Value[c,d]
20	20	3.2	7.1	7.1	15	75	3.4	6.7	6.7
30	30	3.6	6.2	6.5	20	100	3.7	6.1	6.5
40	40	4.0	6.0	6.5	25	130	4.0	6.0	6.5
50	55	4.4	6.0	6.5	30	160	4.3	5.9	6.5
60	65	4.8	6.1	6.5	35	195	4.6	6.0	6.5
70	80	5.1	6.2	6.5	40	235	4.9	6.1	6.5
80	100	5.5	6.5	6.5	4	275	5.2	6.3	6.5
90	115	5.9	6.8	6.8	50	320	5.5	6.5	6.5
100	135	6.3	7.1	7.1	55	370	5.8	6.7	6.7
110	155	6.7	7.4	7.4	60	420	6.1	6.9	6.9
120	180	7.0	7.7	7.7	65	470	6.4	7.2	7.2
130	205	7.4	8.0	8.0	70	530	6.7	7.4	7.4
—	—	—	—	—	75	590	7.0	7.7	7.7
—	—	—	—	—	80	660	7.3	7.9	7.9

[a] For minor-road approach grades that exceed 3 percent, multiply the distance or the time in this table by the appropriate adjustment factor from Table 9-4.

[b] Travel time applies to a vehicle that slows before crossing the intersection but does not stop.

[c] The value of t_g should equal or exceed the appropriate time gap for crossing the major road from a stop-controlled approach.

[d] Values shown are for a passenger car crossing a two-lane highway with no median and with grades of 3 percent or less.

The value of t_g should equal or exceed the appropriate travel time for crossing the major road from a stop-controlled approach, as shown in Table 9-7. The design values for the time gap (t_g) shown in Table 9-9 incorporate these crossing times for two-lane highways and are used to develop the length of the leg of the sight triangle along the major road in Table 9-10. These basic unadjusted lengths are illustrated in Figure 9-19 for passenger cars and should be calculated separately for other design vehicle types.

The distances and times in Table 9-9 should be adjusted for the grade of the minor-road approach using the factors in Table 9-4. If the major road is a divided highway with a median wide enough to store the design vehicle for the crossing maneuver, then only crossing of the near lanes needs to be considered and a departure sight triangle for accelerating from a stopped position in the median should be provided based on Case B3. For median widths not wide enough to store the design vehicle, the crossing width should be adjusted as discussed in Case B1.

Case C2—Left- and Right-Turn Maneuvers

The length of the leg of the approach sight triangle along the minor road to accommodate right turns without stopping (distance a_1 in Figure 9-15A) should be 25 m [82 ft]. This distance is based on the assumption that drivers making left and right turns without stopping will slow to a turning speed of 16 km/h [10 mph]. Distance a_2 for left turns is longer than distance a_1 for right turns as defined in the discussion of "Approach Sight Triangles" in Section 9.5.2.

The leg of the approach sight triangle along the major road (distance b in Figure 9-15A) is similar to the major-road leg of the departure sight triangle for a stop-controlled intersection in Cases B1 and B2. However, the time gaps in Table 9-5 should be increased by 0.5 s to the values shown in Table 9-11. The appropriate lengths of the sight triangle leg are shown in Table 9-12 for passenger cars and in Figure 9-20 for the general design vehicle categories. The minor-road vehicle needs 3.5 s to travel from the decision point to the intersection. This represents additional travel time that is needed at a yield-controlled intersection, but is not needed at a stop-controlled intersection (Case B). However, the acceleration time after entering the major road is 3.0 s less for a yield sign than for a stop sign because the turning vehicle accelerates from 16 km/h [10 mph] rather than from a stop condition. The net 0.5-s increase in travel time for a vehicle turning from a yield-controlled approach is the difference between the 3.5-s increase in travel time and the 3.0-s reduction in travel time.

Departure sight triangles like those provided for stop-controlled approaches (see Cases B1, B2, and B3) should also be provided for yield-controlled approaches to accommodate minor-road vehicles that stop at the yield sign to avoid conflicts with major-road vehicles. However, since approach sight triangles for turning maneuvers at yield-controlled approaches are larger than the departure sight triangles used at stop-controlled intersections, no specific check of departure sight triangles at yield-controlled intersections should be needed.

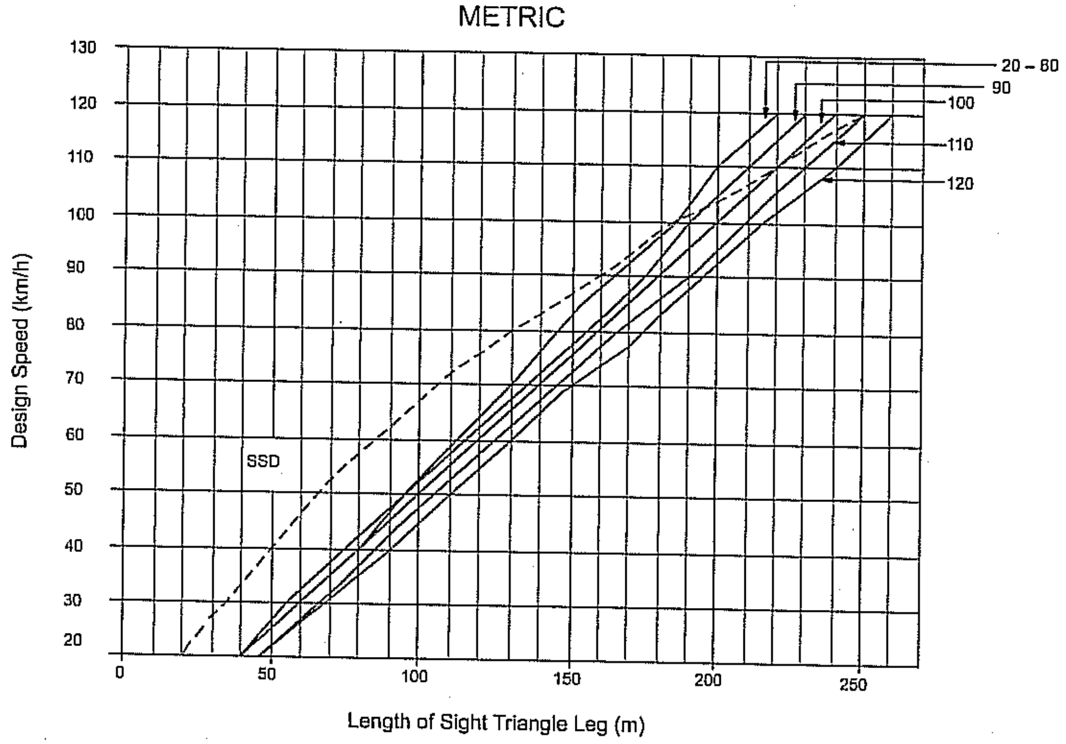
Yield-controlled approaches generally need greater sight distance than stop-controlled approaches, especially at four-leg yield-controlled intersections where the sight distance needs of the crossing maneuver should be considered. If sight distance sufficient for yield control is not available, use of a stop sign instead of a yield sign should be considered. In addition, at locations where the recommended sight distance cannot be provided, consideration should be given to installing regulatory speed signing or other traffic control devices at the intersection on the major road to reduce the speeds of approaching vehicles.

Table 9-10. Length of Sight Triangle Leg along Major Road—Case C1, Crossing Maneuver at Yield-Controlled Intersections

Metric									
Major Road Design Speed (km/h)	Stopping Sight Distance (m)	Design Values (m) Minor-Road Design Speed (km/h)							
		20	30–80	90	100	110	120	130	—
20	20	40	40	40	40	45	45	45	—
30	35	60	55	60	60	65	65	70	—
40	50	80	75	80	80	85	90	90	—
50	65	100	95	95	100	105	110	115	—
60	85	120	110	115	120	125	130	135	—
70	105	140	130	135	140	145	150	160	—
80	130	160	145	155	160	165	175	180	—
90	160	180	165	175	180	190	195	205	—
100	185	200	185	190	200	210	215	225	—
110	220	220	200	210	220	230	240	245	—
120	250	240	220	230	240	250	260	270	—
130	285	260	235	250	260	270	280	290	—

U.S. Customary									
Major Road Design Speed (mph)	Stopping Sight Distance (ft)	Design Values (ft) Minor-Road Design Speed (mph)							
		15	20–50	55	60	65	70	75	80
15	80	150	145	150	155	160	165	170	175
20	115	200	195	200	205	215	220	230	235
25	155	250	240	250	255	265	275	285	295
30	200	300	290	300	305	320	330	340	350
35	250	345	335	345	360	375	385	400	410
40	305	395	385	395	410	425	440	455	465
45	360	445	430	445	460	480	490	510	525
50	425	495	480	495	510	530	545	570	585
55	495	545	530	545	560	585	600	625	640
60	570	595	575	595	610	640	655	680	700
65	645	645	625	645	660	690	710	740	755
70	730	690	670	690	715	745	765	795	815
75	820	740	720	740	765	795	820	850	875
80	910	790	765	790	815	850	875	910	930

Note: Values in the table are for passenger cars and are based on the unadjusted distances and times in Table 9-9. The distances and times in Table 9-9 need to be adjusted using the factors in Table 9-4.



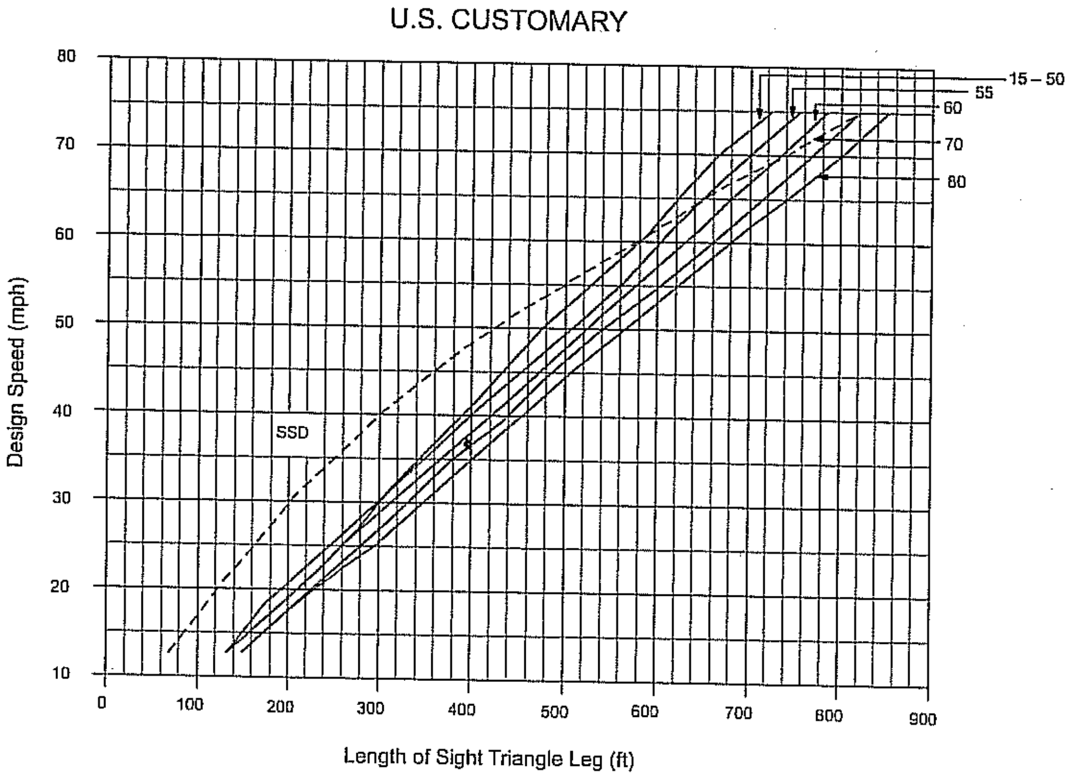


Figure 9-19. Length of Sight Triangle Leg along Major Road for Passenger Cars—Case C1, Crossing Maneuver

Table 9-11. Time Gap for Case C2, Left or Right Turn

Design Vehicle	Time Gap (t_g)(s)
Passenger car	8.0
Single-unit truck	10.0
Combination truck	12.0

Note: Time gaps are for a vehicle to turn right or left onto a two-lane highway with no median. The table values should be adjusted for multilane highways as follows:

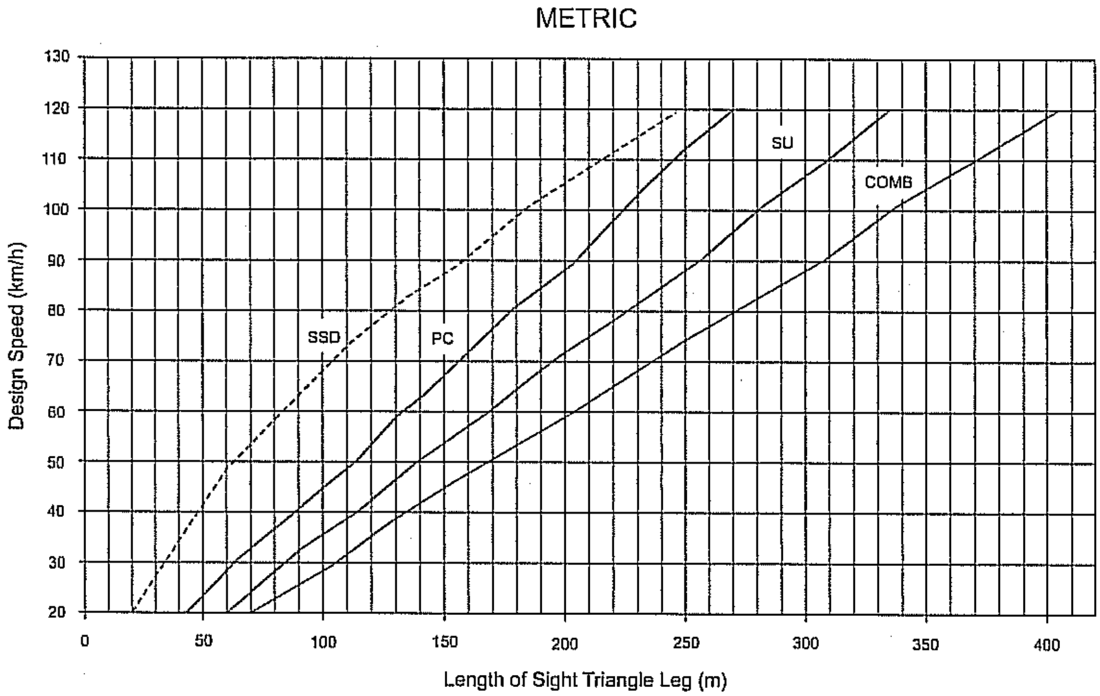
For left turns onto two-way highways with more than two lanes, add 0.5 s for passenger cars or 0.7 s for trucks for each additional lane, from the left, in excess of one, to be crossed by the turning vehicle.

For right turns, no adjustment is needed.

Table 9-12. Design Intersection Sight Distance—Case C2, Left or Right Turn at Yield-Controlled Intersections

Metric				U.S. Customary			
		Length of Leg				Length of Leg	
		Passenger Cars				Passenger Cars	
Design Speed (km/h)	Stopping Sight Distance (m)	Calculated (m)	Design (m)	Design Speed (mph)	Stopping Sight Distance (ft)	Calculated (ft)	Design (ft)
20	20	44.5	45	15	80	176.4	180
30	35	66.7	70	20	115	235.2	240
40	50	89.0	90	25	155	294.0	295
50	65	111.2	115	30	200	352.8	355
60	85	133.4	135	35	250	411.6	415
70	105	155.7	160	40	305	470.4	475
80	130	177.9	180	45	360	529.2	530
90	160	200.2	205	50	425	588.0	590
100	185	222.4	225	55	495	646.8	650
110	220	244.6	245	60	570	705.6	710
120	250	266.9	270	65	645	764.4	765
130	285	289.1	290	70	730	823.2	825
—	—	—	—	75	820	882.0	885
—	—	—	—	80	910	940.8	945

Note: Intersection sight distance shown is for a passenger car making a right or left turn without stopping onto a two-lane road.



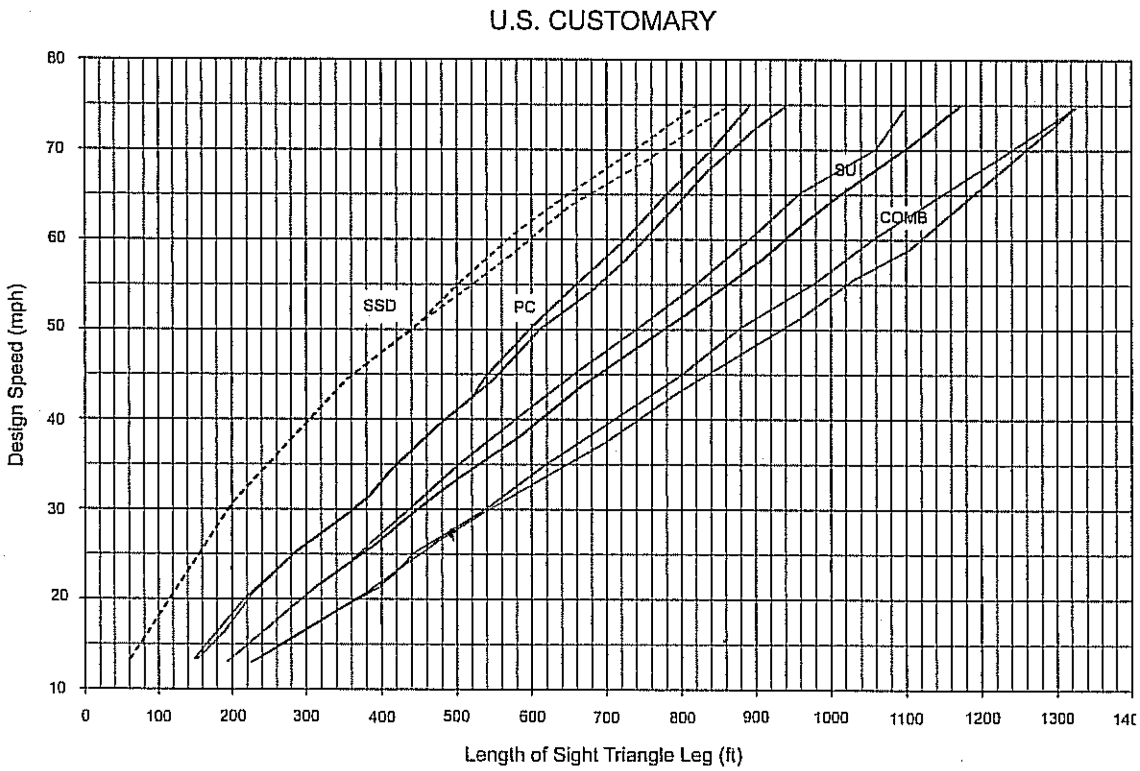


Figure 9-20. Intersection Sight Distance—Case C2, Yield-Controlled Left or Right Turn

Case D—Intersections with Traffic Signal Control

At signalized intersections, the first vehicle stopped on one approach should be visible to the driver of the first vehicle stopped on each of the other approaches. Left-turning vehicles should have sufficient sight distance to select gaps in oncoming traffic and complete left turns. Apart from these sight conditions, there are generally no other approach or departure sight triangles needed for signalized intersections. Signalization may be an appropriate crash countermeasure for higher volume intersections with restricted sight distance that have experienced a pattern of sight-distance related crashes.

However, if the traffic signal is to be placed on two-way flashing operation (i.e., flashing yellow on the major-road approaches and flashing red on the minor-road approaches) under off-peak or nighttime conditions, then the appropriate departure sight triangles for Case B, both to the left and to the right, should be provided for the minor-road approaches. In addition, if right turns on a red signal are to be permitted from any approach, then the appropriate departure sight triangle to the left for Case B2 should be provided to accommodate right turns from that approach.

Case E—Intersections with All-Way Stop Control

At intersections with all-way stop control, the first stopped vehicle on one approach should be visible to the drivers of the first stopped vehicles on each of the other approaches. There are no other sight distance criteria applicable to intersections with all-way stop control and, indeed, all-way stop control may be the best option at a limited number of intersections where sight distance for other control types cannot be attained.

Case F—Left Turns from the Major Road

All locations along a major highway from which vehicles are permitted to turn left across opposing traffic, including intersections and driveways, should have sufficient sight distance to accommodate the left-turn maneuver. Left-turning drivers need sufficient sight distance to decide when to turn left across the lane(s) used by opposing traffic. Sight distance design should be based on a left turn by a stopped vehicle, since a vehicle that turns left without stopping would need less sight distance. The sight distance along the major road to accommodate left turns is the distance traversed at the design speed of the major road in the travel time for the design vehicle given in Table 9-13.

Table 9-13. Time Gap for Case F, Left Turns from the Major Road

Design Vehicle	Time Gap (t_g)(s) at Design Speed of Major Road
Passenger car	5.5
Single-unit truck	6.5
Combination truck	7.5

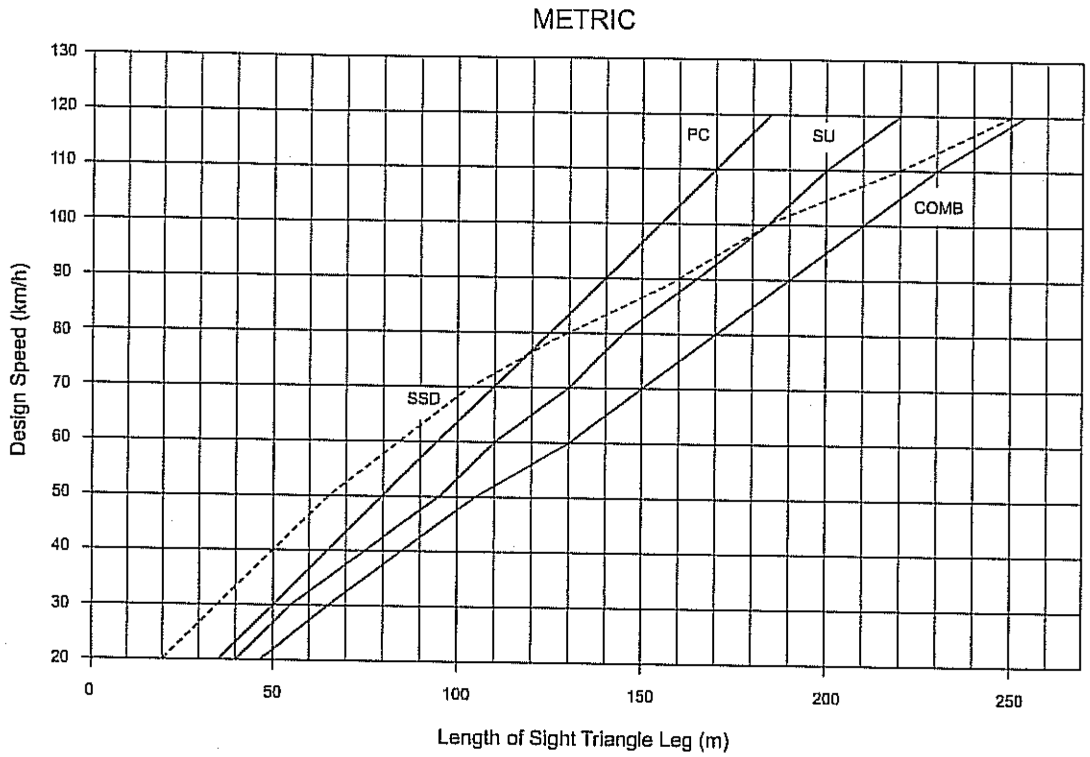
Note: *Adjustment for multilane highways*—For left-turning vehicles that cross more than one opposing lane, add 0.5 s for passenger cars and 0.7 s for trucks for each additional lane to be crossed.

The table also contains appropriate adjustment factors for the number of major-road lanes to be crossed by the turning vehicle. The unadjusted time gap in Table 9-13 for passenger cars was used to develop the sight distances in Table 9-14 and illustrated in Figure 9-21.

Table 9-14. Intersection Sight Distance—Case F, Left Turn from the Major Road

Metric				U.S. Customary			
		Intersection Sight Distance				Intersection Sight Distance	
		Passenger Cars				Passenger Cars	
Design Speed (km/h)	Stopping Sight Distance (m)	Calculated (m)	Design (m)	Design Speed (mph)	Stopping Sight Distance (ft)	Calculated (ft)	Design (ft)
20	20	30.6	35	15	80	121.3	125
30	35	45.9	50	20	115	161.7	165
40	50	61.2	65	25	155	202.1	205
50	65	76.5	80	30	200	242.6	245
60	85	91.7	95	35	250	283.0	285
70	105	107.0	110	40	305	323.4	325
80	130	122.3	125	45	360	363.8	365
90	160	137.6	140	50	425	404.3	405
100	185	152.9	155	55	495	444.7	445
110	220	168.2	170	60	570	485.1	490
120	250	183.5	185	65	645	525.5	530
130	285	198.8	200	70	730	566.0	570
—	—	—	—	75	820	606.4	610
—	—	—	—	80	910	646.8	650

Note: Intersection sight distance shown is for a passenger car making a left turn from an undivided highway. For other conditions and design vehicles, the time gap should be adjusted and the sight distance recalculated.



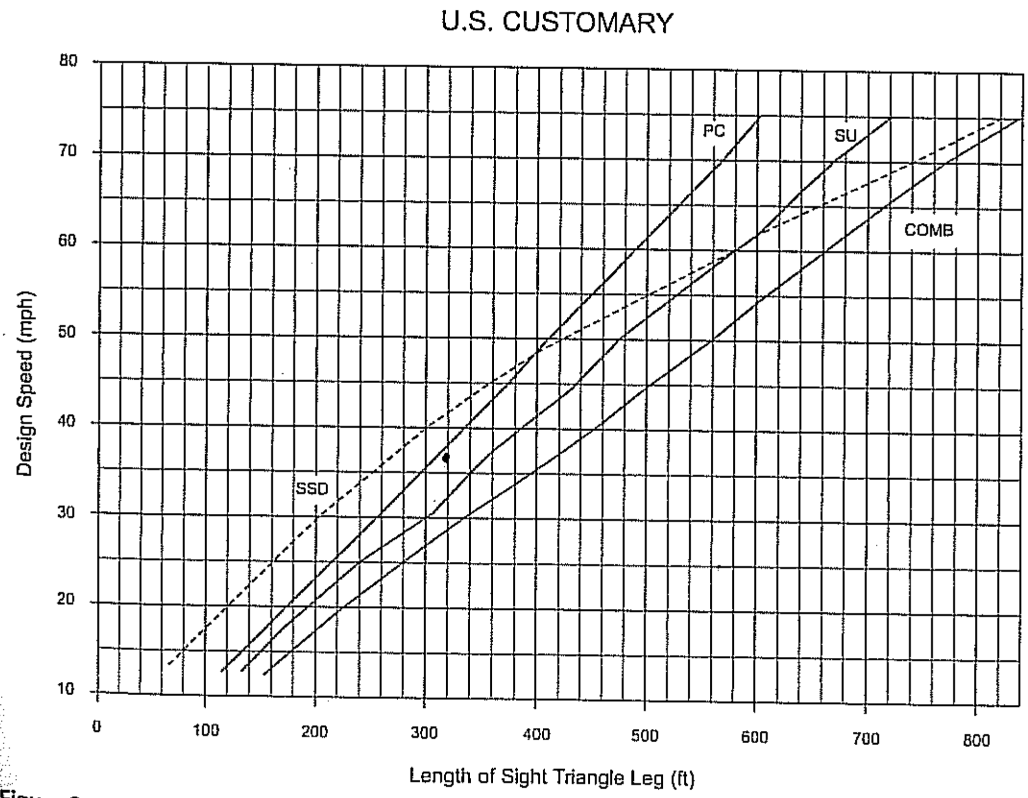


Figure 9-21. Intersection Sight Distance—Case F, Left Turn from the Major Road

If stopping sight distance has been provided continuously along the major road and if sight distance for Case B (stop control) or Case C (yield control) has been provided for each minor-road approach, sight distance will generally be adequate for left turns from the major road. Therefore, no separate check of sight distance for Case F may be needed.

However, at three-leg intersections or driveways located on or near a horizontal curve or crest vertical curve on the major road, the availability of adequate sight distance for left turns from the major road should be checked. In addition, the availability of sight distance for left turns from divided highways should be checked because of the possibility of sight obstructions in the median.

At four-leg intersections on divided highways, opposing vehicles turning left can block a driver's view of oncoming traffic. Figure 9-52, presented in Section 9.7.3, illustrates intersection designs that can be used to offset the opposing left-turn lanes and provide left-turning drivers with a better view of oncoming traffic.

9.5.4 Effect of Skew

When two highways intersect at an angle less than 60 degrees, and when realignment to increase the angle of intersection is not justified, some of the factors for determination of intersection sight distance may need adjustment.

Each of the clear sight triangles described above are applicable to oblique-angle intersections. As shown in Figure 9-22, the legs of the sight triangle will lie along the intersection approaches and each sight triangle will be larger or smaller than the corresponding sight triangle would be at a right-angle intersection. The area within each sight triangle should be clear of potential sight obstructions as described previously.

At an oblique-angle intersection, the length of the travel paths for some turning and crossing maneuvers will be increased. The actual path length for a turning or crossing maneuver can be computed by dividing the total widths of the lanes (plus the median width, where appropriate) to be crossed by the sine of the intersection angle. If the actual path length exceeds the total widths of the lanes to be crossed by 3.6 m [12 ft] or more, then an appropriate number of additional lanes should be considered in applying the adjustment for the number of lanes to be crossed shown in Table 9-5 for Case B1 and in Table 9-7 for Cases B2 and B3. For Case C1, the w term in the equation for the major-road leg of the sight triangle to accommodate the crossing maneuver should also be divided by the sine of the intersection angle to obtain the actual path length. In the obtuse-angle quadrant of an oblique-angle intersection, the angle between the approach leg and the sight line is often so small that drivers can look across the full sight triangle with only a small head movement. However, in the acute-angle quadrant, drivers often need to turn their heads considerably to see across the entire clear sight triangle. For this reason, it is recommended that the sight distance criteria for Case A not be applied to oblique-angle intersections and that sight distances at least equal to those for Case B should be provided, whenever practical.

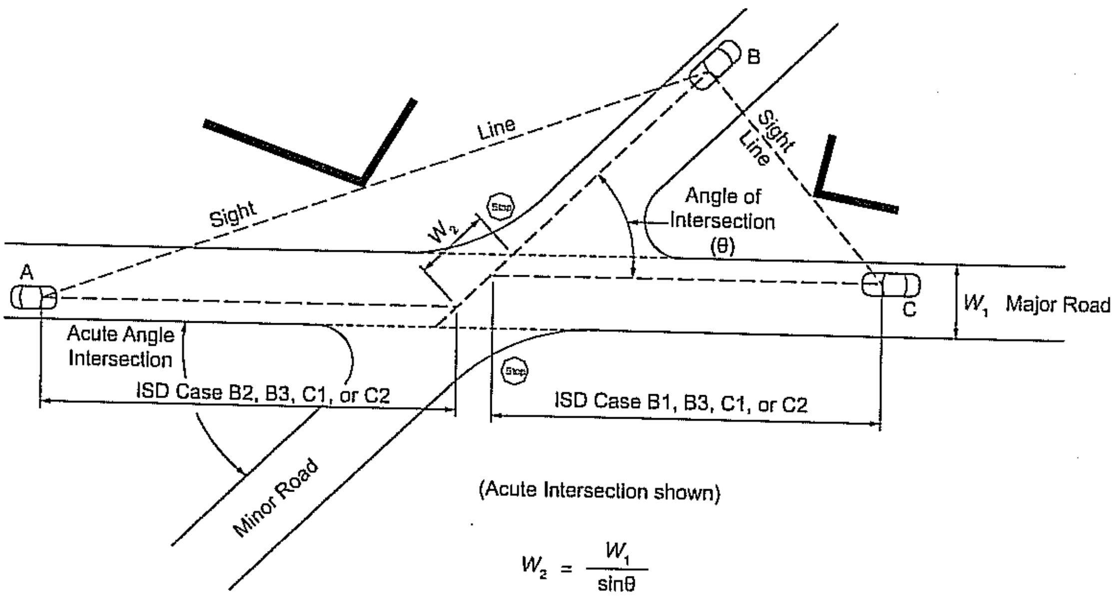


Figure 9-22. Sight Triangles at Skewed Intersections

9.6 TURNING ROADWAYS AND CHANNELIZATION

Turning roadways and channelization are a key aspect of intersection design. This section reviews the types of turning roadways, the basic principles of channelization and island design, the detailed design approaches to free-flow turning roadways at intersections, turning roadways with corner islands, superevelation for turning roadways at intersections, and stopping sight distance for turning roadways.

9.6.1 Types of Turning Roadways

General

The widths of turning roadways for intersections are governed by the volumes of turning traffic and the types of vehicles to be accommodated. In almost all cases, turning roadways are designed for use by right-turning traffic. The widths for right-turning roadways may also be applied to other roadways within an intersection. There are three typical types of right-turning roadways at intersections: (1) a minimum edge-of-traveled-way design, (2) a design with a corner triangular island, and (3) a free-flow design using a simple radius or compound radii. The turning radii and the pavement cross slopes for free-flow right turns are functions of design speed and type of vehicles. For an in-depth discussion of the appropriate design criteria, see Chapter 3.

Minimum Edge-of-Traveled-Way Designs

Where it is appropriate to provide for turning vehicles within minimum space, as at unchannelized intersections, the corner radii should be based on minimum turning path of the selected design vehicles. The sharpest turn that can be made by each design vehicle is shown in Sections 2.1.1 and 2.1.2, and the paths of the inner rear wheel and the front overhang are illustrated. The swept path widths indicated in