Table 4-5. Guidelines for Maximum Side Friction Factor and Minimum Radius (New Construction, Design Volumes from 251 to 400 veh/day, Limited Proportion of Heavy Vehicle Traffic)

U.S. Customary

Design Speed (mph)	Reduced Design Speed (mph)	Maximum Design Side Friction Factor, f_{max}	Minimum Radius (ft), R_{min} — Max. Superelevation Rate (%), e_{max}: 4	6	8	10	12
10	10	0.380	25	25	25	25	25
15	15	0.320	40	40	40	35	35
20	15	0.320	40	40	40	35	35
25	20	0.270	85	80	75	70	70
30	25	0.230	155	145	135	125	120
35	30	0.200	250	230	215	200	190
40	35	0.180	370	340	315	290	270
45	40	0.160	535	485	445	410	380
50	45	0.150	710	645	585	540	500
55	50	0.140	925	835	760	695	640
60	50	0.140	925	835	760	695	640

Metric

Design Speed (km/h)	Reduced Design Speed (km/h)	Maximum Design Side Friction Factor, f_{max}	Minimum Radius (m), R_{min} — Max. Superelevation Rate (%), e_{max}: 4	6	8	10	12
15	15	0.400	10	10	10	10	10
20	20	0.350	10	10	10	10	10
30	25	0.315	15	15	10	10	10
40	30	0.280	20	20	20	20	20
50	40	0.230	45	45	40	40	35
60	50	0.190	85	80	75	70	65
70	60	0.170	135	125	115	105	100
80	65	0.160	165	155	140	130	120
90	75	0.145	240	215	195	180	165
100	85	0.135	325	290	265	240	225

Table 4-6. Guidelines for Maximum Side Friction Factor and Minimum Radius (New Construction, Design Volumes of 400 veh/day or Less, Substantial Proportion of Heavy Vehicle Traffic)

U.S. Customary

Design Speed (mph)	Reduced Design Speed (mph)	Maximum Design Side Friction Factor, f_{max}	Minimum Radius (ft), R_{min} — Max. Superelevation Rate (%), e_{max}: 4	6	8	10	12
10	10	0.380	25	25	25	25	25
15	15	0.320	40	40	40	35	35
20	20	0.270	85	80	75	70	70
25	25	0.230	155	145	135	125	120
30	25	0.230	155	145	135	125	120
35	30	0.200	250	230	215	200	190
40	35	0.180	370	340	315	290	270
45	40	0.160	535	485	445	410	380
50	45	0.150	710	645	590	540	500
55	50	0.140	925	835	760	695	640
60	55	0.130	1190	1060	960	875	805

Metric

Design Speed (km/h)	Reduced Design Speed (km/h)	Maximum Design Side Friction Factor, f_{max}	Minimum Radius (m), R_{min} — Max. Superelevation Rate (%), e_{max}: 4	6	8	10	12
15	15	0.400	10	10	10	10	10
20	20	0.350	10	10	10	10	10
30	30	0.280	20	20	20	20	20
40	40	0.230	45	45	40	40	35
50	45	0.210	65	60	55	50	50
60	55	0.180	110	100	90	85	80
70	65	0.160	165	155	140	130	120
80	70	0.150	205	185	170	155	145
90	80	0.140	280	250	230	210	195
100	90	0.130	375	335	305	275	255

4.4.1.4 Urban Major Access Streets (250 Vehicles per Day or Less) and Urban Residential Streets (400 Vehicles per Day or less)

Horizontal curves on urban major access streets with design volumes of 250 vehicles per day or less and on urban residential streets with design volumes of 400 vehicles per day or less should be designed in accordance with the limiting values of f_{max} and R_{min} presented in Table 4-3, whenever practical. In constrained situations, the limiting values of f_{max} and R_{min} shown in Table 4-4 may be used in place of Table 4-3. Design of superelevation and superelevation transitions for this category of low-volume roads is discussed in Section 4.4.1.8.

4.4.1.5 Urban Major Access Streets (251 to 400 Vehicles per Day)

Horizontal curves on urban major access streets with design volumes from 251 to 400 vehicles per day should be designed in accordance with the limiting values of f_{max} and R_{min} presented in Table 4-3, whenever practical. In constrained situations, the limiting values of fmax and R_{min} shown in Table 4-5 may be used in place of Table 4-3. Design of superelevation and superelevation transitions for this category of low-volume roads is discussed in Section 4.4.1.8.

4.4.1.6 Urban Industrial or Commercial Access Streets (400 Vehicles per Day or Less)

Horizontal curves on urban industrial or commercial access streets should be designed in accordance with the limiting values of f_{max} and R_{min} presented in Table 4-3, whenever practical. In constrained situations, the limiting values of f_{max} and R_{min} shown in Table 4-6 may be used in place of Table 4-3. Design of superelevation and superelevation transitions for this category of low-volume roads is discussed in Section 4.4.1.8.

4.4.1.7 Low-Volume Roads of Any Functional Subclass (401 to 2,000 Vehicles per Day)

Horizontal curves on low-volume roads in any functional subclass should be designed in new construction projects in accordance with the limiting values of f_{max} and R_{min} presented in Table 4-3.

4.4.1.8 Superelevation and Superelevation Transitions

Once the radius for a particular horizontal curve has been determined, the selection of the appropriate superelevation and the design of superelevation transitions should proceed in accordance with the criteria presented in Chapter 3 of the AASHTO Green Book (**5**). Where the horizontal curve design is based on Table 4-3, the superelevation and superelevation transition design should follow the criteria from Chapter 3 of the AASHTO Green Book for the actual roadway design speed. Where the horizontal curve design is based on Tables 4-4, 4-5, or 4-6, the superelevation and superelevation transition design follow the criteria from Chapter 3 of the AASHTO Green Book using the reduced design speed indicated in Tables 4-4, 4-5, or 4-6 in place of the roadway design speed. The criteria in Chapter 3 of the AASHTO Green Book concerning situations where no superelevation is needed apply to low-volume roads based on the roadway design speed or the reduced design speed, as appropriate.

4.4.2 Existing Roads

For improvement projects on existing low-volume roads, the existing horizontal curve geometry should generally be considered acceptable unless there is evidence of a site-specific crash pattern related to horizontal curvature. The following guidelines reflect the results of the risk assessment for horizontal curves on existing roads:

- For curves on low-volume roads with low speeds (design or estimated operating speed of 45 mph [70 km/h] or less), reconstruction without changing the existing curve geometry and cross section is acceptable if the nominal design speed of the curve is within 20 mph or 30 km/h of the design or operating speed, and if there is no clear evidence of a site-specific crash pattern associated with the curve.
- For curves on low-volume roads with higher speeds (design or estimated operating speed greater than 45 mph [70 km/h]), reconstruction without changing the existing curve geometry and cross section is acceptable if the nominal design speed of the curve is within 10 mph or 20 km/h of the design or operating speed, and if there is no clear evidence of a site-specific crash pattern associated with the curve.

Evidence of a site-specific crash pattern may be demonstrated by a history of curve-related crashes (considering at least 5 years, and preferably 10 years, of crash data); physical evidence of curve problems such as skid marks, scarred trees or utility poles, substantial edge rutting or encroachments, etc.; a history of complaints from residents or local police; or measured or known speeds substantially higher (e.g., 20 mph or 30 km/h higher) than the intended design speed. Even with such evidence, curve improvements should focus on low-cost measures designed to control speeds, enhance curve tracking, or mitigate roadside encroachment severity. Except in rare circumstances, there are more cost effective solutions to identified curve problems on low-volume roads than curve flattening and reconstruction.

Acceptable substitutes for curve reconstruction include measures to reduce speed in the curve (signing, rumble strips, pavement markings), measures to improve the roadside within the curve (clearing slopes, widening shoulder through curve), and measures to increase pavement friction within the curve. Reconstruction employing any or all of these measures should be accompanied by appropriate before-and-after studies to monitor their effectiveness. Procedures for before-and-after evaluation studies are presented in Chapter 9 of the AASHTO *Highway Safety Manual* (**2**).

4.5 STOPPING SIGHT DISTANCE

Sight distance is the length of roadway ahead visible to the driver. The available sight distance on a roadway should be sufficiently long to enable a vehicle traveling at or near the design speed to avoid colliding with a stationary object in its path. For new construction projects on higher volume roads with design volumes greater than 2,000 vehicles per day, sight distance at every point on the road should be at least that needed for a poorly performing driver or a poorly equipped vehicle to stop within the available sight distance. The object normally considered in stopping sight distance design is a stopped vehicle in the roadway. On local roads with low design volumes (400 vehicles per day or less), on which stopped vehicles would rarely be expected, provision of sufficient sight distance for a driver to maneuver around a small object on the road, rather than come to a stop, may be appropriate.

Stopping sight distance is generally determined as the sum of two distances: (1) the distance traversed by the vehicle from the instant the driver sights an object necessitating a stop to the instant the brakes are applied; and (2) the distance needed to stop the vehicle from the instant brake application begins. These are referred to as brake reaction distance and braking distance, respectively. Similarly, sight distance to maneuver around an object incorporates a maneuver reaction time and a maneuver time. The current stopping sight distance criteria in the AASHTO Green Book (**5**) are based on the following model:

U.S. Customary	Metric
$SSD = 1.47Vt + 1.075\frac{V^2}{a}$	$SSD = 0.278Vt + 0.039\frac{V^2}{a}$ (4-3)
where: SSD = sight distance, ft; t = brake reaction time, s; V = design speed, mph; and a = deceleration rate, ft/s^2.	where: SSD = sight distance, m; t = brake reaction time, s; V = design speed, km/h; and a = deceleration rate, m/s^2.

The brake reaction time (t) of 2.5 s used in Equation 4-3 represents approximately the 95th percentile of the observed distribution of brake-reaction times. The deceleration rate, a, of 11.2 ft/sec^2 [3.4 m/s^2] used in Equation 4-3 represents approximately the 10th percentile of driver deceleration rate. These values of brake reaction time and driver deceleration rate were developed in research for higher volume roads in NCHRP Report 400 (**7**).

As discussed later in this section, sight distance plays a key role in setting the minimum lengths of crest vertical curves. The AASHTO Green Book (**5**) uses values for height of eye (h_1) and height of object (h_2) equal to 3.5 ft and 2.0 ft [1,080 mm and 600 mm], respectively.

Sight distance criteria applicable to new construction projects and to existing low-volume roads are presented below. The design criteria for stopping sight distance on low-volume roads vary with traffic volume levels and the proximity of intersections, narrow bridges, railroad-highway grade crossings, sharp curves, and steep grades, but the design criteria do not vary between rural and urban areas or between functional subclasses of low-volume roads.

4.5.1 New Construction

Design of newly constructed low-volume roads with design volumes of 400 vehicles per day or less may be based on sight distances lower than those presented in the AASHTO Green Book (**5**). NCHRP Report 400 (**7**) found that collisions at crest vertical curves with limited sight distance are extremely rare events, even on higher volume roadways, and that the object struck in such collisions was predominately another motor vehicle. Furthermore, there was no indication that lengthening of the sight distance at crest vertical curves has any demonstrable effect on reducing the number of collisions. The risk assessment by Neuman (**11**) for roads with average daily traffic volumes of 400 vehicles per day or less concluded that collisions with vehicles stopped in the roadway were far less likely on such roads than even the limited likelihood of collisions with stopped vehicles on higher volume roads and that sight distance values lower than those presented in the AASHTO Green Book (**5**) for higher volume roads can be applied to such roads with minimal effect on crash frequency and severity. Based on the formal risk assessment by Neuman, two sets of alternative sight distance criteria for roads with design volumes of 400 vehicles per day or less are recommended. The maneuver sight distance model developed in NCHRP Report 400 (**7**) is recommended for application to:

- roads with traffic volumes of 100 vehicles per day or less; or
- roads with traffic volumes of 101 to 250 vehicles per day located at lower risk locations, such as locations not in close proximity to intersections, narrow bridges, railroad–highway grade crossings, sharp curves, or steep downgrades.

The sight distance model presented in Equation 4-3 using alternative parameter values for brake-reaction time and driver deceleration is recommended for the following types of low-volume roads:

- roads with design volumes of 101 to 250 vehicles per day located at higher risk locations, such as locations near intersections, narrow bridges, or railroad–highway grade crossings, or in advance of sharp curves and steep downgrades; or
- roads with design volumes of 251 to 400 vehicles per day

The alternative parameter values recommended for use when Equation 4-3 is applied to new construction of roads with design volumes of 400 vehicles per day or less are:

- a brake-reaction time of 2 s, based on the 90th rather than the 95th percentile of observed driver behavior; or
- a driver deceleration of 13.4 ft/s^2 [4.1 m/s^2], based on the 50th percentile rather than the 10th percentile of the observed distribution

Table 4-7 presents recommended design stopping sight distance criteria for new construction on roads with design volumes of 400 vehicles per day or less based on the models discussed above. These criteria may be used in design of both horizontal and crest vertical curves for new construction.

Table 4-7. Design Stopping Sight Distance Guidelines for New Construction of Low-Volume Roads with Design Volumes of 2,000 Vehicles per Day or Less

U.S. Customary					
	Minimum Sight Distance (ft) for Specified Design Traffic Volumes and Location Types				
	0–100 veh/day	101–250 veh/day		251–400 veh/day	401–2,000 veh/day
Design Speed (mph)	All Locations	"Lower Risk" Locations[1]	"Higher Risk" Locations[2]	All Locations	All Locations
15	65	65	65	65	80
20	90	90	95	95	115
25	115	115	125	125	155
30	135	135	165	165	200
35	170	170	205	205	250
40	215	215	250	250	305
45	260	260	300	300	360
50	310	310	350	350	425
55	365	365	405	405	495
60	435	435	470	470	570

Metric					
	Minimum Sight Distance (m) for Specified Design Traffic Volumes and Location Types				
	0–100 veh/day	101–250 veh/day		251–400 veh/day	401–2,000 veh/day
Design Speed (km/h)	All Locations	"Lower Risk" Locations[1]	"Higher Risk" Locations[2]	All Locations	All Locations
20	15	15	15	15	20
30	25	25	30	30	35
40	35	35	40	40	50
50	45	45	55	55	65
60	60	60	70	70	85
70	75	75	90	90	105
80	95	95	110	110	130
90	120	120	130	130	160
100	140	140	155	155	185

[1] Not in close proximity to intersections, narrow bridges, railroad–highway grade crossings, sharp curves, or steep downgrades.

[2] Near intersections, narrow bridges, or railroad–highway grade crossings, or in advance of sharp curves or steep downgrades.

For new construction of roads with design volumes greater than 400 vehicles per day, the stopping sight distance criteria presented in Chapter 3 of the AASHTO Green Book (**5**) should be applied.

4.5.1.1 Sight Distance on Horizontal Curves

Sight distance across the inside of horizontal curves is an element of the design of horizontal alignment. Where there are sight obstructions (such as walls, cut slopes, vegetation, buildings, or longitudinal barriers) on the inside of a horizontal curve, a design to provide adequate sight distance may need an adjustment in the normal highway cross section or a change in alignment if the obstruction cannot be removed. Because of the many variables in alignment and cross sections and in the number, type, and location of possible obstructions, a specific study is usually needed for each condition. With the sight distance specified in Table 4-7 for the appropriate design speed as a control, the designer should check the actual condition and make any needed adjustments in the manner most fitting to provide adequate sight distances.

For general use in the design of a horizontal curve, the sight line is a chord of the horizontal curve, and the applicable stopping sight distance is measured along the centerline of the inside lane around the curve. The minimum width that should be clear of sight obstructions is the middle ordinate of the curve, referred to in geometric design as the horizontal sightline offset, *HSO*, as shown in Figure 4-1.

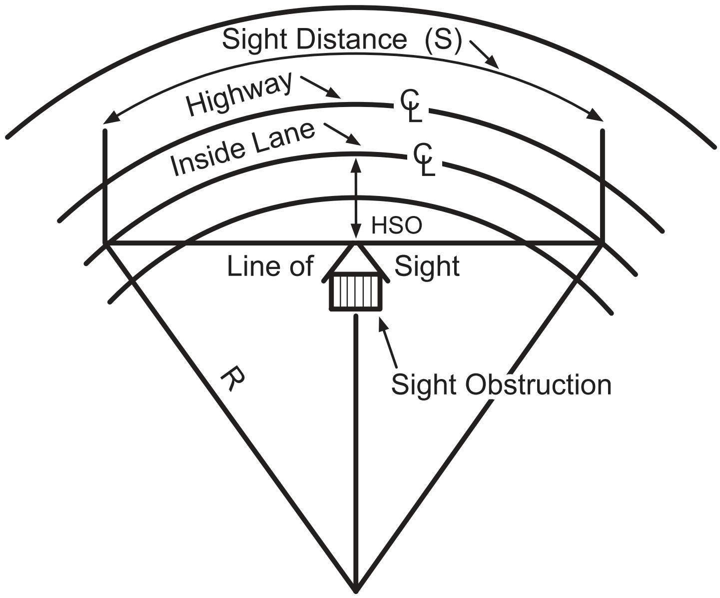

Figure 4-1. Horizontal Curve Showing Stopping Sight Distance Along the Curve and the Horizontal Sightline Offset that Defines the Maximum Unobstructed Width

The horizontal sightline offset can be computed, for any curve whose length exceeds the design sight distance, as shown in Equation 4-4:

U.S. Customary	Metric
$$HSO = R\left[1 - \cos\left(\frac{28.65S}{R}\right)\right]$$	$$HSO = R\left[1 - \cos\left(\frac{28.65S}{R}\right)\right]$$ (4-4)
where: *S* = Sight distance, ft; *R* = Radius of curve, ft; and *HSO* = Horizontal sightline offset, ft.	where: *S* = Sight distance, m; *R* = Radius of curve, m; and *HSO* = Horizontal sightline offset, m.

Table 4-8 presents the horizontal sightline offsets that define the width that should be clear of sight obstructions for a horizontal curve as a function of curve radius and design speed.

Table 4-8. Design Guidelines for Sight Distance on Horizontal Curves for New Construction of Low-Volume Roads

U.S. Customary

All Locations for 0–100 veh/day and "Lower Risk" Locations for 101–250 veh/day[1]

Design Speed (mph)	Stopping Sight Distance (ft)	Width on Inside of Curve Clear of Sight Obstructions[3] (ft) — Radius of Curvature (ft)								
		50	100	200	500	1000	2000	5000	10000	20000
15	65	10.2	5.2	2.6	1.1	0.5	0.3	0.1	0.1	0.0
20	90	—	10.0	5.0	2.0	1.0	0.5	0.2	0.1	0.1
25	115	—	—	8.2	3.3	1.7	0.8	0.3	0.2	0.1
30	135	—	—	11.3	4.5	2.3	1.1	0.5	0.2	0.1
35	170	—	—	—	7.2	3.6	1.8	0.7	0.4	0.2
40	215	—	—	—	11.5	5.8	2.9	1.2	0.6	0.3
45	260	—	—	—	16.8	8.4	4.2	1.7	0.8	0.4
50	310	—	—	—	—	12.0	6.0	2.4	1.2	0.6
55	365	—	—	—	—	16.6	8.3	3.3	1.7	0.8
60	435	—	—	—	—	23.6	11.8	4.7	2.4	1.2

"Higher Risk" Locations for 101–250 veh/day and All Locations for 251–400 veh/day[2]

Design Speed (mph)	Stopping Sight Distance (ft)	Width on Inside of Curve Clear of Sight Obstructions[3] (ft) — Radius of Curvature (ft)								
		50	100	200	500	1000	2000	5000	10000	20000
15	65	10.2	5.2	2.6	1.1	0.5	0.3	0.1	0.1	0.0
20	95	—	11.1	5.6	2.3	1.1	0.6	0.2	0.1	0.1
25	125	—	—	9.7	3.9	2.0	1.0	0.4	0.2	0.1
30	165	—	—	16.8	6.8	3.4	1.7	0.7	0.3	0.2
35	205	—	—	—	10.5	5.2	2.6	1.1	0.5	0.3
40	250	—	—	—	15.5	7.8	3.9	1.6	0.8	0.4
45	300	—	—	—	22.3	11.2	5.6	2.3	1.1	0.6
50	350	—	—	—	—	15.3	7.7	3.1	1.5	0.8
55	405	—	—	—	—	20.4	10.2	4.1	2.1	1.0
60	470	—	—	—	—	27.5	13.8	5.5	2.8	1.4

Metric

All Locations for 0–100 veh/day and "Lower Risk" Locations for 101–250 veh/day[1]

Design Speed (km/h)	Stopping Sight Distance (m)	Width on Inside of Curve Clear of Sight Obstructions[3] (m) — Radius of Curvature (m)								
		10	50	100	200	500	1000	2000	4000	6000
20	15	2.7	0.6	0.3	0.1	0.1	0.0	0.0	0.0	0.0
30	25	—	1.6	0.8	0.4	0.2	0.1	0.0	0.0	0.0
40	35	—	3.0	1.5	0.8	0.3	0.2	0.1	0.0	0.0
50	45	—	—	2.5	1.3	0.5	0.3	0.1	0.1	0.0
60	60	—	—	—	2.2	0.9	0.5	0.2	0.1	0.1
70	75	—	—	—	3.5	1.4	0.7	0.4	0.2	0.1
80	95	—	—	—	5.6	2.3	1.1	0.6	0.3	0.2
90	120	—	—	—	—	3.6	1.8	0.9	0.5	0.3
100	140	—	—	—	—	4.9	2.4	1.2	0.6	0.4

"Higher Risk" Locations for 101–250 veh/day and All Locations for 251–400 veh/day[2]

Design Speed (km/h)	Stopping Sight Distance (m)	Width on Inside of Curve Clear of Sight Obstructions[3] (m) — Radius of Curvature (m)								
		10	50	100	200	500	1000	2000	4000	6000
20	15	2.7	0.6	0.3	0.1	0.1	0.0	0.0	0.0	0.0
30	30	—	2.2	1.1	0.6	0.2	0.1	0.1	0.0	0.0
40	40	—	3.9	2.0	1.0	0.4	0.2	0.1	0.1	0.0
50	55	—	—	3.8	1.9	0.8	0.4	0.2	0.1	0.1
60	70	—	—	—	3.1	1.2	0.6	0.3	0.2	0.1
70	90	—	—	—	5.0	2.0	1.0	0.5	0.3	0.2
80	110	—	—	—	7.5	3.0	1.5	0.8	0.4	0.3
90	130	—	—	—	—	4.2	2.1	1.1	0.5	0.4
100	155	—	—	—	—	6.0	3.0	1.5	0.8	0.5

Continued on next page.