For additional fluids information, see the **FLUID MECHANICS** section.

TRANSPORTATION

U.S. Customary Units

a = deceleration rate (ft/sec^2)
A = absolute value of algebraic difference in grades (%)
e = superelevation (%)
f = side friction factor
$\pm G$ = percent grade divided by 100 (uphill grade "+")
h_1 = height of driver's eyes above the roadway surface (ft)
h_2 = height of object above the roadway surface (ft)
L = length of curve (ft)
L_s = spiral transition length (ft)
R = radius of curve (ft)
S = stopping sight distance (ft)
t = driver reaction time (sec)
V = design speed (mph)
v = vehicle approach speed (fps)
W = width of intersection, curb-to-curb (ft)
l = length of vehicle (ft)
y = length of yellow interval to nearest 0.1 sec (sec)
r = length of red clearance interval to nearest 0.1 sec (sec)

Vehicle Signal Change Interval

$$y = t + \frac{v}{2a \pm 64.4\,G}$$

$$r = \frac{W + l}{v}$$

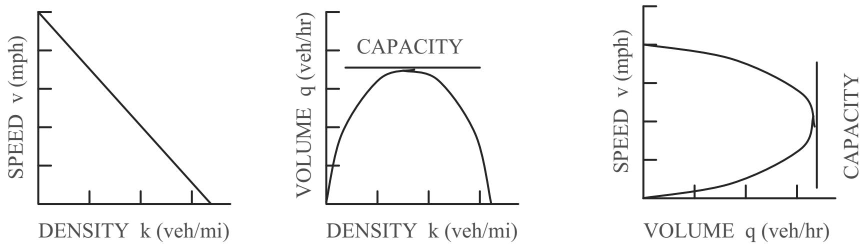
Stopping Sight Distance

$$S = 1.47Vt + \frac{V^2}{30\left(\left(\frac{a}{32.2}\right) \pm G\right)}$$

Transportation Models

See **INDUSTRIAL ENGINEERING** for optimization models and methods, including queueing theory.

Traffic Flow Relationships (q = kv)

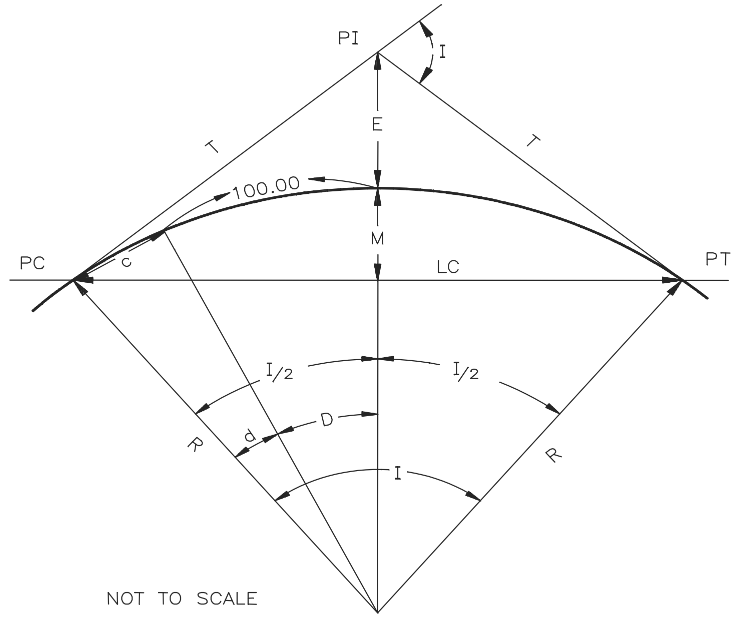


Vertical Curves: Sight Distance Related to Curve Length		
	$S \le L$	$S > L$
Crest Vertical Curve General equation:	$L = \dfrac{AS^2}{100(\sqrt{2h_1} + \sqrt{2h_2})^2}$	$L = 2S - \dfrac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A}$
Standard Criteria: $h_1 = 3.50$ ft and $h_2 = 2.0$ ft:	$L = \dfrac{AS^2}{2{,}158}$	$L = 2S - \dfrac{2{,}158}{A}$
Sag Vertical Curve (based on standard headlight criteria)	$L = \dfrac{AS^2}{400 + 3.5S}$	$L = 2S - \left(\dfrac{400 + 3.5S}{A}\right)$
Sag Vertical Curve (based on riding comfort)	$L = \dfrac{AV^2}{46.5}$	
Sag Vertical Curve (based on adequate sight distance under an overhead structure to see an object beyond a sag vertical curve)	$L = \dfrac{AS^2}{800\left(C - \dfrac{h_1 + h_2}{2}\right)}$	$L = 2S - \dfrac{800}{A}\left(C - \dfrac{h_1 + h_2}{2}\right)$
	$C =$ vertical clearance for overhead structure (overpass) located within 200 feet of the midpoint of the curve	

Horizontal Curves	
Side friction factor (based on superelevation)	$0.01e + f = \dfrac{V^2}{15R}$
Spiral Transition Length	$L_s = \dfrac{3.15V^3}{RC}$ $C =$ rate of increase of lateral acceleration [use 1 ft/sec^3 unless otherwise stated]
Sight Distance (to see around obstruction)	$\text{HSO} = R\left[1 - \cos\left(\dfrac{28.65\,S}{R}\right)\right]$ HSO = Horizontal sight line offset

Horizontal Curve Formulas

D = Degree of Curve, Arc Definition
PC = Point of Curve (also called BC)
PT = Point of Tangent (also called EC)
PI = Point of Intersection
I = Intersection Angle (also called Δ) Angle Between Two Tangents
L = Length of Curve, from PC to PT
T = Tangent Distance
E = External Distance
R = Radius
LC = Length of Long Chord
M = Length of Middle Ordinate
c = Length of Sub-Chord
d = Angle of Sub-Chord
l = Curve Length for Sub-Chord



$$R = \frac{5729.58}{D}$$

$$R = \frac{LC}{2\sin(I/2)}$$

$$T = R\tan(I/2) = \frac{LC}{2\cos(I/2)}$$

$$L = RI\frac{\pi}{180} = \frac{I}{D}100$$

$$M = R[1 - \cos(I/2)]$$

$$\frac{R}{E + R} = \cos(I/2)$$

$$\frac{R - M}{R} = \cos(I/2)$$

$$c = 2R\sin(d/2)$$

$$l = Rd\left(\frac{\pi}{180}\right)$$

$$E = R\left[\frac{1}{\cos(I/2)} - 1\right]$$

Deflection angle per 100 feet of arc length equals $D/2$

LATITUDES AND DEPARTURES

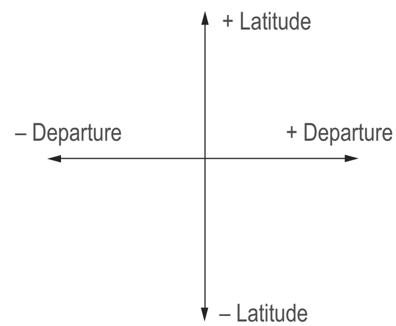


Table 3.1 Stopping Sight Distance

U.S. Customary					Metric				
Design speed (mi/h)	Brake reaction distance (ft)	Braking distance on level (ft)	Stopping sight distance: Calculated (ft)	Stopping sight distance: Design (ft)	Design speed (km/h)	Brake reaction distance (m)	Braking distance on level (m)	Stopping sight distance: Calculated (m)	Stopping sight distance: Design (m)
15	55.1	21.6	76.7	80	20	13.9	4.6	18.5	20
20	73.5	38.4	111.9	115	30	20.9	10.3	31.2	35
25	91.9	60.0	151.9	155	40	27.8	18.4	46.2	50
30	110.3	86.4	196.7	200	50	34.8	28.7	63.5	65
35	128.6	117.6	246.2	250	60	41.7	41.3	83.0	85
40	147.0	153.6	300.6	305	70	48.7	56.2	104.9	105
45	165.4	194.4	359.8	360	80	55.6	73.4	129.0	130
50	183.8	240.0	423.8	425	90	62.6	92.9	155.5	160
55	202.1	290.3	492.4	495	100	69.5	114.7	184.2	185
60	220.5	345.5	566.0	570	110	76.5	138.8	215.3	220
65	238.9	405.5	644.4	645	120	83.4	165.2	248.6	250
70	257.3	470.3	727.6	730	130	90.4	193.8	284.2	285
75	275.6	539.9	815.5	820					
80	294.0	614.3	908.3	910					

Note: Brake reaction distance is based on a time of 2.5 s; a deceleration rate of 11.2 ft/s^2 (3.4 m/s^2) is used to determine calculated stopping sight distance.

Source: American Association of State Highway and Transportation Officials, *A Policy on Geometric Design of Highways and Streets*, Washington, DC, 2001.

TABLE 7-4 Minimum Radius for Limiting Values of e and *f*, Rural Highways and High-Speed Urban Streets

Design Speed (mph)	*Maximum e (%)*	*Limiting Values of f*	*Total (e/100 + f)*	*Calculated Radius (ft)*	*Rounded Radius (ft)*
20	4.0	0.170	0.210	127.4	125
25	4.0	0.165	0.205	203.9	205
30	4.0	0.160	0.200	301.0	300
35	4.0	0.155	0.195	420.2	420
40	4.0	0.150	0.190	563.3	565
45	4.0	0.145	0.185	732.2	730
50	4.0	0.140	0.180	929.0	930
55	4.0	0.130	0.170	1,190.2	1,190
60	4.0	0.120	0.160	1,505.0	1,505
30	6.0	0.160	0.220	273.6	275
35	6.0	0.155	0.215	381.1	380
40	6.0	0.150	0.210	509.6	510
45	6.0	0.145	0.205	660.7	660
50	6.0	0.140	0.200	836.1	835
55	6.0	0.130	0.190	1,065.0	1,065
60	6.0	0.120	0.180	1,337.8	1,340
65	6.0	0.110	0.170	1,662.4	1,660
70	6.0	0.100	0.160	2,048.5	2,050
75	6.0	0.090	0.150	2,508.4	2,510
80	6.0	0.080	0.140	3,057.8	3,060
30	8.0	0.160	0.240	250.8	250
35	8.0	0.155	0.235	348.7	350
40	8.0	0.150	0.230	465.3	465
45	8.0	0.145	0.225	502.0	500
50	8.0	0.140	0.220	760.1	760
55	8.0	0.130	0.210	963.5	965
60	8.0	0.120	0.200	1,204.0	1,205
65	8.0	0.110	0.190	1,487.4	1,485
70	8.0	0.100	0.180	1,820.9	1,820
75	8.0	0.090	0.170	2,213.3	2,215
80	8.0	0.080	0.160	2,675.6	2,675
30	10.0	0.160	0.260	231.5	230
35	10.0	0.155	0.255	321.3	320
40	10.0	0.150	0.250	428.1	430
45	10.0	0.145	0.245	552.9	555
50	10.0	0.140	0.240	696.8	695
55	10.0	0.130	0.230	879.7	880
60	10.0	0.120	0.220	1,094.6	1,095
65	10.0	0.110	0.210	1,345.8	1,345
70	10.0	0.100	0.200	1,838.8	1,840
75	10.0	0.090	0.190	1,980.3	1,980
80	10.0	0.080	0.180	2,378.3	2,380

Source: From *A Policy on Geometric Design of Highways and Streets 2001,* copyright 2001. American Association of State Highway and Transportation Officials, Washington, DC. Used by permission.

QKU:

<u>Linear Speed-Density Model</u>

$$U = U_f \left(1 - \frac{K}{K_j} \right)$$

$$Q = U_f \left(K - \frac{K^2}{K_j} \right)$$

$$K = \frac{K_j \pm \sqrt{K_j^2 - \frac{4QK_j}{U_f}}}{2}$$

$$U = \frac{U_f \pm \sqrt{U_f^2 - \frac{4QU_f}{K_j}}}{2}$$

$$Q_{cap} = \frac{U_f K_j}{4}$$

$$U_{cap} = \frac{U_f}{2}$$

$$K_{cap} = \frac{K_j}{2}$$

Dilemma Zone:

$$X = V \times (Y + AR)$$

$$D = X - (w + l)$$

Intersection Operation:

$$EffectiveGreen = (G + Y + AR) - l$$

$$lane\ capacity = \frac{(G + Y + AR) - l}{C} \times s$$

$$s = \frac{3600}{h_s}$$

Signal Timing:

$$s = \frac{s_0}{1 + P_T}$$

$$C_{\min} = \frac{L \times X_c}{X_c - \sum_{i=1}^{n} \Sigma \left(\frac{CLV}{s} \right)_i}$$

$$(G + Y + AR)_i = \frac{\left(\frac{CLV}{s} \right)_i}{\Sigma \left(\frac{CLV}{s} \right)_i} (C - L) + l_i$$

LOS:

FFS = 75.4 – f_{lw} – f_{lc} – 3.22TRD$^{0.84}$

$$N = \frac{V}{MSF_i\ x\ PHF\ x\ f_{HV}\ x\ f_P}$$

$$PHF = \frac{V}{V_{15} \times 4}$$

$$f_{HV} = \frac{1}{1 + P_T (E_T - 1)}$$

$$Capacity = MSF_E\ x\ N\ \ x\ f_{HV}\ x\ f_p\ xPHF$$

$$D = v_p / S$$

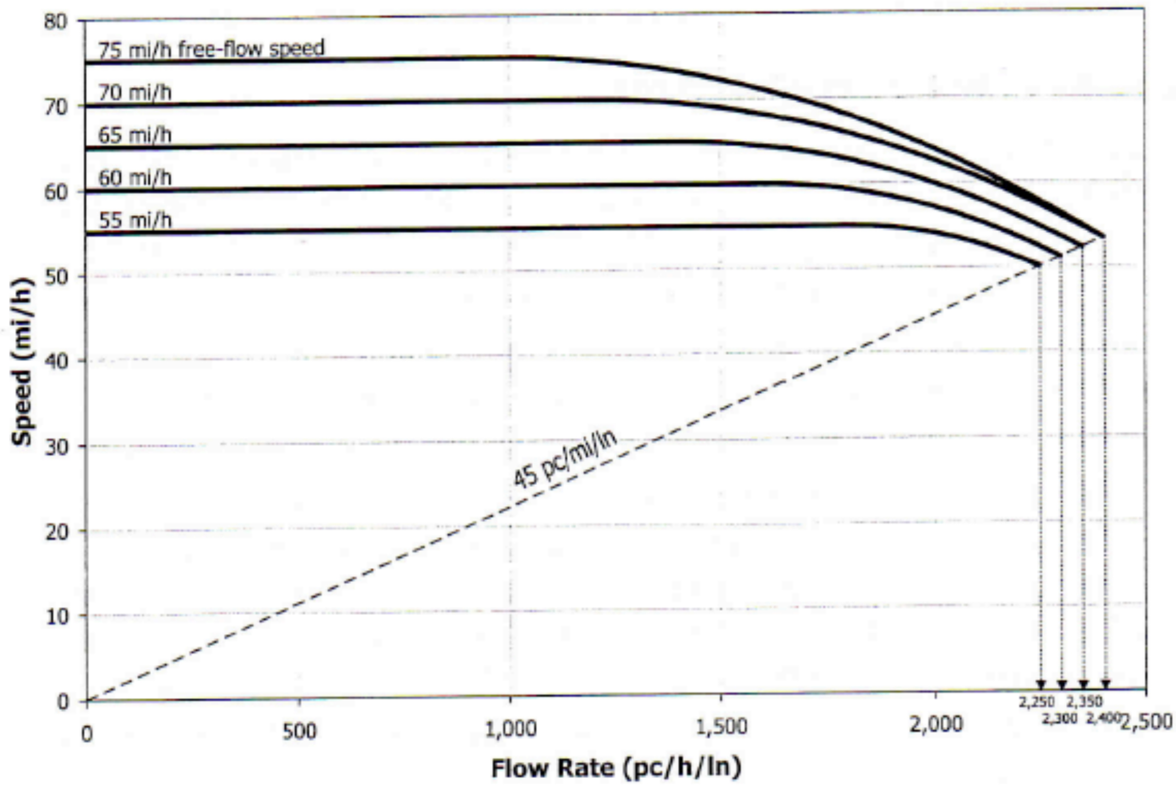
$$v_p = \frac{DDHV}{N\ x\ PHF\ x\ f_{HV}\ x\ f_P}$$

Vehicle	PCE by Type of Terrain Level	 Rolling	 Mountainous
Trucks and buses, E_T	1.5	2.5	4.5
RVs, E_R	1.2	2.0	4.0

Right-Side Lateral Clearance (ft)	*Lanes in One Direction* **2**	 **3**	 **4**	 **5**
≥ 6	0.0	0.0	0.0	0.0
5	0.6	0.4	0.2	0.1
4	1.2	0.8	0.4	0.2
3	1.8	1.2	0.6	0.3
2	2.4	1.6	0.8	0.4
1	3.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

*values in table above are for f_{LC} in mi/hr

Average Lane Width (ft)	*Reduction in FFS,* f_{LW} *(mi/h)*
≥ 12	0.0
≥ 11-12	1.9
≥ 10-11	6.6



FFS (mi/h)	Breakpoint (pc/h/ln)	Flow Rate Range: ≥0 ≤ Breakpoint	Flow Rate Range: >Breakpoint ≤ Capacity
75	1,000	75	$75 - 0.00001107\ (v_p - 1{,}000)^2$
70	1,200	70	$70 - 0.00001160\ (v_p - 1{,}200)^2$
65	1,400	65	$65 - 0.00001418\ (v_p - 1{,}400)^2$
60	1,600	60	$60 - 0.00001816\ (v_p - 1{,}600)^2$
55	1,800	55	$55 - 0.00002469\ (v_p - 1{,}800)^2$

Notes: FFS = free-flow speed, v_p = demand flow rate (pc/h/ln) under equivalent base conditions.

Maximum flow rate for the equations is capacity: 2,400 pc/h/ln for 70- and 75-mph FFS; 2,350 pc/h/ln for 65-mph FFS; 2,300 pc/h/ln for 60-mph FFS; and 2,250 pc/h/ln for 55-mph FFS.

FFS (mi/h)	Target Level of Service				
	A	**B**	**C**	**D**	**E**
75	820	1,310	1,750	2,110	2,400
70	770	1,250	1,690	2,080	2,400
65	710	1,170	1,630	2,030	2,350
60	660	1,080	1,560	2,010	2,300
55	600	990	1,430	1,900	2,250

Note: All values rounded to the nearest 10 pc/h/ln.

LOS	Density (pc/mi/ln)
A	≤11
B	>11–18
C	>18–26
D	>26–35
E	>35–45
F	Demand exceeds capacity >45