Quiz 1 Equation Sheet

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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

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

$$\textit{Theoretical Braking Distance} = \frac{\gamma_b (V_1^2 - V_2^2)}{2g(\eta_b \mu + f_{rl} \pm G)}$$

$$f_{rl} = 0.01\left(1 + \frac{V}{147}\right)$$

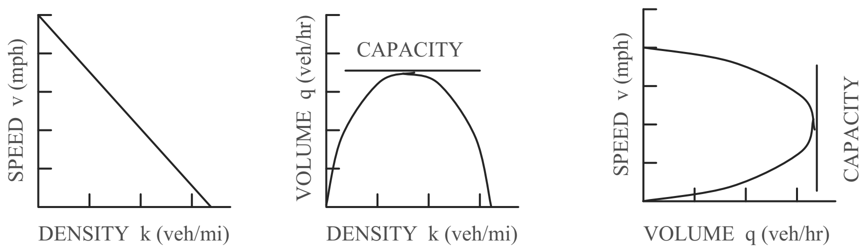
Table 2.4 Typical Values of Coefficients of Road Adhesion

Pavement	Coefficient of road adhesion	
	Maximum	Slide
Good, dry	1.00*	0.80
Good, wet	0.90	0.60
Poor, dry	0.80	0.55
Poor, wet	0.60	0.30
Packed snow or ice	0.25	0.10

Transportation Models

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

Traffic Flow Relationships (q = kv)

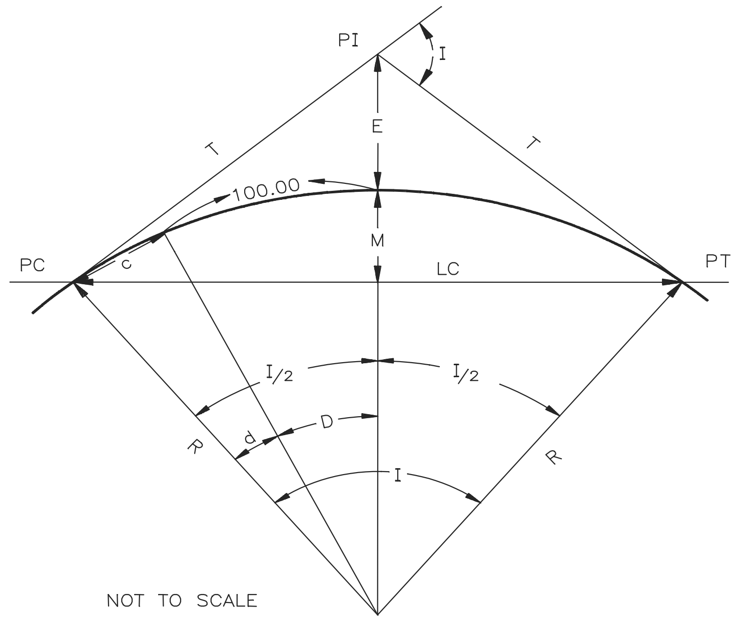


Vertical Curves: Sight Distance Related to Curve Length		
	$S \le L$	$S > L$
Crest Vertical Curve General equation:	$L = \dfrac{AS^2}{100(\sqrt{2h_1}+\sqrt{2h_2})^2}$	$L = 2S - \dfrac{200\left(\sqrt{h_1}+\sqrt{h_2}\right)^2}{A}$
Standard Criteria: $h_1 = 3.50$ ft and $h_2 = 2.0$ ft:	$L = \dfrac{AS^2}{2,158}$	$L = 2S - \dfrac{2,158}{A}$
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)	$\text{HSO} = R\left[1 - \cos\left(\dfrac{28.65S}{R}\right)\right]$ 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



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

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

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

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

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

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

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

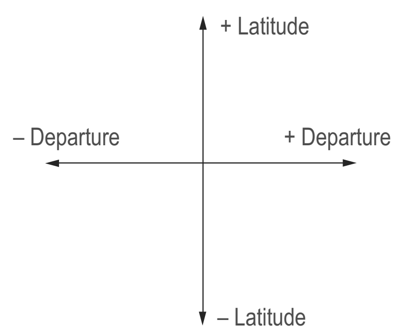
$$c = 2R\sin(d/2)$$

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

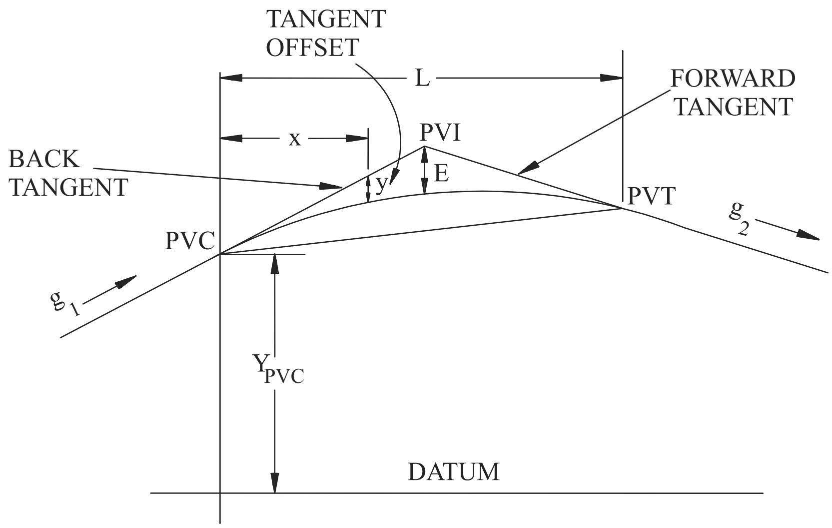
$$E = R\left[\frac{1}{\cos(I/2)} - 1\right]$$

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

LATITUDES AND DEPARTURES



Vertical Curve Formulas



VERTICAL CURVE FORMULAS
NOT TO SCALE

L = Length of Curve (horizontal)

PVC = Point of Vertical Curvature

PVI = Point of Vertical Intersection

PVT = Point of Vertical Tangency

g_1 = Grade of Back Tangent

x = Horizontal Distance from PVC to Point on Curve

g_2 = Grade of Forward Tangent

a = Parabola Constant

y = Tangent Offset

E = Tangent Offset at PVI

r = Rate of Change of Grade

x_m = Horizontal Distance to Min/Max Elevation on Curve = $-\frac{g_1}{2a} = \frac{g_1 L}{g_1 - g_2}$

Tangent Elevation = $Y_{PVC} + g_1 x$ and = $Y_{PVI} + g_2 (x - L/2)$

Curve Elevation = $Y_{PVC} + g_1 x + ax^2 = Y_{PVC} + g_1 x + [(g_2 - g_1)/(2L)]x^2$

$$y = ax^2 \qquad a = \frac{g_2 - g_1}{2L} \qquad E = a\left(\frac{L}{2}\right)^2 \qquad r = \frac{g_2 - g_1}{L}$$

EARTHWORK FORMULAS

Average End Area Formula, $V = L(A_1 + A_2)/2$

Prismoidal Formula, $V = L\,(A_1 + 4A_m + A_2)/6$,

where A_m = area of mid-section, and

L = distance between A_1 and A_2

Pyramid or Cone, $V = h$ (Area of Base)/3

AREA FORMULAS

Area by Coordinates: Area = $[X_A (Y_B - Y_N) + X_B (Y_C - Y_A) + X_C (Y_D - Y_B) + ... + X_N (Y_A - Y_{N-1})] / 2$

Trapezoidal Rule: Area = $w\left(\frac{h_1 + h_n}{2} + h_2 + h_3 + h_4 + \ldots + h_{n-1}\right)$ w = common interval

Simpson's 1/3 Rule: Area = $= w\left[h_1 + 2\left(\sum_{k=3,5,\ldots}^{n-2} h_k\right) + 4\left(\sum_{k=2,4,\ldots}^{n-1} h_k\right) + h_n\right] \Big/ 3$ n must be odd number of measurements

w = common interval

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.

Vertical Curve Offsets

$$Y = \frac{A}{200L} x^2$$

A = | G1 – G2 | *A is in percent form.

$$K = \frac{L}{A}$$

$$x_{hl} = K \times |G_1|$$

Parabolic Equations

$$y = ax^2 + bx + c$$

Where y = roadway elevation at distance x from the PVC.

$a = \frac{G_2 - G_1}{2L}$; b = G_1; c = $ELEV_{PVC}$

*keep in mind that you must use either station/% or ft/decimal for x/G_i.

Table 3.2 Design Controls for Crest Vertical Curves Based on Stopping Sight Distance

U.S. Customary				Metric			
Design speed (mi/h)	Stopping sight distance (ft)	Rate of vertical curvature, K^*		Design speed (km/h)	Stopping sight distance (m)	Rate of vertical curvature, K^*	
		Calculated	Design			Calculated	Design
15	80	3.0	3	20	20	0.6	1
20	115	6.1	7	30	35	1.9	2
25	155	11.1	12	40	50	3.8	4
30	200	18.5	19	50	65	6.4	7
35	250	29.0	29	60	85	11.0	11
40	305	43.1	44	70	105	16.8	17
45	360	60.1	61	80	130	25.7	26
50	425	83.7	84	90	160	38.9	39
55	495	113.5	114	100	185	52.0	52
60	570	150.6	151	110	220	73.6	74
65	645	192.8	193	120	250	95.0	95
70	730	246.9	247	130	285	123.4	124
75	820	311.6	312				
80	910	383.7	384				

*Rate of vertical curvature, K, is the length of curve per percent algebraic difference in intersecting grades (A): $K = L/A$.

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

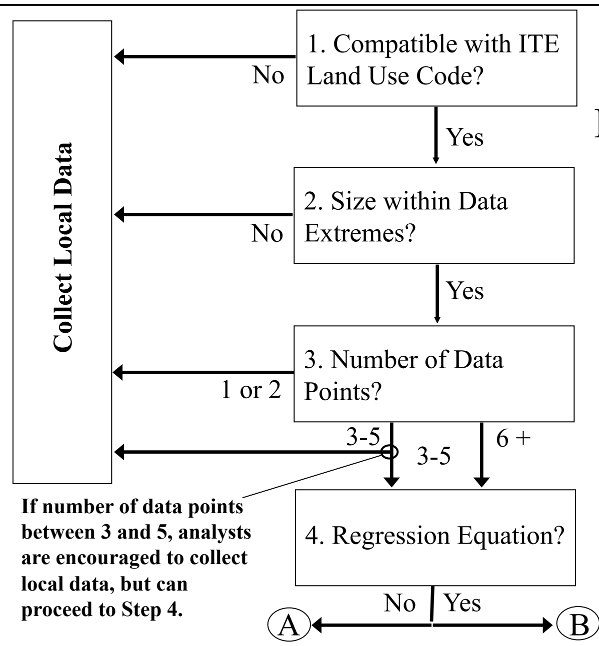
Table 3.3 Design Controls for Sag Vertical Curves Based on Stopping Sight Distance

U.S. Customary				Metric			
Design speed (mi/h)	Stopping sight distance (ft)	Rate of vertical curvature, K^*		Design speed (km/h)	Stopping sight distance (m)	Rate of vertical curvature, K^*	
		Calculated	Design			Calculated	Design
15	80	9.4	10	20	20	2.1	3
20	115	16.5	17	30	35	5.1	6
25	155	25.5	26	40	50	8.5	9
30	200	36.4	37	50	65	12.2	13
35	250	49.0	49	60	85	17.3	18
40	305	63.4	64	70	105	22.6	23
45	360	78.1	79	80	130	29.4	30
50	425	95.7	96	90	160	37.6	38
55	495	114.9	115	100	185	44.6	45
60	570	135.7	136	110	220	54.4	55
65	645	156.5	157	120	250	62.8	63
70	730	180.3	181	130	285	72.7	73
75	820	205.6	206				
80	910	231.0	231				

*Rate of vertical curvature, K, is the length of curve per percent algebraic difference in intersecting grades (A): $K = L/A$.

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

Selection of ITE Rates/Equations, or Collection of Local Data



Source: ITE *Trip Generation Handbook*, 2nd Edition

Trip Generation: Fundamentals and Applications (Module 1)

Selection of ITE Rates/ Equations, or Collection of Local Data (cont.)

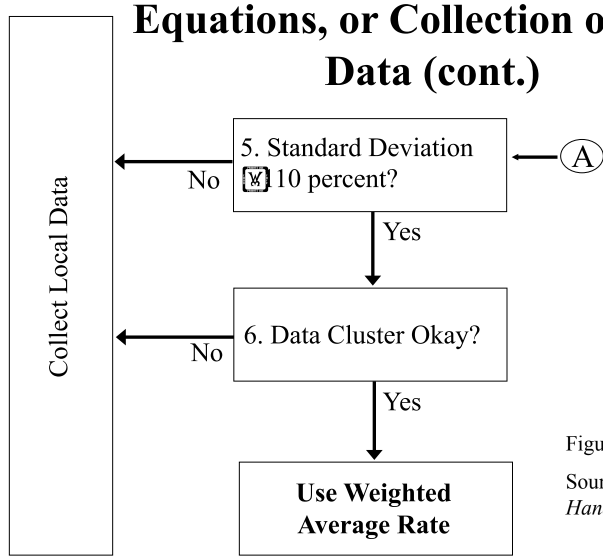
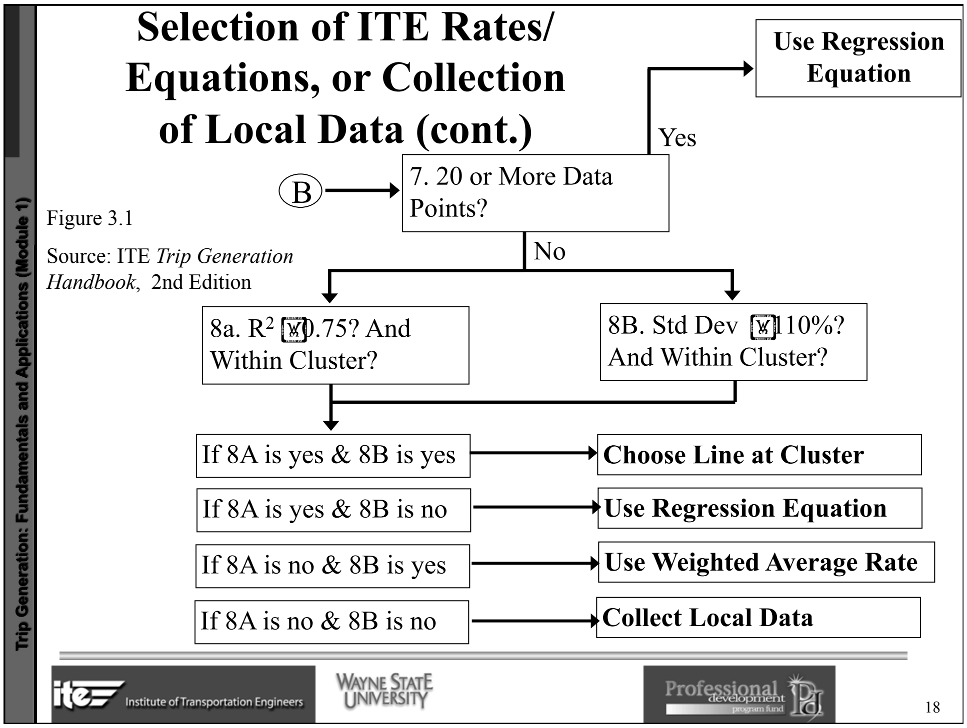


Figure 3.1

Source: ITE *Trip Generation Handbook*, 2nd Edition


Selection of ITE Rates/ Equations, or Collection of Local Data (cont.)
Figure 3.1
Source: ITE *Trip Generation Handbook*, 2nd Edition
B
7. 20 or More Data Points?
Yes
Use Regression Equation
No
8a. R^2 ≥0.75? And Within Cluster?
8B. Std Dev ≤110%? And Within Cluster?
If 8A is yes & 8B is yes
Choose Line at Cluster
If 8A is yes & 8B is no
Use Regression Equation
If 8A is no & 8B is yes
Use Weighted Average Rate
If 8A is no & 8B is no
Collect Local Data
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