Equations: Quiz 1

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

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

TRANSPORTATION

Stopping Sight Distance

U.S. Customary Units Equation

$$S = \frac{V^2}{30[(a/32.2) \pm G]} + 1.47Vt \qquad \text{(Practical SSD)}$$

Metric Equation:

$$S = \frac{V^2}{254[(a/9.81) \pm G]} + 0.278Vt,$$

where (as appropriate):

S = stopping sight distance (ft or m),
G = percent grade divided by 100,
V = design speed (mph or km/h),
a = deceleration rate (ft/s^2 or m/s^2),
= 11.2 ft/s^2 = 3.4 m/s^2 and
t = driver reaction time (s).

Sight Distance Related to Curve Length

a. Crest Vertical Curve (general equations):

$$L = \frac{AS^2}{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2} \qquad \text{for } S \le L$$

$$L = 2S - \frac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A} \qquad \text{for } S > L$$

where

L = length of vertical curve (ft or m),
A = algebraic difference in grades (%),
S = sight distance for stopping or passing, (ft or m),
h_1 = height of drivers' eyes above the roadway surface (ft or m), and
h_2 = height of object above the roadway surface (ft or m).

U.S. Customary Units:

When $h_1 = 3.50$ ft and $h_2 = 2.0$ ft,

$$L = \frac{AS^2}{2{,}158} \qquad \text{for } S \le L$$

$$L = 2S - \frac{2{,}158}{A} \qquad \text{for } S > L$$

Metric Units:

When $h_1 = 1{,}080$ mm and $h_2 = 600$ mm,

$$L = \frac{AS^2}{658} \qquad \text{for } S \le L$$

$$L = 2S - \frac{658}{A} \qquad \text{for } S > L$$

b. Sag Vertical Curve (based on standard headlight criteria):

U.S. Customary Units

$$L = \frac{AS^2}{400 + 3.5\,S} \qquad \text{for } S \le L$$

$$L = 2S - \frac{400 + 3.5\,A}{A} \qquad \text{for } S > L$$

Metric Units

$$L = \frac{AS^2}{120 + 3.5\,S} \qquad \text{for } S \le L$$

$$L = 2S - \frac{120 + 3.5\,A}{A} \qquad \text{for } S > L$$

c. Sag Vertical Curve (based on adequate sight distance under an overhead structure to see an object beyond a sag vertical curve)

$$L = \frac{AS^2}{800}\left(C - \frac{h_1 + h_2}{2}\right)^{-1} \qquad \text{for } S \le L$$

$$L = 2S - \frac{800}{A}\left(C - \frac{h_1 + h_2}{2}\right) \qquad \text{for } S > L$$

where

C = vertical clearance for overhead structure (underpass) located within 200 ft (60 m) of the midpoint of the curve (ft or m).

d. Sag Vertical Curve (based on riding comfort):

U.S. Customary Units

$$L = \frac{AV^2}{46.5},$$

Metric Units

$$L = \frac{AV^2}{395},$$

where (as appropriate):

L = length of vertical curve (ft or m),
V = design speed (mph or km/hr), and
A = algebraic difference in grades (%)

e. Horizontal curve (to see around obstruction):

$$M = R\left[1 - \cos\left(\frac{28.65\,S}{R}\right)\right]$$

where

R = radius (ft or m)
M = middle ordinate (ft or m),
S = stopping sight distance (ft or m).

Superelevation of Horizontal Curves

a. Highways:

U.S. Customary Units:

$$\frac{e}{100} + f = \frac{V^2}{15R}$$

Metric Units:

$$\frac{e}{100} + f = \frac{V^2}{127R}$$

where (as appropriate):

e = superelevation (%),
f = side-friction factor,
V = vehicle speed (mph or km/hr), and
R = radius of curve (ft or m).

b. Railroads:

$$E = \frac{Gv^2}{gR}$$

where

E = equilibrium elevation of outer rail (in.),
G = effective gage (center-to-center of rails) (in.),
v = train speed (ft/s),
g = acceleration of gravity (ft/s²), and
R = radius of curve (ft).

Table 2.4 Typical Values of Coefficients of Road Adhesion

	Coefficient of road adhesion	
Pavement	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

Table 3.1 Stopping Sight Distance

U.S. Customary				
Design speed (mi/h)	Brake reaction distance (ft)	Braking distance on level (ft)	Stopping sight distance: Calculated (ft)	Stopping sight distance: Design (ft)
15	55.1	21.6	76.7	80
20	73.5	38.4	111.9	115
25	91.9	60.0	151.9	155
30	110.3	86.4	196.7	200
35	128.6	117.6	246.2	250
40	147.0	153.6	300.6	305
45	165.4	194.4	359.8	360
50	183.8	240.0	423.8	425
55	202.1	290.3	492.4	495
60	220.5	345.5	566.0	570
65	238.9	405.5	644.4	645
70	257.3	470.3	727.6	730
75	275.6	539.9	815.5	820
80	294.0	614.3	908.3	910

Metric				
Design speed (km/h)	Brake reaction distance (m)	Braking distance on level (m)	Stopping sight distance: Calculated (m)	Stopping sight distance: Design (m)
20	13.9	4.6	18.5	20
30	20.9	10.3	31.2	35
40	27.8	18.4	46.2	50
50	34.8	28.7	63.5	65
60	41.7	41.3	83.0	85
70	48.7	56.2	104.9	105
80	55.6	73.4	129.0	130
90	62.6	92.9	155.5	160
100	69.5	114.7	184.2	185
110	76.5	138.8	215.3	220
120	83.4	165.2	248.6	250
130	90.4	193.8	284.2	285

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.

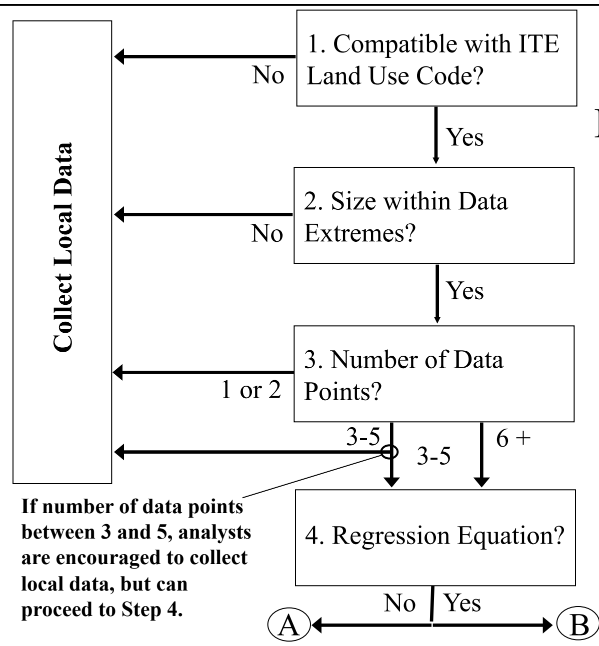
Table 3.3 Design Controls for Sag Vertical Curves Based on Stopping Sight Distance

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

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

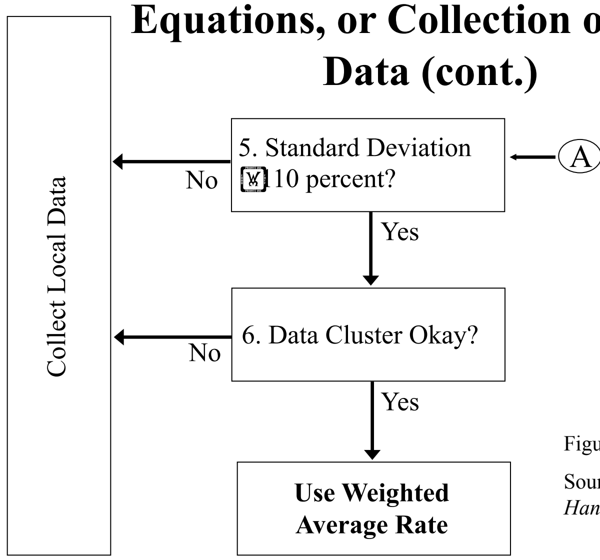
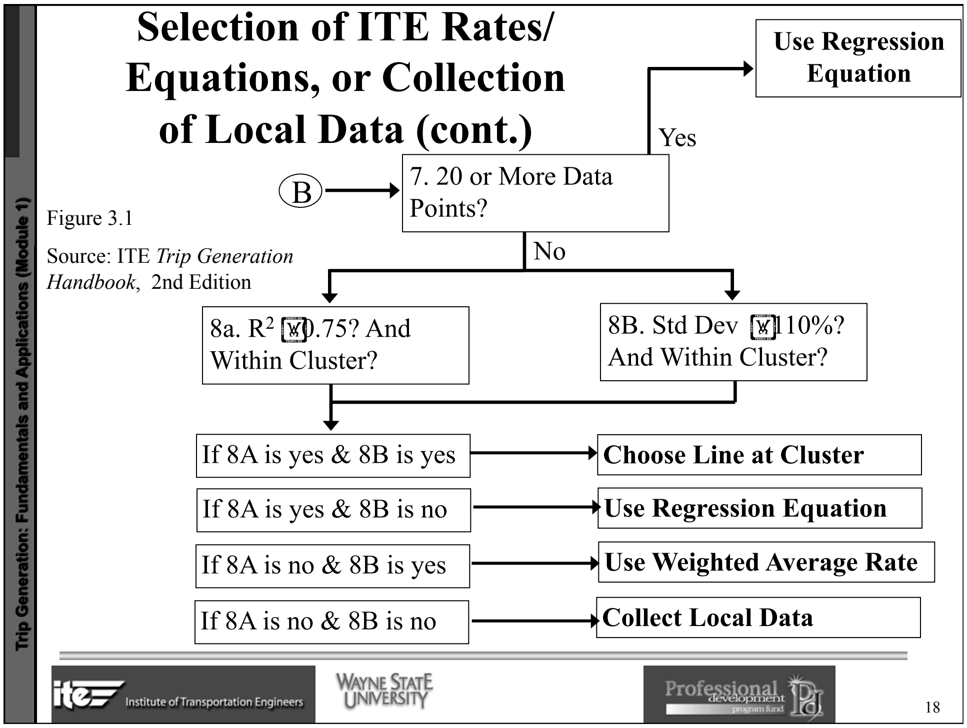


Figure 3.1

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. R2 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
Trip Generation: Fundamentals and Applications (Module 1)
Institute of Transportation Engineers
Wayne State University
Professional development program fund
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