THE NATIONAL COUNCIL OF EXAMINERS FOR ENGINEERING AND SURVEYING
PRINCIPLES AND PRACTICE OF ENGINEERING EXAMINATION

TRANSPORTATION DESIGN STANDARDS

EFFECTIVE with the October 2005 Examination

ABBREVIATION DESIGN STANDARD TITLE

AASHTO *A Policy on Geometric Design of Highways and Streets,* 2001 Edition (4th Edition), American Association of State Highway & Transportation Officials, Washington, DC

ABBREVIATION DESIGN STANDARD TTTLE
AASHTO A policy on Geometric Design of Highways and Streets, 2001 Edition, American Association of State Highway and Transportation Officials, Washington, DC

AASHTO *Design of Pavement Structures,* 1993 Edition, American Association of State Highway & Transportation Officials, Washington, DC

AASHTO *Roadside Design Guide,* 2002 Edition, American Association of State Highway & Transportation Officials, Washington, DC

AI *The Asphalt Handbook (MS-4),* 1989 Edition, Asphalt Institute, College Park, MD

HCM *Highway Capacity Manual (HCM 2000)*, 2000 Edition, Transportation Research Board—National Research Council, Washington, DC

MUTCD *Manual on Uniform Traffic Control Devices,* 2003, US Department of

Transportation—Federal Highway Administration, Washington, DC

PCA *Design and Control of Concrete Mixtures,* 2002, Fourteenth Edition, Portland Cement Association, Skokie, IL

ITE *Traffic Engineering Handbook,* 1999, Fifth Edition, Institute of Transportation Engineers, Washington, DC
Transportation

Capacity and LOS Analysis – Freeway, Highway, Intersections

Freeway (summary worksheet on page 23-16 of HCM, 2000)

$V = v_p * \mathbf{PHF} * N * f_{HV} * f_p$ (Eq 23-2 on Page 23-7 HCM,2000)

- v_p = 15-minute passenger car equivalent flow rate per lane (pcphpl)
- V = hourly volume (vph)
- PHF = peak hour factor
- N = number of lanes in each direction
- f_{HV} = heavy – vehicle adjustment factor (use eq.23-3 on page 23-8 of HCM,2000 factors from Exhibit 23-9 and 23-10 or 23-11 depending on given grade information)
- f_p = driver population factor (0.85 to 1.0)

$FFS = FFS_i - f_{LW} - f_{LC} - f_N - f_{ID}$ (Eq 23-1 on Page 23-4 HCM, 2000)

- FFS = estimated free-flow speed
- FFS_i = ideal free-flow speed, 70-75 mph
- f_{LW} = adjustment for lane width (Exhibit 23-4, page 23-6)
- f_{LC} = adjustment for right shoulder clearance (Exhibit 23-5 page 23-6)
- f_N = adjustment for number of lanes (Exhibit 23-6 on page 23-6)
- f_{ID} = adjustment for interchange density (Exhibit 23-7 on page 23-7)

Determining Freeway Level of Service procedure (Exhibit 23-1,Page 23-2, HCM,2000)

Multilane Highways (page 12-1 through 12-10 of HCM, 2000)

$V = v_p * PHF * N * f_{HV}$ (Eq 21-3 on Page 21-7 HCM, 2000)

v_p = 15-minute passenger car equivalent flow rate per lane (pcphpl)
V = hourly volume (vph)
PHF = peak hour factor
N = number of lanes in each direction
f_{HV} = heavy-vehicle adjustment factor (use eq. 21-4 on page 21-7 of HCM, 2000 factors from Exhibit 21-8,21-9,21-10 or 21-11depending on given grade information)

$FFS = FFS_I - f_M - f_{LW} - f_{LC} - f_A$ (Eq 21-1 on Page 21-5 HCM,2000)

FFS = estimated free-flow speed
FFS = ideal free-flow speed
f_M = adjustment for median type (Exhibit 21-6 on page 21-6, HCM 2000
f_{LW} = adjustment for lane width (Exhibit 21-4 on page 21-5)
f_{LC} = adjustment for lateral clearance (Exhibit 21-5 on page 21-6)
f_A = adjustment for access points (Exhibit 21-7 on page 21-7)

Determining Multilane Highways Level of Service procedure (Exhibit 21-1, HCM,2000)

Two-Lane Highways (page 12-11 through 12-19 of HCM 2000)

The methodology to compute LOS for a two-lane highway is given in Exhibit 20-1, p.20-2 of HCM 2000

$FFS = BFFS - f_{LS} - f_A$ (eq.20-2, p. 20-5 , HCM 2000)

FFS = estimated free flow speed
BFFS = base free flow speed or ideal free flow speed
f_{LS} = adjustment for lane width and shoulder width (Exhibit 20-5, p.20-6)
f_A = adjustment for access points (Exhibit 20-6)

$$v_p = \frac{V}{PHF * f_G * f_{HV}}$$ (eq.20-3, 20-6, HCM 2000)

v_p = 15-minute passenger car equivalent flow rate per lane (pcphpl)
V = demand hourly volume (vph)
PHF = peak hour factor
f_G = grade adjustment factor (exhibit 20-7 or 20-8 depending on the flow characteristic being computed)
f_{HV} = heavy-vehicle adjustment factor (use equ.20-4, page 20-8 and Exhibits 20-9, 20-10, 20-15, 20-16, 20-17, or 20-18 depending on the grade and its purpose)

$ATS = FFS - 0.00776 v_p - f_{np}$

ATS = average travel speed for both directions of travel combined (mi/h)
FFS = free flow speed
v_p = passenger-car equivalent flow rate for peak 15-min period (pc/h)
f_{np} = adjustment for percentage of no passing zones (Exhibit 20-11)

$PTSF = BPTSF + f_{d/np}$
PTSF = percent time spent following
BPTSF = base percent time spent following for both directions of travel combined
$f_{d/np}$ = adjustment for the combined effect of the directional distribution of traffic and of the percentage of no passing zones on the percent time spent following, Exhibit 20-12, p. 20-11, HCM 2000
BPTSF $= 100(1 - e^{-0.000879 * v_p})$

Traffic Control Devices, Signal Timing

Signal Timing (see also Appendix B Chapter 16, HCM 2000)

Cycle length

$$C_o = \frac{1.5L + 5}{1 - \sum Y_i}$$

C_o	= optimal cycle length, seconds
L	= total lost time per cycle, seconds
Y_i	= maximum value of ratios of approach flows to saturation flows for all traffic streams using phase i, (V_i/s_i)
ϕ	= number of phases
V_i	= flow during phase i
S_i	= saturation flow
Y_i	= V_i/S_i
L	= $\Sigma 1_i + R$
1_i	≈3.5 sec per phase
R	≈1 sec

Amber Time

$$\tau_{min} = \delta + \frac{(W + L)}{u_0} + \frac{u_0}{2(a + Gg)}$$

τ_{min}	= minimum amber or yellow interval to eliminate a dilemma zone
δ	= perception reaction time (seconds), usually 1 second in this case
a	= braking acceleration rate (usually about 0.27g)
G	= grade of the road (decimal form)
u_0	= speed limit (ft/sec)
g	= acceleration due to gravity (32.3 ft/s^2)
W	= the width of the intersection (feet)
L	= the length of the design vehicle (feet)

Saturation

$s = s_o\ N\ f_W\ f_{HV}\ f_g\ f_P\ f_{bb}\ f_a\ f_{LU}\ f_{RT}\ f_{LT} f_{Lpb} f_{Rpb}$

s	= saturation flow for the lane group, vphg
s_0	= base saturation rate per lane, usually 1900 pcphpl
N	= number of lanes in analysis group
f_w	= adjustment factor for lane width (Exhibit 16-7 on page 16-11, 2000 HCM)
f_{HV}	= Heavy vehicle factor (Exhibit 16-7 on page 16-11, HCM 2000)
f_g	= grade factor (Exhibit 16-7 on page 16-11, HCM 2000)
f_p	= parking factor (Exhibit 16-7 on page 16-11, HCM 2000)
f_{bb}	= bus blockage factor (Exhibit 16-7 on page 16-11, HCM 2000)
f_a	= area factor (Exhibit 16-7 on page 16-11, HCM 2000)
f_{LU}	= Lane utilization factor (Exhibit 16-7 on page 16-11, HCM 2000)
f_{RT}	= right turn factor (Exhibit 16-7 on page 16-11, HCM 2000)
f_{LT}	= left turn factor (Exhibit 16-7 on page 16-11, HCM 2000)
f_{Lpb}	= pedestrian adjustment factor for left turn movements (Exhibit 16-7 on page 16-11, HCM 2000)
f_{Rpb}	= pedestrian adjustment factor for right turn movements (Exhibit 16-7 on page 16-11, HCM 2000)

Degree of Saturation

$X_i = (v/c)_i = v_i/(s_i g_i/C) = v_i C/(s_i g_i)$ (eq. 16-7, p.16-14, HCM 2000)

X_i	= $(v/c)_i$ = ration for lane group i,
v_i	= actual or projected demand flow rate for lane group i, vphg
gi	= effective green time for lane group i, seconds
C	= cycle length in seconds

Capacity

$c_i = s_i *(g_i/C)$ (eq.16-6, p. 16-14, HCM 2000)

c_i	= capacity of lane group i, vph
s_i	= saturation flow rate for lane group i, vphg
g_i	= effective green time for lane group i, seconds
C	= cycle length in seconds

g_i/C = effective green ratio for group i

g_i = $G_i + Y_i - t_L$

Volumes & Peak Hour Factors

- **Convert speed from mph to feet, multiply by 1.47**
- **PHF = Peak Hour Factor represents a measure of the worst 15-minutes during the peak**

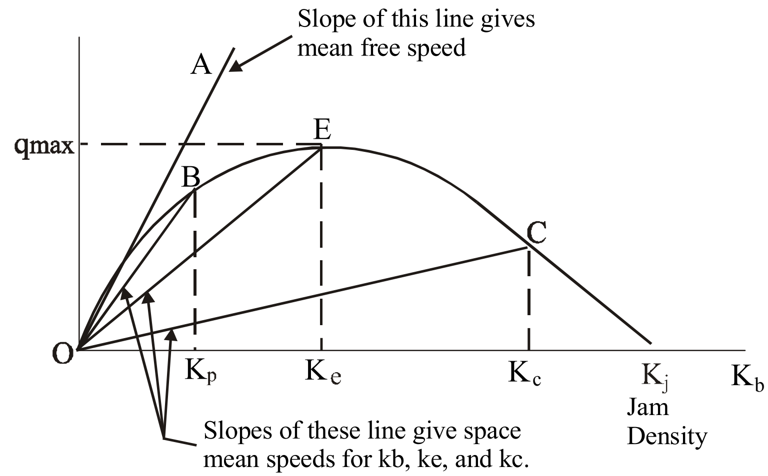
(Theoretical range from 0.25 to 1.0)

$$PHF = \frac{\text{Volume during peak hour}}{\text{4*volume during the peak 15-minute within the peak hour}}$$

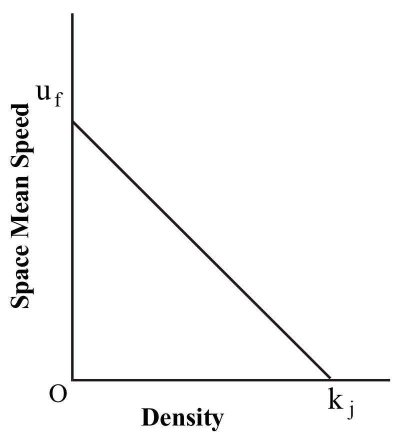
DHV **= Design Hour Volume represents the worst 15-minutes flows during the peak hour converted into hourly volume**

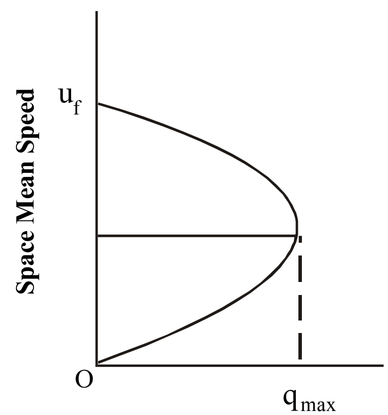
$$VHV = \frac{\text{Volume during peak hour}}{\text{PHF}}$$

Fundamental Diagrams of Traffic Flow



(a) Flow versus density





(b) Space mean speed versus density (c) Space mean speed versus volume

Traffic Flow Theory – Speed-flow-density, shock wave, gap acceptance, queuing

Speed Flow-Density

Macroscopic Approach (Greenshield's model)

$$q_{\max} = \frac{k_1 u_f}{4} = u_0 k_0 \qquad k_o = \frac{k_j}{2} \qquad u_o = \frac{u_f}{2}$$

$$q = u_f k - \frac{u_f k^2}{k_j} \qquad h_t = 1/q = headway \qquad h_d = 1/k = gap$$

$$u_s = u_f - \frac{u_f k}{k_j} \qquad u_s^2 = u_f u_s - \frac{u_f q}{k_j}$$

q	=	flow (vehicles per hour)	u	=	speed (miles per hour)
q_{max}	=	flow (vehicles per hour)	u_o	=	optimum speed (miles per hour)
k	=	density (vehicles per mile)	u_f	=	free speed (miles per hour)
k_o	=	optimum density (vehicles per mile)	h_d	=	gap (feet)
k_j	=	jam density (vehicles per mile)	h_t	=	headway (seconds)

Shock Waves

$$u_w = \frac{q_2 - q_1}{k_2 - k_1}$$

u_w	= speed of the shock wave
q_2	= flow downstream of the bottleneck
q_1	= flow upstream of the bottleneck
k_2	= density downstream of the bottleneck
k_1	= density upstream of the bottleneck

Accidents

Intersection Accident rates

RMEV = $\frac{A*1,000,000}{VMT}$

RMEV = Rate per million of entering vehicles;
A = accidents (total or by type) occurring in 1 year at that location
V = Average daily traffic (ADT * 365 days)

Roadway Sections Accident rates

RMVM = $\frac{A*100,000,000}{V}$

RMVM = Rate per 100 million vehicle miles;
A = accidents (total or by type) occurring at that location during a given period
VMT = total vehicle miles traveled during that given period (ADT* day in study * length of road)

Expected Accident Values

The reduced accidents are equal to the related accidents (RA) multiplied by the accident reduction factor (AR)

AR = the accident reduction factor; RA = the related accidents
$AR = AR_1+(1-AR_1)AR_2+(1-AR_1)(1-AR_2)AR_3+(1-AR_1)(1-AR_2)(1-AR_3)AR_4$
Reduced Accidents = RA (AR)

Photogrammetry

The relationship governing aerial photogrammetry that is required is given by:

$$S = \frac{f}{H - h}$$

where S = photographic scale = 1/24,000

f = camera focal length (feet) = 5.5/12

H = aircraft height (feet)

h = average elevation of terrain (feet) = 2,450

Geometric Design

Horizontal Curve Radii and Super-Elevation

Stopping Sight Distance – Reaction and Braking

$$SSD = PIEV + Braking \Rightarrow t(1.47)(u_i) + \frac{(u_1^2 - u_2^2)}{30(f \pm G)}$$

$$= PIEV + Braking \Rightarrow t(1.47)(u_i) + \frac{(u_1^2 - u_2^2)}{30(a/g \pm G)}$$

AASHTO represents f as $\frac{a}{g}$

u_i = initial speed in mph
u_f = final speed in mph
t = reaction time in seconds (usually 2.5 seconds assumed)
G = grade of road in decimal form (2% is .02)

a = recommended deceleration rate = 11.2 ft/sec^2
g = acceleration due to gravity = 32.2 ft/sec^2
(refer p.111-114, AASHTO 2001)

$$R_{min} = \frac{u^2}{15(e + f_s)}$$

R_{min} = minimum safe radius in feet

u = speed in mph

Super elevation runoff see Exhibit3-29, page 174, (AASHTO 2001)

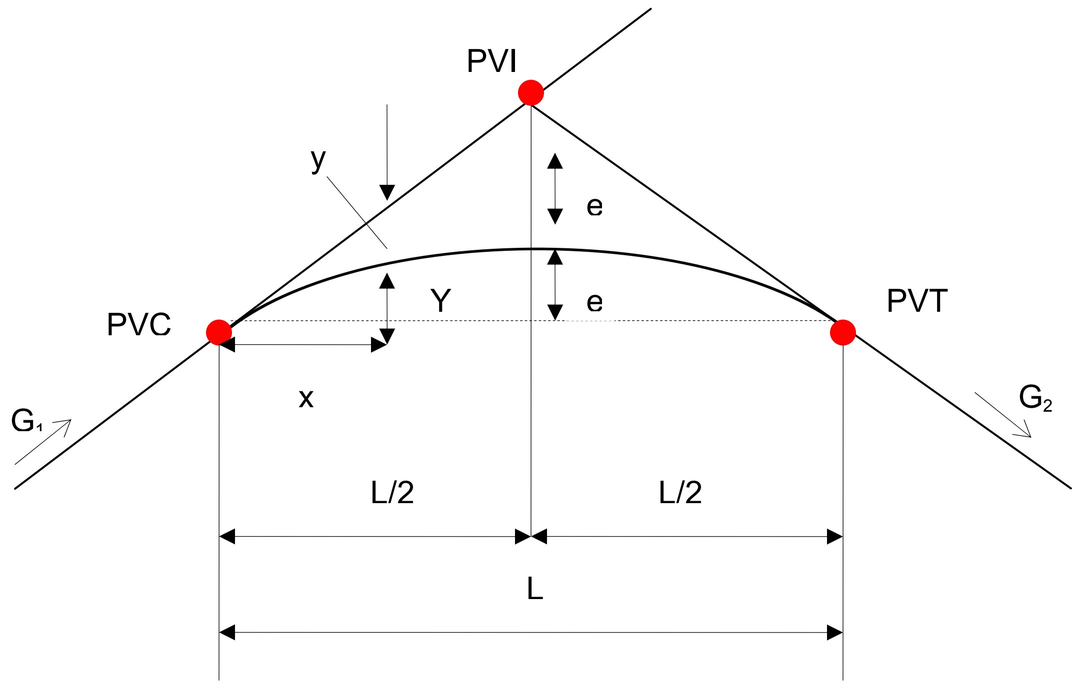
e = super elevation (ranges from 0 to 0.12)

f_s= side friction based on speed and super elevation (Exhibit 3-14 on page 145, AASHTO 2001)

PCE = Passenger Car Equivalents - a measure that converts trucks and busses into a representative passenger car value.

Vertical and Horizontal Curves, Stationing

Vertical Curves



For the simple parabolic curve, the vertical offset 'y' at any point 'x' along the curve is given by:

$$y = -\left(\frac{G_2 - G_1}{2L}\right)x^2$$

where Y = the elevation of the curve at a point x along the curve,

y, measured downward from the tangent, gives the vertical offset at any point x along the curve.

The max and min points are given by differentiating wrt x, and equating to zero:

$$\frac{dy}{dx} = \left(\frac{G_2 - G_1}{L}\right)x + G_1 = 0$$

$$x = \frac{LG_1}{G_1 - G_2} \quad and \quad y = \frac{LG_1^2}{2(G_1 - G_2)}$$

$$L_{\min} = 2S - \frac{2158}{A}$$ (S>L)

$$L_{\min} = \frac{AS^2}{2158}$$ (S<L)

OR $L_{\min} = KA$

<u>Sag</u>

$$L_{\min} = 2S - \frac{(400 + 3.5S)}{A}$$ (S>L)

$$L_{\min} = \frac{AS^2}{(400 + 3.5S)}$$ (S<L)

Appearance $L_{\min} = 100A$

Comfort $L_{\min} = \dfrac{Au^2}{46.5}$

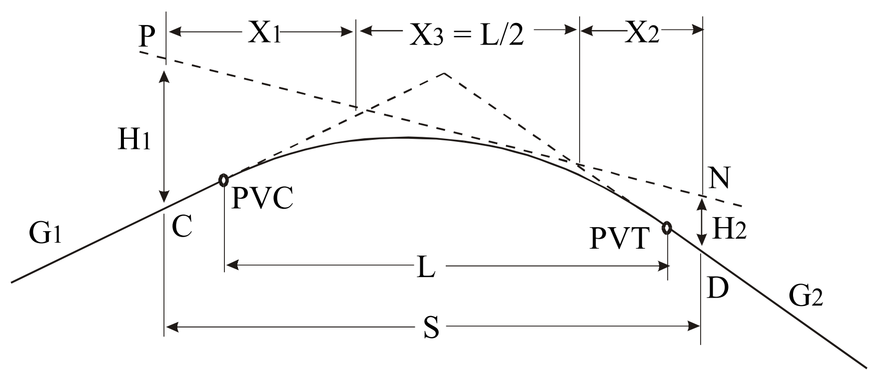
Spiral Curve $L_{\min} = \dfrac{3.15u^3}{RC}$

L_{min} = minimum length of spiral curve
R = radius in feet
S = Stopping sight distance in feet
A = Arithmetic grade difference between approach and departure tangents
u = speed in mph

C = rate of increase of centripetal acceleration, ft/sec^2 (Ranges from 1 to 3)
K = a factor for vertical curves used as an alternative to the equation.

K factors are found in the 2001 AASHTO, page 276, Exhibit 3-77 for crests and page 280 Exhibit 3-79 for sags.

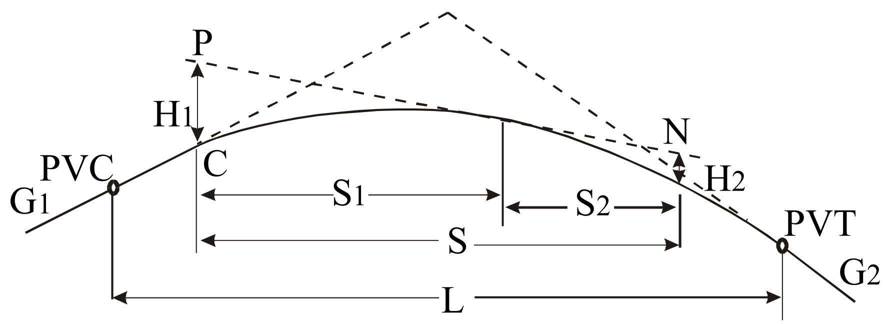
Sight Distance of Crest Vertical Curve (S<L)



L = length of vertical curve (ft)
S = sight distance (ft)
H_1 = height of eye above roadway surface (ft)
H_2 = height of object above roadway surface (ft)
G1 = slope of first tangent

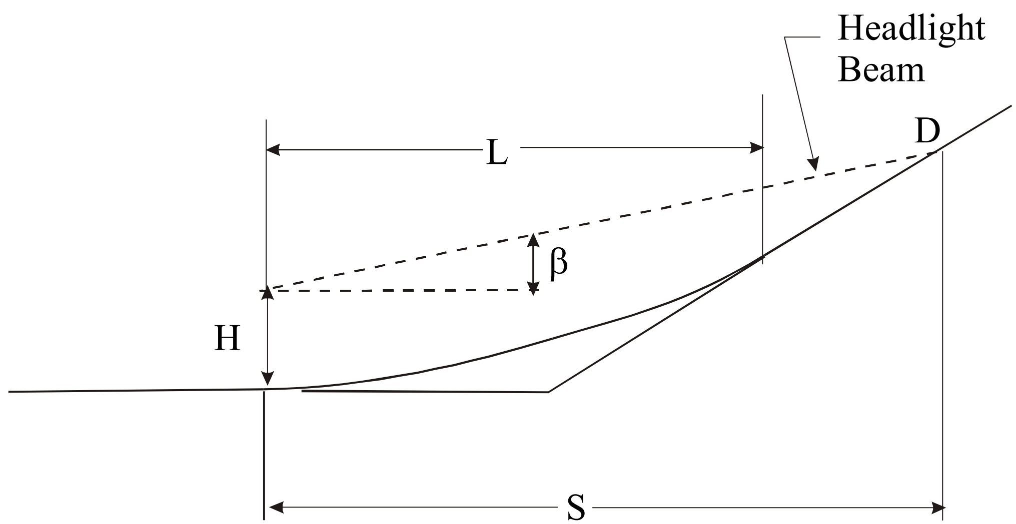
G2 = slope of second tangent
PVC = point of vertical curve
PVT = point of vertical tangent

Sight Distance of Crest Vertical Curve (S>L)



L	= length of vertical curve (ft)
S	= sight distance (ft)
H_1	= height of eye above roadway surface (ft)
H_2	= height of object above roadway surface (ft)
G_1	= slope of first tangent
G_2	= slope of second tangent
PVC	= point of vertical curve
PVT	= point of vertical tangent

Headlight Sight Distance on Sag Vertical Curves (S>L)



Vertical Curve Stationing

BVC = PVI – ½ L
EVC = PVI + ½ L

$$Y = \frac{A}{200L} x2$$

$$X_{high} = \frac{L * G_1^{\ 2}}{(G_1 - G_2)}$$

$$Y_{high} = \frac{L * G_1^2}{200 * (G_1 - G_2)}$$

Horizontal Curve

R = 5729.6/D

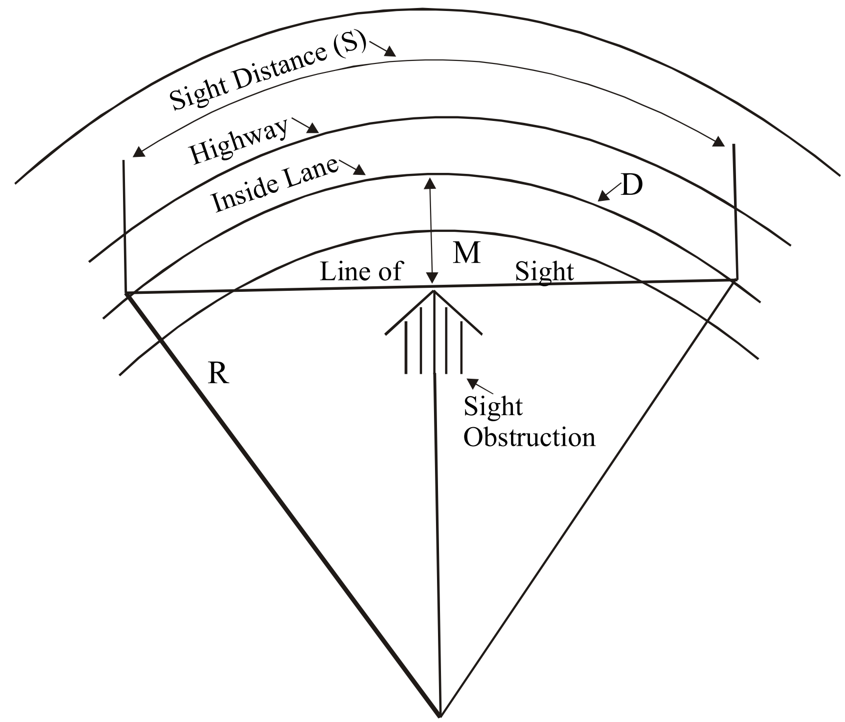
D	= Degree of Curve (angle per 100 feet)
R	= radius in feet
T	= R tan (Δ/2)
C	= 2*R*sin (Δ/2)
M	= *R* (1 – cos(Δ/2))
L	$= \frac{R\text{D}p}{180}$

Horizontal Stationing

$$1_1 = \frac{R\pi\delta_1}{180}$$

$$\frac{L_1}{d_1} = \frac{L}{D} = \frac{L_2}{d_2}$$

C_1 = 2Rsin (δ_1/2)
C_D = 2Rsin (D/2)
C_2 = 2Rsin (δ_2/2)



$$M = \frac{5730}{D} \quad \frac{(1 - C\text{os } SD)}{200}$$

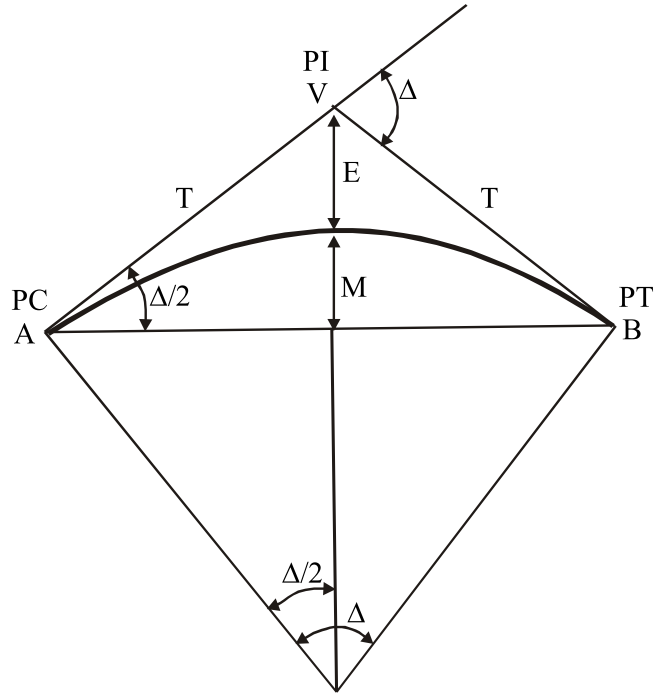
$$R = \frac{5730}{D} \text{ and } \theta = \frac{SD}{200}$$

$$M = R(1 - \cos\theta)$$

$$M = R\left[1 - Cos\frac{28.65S}{R}\right]$$

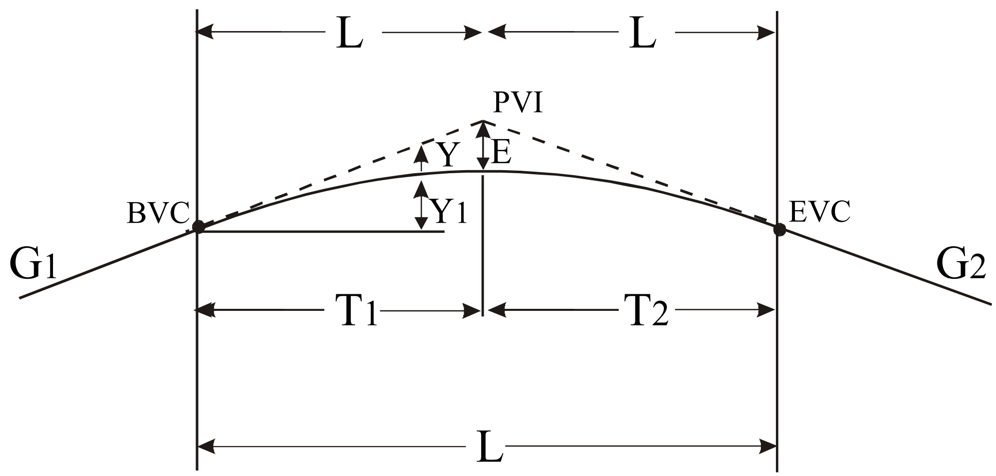
where
S = Stopping Sight Distance (ft)
D = Degree of Curve
M = Middle Ordinate (ft)
R = Radius (ft)

Layout of a Simple Horizontal Curve



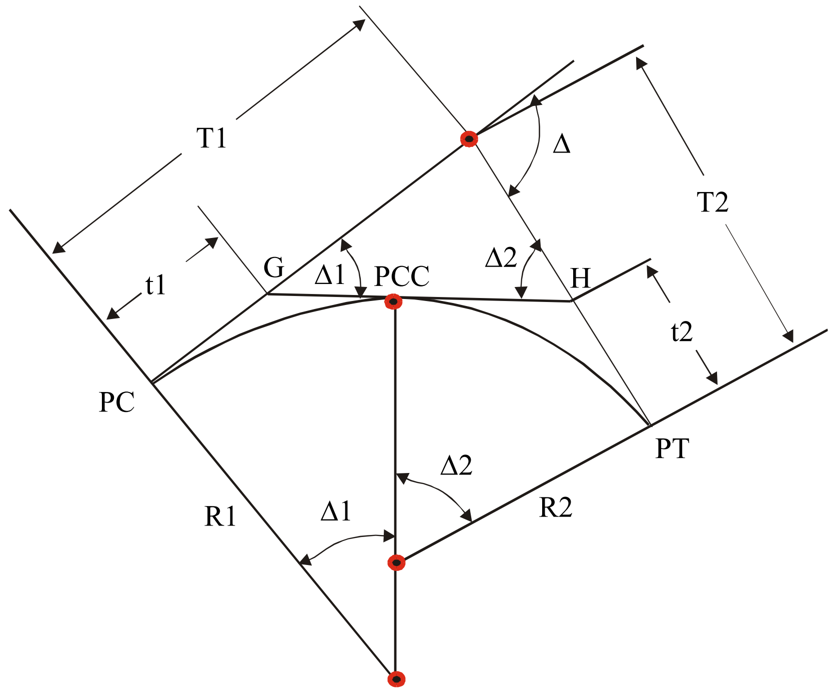
R = radius of circular curve
T = tangent length
Δ = deflection angle
M = middle ordinate
PC = point of curve
PT = point of tangent
PI = point of intersection
E = external distance

Layout of a Crest Vertical Curve for Design



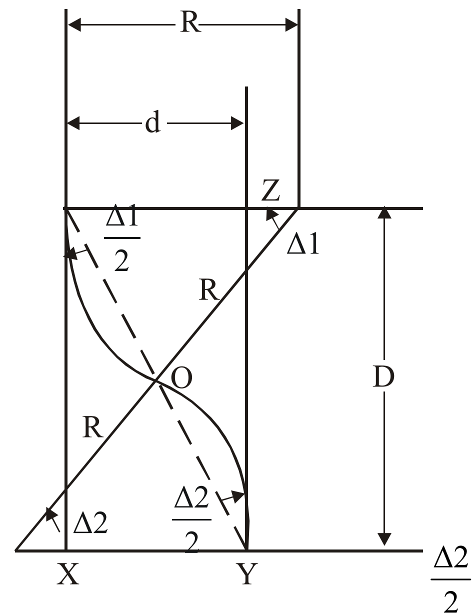
PVI = point of vertical intersection
BVC = beginning of vertical curve (same point as PVT)
E = external distance
G_1, G_2 = grades of tangents (%)
L = length of curve
A = algebraic difference of grades, $G_1 - G_2$

Layout of a Compound Curve



R_1, R_2 = radii of simple curves forming compound curve
Δ_1, Δ_2 = deflection angles of simple curves
Δ = deflection angle of compound curve
t_1, t_2 = tangent lengths of simple curves
T_1, T_2 = tangent lengths of compound curve
PCC = point of compound curve
PI = point of intersection
PC = point of curve
PT = point of tangent

Geometry of a Reverse Curve with Parallel Tangents



R = radius of simple curves
Δ_1, Δ_2 = deflection angle of simple curves
d = distance between parallel tangents
D = distance between tangent points

Transportation Planning

Planning Directional Traffic

DDHV = AADT*K*D; DDHV = Directional Design-Hour Volume

AADT = Average Annual Daily Traffic
K = proportion of AADT during peak hour, (range from 0.08 to 0.12 in urban areas)
D = directional percentage in peak hour for the peak direction

Earthworks & the Mass-haul diagram

$$V = \frac{L(A_1 + A_2)}{54}$$ End Area Method

Most common method and likely to be on the PE

Pyramidal Method

$$V = \frac{L(area\ of\ base * length)}{6}$$

For more accuracy than the end area method

V = Volume (ft^2)
A_1 and A_2 = end areas (ft^2)
A_m = middle area determined by averaging linear dimensions of end sections (ft^2)

Parking

Space Hours of Demand

$D = \Sigma n_i t_i$

D = space hours demand for a specific time period
t_i = midparking duration of the ith class
n_i = number of vehicles parked for the ith duration range

Space Hours of Supply

$S = f\Sigma t_i$

S = space hours supply for a specfic time period
t_i = legal parking duration in hours for the space
f = efficiency factor

Geotechnics

Soil Properties

Property	symbol	units
moisture content	w	%
bulk density	γ	pounds per cubic foot
submerged density	γ^1	pound per cubic foot
dry density	γ_d	pounds per cubic foot
unit weight of water	γ_w	pounds per cubic foot
saturated density	γ_{sat}	pounds per cubic foot
specific gravity	Gs	dimenstionless
soil volulme	V	cubic feet
volume of voids	Vv	cubic feet
volume of air	Va	cubic feet
volume of water	Vw	cubic feet
volume of solids	Vs	cubic feet
soil weight	W	pounds
weight of water	W_w	pounds
weight of solids	W_s	pounds
	W	$= W_w + W_s$
	w	$= (W_w/W_S) * 100$
	γ_w	$= W_w/V_w$
	$(G_s * \gamma_w)$	$= W_s/V_s$
	e	$= V_v/V_s$
	n	$= V_v/V = V_v/(V_v + V_s)$
	y	$= W/V$
	γ_d	$= W_s/V$
	γ_d	$= y/(1+w)$
	γ_{sat}	$= Y_d + n\ y_w$

Vertical Stress

$\Delta p_{av} = 1/6(\Delta p_A + 4p_B + \Delta p_C)$

Permeability

Darcy's law – Aquifer Flow
$q = kiA$

- q = the flow (gal/min)
- k = coefficient of permeability (ft/day)
- i = hydraulic gradient
- A = cross–sectional area (ft^2)

Darcy's Law states that the permeability of a soil is given by:
$k = 1/Ai$
The permeability of a soil stratum overlying an impermeable layer is given by:

$$k = \frac{qx \log_e(r_2 / r_1)}{\pi(h_1^2 - h_2^1)}$$

where

- q = steady state well discharge; r_1 = distance to first observation well
- h_1 = piezometric height above impermeable layer, at observation hole (1)
- h_2 = piezometric height above impermeable layer, at observation hole (2)

The AASHTO Soil Classification System

Group Index empirical formula:

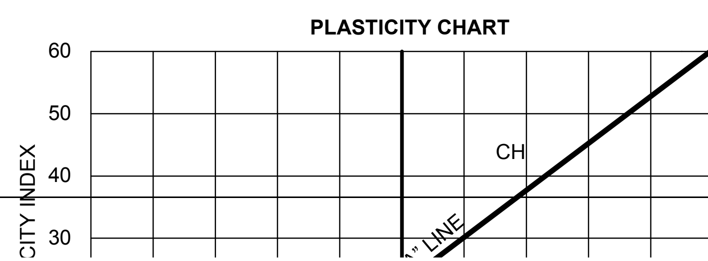
GI = (F – 35)[0.2 + 0.005(LL – 40)] + 0.01 (F – 15)(PI – 10)

where

GI = Group Index; F = % soil passing the #200 (0.075mm) sieve; LL & PI are the Liquid Limit and Plasticity Indices expressed as integers.

Unified soil classification system (ASTM D-2487)

Major Divisions			Group Symbols		Typical Names	Laboratory Classification Criteria			
Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW		Well-graded gravels, gravel-sand mixtures, little or no fines	Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No 200 sieve size), coarse-grained soils are classified as follows	Less than 5 percent GW,G{,SW, SP More than 12 percent GM, GC, SM, SC 5 to 12 percent *Borderline* cases requiring dual symbols[b]	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_u = \frac{(D_{30})^2}{D_{10} x D_{60}}$ between 1 and 3	
			GP		Poorly graded gravels, gravel-sand mixtures, little or no fines			Not meeting all gradiation requirements for GW	
		Gravels with fines (appreciable amount	GM^2	d	Silty gravels, gravel-sand mixtures			Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are *borderline* cases requiring use of dueal symbols
				u					
			GC		Clayey gravels, gravel-sand-clay mixtures.			Atterberg limits below "A" line with PI greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW		Well-graded sands, gravelly sands, little or no fines			Not meeting all gradation requirements for SW	
			SP		Poorly graded sand, gravelly sands, little or no fines			$C_u = \frac{D_{60}}{D_{10}}$ greater than 6 $C_u = \frac{(D_{30})}{D_{10} x D_{60}}$ between 1 and 3	
		Sands with fines (Appreciable amount of fines)	SM[a]	d	Silty sands, sand-silt mixtures			Not meeting all gradation requirements for SW	
				u					
			SC		Clayey sands, sand-clay mixtures			Atterberg limits above "A" line or PI less than 4	Limits plotting in hatched zone with PI between 4 and 7 are *borderline* cases requiring use of dual symbols.
								Atterberg limits above "A"line with PI greater than 7	
Fine-grained soils (More than half material is smaller than No. 200 sieve)	Silts and clays (Li1uid limit less than 50)		ML		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity				
			CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays				



		OL	Organic silts and organic silty clays of low plasticity	
	Silts and clays (Liquid limit greater than 50)	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	
		CH	Inorganic clays of medium to high plasticity, organic silts	
		OH	Organic clays of medium to high plasticity, organic silts	
	Hightly organic soils	Pt	Peat and other highly organic soils	

[a] Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is bases on Atterberg limits; suffix d used when LL is 28 or less and the PI is 6 or less; the suffix u used when LL is greater than 28.
[b] Borderline classification, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example GW-GC, well graded gravel- sand mixture with clay binder

Coulomb's Equation

$\tau = c + \sigma \tan\phi$

where

τ = shear stress, in lb/in^2
c = cohesion, in lb/in^2
σ = normal stress, in lb/in^2
ϕ = friction angle, in degrees

Triaxial Stress Tests

The normal and shear stress on a plane of any angle can be found as:

$$\sigma_\theta = \frac{1}{2}(\sigma_A + \sigma_R) + \frac{1}{2}(\sigma_A - \sigma_R)\cos 2\theta$$

$$\tau_\theta = +\frac{1}{2}(\sigma_A - \sigma_R)\sin 2\theta$$

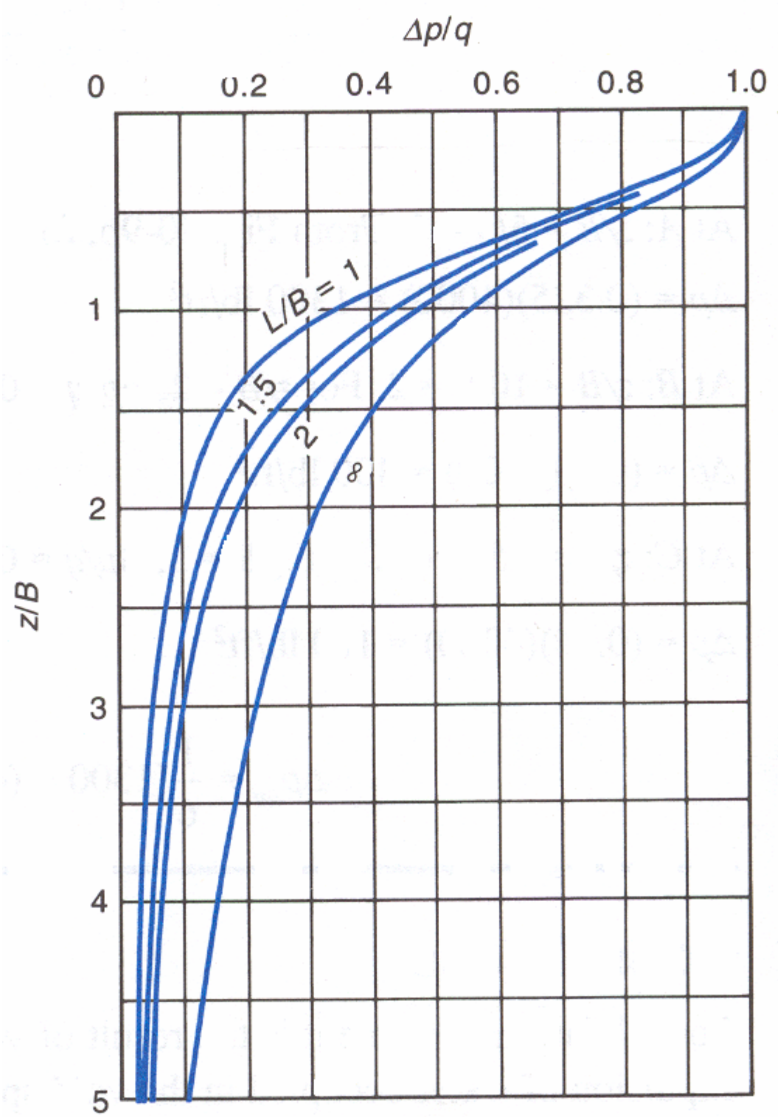
The plane of failure is inclined at the angle $\theta = 45^\circ + \frac{1}{2}\phi$ obtained from Coulomb's equation.

Effective stress parameters: $S_{us} = c' + \sigma' \tan\phi'$, where c' and ϕ' are the effective stress parameters. The effective soil pressure is given by $\sigma' = \sigma - \mu$.

Boussinesq's Equation

The equation determines the increase in vertical stress (Δp) at a point A in a soil mass due to a point load (Q) on the surface which can be expressed as

$$\Delta p = \frac{3Q}{2\pi} \frac{z^3}{(r^2 + z^2)^{5/2}} \quad \text{where } r = \sqrt{x^2 + y^2}$$



An approximation to Boussinesq's equation is represented in the graph below that relates the increase in stress, Δp, below the center of a foundation, due to the distributed load q.

Consolidation Theory

Consolidation settlement is provided by the following:

$$S = \frac{CcH}{1+e_0}\log\frac{p_0+\Delta p}{p_0}$$

where

- S = settlement, in inches
- Cc = compression index (slope of e-log p plot)
- H = thickness of compressible layer
- p_0 = mean overburden pressure
- Δp = increase in pressure (usually due to fill)

For undisturbed clays (Skempton):

Cc = 0.009(LL – 10)

The time of consolidation relationship is provided by the following:

$$T_v = \frac{c_v t}{h^2}$$

where

- T_v = time factor
- c_v = coefficient of consolidation
- t = time
- h = thickness of sample clay layer

Lateral Earth Pressure

The coefficient of active pressure, K_a is provided by:

The coefficient of passive pressure, K_p is provided by:

$$K_A = \frac{1-\sin\phi}{1+\sin\phi}$$

$$K_p = \frac{1+\sin\phi}{1-\sin\phi}$$

And the total active thrust, P_A is provided by:

$P_A = \frac{1}{2} k_A \gamma H^2$

where

- K_A = coefficient of active pressure
- P_A = total active thrust
- H = height of soil retained
- ϕ = angle of friction

Active pressures are given by:

$P_A = K_A \gamma_z - 2c\sqrt{K_A}$

Passive pressure are given by:

$Pp = K_p \gamma z + 2c\sqrt{K_p}$

Water Engineering

Rational Method

Q = CIA

Q = cubic feet per second (cfs); C = coefficient of imperviousness; I = intensity of rainfall (in/hr); A = Area (acres)
1.008cfs = 1.00 acre-in/hr

C_w = weighted coefficient

$$C_w = \frac{\sum C_i A_i}{\sum A}$$

Time of concentration, Tc = L/V = distance traveled /velocity

Time of concentration is the duration of design storm length and is used to find the intensity (in/hr) from I-T-T curves for a given area.

Manning's Equation

$$Q = \frac{1.49}{n} r_H{}^{2/3} S^{1/2} A$$

n = manning roughness coefficient
A = Area of cross – section (ft2)
r_H= hydraulic radius (A/P) (1ft)
S = slope (ft/ft)
Q= flow (cfs)
v = velocity of the flow (ft/sec)

Hazen-Williams Equation

$V = k_1 C R^{0.63} S^{0.54}$, where

C = roughness coefficient
k_1 = 0.849 for SI units, and
k_1 = 1.318 for USCS units,
R = hydraulic radius (ft or m),
S = slope of energy gradeline,
= h_f/L (ft/ft or m/m), and
V = velocity (ft/s or m/s).

Values of Hazen-Williams Coefficient C

Pipe Material	C
Concrete(regardless of age)	130
Cast iron:	
New	130
5 yr old	120
20 yr old	100
Welded steel, new	120
Wood stave (regardless of age)	120
Vitrified clay	110
Riveted steel, new	110
Brick Sewers	100
Asbestos-cement	140
Plastic	150

Friction loss in open channel flow

h_f = SL

$$h_f = \frac{Ln^2v^2}{2.21(r_H)^{4/3}}$$

h_f =friction loss in feet
L =length of pipe in feet
n = manning's roughness factor
v = the flow velocity in ft/sec
r_H = the hydraulic radius
S =slope

Circular Pipe Flow

For a half-full circular pipe
Diameter, D equals 2* the depth of the water which is related by:

$D = 2d = 1.73\ (n*Q*S^{-1/2})^{3/8}$

For full pipe flow:

$D = d = 1.33\ (n*Q*S^{-1/2})^{3/8}$

<u>where:</u>

D is the diameter of the pipe, in feet
d is the flow height in the pipe, in feet
n is the roughness coefficient
Q is the flow in cfs
S is the slope

Froude Number

$$N_{FR} = \frac{v}{(gd)^{1/2}}$$

<u>where:</u>

N_{FR} is a dimensionless number
d is the flow height in feet
v is the flow velocity in ft/sec
g is the gravitational constant 32.2 ft/sec^2

Hydraulic Jumps

$$v_1^{\ 2} = \frac{gd_2(d_1 + d_2)}{2d_1}$$

$$d_1 = -1/2d_1 + \left[\frac{2v_2^2d_1^2}{g} + \frac{d_1^2}{4}\right]^{1/2} \ ; \ d_2 = -1/2d_2 + \left[\frac{2v_1^2d_1^2}{g} + \frac{d_1^2}{4}\right]^{1/2}$$

$$\Delta E = \left[d_1 + \frac{v_1^{\ 2}}{2g}\right] - \left[d_2 + \frac{v_2^{\ 2}}{2g}\right]$$

<u>where</u>

v_1 is the velocity prior to the jump in ft/sec
d_1 is the depth of the flow prior to the jump in ft
v_2 is the velocity following the jump in ft/sec
d_2 is the depth of the flow following the jump in ft
ΔE is the change in energy in feet

Rectangular Sections

$$d_c^{\,3} = \frac{Q^2}{gw^2}$$

$$d_c = 2/3\,E_c$$

$$v_c = (gd_c)^{1/2}$$

d_c is the critical flow
v_c is the critical velocity, ft/sec
E_c is the specific energy in feet
Q is the flow in cfs
w is the width in feet

Non-Uniform Sections

$$\frac{Q^2}{g} = \frac{A^3}{b}$$

where

b is the surface water width in feet
A is the cross-sectional area of the flow in ft^2
Q is the flow in cfs
g is the gravitational constant, 32.2 ft/sec2

Miscellaneous

Concrete / Asphalt

Absolute volume of aggregates = $\dfrac{\text{aggregate ratio * cement weight}}{\text{Specific gravity of fines * specific gravity of water}}$

Volume (%) = $\dfrac{\text{Weight (lb)}}{SG * SG_{water}}$

ESAL is equivalent single axle load which is defined as 18,000 lbs. It is used in road design to estimate equivalent loads applied to the surface.

ESAL total is the sum of each category of truck

ESAL = Design lane factor * % category * days per year * axles * truck factor

$ESAL_{total} = ESAL_1 + ESAL_2$

ENGINEERING ECONOMICS

Factor Name	Converts	Symbol	Formula
Single Payment Compound Amount	to *F* given *P*	(*F*/*P*, *i*%, *n*)	$(1+i)^n$
Single Payment Present Worth	to *P* given *F*	(*P*/*F*, *i*%, *n*)	$(1+i)^{\mathrm{n}}$
Uniform Series Sinking Fund	to *A* given *F*	(*A*/*F*, *i*%, *n*)	$\frac{i}{(1+i)^n}-1$
Capital Recovery	to *A* given *P*	(*A*/*P*, *i*%, *n*)	$\frac{i(1+i)^n}{(1+i)^n-1}$
Uniform Series Compound Amount	to *F* given *A*	(*F*/*A*, *i*%, *n*)	$\frac{(l+i)^n-1}{i}$
Uniform Series Present Worth	to *P* given *A*	(*P*/*A*, *i*%, *n*)	$\frac{(l+i)^n-1}{i(1+i)^n}$
Uniform Gradient** Present Worth	to *P* given *G*	(*P*/*G* ,*i*%, *n*)	$\frac{(1+i)^n-1}{i^2(1+i)^n}-\frac{n}{i(1+i)^n}$
Uniform Gradient † Future Worth	to *F* given *G*	(*F*/*G*, *i*%,*n*)	$\frac{(1=i)^n-1}{i^2}-\frac{n}{i}$
Uniform Gradient ‡ Uniform Series	to *A* given *G*	(*A*/*G*, *i*%, *n*)	$\frac{1}{i}-\frac{n}{1=i)^n-1}$

NOMENCLATURE AND DEFINITIONS

A = Uniform amount per interest period
B = Benefit
BV = Book Value
C = Cost
d = Combined interest rate per interest period
Dj = Depreciation in year *j*
F = Future worth, value, or amount
f = General inflation rate per interest period
G = Uniform gradient amount per interest period
ι = Interest rate per interest period
i_e = Annual effective interest rate
m = Number of compounding periods per year

n = Number of compounding periods; or the expected life of an asset
P = Present worth, value, or amount
r = Nominal annual interest rate
S_n = Expected salvage value in year n

Subscripts
j = at time j
n = at time n
** = *P/G=(F/G)/(F/P) = (P/A)x(A/G)*
† = *F/G=(F/A – n)/i=(F/A)x(A/G)*
‡ = *A/G*=[1 – *n(A/F*]*/i*

NON-Annual Compounding

$$i_e = \left(1 + \frac{r}{m}\right)^m - 1$$

Discount Factors for <u>Continuous Compounding</u>

(n is the number of years)

$(F/P,r\%,n) = e^{r\,n}$

$(P/F,r\%,n) = e^{-r\,n}$

$$(A/F,r\%.n) = \frac{e^r - 1}{e^{rn} - 1}$$

$$(F/A,r\%,n) = \frac{e^{rn} - 1}{e^r - 1}$$

$$(A/P,r\%,n) = \frac{e^r - 1}{1 - e^{-rn}}$$

$$(P/A,r\%,n) = \frac{1 - e^{-rn}}{e^r - 1}$$

BOOK VALUE

BV=initial cost $-\Sigma D_j$