PHASE RELATIONSHIPS

void ratio $e = \frac{V_{voids}}{V_{solids}} = e_{max} - D_R(e_{max} - e_{min}) = \frac{G_s \cdot \gamma_{water}}{\gamma_d} - 1$

(D_R — relative density)

porosity $n = \frac{V_{voids}}{V_{Total}} \times 100\% = \frac{e}{1+e}$

water content $w = \frac{W_{water}}{W_{soil}} \times 100\%$

$W_{water} = W_{wet} - W_{dry}$

$W_{solids} = W_{dry}$

percent saturation $S = \frac{V_{water}}{V_{voids}} \times 100\% = \frac{w\,G_s}{e}$ (w — water content)

specific gravity of solids $G_s = \frac{\gamma_{solids}}{\gamma_{water}} = \frac{W_{water}}{V_{solids}} \div \gamma_{water}$ ~2.65-2.80

density $\rho = \frac{Mass}{V_{total}}$

total unit weight $\gamma = \gamma_{total} = \gamma_{wet\ moist\ sat} = \frac{W_T}{V_T} = \rho \cdot g = \gamma_d(1+w)$

dry unit weight $\gamma_{dry} = \frac{W_{solids}}{V_T} = \frac{\gamma_{wet}}{1 + \frac{water\ cont}{100}} = \frac{G_s \cdot \gamma_{water}}{1+e}$ ($\frac{water\ cont}{100}$ — $w\%$)

$Se = watcon. \cdot G_s$ (w as decimal)

1 gal water = 8.34 lb

$\gamma_{water} = 62.4 \frac{lb}{ft^3}$

$\frac{g}{cm^3} \cdot 62.4 pcf = \frac{lb}{ft^3}$

$\frac{27 ft^3}{yd^3}$

* convert all percents to decimals

Atterberg Limits:

$PI = LL - PL$

(%) $LI = \frac{W_f - PL}{PI}$

in situ field moisture

shear fracture type

<0 brittle

0-1 plastic solid

>1 viscous liquid

GRAIN SIZE DISTRIBUTION:

$C_u = \frac{D_{60}}{D_{10}}$ — 10% passing

uniformity coeff.

D_{10} is smaller size than D_{60}

$C_c = C_z = \frac{(D_{30})^2}{D_{10} \times D_{60}}$

coeff. curvature

SANDS well graded	GRAVELS well graded
$C_u > 6$	$C_u > 4$
and	and
$1 < C_c < 3$	$1 < C_c < 3$

pg. 38 Lytton Flowchart / Plasticity Index

SOIL CLASSIFICATION:

A-line $PI = 0.73(LL-20)$

U-line $PI = 0.9(LL-8)$

AASHTO GROUP Index GI pg. 41 chart

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

round to whole #s

negative → 0

F = % passing #200

PGI for A-7-6 / A-7-5

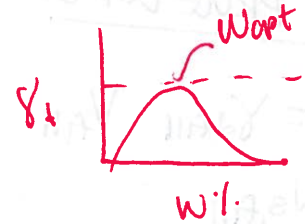
USDA pg. 45 chart

adjust for gravel $New\% = \frac{\text{initial \% sand/silt/clay}}{100 - \text{\% gravel}}$

Proctor Compaction Curves:

$\gamma_{d\text{ zero air voids}} = \dfrac{G_s \cdot \gamma_{wat}}{1 + [w \cdot G_s]}$

(theoretical max dry unit weight)



Relative Compaction

$RC = \dfrac{\text{dry unit weight attained in field}}{\text{max } \gamma_d \text{ from proctor test}} = \dfrac{\gamma_{df}}{\gamma_{d\,max}}$

use nuclear density or sand cone method

Compaction

- Future settlement reduced
- strength & stability increased
- bearing capacity increased
- volume changes reduced

Relative Density

$D_r = \dfrac{e_{max} - e}{e_{max} - e_{min}} = \left[\dfrac{(\gamma_d - \gamma_{d\,min})}{\gamma_{d\,max} - \gamma_{d\,min}}\right] \dfrac{\gamma_{d\,max}}{\gamma_d} = \left[\dfrac{\gamma - \gamma_{min}}{\gamma_{max} - \gamma_{min}}\right] \dfrac{\gamma_{max}}{\gamma}$

($e_{max} - e_{min}$ from lab tests)

$e = e_{max} - D_r(e_{max} - e_{min})$

change in layer height due to ΔD_r or Δe

$\dfrac{\Delta H}{H_0} = \dfrac{\Delta e}{1 + e_0} = \varepsilon_v$ ← decimal

expansion of soils pg. 58/59

Frost Action pg. 60

DUMP TRUCK PROCEDURE

volume to transport $= V_{cut} \cdot BF$ — bulking factor

$= V_{cut} \cdot (1 + SF)$ — swell factor

pg. 602 for BF/SF

BORROW PIT PROCEDURES:

$$\gamma_{d\,cut} \cdot V_{cut} = \gamma_{d\,fill} \cdot V_{fill}$$

$$W_{s\,cut} = W_{s,fill}$$

$$V_{s\,cut} \neq V_{s\,FILL}$$

1. use RC to obtain $\gamma_{d\,fill}$ (aka γ_{df})
   $RC = \frac{\gamma_{d\,fill}}{\gamma_{d\,max}}$
2. convert $\gamma_{T\,cut}$ to $\gamma_{T\,fill}$ by dividing by $(1+w)$
   $\gamma_{df} = \frac{\gamma_{cut}}{1+w}$ — w: water content
3. weight of water to add $= \Delta W = W_{fill} - W_{cut}$

$$\Delta W = \Delta w (\gamma_{d\,fill}) V_{T\,fill}$$

1 gal = 8.34 lb

$27\,ft^3 = 1\,yd^3$

WATER EQUATIONS:

Bernoulli eqn for seepage:

$$h = \frac{U_{pore}}{\gamma_w} + Z$$ — Z: elevation head

Darcy's Law:

$$q = VA = KiA = K\frac{\Delta h}{L}A$$

$$V_s = \text{seepage velocity actual} = \frac{V}{n} = \text{velocity} \cdot \frac{V_T}{V_V}$$ — n: porosity, e/n

$$q V_T / A_{gross} V_{voids}$$

Permeability by constant head test: coarse grained

$$K = \frac{VL}{Aht}$$

- V: in^3
- L: in, length of specimen
- A: in^2
- t: sec
- h: Δh (in)

Permeability by falling head test: fine grained

$$K = 2.303\left[\frac{aL}{At}\right]\log_{10}\left(\frac{h_1}{h_2}\right)$$

- A: area specimen
- a: area of burette
- h_1: initial head drop
- h_2: final head drop

$$= \left[\frac{aL}{At}\right]\ln\left(\frac{h_1}{h_2}\right)$$

SEEPAGE AND FLOW NETS

Unit flow rate beneath a structure by a flow net:

$q = k\left(\frac{n_f}{n_d}\right)\Delta H$ — diff btw head & tailwater

- n_f — # flow channels
- n_d — # equipot. lines = n_d+1 or count across spaces

total head at point p within flow net:

$h_p = H_1 - n_{dp}\left(\frac{\Delta H}{n_d}\right)$

- H_1 — h@ headwater
- n_{dp} — # equipot. drops from H_1 to point p

Δh_p — divide ΔH by # equipot. lines to get the Δh_p at each equipot. line & count over to h_p at a certain point

pore pressure at point p:

$u_p = \gamma_w(h_p - Z)$

pore pressure: depth from ground
$u = \gamma_w(Z - D_w)$ — DTW from ground

hydraulic gradient: $i_E = \frac{\Delta h}{\Delta L}$

- Δh — ($\Delta H / n_d$), i.e. change in head btw 2 equip. lines
- ΔL — last flow space; increment of Length in plane of flow net, not perp. to flow

critical h.g.: $i_{cr} = \frac{\gamma_b}{\gamma_w}$ — $\gamma_b = \gamma_{sat} - \gamma_w$

* $\gamma_{sat} \neq \gamma_{buoyant}$ $\gamma_b = \gamma_{sat} - \gamma_{water}$

FS against quicksand: $FS = \frac{i_{CR}}{i_E}$ — i_E — exit gradient

STRESSES

total stress (if no surface loading & horizon. ground)
$$\sigma_v = \sum_1^t (\gamma_i)(t_i) - \gamma_{wat}(t)$$
γ of layer i; t_i — thickness

change due to applied load — $\Delta \sigma_v = PI$
P — press @ base of footing; I — intensity <1

effective stress
$$\sigma' = \sigma - u$$
where $u = \gamma_{water} d = \gamma_{water}(Z - DTW)$

poisson's ratio
$$v = \frac{\varepsilon_h}{\varepsilon_v}$$
ε_h — horizont. strain

SHEAR STRENGTH

c is y-axis

Mohr-Coulomb strength envelope for shear failure
$$\tau'_f = c' + \sigma' \tan \phi'$$
— effective stress conditions; ϕ' — angle internal friction

normal stress conditions
$$\tau_f = c + \sigma \tan \phi$$
c — eff. cohesion

UU test [unconsol. undrained] shear strength
$$S_u = c = \frac{\sigma_1 - \sigma_3}{2}$$

when c = 0:

major stress — σ_1, minor — σ_3
$$\frac{\sigma_1}{\sigma_3} = \tan^2\left(45 + \frac{\phi}{2}\right)$$
ϕ — angle internal friction of the soil

total angle internal friction of soil
$$\phi = 2\left[\tan^{-1}\left(\frac{\sigma_1}{\sigma_3}\right)^{1/2} - 45°\right]$$

LATERAL EARTH PRESSURES

(lb) $F = \overset{(psf)}{\sigma} A^{(ft^2)}$

eff. horiz. pressure @ spec. depth: $\sigma_h' = K \sigma_v'$ — eff. vert. stress @ depth

↳ earth press. coeff.

$\sigma_h' = \sigma_h - u$

RANKINE COEFFICIENTS:

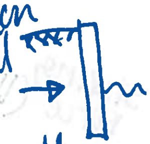
$K_0 = 1 - \sin\phi'$ (empirical for sand)

$= 0.19 + 0.233 \log(PI)$ (empir. for normally consolidated clays)

] 1D settlement cases

$K_a = \tan^2(45 - \phi'/2) = 1/\tan^2(45 + \frac{\phi'}{2}) = 1/K_p$

] lateral extension, retaining wall, dam, soil towards wall



$K_p = \tan^2(45 + \phi'/2) = 1/K_a$] wall towards soil

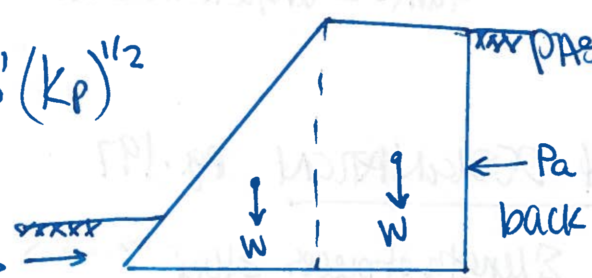
RANKINE PRESSURES:

eff. horiz. active force; vertical back of wall: $\sigma_{ha}' = K_a \sigma_v' - 2c'(K_a)^{1/2}$

* ACTIVE = TOWARDS WALL

eff. horiz. passive force; no soil-toe/stem friction: $\sigma_{hp}' = K_p \sigma_v' + 2c'(K_p)^{1/2}$

PASSIVE = AWAY FROM WALL

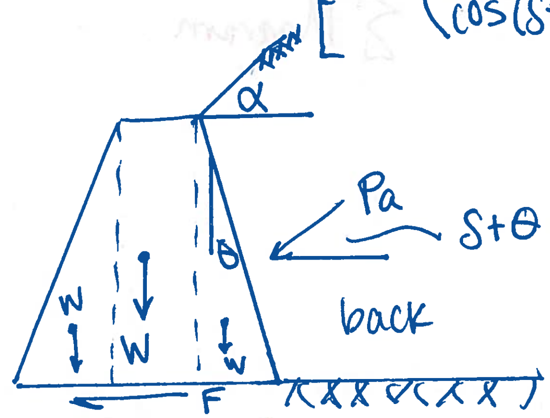


c=0 sand
φ=0 sat. clay

COULOMB COEFFICIENTS:

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos^2\theta \cos(\delta+\theta)\left[1 + \left(\frac{\sin(\delta+\phi)\sin(\phi-\alpha)}{\cos(\delta+\theta)\cos(\theta-\alpha)}\right)^{1/2}\right]^2}$$

pg. 115



φ' = φ internal angle fric.

δ fric. coeff w/ wall & soil

α angle soil surcharge w/ horizontal

θ angle back of wall w/ vertical

COULOMB PRESSURES:

$P_a = \frac{1}{2} K_a \gamma' H^2 - 2c'(K_a)^{1/2}$ $\quad P_p = \frac{1}{2} K_p \gamma' H^2 + 2c'(K_p)^{1/2}$

SLOPE STABILITY

slope stability #

$$N_s = \frac{\gamma' H}{c} = \frac{\gamma H}{c}$$

$$n_d = \frac{H+D}{H}$$ if $D > 5H$ $n_d = \infty$, $N_s = 5.52$

$$FS = \frac{N_s \cdot c}{\gamma H} = \frac{N_s \cdot c}{\gamma' H}$$

$c > 0$
$\phi > 0$ cohesive soils aka clay
Pg. 136/137 notes & diagram

$c = 0$ cohesionless aka sand
$\phi > 0$

$\phi = 0$ for saturated clay

sliding force (16) $F_s = W \sin\alpha$

weight soil layer $W = \frac{Lh\gamma}{2}$

resisting force $R_s = cL + W\cos\alpha + \tan\delta$

$$FS_{sliding} = \frac{\tan\phi}{\tan\beta}$$ — β angle from horiz.

ROCK QUALITY DESIGNATION pg. 197

$$RQD = \frac{\Sigma \text{ length of pieces} \geq 10\text{cm (3.94in)}}{\text{length of core advance}}$$

aka recovery ratio

$$FS_{sliding} = \frac{\Sigma F_{resist}}{\Sigma F_{driving}} \qquad FS_{overturn} = \frac{\Sigma M_{resist}}{\Sigma M_{overturn}}$$

CONSOLIDATION FOR SATURATED CLAYS

* clay has long-term settlement

PRIMARY:

$$S_c = \frac{C_s H}{1+e_o} \log\left(\frac{\sigma_p'}{\sigma_{vo}'}\right) + \frac{C_c H}{1+e_o} \log\left(\frac{\sigma_f'}{\sigma_p'}\right)$$

- S_c — settlement (units of ΔH)
- H — thickness of layer
- C_s — swell index (C_r)
- σ_p' — preconsolid. stress
- σ_{vo}' — initial vertical stress
- σ_f' — final stress after load

Terzaghi's factor no units:

$$T_v = \frac{C_v t}{(H_{dr})^2}$$

- C_v — coeff. of consolidation
- H_{dr} — length drainage path; sometimes $\frac{1}{2}H$

time for consolidation to occur:

$$t = \frac{T_v (H_{dr})^2}{C_v}$$

- C_v — A/t

over-consolidation ratio:

$$OCR = \frac{\sigma_p'}{\sigma_{vo}'}$$

$\sigma_{vo}' < \sigma_p'$ overconsolidated

$\sigma_{vo}' = \sigma_p'$ normally consolidated

degree consolidation:

$$U_z = \frac{u_o - u}{u_o}$$

- u — excess pore press. @ t
- u_o — initial excess pore pressure @ $t=0$

pg. 146 table

SECONDARY: OF SAT. CLAY

$$|S_s| = \frac{C_\alpha H}{1+e_p} \log\left(\frac{t}{t_p}\right)$$

- C_α — coeff. second. consol.
- t_p — time to end of prim. consol. $\frac{T_v (H_{dr})^2}{C_v}$
- e_p — void ratio at end of prim. consolidation

$$t_p = \frac{(H_{dr})^2}{C_v}$$

SETTLEMENT IN SAND

settlement on footing: $S_F = S_P \left[\frac{2B_F}{(B_F + B_P)} \right]^2$

- S_P – measured test plate settlement
- B_F – footing width
- B_P – plate width

1 ton = 2000 lb
1 kip = 1000 lb

BEARING CAPACITY: pg. 158 chart

ult. bear. cap. (psf): $q_{ult} = cN_c S_c i_c d_c + \gamma_1' D_f N_q S_q i_q d_q + \frac{1}{2} B \gamma_2' N_\gamma S_\gamma i_\gamma d_\gamma$

where,
S = shape
i = inclination
d = depth
(pg. 156)

allowable/design bearing cap.: $q_a = \frac{q_{ult}}{FS}$

IF backfilled...

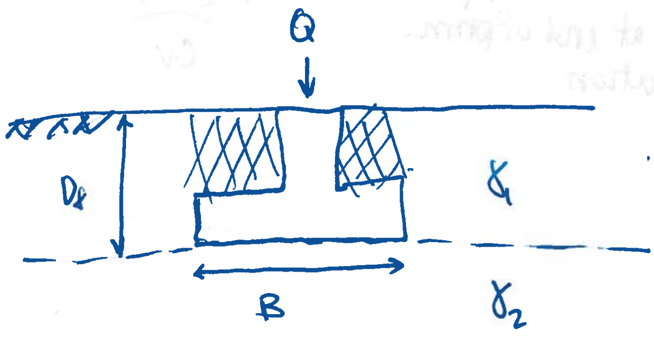
$q_{ult(net)} = q_{ult} - q$ – pressure backfilling footing

$q_{a(net)} = \frac{q_{ult(net)}}{FS}$

(psf) $q = \gamma_1' D_f$

- γ_1' – eff. γ on footing
- D_f – dist. from ground surface to bottom footing

(lb) $F = qA = \sigma A$
(lb/ft) $= qL$



strip footings $L \geq 10B$
shapes = 1

sq./circular $B = L$
$B/L = 1$

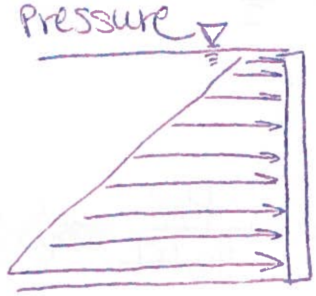
wind load, $p = 0.00256V^2$

V = speed, mph

p = pressure, lb/ft^2

force acts at centroid of area

Hydrostatic Pressure



acts 2/3 from water surface

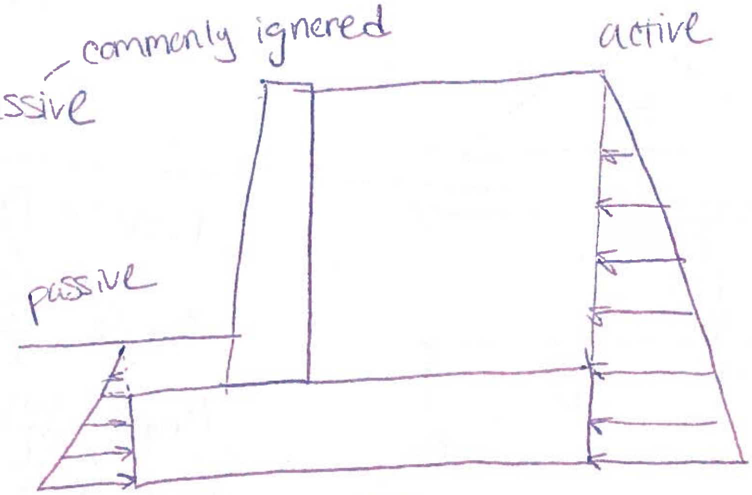
$p = h\gamma$

earth pressure

at rest, active, and passive

$p_A = K_A \gamma h$ (acting at base)

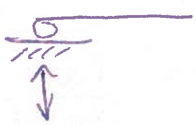
$P_A = \frac{1}{2} K_a \gamma h^2$ (total force)



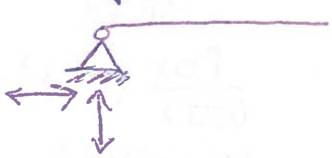
Load combinations with factors provided on STR II

Analysis of Determinate Structures

- roller



- pinned



- fixed

A determinate structure has as many unknown support reactions as there are equations of equilibrium:

$\Sigma F_x = 0$

$\Sigma F_y = 0$

$\Sigma M = 0$

Reactions, Shear, + Moment Diagrams

max shear occurs at supports

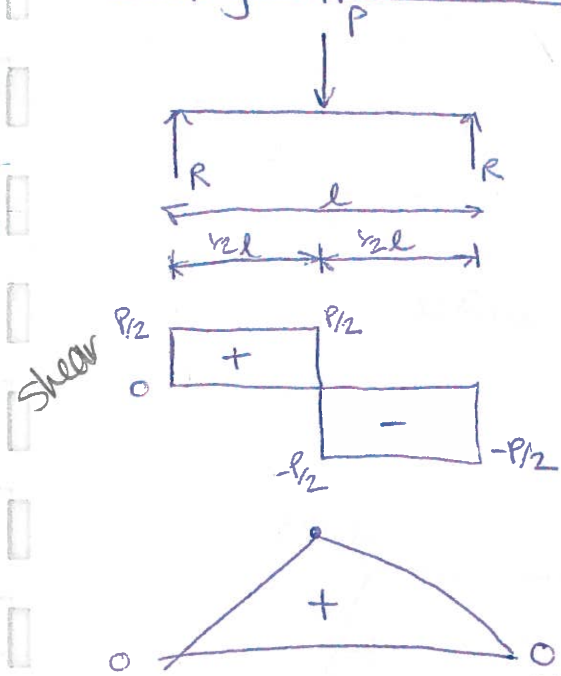
change in moment = area under shear diagram

maximum moment occurs at points of zero shear

max positive moment when shear changes from positive to negative

max negative moment " " " negative to positive

Simply supported beam



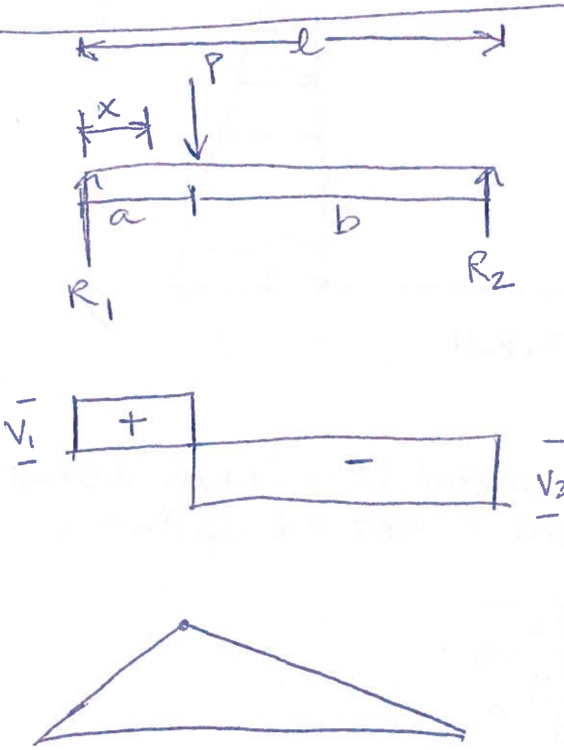
$R = V = P/2$

$M_{max} = \frac{Pl}{4}$

$M_x \text{ if } \left(x \leq \frac{l}{2}\right) = \frac{Px}{2}$

$\Delta_{max} = \frac{Pl^3}{48EI}$

$\Delta_x \left(\text{when } x < \frac{l}{2}\right) = \frac{Px}{48EI}(3l^2 - 4x^2)$



$R_1 = V_1 = \frac{Pb}{l}$

$R_2 = V_2 = \frac{Pa}{l}$

$M_{max} = \frac{Pab}{l}$

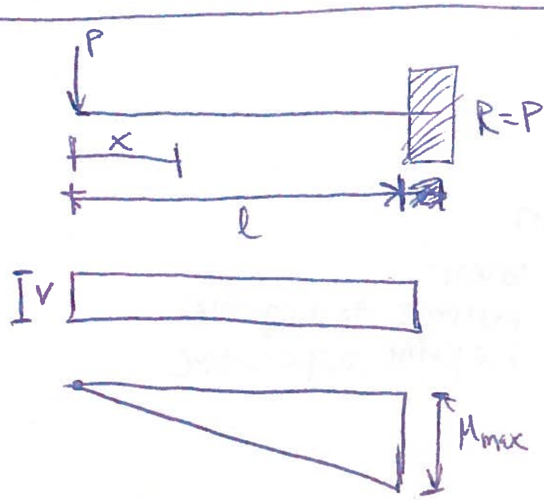
$M_x (x < b) = \frac{Pbx}{l}$

$\Delta_{max} \text{ at } x = \sqrt{\frac{a(a+2b)}{3}} \text{ when } a > b = \frac{Pab(a+2b)\sqrt{3a(a+2b)}}{27EIl}$

$\Delta_p (\text{at load point}) = \frac{Pa^2b^2}{3EIl}$

$\Delta_x (x < a) = \frac{Pbx}{6EIl}(l^2 - b^2 - x^2)$

$\Delta_x (x > a) = \frac{Pa(l-x)}{6EIl}(2lx - x^2 - a^2)$



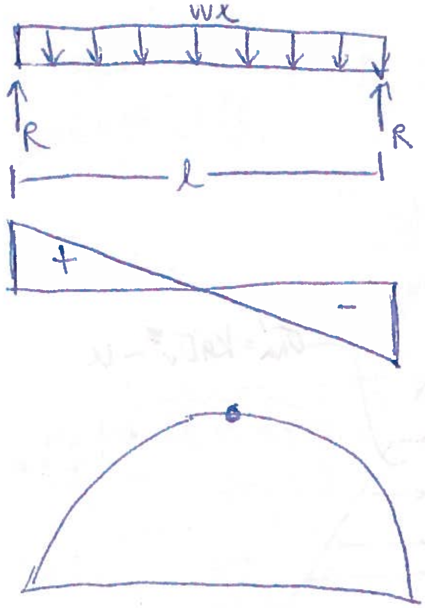
$R = V = P$

$M_{max} (\text{at fixed end}) = Pl$

$M_x = Px$

$\Delta_{max} (\text{at free end}) = \frac{Pl^3}{3EI}$

$\Delta_x = \frac{P}{6EI}(2l^3 - 3l^2x + x^3)$



$$R = V = \frac{wl}{2}$$

$$V_x = w\left(\frac{l}{2} - x\right)$$

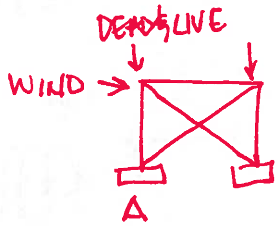
$$M_{max}\ (\text{at center}) = \frac{wl^2}{8}$$

$$M_x = \frac{wx}{2}(l - x)$$

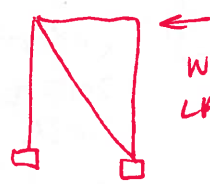
$$\Delta_{max}\ (\text{at center}) = \frac{5wl^4}{384EI}$$

$$\Delta_x = \frac{wx}{24EI}(l^3 - 2lx^2 + x^3)$$

DESIGN FOR OVERTURN/ UPLIFT OF FOOTING A:

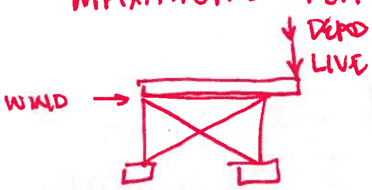


DEAD + WIND



WILL NOT RESIST LATERAL LOAD

MAXIMUM UPLIFT AT FOOTING A:



DEAD + LIVE + WIND

Retaining Walls

$$F.S._{sliding} = \frac{\mu(\Sigma W_i)}{\frac{1}{2}K_a \gamma_s h^2}$$ frictional force, resisting

$$FS_{sliding} = \frac{\Sigma F_R}{\Sigma F_D}$$

$F_{R2} = N \tan \delta_{sc}$
$= (W_i) \tan \delta_{sc}$

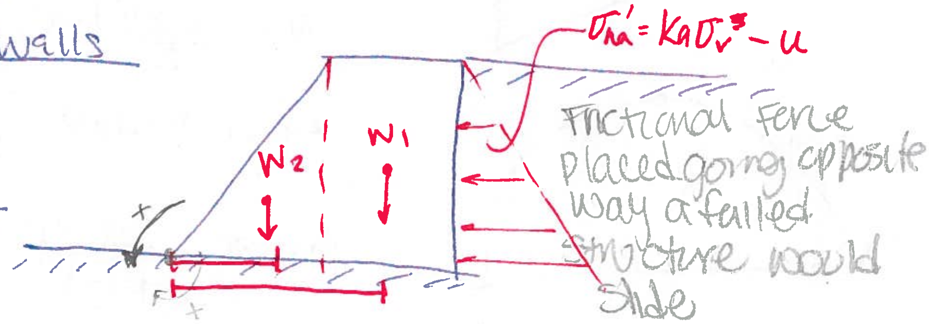
$$F.S._{overturn} = \frac{\Sigma(W_i \times d_i)}{h/3\left(\frac{1}{2}K_a \gamma_s h^2\right)}$$ moment

$$FS_{overturning} = \frac{\Sigma M_R}{\Sigma M_O}$$

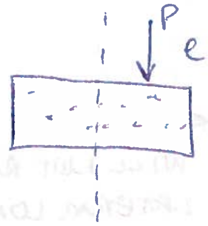
Sub-grade Building Walls

$R_{max} = V_{max} = \frac{wL}{3}$

$M_{max} = \frac{wL^2}{9\sqrt{3}} = 0.0642\,wL^2$

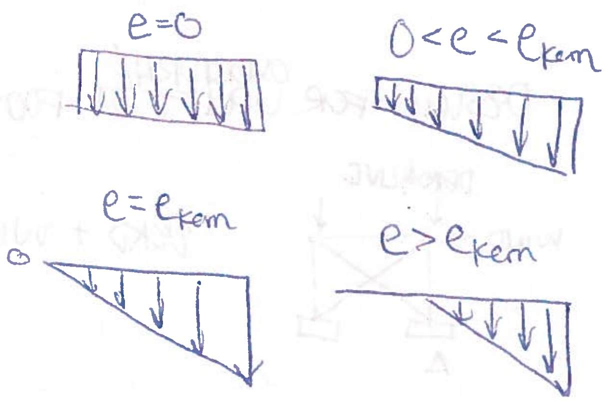


Column Footings



eccentricity req'd to have zero bearing stress at one side of footing

$e = \frac{M}{P}$



* GO TO PAGE 157

Member Bending Stiffness (opposite of deflections)

$$K\left(k/in^2\right) = \frac{EI}{L}$$

most efficient x-section for bending is an I shaped member as it maximizes area away from neutral axis

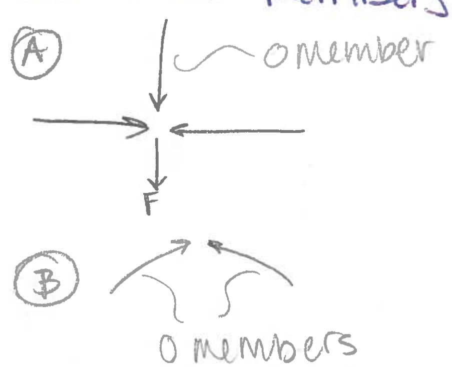
Truss Analysis

Support reactions must be determined first

Method of Joints should only be used if unknown force frames into a support ... can only use $\Sigma F_x = 0$ and $\Sigma F_y = 0$

Method of Sections - sum moments about point where lines of action of other unknown bar forces intersect

Zero-force members - Ⓐ occurs when only three members frame into a joint and two members are colinear.
Ⓑ If only two members frame into a joint without an applied load and are not co-linear both members are zero-force.



Properties of Steel

$E = 29{,}000$ ksi

Yield stress = F_y

Tensile Strength = F_u

Shear strength is 60% of tensile

ASTM	Grade	F_y (ksi)	F_u (ksi)
A36		36	58-80
A572	42	42	60
	50	50	65
	60	60	75
	65	65	80
A992		50	65
A588	50	50	70

Cement & Concrete

$E_c = 57{,}000\sqrt{f_c'}$ — f_c' - compressive stress, psi

- Type I - general purpose
- Type II - for hot weather for large structures (moderate sulfate resistant)
- Type III - high early strength
- Type IV - low heat for large structures
- Type V - sulfate resistant

Fines improve workability

Consolidates increases strength (decreases water & voids)

Fly ash - increases durability, decreases permeability, retards setting time

Silica fume - similar to fly ash

Coarser aggregate → higher strength

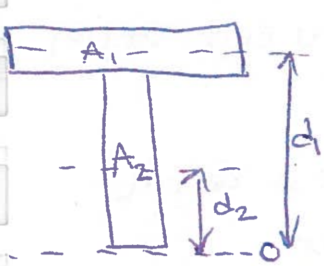
Steel Section Properties

- if two shapes have equal weight, the deeper section will be more efficient for controlling beam deflections

Parallel axis theorem

$I_x = \Sigma I' + Ad^2$

I' is moment of inertia of each element about its centroid, A = x-sectional area of each element, & d is the distance between the element centroid & the centroid of the entire cross section.



Centroid of entire cross section $= \dfrac{A_1 d_1 + A_2 d_2}{A_1 + A_2}$

Greatest flexural rigidity about x-axis

Reinforcing Steel Props Bar No.	Diameter (in)	Area (in^2)	Weight (lb/ft)
3	0.375	0.11	0.376
4	0.50	0.20	0.668
5	0.625	0.31	1.043
6	0.750	0.44	1.502
7	0.875	0.60	2.044
8	1.000	0.79	2.670
9	1.128	1.00	3.400
10	1.270	1.27	4.303
11	1.410	1.56	5.313
14	1.693	2.25	7.65
18	2.257	4.00	13.60

Concrete Mix Design

$\gamma = \frac{wt.}{vol.}$

cement bulk density = 94 pcf
cement solid density = 195 pcf
sack of cement = 94 lb

first determine yield of mix ratio per sack of cement
convert mix ratio to weight if given in volume

X : X : X — cement | sand | gravel

w_c ratio 7:1 — 7 gallons per 1 sack

#Look @ Example on page 29

air-entrainment – increases durability, workability, reduces bleeding
reduces compressive strength
increases permeability → increased corrosion of steel

Stresses

$\sigma_{axial} = \frac{P}{A}$ $\quad \delta = \frac{PL}{AE}$ (axis elongation)

$\sigma_{bending} = f_b = \frac{My}{I}$

y = distance from neutral axis to cross section of interest
I = moment of inertia
M = moment at specific cross section

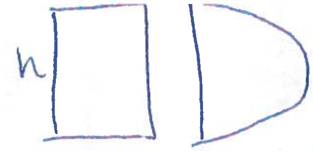
$\sigma_{b,max} = f_{b,max} = \frac{Mc}{I}$

c = distance to extreme fiber

$\sigma_b = f_b = \frac{M}{S}$ $\quad S = \frac{bh^2}{6}, \quad S = \frac{I}{c} = \frac{bh^3 \, 2}{12 \, h} = \frac{bh^2}{6}$

Shear Stress

$$\tau_v = f_v = \frac{VQ}{Ib}$$



Q = statical moment (first area moment) of the area of the cross section above the point of interest on the cross section.

$$\tau_{v,max} = \frac{3}{2}\frac{V}{A}$$ (rectangular cross section)

$$\tau_{v,max} = \frac{V}{d \cdot t_w}$$ (for a W shape loaded about the x-axis)

Concrete Design, singly reinforced beams

assumed depth of compressive zone to determine design moment capacity:

$$a = \frac{A_s f_y}{0.85 f'_c b}$$

A_s = area of steel
f_y = yield strength of steel
f'_c = given
b = width of cross section

nominal moment capacity:

$$M_n = A_s f_y \left(d - \frac{a}{2}\right)$$

(d = depth of cross section)

DON'T FORGET TO MULTIPLY BY REDUCTION FACTOR TO CONVERT NOMINAL TO ULTIMATE MOMENT (DESIGN)

Reinforced Concrete Floor Slabs

See STR pg. 36

Steel Columns

- Design strength based on buckling
  - global - based on Euler buckling behavior (both ends pinned)
  - local

Critical buckling load (Euler) =

$$P_{cr} = \frac{\pi^2 EI}{L^2}$$

or, in terms of stress:

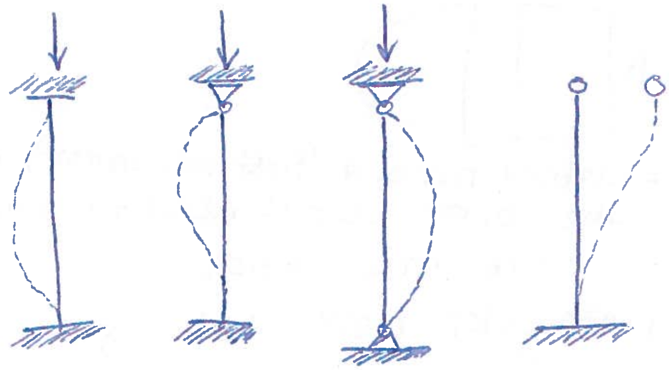
$$\sigma_{cr} = \frac{\pi^2 E}{(L/r)^2}$$

(r = radius of gyration)

L/r = slenderness ration

Effective column length factor, K, relates other end conditions back to Euler

Buckled Shape



STR47

K value — 0.5 — 0.7 — 1.0 — 2.0

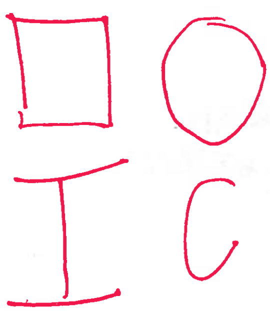
Relative Stiffness of Columns

when the ends of a column are not fixed or pinned, calculate G, and find K from the chart on STR48

G = 1.0 ~~pinned~~ fixed

G = 10.0 ~~fixed~~ pinned

$$G = \frac{\sum \frac{I_{columns}}{L_{columns}}}{\sum \frac{I_{girders}}{L_{girders}}}$$



TORSIONALLY STRONG

TORSIONALLY WEAK

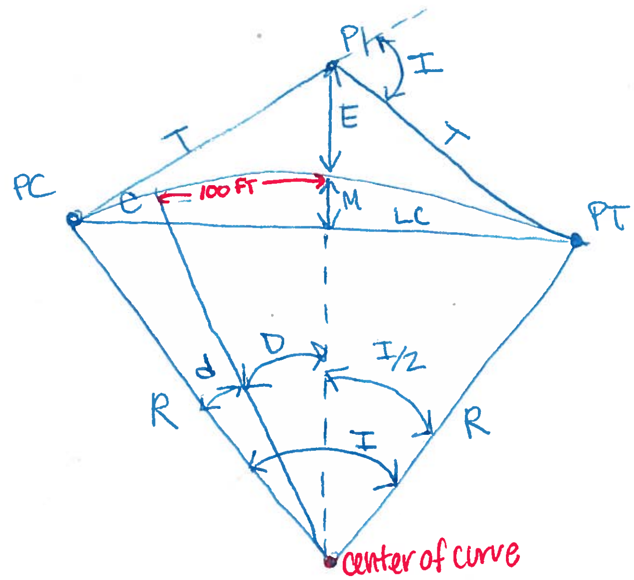
TRANSPORTATION

DOWNLOAD MUTCD, 2009 and Revisions 1&2 dated May 2012

Horizontal Curves

PC = PI − T
PT = PC + L

PC or BC = Point of Curve (Back tangent)
PT or EC = Point of Tangent (Forward tangent)
PI = Point of Intersection
I = intersection or deflection angle (Δ), angle btw 2 tangents
L = length of curve (From PC to PT)
T = tangent distance (From PI to PC or PT)
E = external distance (shortest dist. from PI to curve)
R = radius
LC = length of long chord (from PC to PT directly)
M = length of middle ordinate (direct distance from middle of LC to curve)
c = length of sub-chord
d = angle of sub-chord
l = curve length of sub-chord
D = degree of curve, Arc definition



$$R = \frac{5{,}729.58}{D}$$

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

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

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

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

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

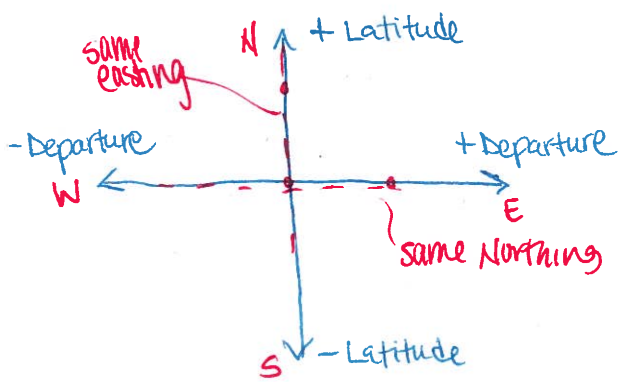
$$\frac{R-M}{R} = \cos\left(\frac{I}{2}\right)$$

$$c = 2R\sin\left(\frac{d}{2}\right)$$

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

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

Deflection angle I per 100 ft of arc length = $\frac{D}{2}$



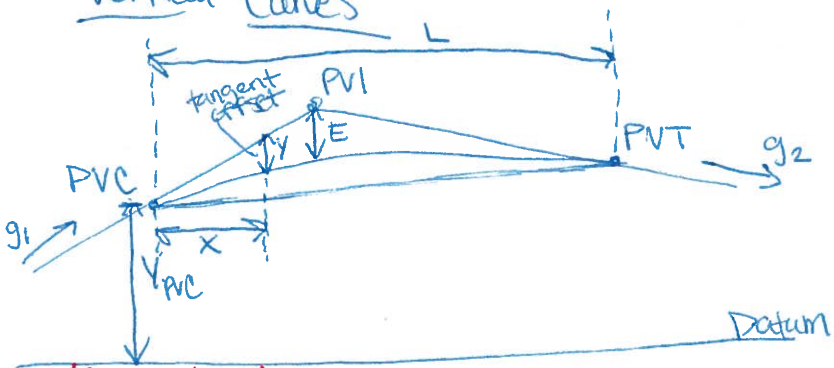
$$Y_{VPC} = Y_{VPI} - g_1\left[\frac{L}{2}\right]$$

$$Y_{VPT} = Y_{VPI} + g_2\left[\frac{L}{2}\right]$$

$$X_{VPT} = X_{VPI} + \frac{L}{2}$$

$$X_{VPC} = X_{VPI} - \frac{L}{2}$$

Vertical Curves



PVC - point of vertical curvature

PVI - point of vertical Intersection

g_1 - grade of back tangent

g_2 - grade of forward tangent

GRADES IN PERCENT FORM!

y = tangent offset

L = length of curve (horizontal)

x = horizontal distance from PVC to any point on curve

X_m = horizontal distance to min/max elevation on curve $= \frac{-g_1}{2a} = \frac{g_1 L}{g_1 - g_2}$

High POINT OF CURVE $= X_{PVC} + X_m$ and $Y_{PVC} + Y_m + g_1 X_m$

a = parabola constant

r = rate of change of grade $= \frac{\Delta g}{L} \left[\frac{\%}{ft}\right]$

tangent elevation $= Y_{PVC} + g_1 x$

and

$= Y_{PVI} + g_2\left(x - \frac{L}{2}\right)$

y = curve elevation $= Y_{PVC} + g_1 x + a x^2 = Y_{PVC} + g_1 x + \left[\frac{g_2 - g_1}{2L}\right] x^2$ $\therefore y' = g_1 + \left(\frac{g_2 - g_1}{L}\right) x$

slope of tangent to curve

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

E = tangent offset at PVI

Earthwork & Area Formulas → pg. 15

Traffic Volume

Seasonal factor $= \frac{\text{avg. traffic of certain months}}{\text{total avg. of sample}}$

jam density $= \frac{\text{veh.}}{\text{mile}}$

$PHF = \frac{V_{max, 1HR}}{4 * V_{15}}$

TRANSPORTATION FORMULAS AND DATA

AASHTO DESIGN VEHICLES

Design vehicles have been established by AASHTO for the design of geometric features. AASHTO [page 2-4 Table 2-1b)

P = Passenger Car
SU-30 = Single Unit Truck
SU-40 = Single Unit Truck (three axle)
BUS-40 = Intercity Bus
BUS-45 = Intercity Bus
CITY BUS = City Transit Bus
S-BUS 36 = Conventional School Bus
S-BUS 40 = Large School Bus
A-BUS = Articulated Bus
WB-40 = Intermediate Semitrailer
WB-62 = Interstate Semi-Trailer
WB-67 = Interstate Semi-Trailer
WB-67D = Double Bottom Semi-Trailer
WB-92D = Rocky Mountain Double Semi-Trailer
WB-100T = Triple Semi-Trailer
WB-109D = Turnpike Double Semi-Trailer
MH = Motorhome
P/T = Car and Campus Trailer
P/B = Car and Boat Trailer
MH/B = Motor Home and Boat Trailer

Stopping Sight Distance = SSD = S

SSD = S = 1.47VT + V^2/[30(a/32.2+/-g)]

V = Vehicle Speed
T = Driver Reaction time = 2.5 seconds
a= deceleration rate = 11.2 ft/s^2
g= roadway grade as a decimal

+ grade is uphill
-grade is downhill

* SF = avg months of interest / total avg

For additional fluids information, see the FLUID MECHANICS section.

TRANSPORTATION

U.S. Customary Units

a = deceleration rate (ft/sec²)
A = algebraic difference in grades (%)
C = vertical clearance for overhead structure (overpass) located within 200 feet of the midpoint of the curve
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

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

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

Stopping Sight Distance

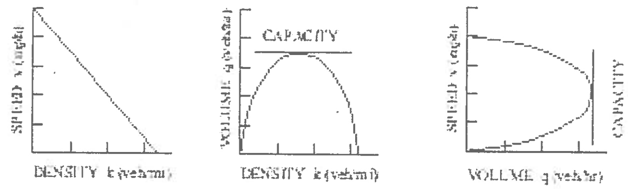
$$S = 1.47Vt + \frac{V^2}{30\left(\left(\frac{a}{32.2}\right) \pm G\right)}$$

162 CIVIL ENGINEERING

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:	$L = \dfrac{AS^2}{100(\sqrt{2h_1}+\sqrt{2h_2})^2}$	$L = 2S - \dfrac{200(\sqrt{h_1}+\sqrt{h_2})^2}{A}$
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)	$HSO = R\left[1 - \cos\left(\dfrac{28.65S}{R}\right)\right]$ HSO = Horizontal sight line offset

A Basic Circular Curve Elements (e.g. middle ordinate, length, chord, radius)

Know definitions and symbols

R = Radius
D = Degree of Curve
L = Length of Curve
T = Tangent
M = Middle Ordinate
E = External Distance
I = Central Angle
PI = Point of Intersection
PT = Point of Tangency
PC = Point of Curvature

Azimuth is given as a clockwise angle from the reference direction (usually north). Azimuths cannot exceed 360 degrees.

Bearing: the bearing of a line is referenced to the quadrant in which the line falls and the angle that the line makes with the meridian in that quadrant. It is necessary to specify the two cardinal directions that define the quadrant in which the line is found. The north and south directions are always specified first. A bearing contains an angle and a direction from a reference line either north or south. A bearing may not have an angular component exceeding 90 degrees.

Latitude is the distance that the line extends in a north or south direction. A line that runs towards the north has a positive latitude. A line that runs toward the south has a negative latitude.

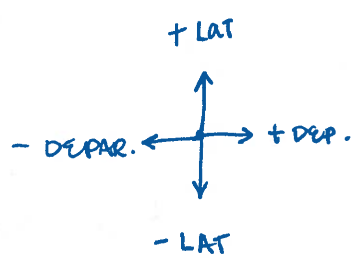
Departure is the distance that a line extends in the east or west direction. A line that runs toward the east has a positive departure. A line that runs toward the west has a negative departure.

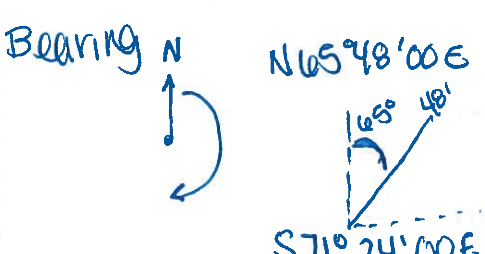
Back Tangent is from PC to PI

Ahead or forward Tangent is from PI to PT

PC = PI – T

PT = PC + L





Stopping Sight Distance on level Roadways From Page 3-4 Table 3-1 AASHTO Geometric Design

Design Speed (mph)	Brake Reaction Distance (feet)	Braking Distance on Level (feet)	Stopping Sight Distance	
			Calculated (feet)	Design (feet)
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	815.3	820
80	294.0	614.3	908.3	910

Note: Brake reaction distance predicated on a brake reaction time of 2.5 seconds; deceleration rate of 11.2 ft/s^2 used to determine calculated sight distance.

CONSTRUCTION

DOWNLOAD OSHA 29 CFR PART 1926

Costs & Quantities pg. 32-45

Outside perimeter = 2 (length + width + recesses)

Inside perimeter = OP - 8* footing width

Mean perimeter = OP - 4* footing width = IP + 4 * footing width (used to calculate volume)

BF = board foot = $\frac{\text{length (ft)} * \text{nominal size (in x in)}}{12\ in/ft}$

SFCA = sq. ft. of contact area

FACTOR OF SAFETY:

1.3 - 1.5 PERMAN. SLOPES

3.0 DAM

1.0 NO F.S.

Formwork Conversions → pg. 32 (gross area of forms)

Steel bar sizes/wt.'s → pg. 32 (rebar info)

Bricks: X x/x in * X x/x in * X x/x in

(depth into wall, height, length)

A_{brick} = (height + mortar joint)(length + mortar joint)

$N_{bricks} = \frac{\text{outside area of wall}}{\text{area of one brick } (A_{brick})} * (1 + \text{waste factor})$

Project Planning pg. 46 -

Formulas → pg. 46

Critical activity → early start and late start are the same OR early finish and late finish are the same

early start → longest it could take

Means & Methods

productivity: $= \frac{(\text{capacity})(\text{efficiency})(\text{fill factor})}{\text{cycle time}}$ — production / hour ≤ 1

equipment productivity:

Loader production $= \frac{3600\, Q * F * E}{T * 60 (1 + \text{SWELL})}$ $\left(\frac{cy}{hr}\right)$

(Q = heaped bucket capacity (LCY), F = bucket fill factor, E = efficiency $\frac{min}{hr}$, T = cycle time (sec))

Loader production $= \frac{3600\, Q F E W}{T * 60 * 2000}$ $\frac{ton}{hr}$ (W = aggregate weight lb/cy)

Trucks req'd $= \frac{\text{truck cycle time}}{\text{loader cycle time}}$

Prismoidal Formula

$$V = \frac{L}{6} * (A_1 + 4A_m + A_2)$$

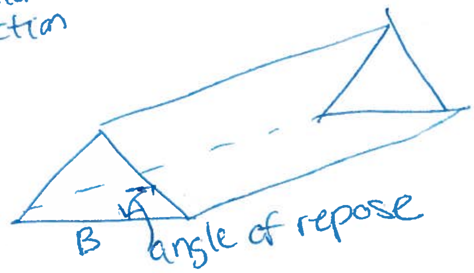
- L: distance btw A_1 & A_2
- A_1: end section
- A_m: midsection
- A_2: end section

Average end Area Formula

$$V = L\frac{(A_1 + A_2)}{2}$$

$$CCY < BCY < LCY$$

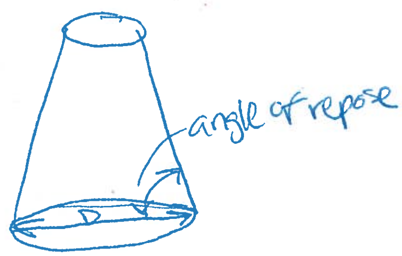
- CCY: compacted
- BCY: bulk
- LCY: loose



PYRAMID OR CONE

$$V = \frac{h\,(\text{Area of base})}{3}$$

$$B = \frac{4V}{L \tan R}$$ V in <u>loose</u> cubic yards



$$D = \left(\frac{7.64V}{\tan R}\right)^{1/3}$$ V is in <u>loose</u> CY

$$H = 0.5 D \tan R$$

use average depth and given area to calculate excavation volume

$$CCY = BCY(1-D)$$ (D = shrinkage factor)

$$BCY = LF * LCY$$ (LF = load factor)

$$LCY = (1+S)(BCY)$$ (S = swell factor)

Area by coordinates

$$A = \left[X_A(Y_B - Y_N) + X_B(Y_C - Y_A) + X_C(Y_D - Y_B) + \ldots + X_N(Y_A - Y_{N-1})\right] \cdot \frac{1}{2}$$

Trapezoidal Rule

$$A = \left[\frac{h_1 + h_2}{2} + h_2 + h_3 + h_4 + \ldots + h_{n-1}\right] w$$

where w = common interval

Simpson's ⅓ Rule

$$A = \left(h_1 + 2\left[\sum_{t=1,3,\ldots}^{n-2} h_t\right] + 4\left[\sum_{t=2,4,\ldots}^{n-1} h_t\right] + h_n\right) \cdot w \cdot \frac{1}{3}$$

Construction Theoretical:

Milestone Gantt - has duration
Gantt w/ dependencies - has arrows
baseline gantt - actual plan
timeline gantt

Activity on arrow network - early start is longest day

Floor slab uses to sep. rebar from ground
- precast cement blocks
- metal chairs
- wire bolsters
- plastic bar supports

Joints:
construction - doweled to ensure complete load transfers when subsequent slabs are paved

control joints - no dowels; saw cutting where cracking would occur

contraction joint] concrete slides along dowel
expansion joint]

Isolation joint - slabs from columns, footings, & walls

Cement - spray w/ water in hot weather

Asphalt - too low air voids shortens lifespan
if too cold ∴ poor compaction
260°F - 280°F at time of spreading

compressive strength of concrete depends on water:cement ratio

If cycle time < load time there is always a truck waiting

stormwater erosion:
- sheet erosion
- rill erosion (NASA)
- gully erosion

6 psi tires in vehicles of streambanks

Need NPDES permit if it disturbs land

D x H x L

3 5/8" x 2 1/4" x 8"

+ MORTAR = 3/8"

STD NON-MODULAR

$N = \frac{A_W}{A_B} \times WF \times LAYERS$ (Area brick wall; Area brick; WASTE FACTOR)

FORMULAS AND DATA

Earthwork Construction and Layout

V = Volume of Earthwork in cubic yards or cubic feet.

1 cubic yard = 27 cubic feet

2000lb = 1 ton

L = Distance (spacing) between cross-sections in feet.

L = Length of a triangular spoil pile in feet.

R = Angle of Repose in degrees (a property of a soil).

B = Base width of triangular spoil pile in feet.

H = Height of a triangular or conical spoil pile in feet.

D = Diameter of a conical spoil pile in feet

A_i = cross section area in square feet

Average end area method: $V = (0.5)(A_1 + A_2)(L)/27$

Prismoidal formula: $V = (L/6)*(A_1 + 4A_m + A_2)$

Triangular Spoil Bank: $B = (4V/(L*\tan R))^{0.5}$

Triangular Spoil Bank: H = 0.5*B**tanR

Conical Spoil Pile: $D = (7.64V/(\tan R))^{0.33}$

Conical Spoil Pile: H = 0.5*D*tan(R)

Overhaul (cy-stations) = Overhaul volume (cy) * 0verhaul distance (stations)

Overhaul distance (stations) = Total haul – Free haul (stations)

Total haul = distance (stations) between centers of mass outside free haul

H = E/O = Excavation cost/Over haul cost

E = Excavation cost in $/cy

O = Overhaul cost in $/cy-ft

Length of economical haul = Free haul distance + H

DOUBLE WYTHE = 2 LAYERS

FORMULAS AND DATA

Earthwork Construction and Layout

Earthwork volume for a grid (in CF) = (Average cut depth in feet) * (Area of grid in SF)

If multiple grids, then sum volumes of each grid

Q = "Area in a section of a mass haul diagram in cy-stations

V = Maximum or minimum volume in CY that corresponds with the Q.

Average Haul distance = Q/V

Estimating Quantities and Costs

(FT) Outside Perimeter = 2 × (length + width + recess)

OP = 2(L + W + R)

(FT) Inside perimeter = OP – 8*footing width

(FT³) (FT) (FT²)
V = OP · A

IP = OP – 8w

(FT) Mean Perimeter = OP –4* footing width = IP +4* footing width

(FT) MP = OP – 4w = IP + 4w

BF = board foot = [Length (feet)]*[nominal size (inches x inches)]/(12 inches/foot)

SFCA = square foot of contact area FOR FORMS

FORMWORK = OP x H x 2 (INSIDE)

Formwork Conversions

To Obtain Gross area of Forms	Multiply Net Areas by
Industrialize Wall Forms	1.20
Table forms for slabs	1.10
Tunnel and half-Tunnel forms	1.15

1 CREW
1 MAN HR = 1 MEMBER OF CREW

FORMULAS AND DATA

Scheduling

INTERFERING FLOAT (IF) of activity j = (LATE FINISH (LF) of activity j) – (SMALLEST EARLY START (ES) OF ALL SUCCESSOR ACTIVITIES)

FREE FLOAT (FF) of activity j = (MINIMUM EARLY START (ES) OF ALL SUCCESSOR ACTIVITIES) – (EARLY FINISH of activity j)

TF = FF + IF — TOTAL FLOAT = FREE FLOAT + INTERF. FLOAT
TF = LS – ES — " = LATE START – EARLY START
TF = LF – EF — " = LATE FINISH – EARLY FINISH

Forward Pass = (EF) Early Finish$_n$ =(ES) Early Start$_n$ + (D) Duration$_n$

Backward Pass: = (LS) = Late Start$_n$ = (LF) Late Finish$_n$ – (D) Duration$_n$

Lag = the amount of time an activity must be delayed from the start of finish of a predecessor.

Lead = the amount of time by which an activity precedes the start or finish of a successor.

Four precedence relations ships are:

Finish to Start (FS)

Early Start (ES) $_{n+1}$ = Early Finish (EF)$_n$ + Lag

Late Finish (LF) $_n$ = Late Start (LS) $_{n+1}$ - Lag

Start to Start (SS)

Early Start (ES) $_{n+1}$ = Early Start (ES)$_n$ + Lag

Late Finish (LF) $_n$ = Late Start (LS) $_{n+1}$ - Lag

Finish to Finish (FF)

Early Start (ES) $_{n+1}$ = Early Finish (EF)$_n$ + Lag – Duration (D)$_{n+1}$

Late Finish (LF) $_n$ = Late Start (LS) $_{n+1}$ - Lag

Start to Finish (SF)

TYPE

MILESTONES → HAVE DURATION
DEPENDENCIES → HAVE ARROWS
BASELINE → ACTUAL PLAN
TIMELINE → MONTHS/DAYS/ETC.

Probable Production = capacity * Eff of 1 Fc / cycle time

Efficiency = Xmin/hr / 60min/hr

Start by Finding man-hours available w/ all crews working
EARLY START = LONGEST PATH

PRODUCTIVITY = # TEAM TOTAL MEN/CREW × EFF × [60 MIN/HR × 8 HR/DAY] × # FIXTURE / MIN TO INSTALL × [1 CREW / MEN]

CORRESPONDS TO

FORMULAS AND DATA

TEMPORARY STRUCTURES FORMWORK

P (psf) = C_c*C_w*(150 + 9000R/T) for R < 7 ft/hr and H < 14 ft

P (psf) = C_c*C_w *(150 + 43,400/T + 2800R/T) for H > 14 ft and 7 < R < 15 ft/h

Pmin (psf) = C_w*(600)

Pmax (psf) = (Unit Weight)*H

P = Concrete lateral pressue (psf)

W = Unit Weight of concrete use 150 pcf unless otherwise given.

H = Height of wall or column in feet.

R = Rate of placement of concrete in feet per hour

T = Temperature of concrete at time of placement in degrees Fahrenheit.

Concrete Unit Weight Coefficients (C_w) from ACI 347-04 Section 2.2, Table 2.1

Unit Weight of Concrete (w)	Cw
Less than 140 pcf	C_w = 0.5(1 + w/145) but not less than 0.8
140 to 150 pcf	1.0
More than 150 pcf	C_w = w/145

Concrete Chemistry Coefficients (Cc) from ACI 347-04 Section 2.2, Table 2.2

Cement Type	Slag	Fly Ash	Retarders	C_c
I, II, or III	None	None	None	1.0
			Included	1.2
Any	Less than 70 %	Less than 40%	None	1.2
			Included	1.4
	Greater than or equal to 70 %	Greater than or equal to 40 %	None	1.4
			Included	1.4

FORMULAS AND DATA

Reinforcement Bar Size and Weights

Bar #	Diameter Inch	Area (sq. in.)	Weight (lb/ft)
3	0.375	0.11	0.376
4	0.500	0.20	0.668
5	0.625	0.31	1.043
6	0.750	0.44	1.502
7	0.875	0.60	2.044
8	1.000	0.79	2.670
9	1.128	1.00	3.400
10	1.270	1.27	4.30
11	1.410	1.56	5.31
14	1.693	2.25	7.65
18	2.257	4.00	13.60

Construction Operations and Methods (P.M. Topic)

SCHEDULE VARIANCE = BCWP – BCWS

COST VARIANCE = BCWP – ACWP

BCWS = Budgeted Cost of Work Scheduled

BCWP = Budgeted Cost of Work Performed = Earned Value

ACWP = Actual Cost of Work Performed

LOADER PRODUCTION = (3600*Q*F*E)/[T*60*(1+SWELL)]

LOADER PRODUCTION = (3600*Q*F*E*W)/[T*60*2000]

Q = Heaped bucket capacity (LCY)

F = Bucket fill factor

E = Efficiency (minutes per hour)

T = Cycle time (seconds)

W = Aggregate weight (LB/CY)

FORMULAS AND DATA

<u>Worker Health, Safety and Environment (P.M. Topic)</u>

Incidence Rate = IR = 200,000N/EH

Incidence Rate = the number of recordable injuries and illnesses occurring among a given number of full-time workers (usually 100 full-time workers) over a given period of time (usually one-year).

N = Number of reportable injuries and illnesses.

EH = Employee Hours

EMR = Experience Modification Rate

EMR = A measure of how your accident loss prevention and control practices compare to other in the construction industry. The EMR compares your worker's compensation claims experience to other employers of similar size operating in the same type of construction business. An EMR of 1.0 indicates that you are at the industry average. An EMR of 0.75 indicates that you are 25% better than the industry average. An EMR of 1,25 indicates that you are 25% worse than the industry average.