Water Resources

- probability, $p = \frac{1}{F}$ F = recurrence interval, frequency

  $p = 1 - \left(1 - \frac{1}{F}\right)^n$ $p_{not} = 1 - p$ [pg. 5]

  $p(n,N) = \frac{N!}{n!(N-n)!} p^n (1-p)^{N-n}$ n occurrences
  N trials

- Discharge, $Q = \frac{V}{t}$ V = volume, direct runoff, area under curve
  * watch units $V = Qt$ t = time [pg. 7]

- water budget [pg. 13]
  Change in stored water, ΔS = Inflows − outflows
  $\Delta S = [P + Q_{in}] - [F + Q_{out}]$
  Inflows: precipitation, P; surface runoff, Q_{in}
  Outflows: infiltration, F; discharge, Q_{out}

  $\text{Depth} = \frac{\text{Volume}}{\text{Surface Area}}$

- time of concentration, t_c [pg. 14]
  $t = L/V$ $\downarrow T_c = \uparrow I = \uparrow Q$ [relationships pg. 15-16]

- rational equation [pg. 17] - peak flows
  $Q = CIA$
  Q_{peak} (ft³/sec) C - runoff coefficient (weighted) $\left(\Sigma C_i A_{di} / A_{Total}\right)$
  I - Storm intensity (in/hr) based on T_c A_d = drainage area (acres)

- curve number [pg. 20] - net rainfall
  $Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$ Q - depth (in)
  P - precipitation (in)
  $S = \frac{1000}{CN} - 10$ S - storage capacity (in)
  ↑CN ⇒ more runoff

  Volume = Depth × Area
  $V_{runoff} = Q_{runoff} \times A_d$

‖CLOSED CONDUIT‖

- continuity equation [pg. 27] $Q_{in} = Q_{out}$ $Q = Q_1 = A_1 v_1 = A_2 v_2 = Q_2$
  - Q - flow rate (ft^3/s)
  - A - cross sectional area (ft^2) $Q = vA$ $v = Q/A$
  - v - velocity (ft/s)
- bernoulli equation [pg. 28] - total energy head, H
  - $H\ (ft) = h_v + h_p + h_z$
  - velocity head, $h_v = v^2/2g$ (ft) (Kinetic energy)
  - pressure head, $h_p = P/\gamma$ (ft) $\gamma_{water} = 62.4\ lbf/ft^3$
  - elevation head, $h_z = z$ (potential energy)
  - friction loss, h_f
  - minor loss, h_m $H_1 = H_2 + h_f + h_m$

$$[h_{v_1} + h_{p_1} + h_{z_1}] = [h_{v_2} + h_{p_2} + h_{z_2}] + h_f + h_m$$

pump adds energy ; turbine removes energy

$$H_1 + h_{pump} = H_2 + (h_f + h_m) + h_{turbine}$$

- reynolds number [pg. 30] - friction losses
  - $Re = \frac{D_h v}{\nu^*}$ D_h = hydraulic diameter (ft)
  - V = velocity (ft/s)
  - ν^* = Kinematic velocity (ft^2/s)
  - $Re > 4000$ turbulent flow
- darcy-weisbach equation - friction head [pg. 31]
  - $h_f = \frac{fLv^2}{2Dg}$ h_f = friction head (ft)
  - f = Darcy's friction factor
    - laminar - $f = 64/Re$
    - turbulent - need Re & ε/D > Appendix
    - ε = specific roughness
  - L = length of pipe (ft)
  - V = fluid velocity (ft/s)
  - D = inside pipe diameter (ft)
  - $V = \sqrt{\frac{2Dgh_f}{fL}}$

$$\boxed{\frac{2.31\,ft}{psi}}$$

Water Resources, cont.

- hazen-williams equation [pg. 33] - turbulent flow only!

$$h_f = \frac{3.022 v^{1.85} L}{C^{1.85} D^{1.17}}$$

h_f = friction head (ft)
v = fluid velocity (ft/s)
L = pipe length (ft)
C = friction coefficient (Appendix
D = inside pipe diameter (ft)

$$v = \left(\frac{h_f C^{1.85} D^{1.17}}{3.022 L}\right)^{0.541}$$

$$\frac{\Delta P}{\gamma} = h_f$$

$$L = \frac{h_f C^{1.85} D^{1.17}}{3.022 v^{1.85}} \; ; \; D = \left(\frac{3.022 v^{1.85} L}{C^{1.85} h_f}\right)^{0.855} \; ; \; C = \left(\frac{3.022 v^{1.85} L}{D^{1.17} h_f}\right)^{0.541}$$

- equivalent lengths [pg. 35] $L_{TOTAL} = L_{actual} + \Sigma L_{equiv}$
- loss coefficients [pg. 36] $h_{minor} = K \frac{v^2}{2g}$
- pipe networks [pg. 37]

series - $h_{f\,total} = h_{fa} + h_{fb}$

parallel - $h_{fa} = h_{fb} = h_{f1-2}$

$Q_1 = Q_a + Q_b = Q_2$

OPEN CHANNEL FLOW

- mannings equation [pg. 42]

$$v = \frac{1.49}{n} R^{2/3} S^{1/2}$$

$$Q = vA$$

v - velocity (ft/s)
n - Manning's coefficient
R - hydraulic radius (ft)
$R = \frac{\text{area}}{\text{wetted perimeter}}$
S - slope of channel (ft/ft)
A - flow area (ft²)

most efficient trapezoid > $b = \frac{2d}{\sqrt{3}}$ $A = \sqrt{3} d^2$

most efficient rectangle > $d = \frac{w}{2}$

- normal depth [pg. 44] $d_n = 1.335\left(\frac{nQ}{\sqrt{S}}\right)^{3/8}$

  $Q_{full} = \frac{0.463 D^{8/3}\sqrt{S}}{n}$; $V_{full} = \frac{0.591 D^{2/3}\sqrt{S}}{n}$; $Q_{half\text{-}full} = 0.5 Q_{full}$

- given flow depth d, find Q or b - Appendix 19E

  $Q = \frac{K}{n} d^{8/3}\sqrt{S} \Rightarrow K = \frac{Qn}{d^{8/3}\sqrt{S}}$

- given bottom width b, find Q or d - Appendix 19F

  $Q = \frac{K'}{n} b^{8/3}\sqrt{S} \Rightarrow K' = \frac{Qn}{b^{8/3}\sqrt{S}}$

  [pg. 46]

- gutter flow [pg. 48]

  $Q = \frac{0.56}{n} S_x^{1.67} S^{0.5} T^{2.67}$

  $T = \frac{(1.79Qn)^{3/8}}{S_x^{5/8} S^{3/16}}$

  *spread into travel lane = T - gutter or shoulder width

  Q = flow rate in gutter (ft³/s)
  n = manning's n
  S_x = road cross slope (ft/ft)
  S = longitudinal (direction of flow) slope (ft/ft)
  T = spread, top width of flow (ft)

- sharp-crested weir [pg. 49] $Q = \frac{2}{3} C_1 b (H^{3/2}) \sqrt{2g}$

  $b_{actual} - 0.1NH = b_{effective}$

- trapezoidal weir [pg. 49] $Q = \frac{2}{3} C_d b (H^{3/2}) \sqrt{2g}$
- triangular weir [pg. 50] $Q = C_2 \left(\frac{8}{15} \tan\frac{\theta}{2}\right)(H^{5/2})\sqrt{2g}$
- broad-crested weir/spillway [pg. 50] $Q = C_s b \left(H + \frac{v^2}{2g}\right)^{3/2}$
- culvert flow classifications [pg. 54]

Structures & Materials

- shear & moment diagrams [pg.17]
  $\boxed{\text{Appendix 44.A pg. A-67 CERM}}$
- determinacy of trusses [pg. 26]
  m = number of members
  r = number of reactions
  j = number of joints
  $m+r < 2j \Rightarrow$ unstable
  $m+r = 2j \rightarrow$ statically determinate
  $m+r > 2j \rightarrow$ statically indeterminate
  check stability visually
- method of joints [pg. 30] - at each joint - $\Sigma F_H = 0$, $\Sigma F_V = 0$
  forces are applied loads, reactions & member forces
- method of sections [pg.31] - cut the tress into 2 sections
  each section is a free body diagram & in equilibrium
  cut into any direction through <u>3</u> members
- beam deflections [pg. 38]
  depends on beam type - see $\boxed{\text{CERM Appendix 44.A}}$
- axial stress $\sigma = \frac{P}{A}$ [pg.41]
- shear stress $v = \frac{V}{A}$ v_{max} rectangle $= \frac{3V}{2bh}$ [pg.41] $v = \frac{V}{t_w d}$ (steel)
  P = axial load V = shear (force units)
- bending (flexural stresses) [pg.43] $f_b = \frac{My}{I}$
  M = moment
  I = moment of inertia of cross section
  y = distance from neutral axis
  $f_{b,max} = \frac{Mc}{I} = \frac{M}{S}$
  $c = y_{max} = (h/2)$ $S = I/c$
  rectangle
  $I = \frac{bh^3}{12}$ $S = \frac{bh^2}{6}$
  $c = y_{max} = h/2$
- properties of concrete [pg.51]
  modulus of rupture $= f_r = 7.5\sqrt{f'_c}$
  shear strength $= V_c = 2\sqrt{f'_c}\,bd$
  modulus of elasticity $= E_c = 57000\sqrt{f'_c}$
  ★ $\boxed{\sqrt{f'_c} \Rightarrow psi}$ ★
  density = 150 pcf

- strength reduction factors [pg. 57]

  moment/flexure $\phi = 0.90$; shear $\phi = 0.75$

- rebar properties [pg. 58]

- concrete – force – couple system [pg. 60]

  $T_s = A_s f_y$

  $C_c = 0.85 f'_c a b$

  $C_c = T_s$

  rectangular beams

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

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

  – design moment capacity

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

  $\phi = 0.90$

  T-sections → effective width, b_e

  $a = \frac{A_s f_y}{0.85 f'_c b_e}$ compare to h_f

- shear resistance [pg. 82] $V_s = \frac{A_v f_y d}{s}$

  $V_u = \underset{\text{nominal}}{\phi V_n} = \phi(V_c + V_s)$

  V_u ↓ design applied

  $\phi = 0.75$

  $V_s = \frac{V_u}{\phi} - V_c$

  A_v = total stirrup area $= n * A_b$

  n = # of stirrup legs

  A_b = area of stirrup bar

  d = effective depth

  s = stirrup spacing

  f_y = yield strength

- stirrup spacing [pg. 83]

  $s = \frac{A_v f_y d}{(V_s)_{req}}$

- allowable soil pressure [pg. 91]

  $\frac{\text{service loads (DL, LL, etc)}}{\text{footing area}} \leq$ allowable soil pressure

- one-way bending shear [pg. 95]

  $V_c = 2\sqrt{f'_c}\, b d$ tributary area $= b \cdot x$

  $V_u = q_u$ (tributary area) $\phi V_c > V_u$

  $V_u = q_u \cdot b \cdot x$

  $\phi V_n = \phi(V_s + V_c) \geq V_u$

  $x = \frac{b}{2} - \frac{c}{2} - d$

  $V_s = 0$

Structures & Materials, cont

- two-way (punching shear) [pg. 99]

  $\phi V_n = \phi(V_s + V_c) \geq V_u$ find smallest V_c

  $V_u = q_u \times$ tributary area

- footing flexure [pg. 101]

  $q_u = \frac{P_u}{ab}$ $M_{A-A} = q_u b f \left(\frac{f}{2}\right)$

- columns [pg. 106]

  - non-sway (braced) frames

    $\frac{K_b L_u}{r} \leq 34 - 12\left(\frac{M_1}{M_2}\right) \leq 40$

  - sway (unbraced) frames

    $\frac{K_u L_u}{r} \leq 22$

- short column design [pg. 111]

  $e = 0$ $\phi P_0 = \phi[0.85 f'_c (A_g - A_{st}) + f_y A_{st}]$

  w/ ties $\phi P_n = 0.80 \phi [0.85 f'_c (A_g - A_{st}) + f_y A_{st}] \geq P_u$

  $\phi = 0.65$

  w/ spirals $\phi P_n = 0.85 \phi [0.85 f'_c (A_g - A_{st}) + f_y A_{st}] \geq P_u$

  $\phi = 0.75$

- Steel shear [pg. 130]

  $f_v = \frac{V}{t_w d}$; shear stress, $F_{v\,allowable} = 0.6 F_y / \Omega = 0.4 F_y$ $\Omega = 1.5$

  $F_{v\,ultimate} = \phi 0.6 F_y = 0.6 F_y$ $\phi = 1.0$

- deflection [pg. 133]

  $\Delta_{LL} \leq \frac{L}{360}$ $\Delta_{total} \leq \frac{L}{240}$

Geotechnical

- phase relationships - see table of equations in notes pgs. 2-3

- relative density - pg. 5

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}} \quad \text{OR} \quad D_r = \left(\frac{\gamma_d - (\gamma_d)_{min}}{(\gamma_d)_{max} - (\gamma_d)_{min}}\right)\left(\frac{(\gamma_d)_{max}}{\gamma_d}\right)$$

- coefficient of uniformity

$$C_u = \frac{D_{60}}{D_{10}}$$

- coefficient of curvature, C_c (or coef. of gradation, C_z)

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

- atterberg limits, LL, PL, PI

$$PI = LL - PL$$

- AASHTO Classification System
  notes pgs. 12-14
  need to calculate group index
- Unified soil classification system
  notes pgs. 15-20
- rock quality designation (RQD)

$$RQD = \frac{\Sigma \text{lengths of intact pieces of core} > 100\text{mm}}{\text{length of core advance}} \times 100\%$$

  see notes pg. 24 for descriptions
- Standard penetration test (SPT)
  N value = sum of blows for 2nd increment (6"-12") and 3rd increment (12" to 18") ⇒ # of blows per foot

- proctor laboratory tests → find maximum dry unit weight and optimum moisture content (pg. 34)

  $\gamma = \frac{W}{V}$ $\gamma_d = \frac{\gamma}{1+w}$

- field density tests (pg. 36)

  sand cone method ⇒ $V_{hole} = \frac{(W_0 - W_f) - W_{cone}}{\gamma_{sand}} = \frac{(W_0 - W_f)}{\gamma_{sand}} - V_{cone}$

  $\gamma_d = \frac{\gamma}{1+w} = \frac{W_{hole}}{V_{hole}(1+w)}$

  relative compaction, RC = $\frac{\text{field dry unit weight}}{\text{max dry unit weight}} = \frac{(\gamma_d)_{field}}{(\gamma_d)_{max}} \times 100\%$

- california bearing ratio (pg. 39) → harder surface, higher CBR

  $CBR = \frac{\text{actual stress}}{\text{standard stress}} \times 100$ $CBR_{0.1} = \frac{\sigma_{0.1}}{1000\,psi} \times 100$

  typically taken as $CBR_{0.1}$ where $CBR_{0.2} < CBR_{0.1}$ $CBR_{0.2} = \frac{\sigma_{0.2}}{1000\,psi} \times 100$

- subgrade modulus - slope of line of stress vs deflection modulus of subgrade reaction, K pg. 40

- resilient modulus, M_R pg. 41

  $M_R = (1500)CBR$ OR $M_R = 2555(CBR)^{0.64}$

- Correlations of expansive soils with Atterberg Limits pg. 42

- hydraulic conductivity in soils (pg. 50)

  $K = \frac{VL}{\Delta h A t}$ (coarse grained)

  $K = \left(2.303 \frac{aL}{At} \log_{10} \frac{h_0}{h_1}\right) = \left(\frac{aL}{At} \ln \frac{h_0}{h_1}\right)$

Geotechnical, cont.

- flow nets - pg. 53

  $Q = K\Delta h \frac{N_f}{N_d} L$

  N_f = # of flow channels in flow net

  N_d = # of potential drops

- vertical stress - pg. 55

  $\sigma_v = \sum \gamma_i z_i$

  σ_v = total vertical stress

  γ_i = total unit weight of soil layer(s)

  z_i = thickness of soil layer(s)

- pore water pressure - pg. 56

  $u = \gamma_w h_p$

  u = pore water pressure

  γ_w = unit weight of water

  h_p = pressure head at point of interest ($h_p = h - h_z$)

  hydrostatic case

  $u = \gamma_w z_w$

  u = pore water pressure

  γ_w = unit weight of water

  z_w = depth below groundwater surface

- effective vertical stress - pg. 58

  $\sigma_v' = \sigma_v - u$

  σ_v' = effective vertical stress

  σ_v = total vertical stress

  u = pore water pressure

- pressure distribution - pg. 59

  point load → $\Delta\sigma = \left(\frac{3P}{2\pi z^2}\right)\left(\frac{1}{1+(r/z)^2}\right)^{2.5}$

  If $r = 0$, $\Delta\sigma = \frac{3P}{2\pi z^2}$

  $\Delta\sigma$ = increase in vertical stress

  z = depth

  r = radial distance

  P = point load

- pressure distribution

uniform load ⇒ $\Delta\sigma = qI$ q = applied bearing pressure

pg. 59-66 $q = \frac{\text{load}}{\text{area}}$

Appendix 40.B
CERM

I = influence factor - see tables

- average vertical stress below footings pg. 67
- consolidation of NC clays - pg. 72

$$S_c = \sum\left(\frac{C_c}{1+e_0}\right)H\log\left(\frac{\sigma'_f}{\sigma'_0}\right)$$

S_c = primary consolidation settlement
σ'_0 = initial effective overburden pressure
H = thickness soil layer
C_c = compression index
σ'_f = final effective overburden pressure $(\sigma'_0 + \Delta\sigma)$
e_0 = initial void ratio

- consolidation of OC clays - pg. 74-75

$\sigma'_f \leq \sigma'_c$ OR $\sigma'_f > \sigma'_c$
case 1 case 2

- rate of consolidation - pg. 76

$$T_v = \frac{C_v t}{H_d^2}$$

T_v = time factor t = time
C_v = coefficient of consolidation
H_d = length of the drainage path
= $H/2$ for two-way drainage
= H for one-way drainage

- Shear strength - shallow spread foundations - pg. 79

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

τ = shear strength
σ' = effective stress normal to shearing plane
ϕ' = effective internal angle of friction
c' = cohesion

Geotechnical, cont.

- bearing pressure - shallow spread foundations - pg. 83
  - gross bearing pressure, $Q_g = \frac{P_g}{A}$
    P_g = gross vertical load $= P_{net} + W_c + W_s$
    W_c = weight of footing
    W_s = weight of soil
    A = area of applied pressure
  - net bearing pressure, $q_{net} = \frac{P_{net}}{A}$
    P_{net} = net vertical load
  - net allowable bearing pressure $(q_{net})_{all} = \frac{q_{net}}{FS} = \frac{(P_{net})_{all}}{A}$
    q_{net} = bearing capacity
- ultimate bearing capacity - pg. 84
  $q_{ult} = cN_c + \gamma D_f N_q + 0.5\gamma B N_\gamma$
  c = cohesion
  γ = unit weight of soil
  D_f = depth of footing
  B = width of footing
  N_c, N_q, N_γ based on ϕ of soil
- net bearing capacity - $q_{net} = q_{ult} - \bar{\gamma} D_f$
- net allowable bearing capacity - $(q_{net})_{all} = \frac{q_{net}}{FS}$
- ultimate bearing capacity w/ shape factors - pg. 87
  $q_{ult} = cN_cS_c + \gamma D_f N_q + 0.5\gamma B N_\gamma S_\gamma$
- bearing capacity in clay
  $q_{ult} = cN_cS_c + \gamma D_f$
  $q_{net} = cN_cS_c$ ← resting on clay
- undrained shear strength in clay
  $S_u = c = \frac{q_u}{2}$

- bearing capacity in sand

  $q_{ult} = \gamma D_f N_q + 0.5 \gamma B N_\gamma S_\gamma$

  $q_{net} = \gamma D_f (N_q - 1) + 0.5 \gamma B N_\gamma S_\gamma$

- effect of groundwater table on bearing capacity - pg. 91

  case 1 - $D_f \geq D_1 \geq 0$

  case 2 - $B > d > 0$ $[d = B]$

  case 3 - $d \geq B$

- eccentricity - pg. 93

  $e = \frac{M}{P}$ M = moment on footing

  P = vertical load on footing

- lateral earth pressure

  $K_0 \approx 1 - \sin\phi'$

  $p_a = K_a \gamma H - 2c\sqrt{K_a}$ $z_{cr} = \frac{2c}{\gamma\sqrt{K_a}}$ $R_a = \frac{1}{2} p_a H$

  $= \frac{1}{2} K_a \gamma H^2$

  $p_p = K_p \gamma H + 2c\sqrt{K_p}$ $R_p = \frac{1}{2} p_p H$

  $= \frac{1}{2} K_p \gamma H^2$

- Rankine - pg. 100

  $K_a = \tan^2(45° - \phi/2)$

  $K_p = \tan^2(45° + \phi/2)$ $\beta = 0$ (level) different cases pgs. 101 - 103

  case 1 - $R_a = \frac{\gamma H^2 K_a}{2}$ $M_a = R_a \frac{H}{3}$

- overturning about toe - pg. 107

  $FS_{OT} = \frac{\Sigma M_R}{\Sigma M_0}$ - resist overturning

  - cause overturning

- sliding - pg. 107 $FS_{SL} = \frac{\Sigma F_R}{\Sigma F_D}$ - resisting forces

  - driving forces

Geotechnical, cont.

- Slope stability - pg. 112

$$FS = \frac{N_0 c}{\gamma_t H}$$

N_0 = Stability number

γ_t = total unit weight of soil

$d = D/H$

c = cohesion (undrained shear strength)

H = height of slope

$$FS = \frac{\tan\phi}{\tan\beta}$$

Construction & Materials

- Swell [pg. 1-3]
  ↓
  a soil increases in volume when it is excavated

$$\text{swell\%} = \left(\frac{\text{Bank density}}{\text{loose density}} - 1\right) \times 100$$

$$\text{load factor} = \frac{\text{loose density}}{\text{bank density}}$$

} swell density

$$V_{\text{loose}} = \left(\frac{100\% + \%\text{ swell}}{100\%}\right) \times V_{\text{bank}} = \frac{V_{\text{bank}}}{\text{load factor}}$$

$$\text{load factor} = (1 + \text{decimal swell})^{-1}$$

$$\text{bank volume} = \text{loose volume} \times \text{load factor}$$

} swell volume

- Shrinkage [pg. 1-5] → a soil decreases in volume when it is compacted

$$\text{shrinkage \%} = \left(1 - \frac{\text{Bank density}}{\text{compacted density}}\right) \times 100$$

$$\text{shrinkage factor} = 1 - \text{shrinkage (\% decimal)}$$

} shrinkage density

$$V_{\text{compacted}} = \left(\frac{100\% - \%\text{ shrinkage}}{100\%}\right) \times V_{\text{bank}}$$

$$\text{compacted volume} = \text{bank volume} \times \text{shrinkage factor}$$

} shrinkage volume

- dry unit weight [pg. 1-9]

$$\text{dry unit weight} = \frac{\text{total unit weight}}{(1 + \text{water content})}$$

$$\text{shrinkage factor based on dry unit weight} = \frac{\text{volume of compacted material}}{\text{volume of borrow material}}$$

> dry unit weight values

- relative compaction [pg. 1-10]

$$RC = \frac{100 \times \text{field dry density (PCF)}}{\text{laboratory maximum dry density (PCF)}}$$

$$(\text{required fill}) \times (\text{compaction \%}) \times (\text{relative compaction})^{-1} = \text{excavated volume (borrow)}$$

- OSHA Soil classification [pg. 1-24]
  - type A max slope 3/4:1 (53°)
  - type B max slope 1:1 (45°)
  - type C max slope 1½:1 (34°)
  - * layered soils [pg. 1-25]

- average end area [pg. 1-28]

  $V = \frac{L(A_1+A_2)}{2}$ if end area is small or 0, $V_{pyramid} = \frac{LA_{base}}{3}$ [pg. 1-31]

  prismoidal formula → if end areas differ greatly or ground surface is irregular $V = \frac{L}{6}(A_1+4A_m+A_2)$ [pg. 1-33]

- surveying [pg. 1-38]

  BM + BS = HI ; HI - FS = TP elevation

- trigonometric leveling [pg. 1-41]

  $elev_{BM} = elev_R + HI - [(\text{Horizontal Distance})\tan\alpha] + BS$

  $elev_R = elev_{BM} - HI + HD\tan\alpha + BS$

- geometric properties [pg. 2-57]

  $X_{inside} = X_{outside} - 2(\text{thickness})$; $Y_{inside} = Y_{outside} - 2(\text{thickness})$

  cross sectional area $= 2(\text{thickness})(X_{outside} + Y_{inside})$

  $= 2(\text{thickness})(X_{inside} + Y_{outside})$

  outside perimeter $2(X_{out} + Y_{out})$

  inside perimeter $2(X_{in} + Y_{in})$

  w/ recesses along face:

  outside perimeter = (2)(length + width + recess)

  inside perimeter = outside perimeter + [(4)(2)(-thickness)]

  mean perimeter = outside perimeter - [(4)(2)(thickness/2)]

- wire-rope stretch [pg. 3-12]

  constructional stretch = const. stretch % x length

  elastic stretch $= \frac{PL}{AE}$

  P = change in load

  L = length

  A = area of steel

  E = modulus of elasticity

- project scheduling [pg. 4-2]

  $duration_{activity} = \frac{\text{area}}{\text{productivity} \times \text{crew size}}$

concrete compressive strength [pg. 5-32] $f'_c = P/A$

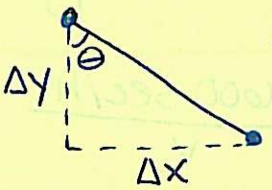
concrete tensile strength [pg. 5-33] $f_{ct} = \frac{2P}{\pi DL}$

Geometrics (Transportation)

- bearings - by quadrant NW|NE / SW|SE
- azimuths - from north & clockwise

> [pg.2]

- latitude - north (+) south (-)
- departure - east (+) west (-)



Δy - lat - $\cos\theta$
Δx - dep - $\sin\theta$
[pg. 3]

- horizontal curves [pg.5]

  $\boxed{\text{CERM equations 79.1-79.10 Fig. 79.1 pgs. 79-2 \& 79-3}}$

- horizontal curve stationing

  $\boxed{\text{CERM equations 79.11 \& 79.12 pg. 79-3}}$

  $PC = PI - T$; $PT = PC + L$

- vertical curves [pg.8]

  $\boxed{\text{CERM equations 79.46-76.49 Fig. 79.10 pgs. 79-11 \& 79-12}}$

  $R = \frac{G_2 - G_1}{L_{sta}}$; $x = -G_1/R$; highest point location $= BVC_{sta} + x$

  $elev_{@x} = (R/2)x^2 + G_1(x) + BVC_{elev}$

  tangent slope $= G_1 + \left(\frac{G_2 - G_1}{L}\right)x$

  $L = KA$ $\quad A = |G_2 - G_1|$

  K ⇒ crest $\boxed{\text{CERM Fig. 79.13}}$
  sag $\boxed{\text{CERM Fig. 7915}}$
  > or HCM

- speed characteristics [pg.11]

  time mean speed $S_t = \frac{\Sigma S_i}{n}$

  space mean speed $S_s = \frac{nL}{\Sigma t_i}$

- Speed, flow & density relationships [pg. 14]

$$\text{density}, D = \frac{V}{S}$$

V = flow / rate of flow / volume

S = space mean speed

$\boxed{\text{CERM pg. 73-6}}$

$$\text{spacing in ft} = \frac{5280\ \text{ft/mile}}{D}$$

$$\text{headway} = \frac{3600\ \text{sec/hr}}{V} \qquad \text{headway} = \frac{\text{spacing}}{S}$$

- Speed, distance, time & acceleration relationships [pg. 15]

$\boxed{\text{CERM pg. 71-4 Table 71.1}}$ uniform acceleration formulas

- Volume parameters [pg. 17]

AADT = total yearly volume / 365

= 24 hr count * daily variation factor * monthly variation factor

DHV = K-factor * AADT

DDHV = D * DHV

= D * K * AADT

$$\text{D-factor} = \frac{\text{peak direction hourly volume}}{\text{two-way hourly volume}}$$

$$\text{PHF} = \frac{\text{actual hourly volume}}{\text{peak rate of flow}} = \frac{V_{vph}}{4 * V_{15\,min\ peak}} \le 1$$

$\boxed{\text{CERM pgs. 73-4 \& 73-5}}$

Hi Bree!

Transportation

- density, $D = \frac{V_p}{V}$ V_p = flow rate
  V = velocity/speed

spacing = $\frac{1 \text{ mi-lane}}{D}$

distance between cars = spacing - average car length

- peak hour flow rate, $V_p = \frac{V}{(PHF)(\text{no. of lanes}) f_{HV} f_p}$

  V = volume

  PHF = peak hour factor $f_p = 1.0$ for commuter traffic

  $f_{HV} = \frac{1}{1+P_T(E_T-1)+P_R(E_R-1)}$ $\boxed{\text{HCM pg. 11-15 for } E_T, E_R}$

  $= \frac{1}{1+P_{HV}(E_{HV}-1)}$ if RV percentage is 1/5 of trucks and buses counted together

- LOS freeway
  - calculate f_{HV}
  - calculate V_p
  - Calculate $FFS = 75.4 - f_{LW} - f_{LC} - 3.22\,TRD^{0.84}$ $\boxed{\text{HCM pg. 11-11}}$
    - f_{LW} = lane width adjustment HCM 11-8
    - f_{LC} = right side lateral clearance adjustment HCM 11-9
    - TRD = total ramp density pg. 11-12
  - Calculate density, $D = \frac{V_p}{FFS}$
  - use HCM 11-5 to find LOS $\boxed{\text{HCM pg. 11-7}}$

- geometric design - shift forward tangent, keep PC station, new radius? (6min #11)
  - given PI station - find $T = R_1 \tan(I/2)$
    - find $PC_{sta} = PI_{sta} - T$
    - find new tangent length (δ = added length)
      $\delta T = \frac{\text{offset}}{\sin I}$ new $T = T + \delta T$
    - find new $R_2 = \frac{\text{new } T}{\tan(I/2)}$

- minimum radius given superelevation, e%.

$$\frac{e}{100} + f_{max} = \frac{V^2}{15R} \; ; \; R = \frac{V^2}{15(\frac{e}{100} + f_{max})}$$

find f_{max} Green BOOK pg. 3-31 & 3-32

- position of low point - vertical curve

$$x = \frac{G_1 L}{G_1 - G_2}$$

- queue length / time to clear (6 mins # 27, 28)

total queue = Σ arrivals - Σ departures

= arrivals during blockage + arrivals during queue dissipation

- departures during lane blockage

- departures during queue dissipation

- braking distance

$S_b = S_s - S_r$ S_b = braking distance ; S_s = total distance

S_r = perception-reaction distance

$$S_r = vt$$

$$S_b = \frac{v_1^2 - v_2^2}{2(f+G)} \; ; \; f = \frac{v_1^2}{2gS_b}$$

- Speed between station (6 mins # 30)

$$S_{total} = S_{accel} + S_{decel} + S_{running}$$

$$S_{accel} = \frac{V^2 - V_0^2}{2a} \; ; \; S_{decel} = \frac{V^2 - V_0^2}{2d} \; ; \; S_{running} = S_{total} - S_{accel} - S_{decel}$$

$$t_{accel} = \frac{V - V_0}{a} \; ; \; t_{decel} = \frac{V - V_0}{d} \; ; \; t_{running} = \frac{S_{running}}{V}$$

find $t_{total} = t_{accel} + t_{decel} + t_{running}$

$$V = \frac{S_{total}}{t_{total}}$$

remember units

Transportation, cont.

- crosswalk width - $\boxed{\text{HCM pg. 23-11}}$

$$V_p = \frac{V_{15}}{(15\,\text{min})W_e} \qquad V_{15} = \frac{V}{4(PHF)} \qquad W_E = \frac{V_{15}}{15 V_p}$$

- parking spaces (6 mins # 40-43)

$$\text{no of spaces} = \left(\frac{\text{total lot area}}{\text{area needed per space}}\right)\left(\begin{matrix}\text{proportion of}\\ \text{area usable}\end{matrix}\right)$$

- Webster's method - cycle length (6 mins # 45)

$X_i = \frac{V_i}{C_i}$ X= flow ratio C= capacity (vph)

V= volume (vph)

$CS = \sum X_i$ CS= critical sum

$C_0 = \frac{(1.5)L + 5\,\text{sec}}{1 - CS}$ C_0 = optimal cycle length

L= lost time per cycle

- Saturation flow rate

$\boxed{\text{HCM pg. 18-35 - 18.38}}$ - signalized intersection

- superelevation transition (6 mins # 68-69)

If normal slope is same direction as superelevation for that curve (i.e. normal slope down to right & full superelevation for right hand curve → no reverse cross slope)

required slope transition = full super - normal slope ⇒ $e_{full} - e_{normal}$

$$\text{min. transition time} = \frac{\text{required slope transition}}{\text{slope change rate}}$$

length of superelevation L_{min} = (min transition time)(speed) ↗ ft/sec

edge profile change Δe = (pavement width)(slope change) ↘ $e_{full} - e_{normal}$

$L = \Delta e$ (change rate)

- find coordinate of PT given PI (6 min # 71)
  - find $T = R\tan(I/2)$
  - $N_{PT} = N_{PI} + T\sin(90° - \text{bearing angle})$
- bearing of ahead tangent (6 min # 72)

  $T = \sqrt{(N_{p1} - N_{pc})^2 + (E_{p1} - E_{pc})^2}$; $I = 2\arctan(T/R)$

  bearing $= 90° - 43°$
- external distance for spiral cure (6min # 76)

  $E = (R+p)(\sec I/2) - R$

  $p = y - R(1 - \cos I_s)$

  $y = \frac{L_s^2}{6R}$ $\quad I_s = \left(\frac{L_s}{200}\right)\left(\frac{(180°)(100)}{\pi R}\right)$
- spirals (6min # 77-80)

  $e_{change} = e_{full} - e_{normal}$

  $\Delta e = e_{change}\, w(\#\text{ of lanes})$ $\quad w =$ lane width

  $L = (\Delta e)G_r$ $\quad G_r =$ edge transition rate

  spiral offset, $p = y_s - R(1 - \cos I_s)$

  $y_s = \frac{L_s^2}{6R}$ $\quad I_s = \left(\frac{L_s}{200}\right)(D)$
- vertical curve

  $L = \frac{AS^2}{2158}$ $\quad A = |G_1 - G_2|$; $S > L$ $\quad L = 2S - \frac{2158}{A}$

  $L = KA$

  $S = \sqrt{\frac{2158L}{A}}$

  Stopping sight distance

  $L = \frac{AS^2}{400 + 3.5S}$ OR $L = 2S - \frac{400 + 3.5S}{A}$

Transportation, cont.

- sight obstruction (6 min #84)

  $Z_{clearance} = \text{edge clearance} + \frac{\text{lane width}}{2}$

  $M = R\left(1-\cos I/2\right)$ $\frac{M}{R} = 1-\cos I/2 \rightarrow \text{find } I$

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

- Skid & friction factor

  $S = \frac{V_0^2}{2g(f+G)}$; $V_0 = \sqrt{(\text{skid distance})(2g)(f+G)}$

  $S = \frac{V_1^2 - V_2^2}{2d} = \frac{V_1^2 - V_2^2}{2g(f+G)}$; $V_2 = \sqrt{V_1^2 - S_b(30)(f+G)}$

- Segment crash rate, $R = \frac{(\#\text{ of injury accidents})(10^8)}{(\text{ADT})(\text{no. of years})(365\ \frac{\text{days}}{\text{yr}})L}$

- pedestrian service time $\boxed{\text{HCM pg. 18-67}}$

  If crosswalk width >10' - eq. 18-65

  If crosswalk width <10' - eq. 18-66

- Offset $= t = \frac{L}{S}$ (block length ft) / (veh. speed ft/s)

- SSD - sag vertical curve - $\boxed{\text{Green Book pg. 3-161 Table 3-36}}$

  $L = KA$ K from table

  $A = |G_2 - G_1|$

  - crest vertical curve - $\boxed{\text{Green Book pg. 3-155 Table 3-34}}$

    $L = KA$ K from table

    $A = |G_2 - G_1|$

- delineator spacing - $\boxed{\text{MUTCD Table 3F-1 pg. 478}}$

  $S = 3\sqrt{R-50}$

- walkway LOS – [redacted] GB pg. 23-3
  - exhibit 23-1 LOS for walkways
  - exhibit 23-2 LOS for platoons
- peak flow rate, $V_p = \frac{V}{PHF}$ V = volume = ADT × peak hour volume
- horizontal curve – minimum radius
  [redacted] GB pg. 3-32 table 3-7 $R_{min} = \frac{V_D^2}{15(0.01e_{max} + f_{max})}$
- PSD – crest vertical curve – [redacted] GB pg. 3-157 table 3-35
  $K = L/A$
- rate of superelevation OR side friction factor
  $f = \frac{V^2}{15R} - 0.01e$; $e = \frac{V^2}{15R} - f$ [redacted] GB pg. 3-20 eqn. 3-7
- minimum ramp acceleration lengths
  Green Book pg. 10-110 table 10-3 *watch headings
- RxR sight distance – $d_H = AV_v t + \frac{BV_v^2}{a} + D + de$
  Green Book pg. 9-187 eqn 9-3 OR table 9-32 pg. 9-191
- horizontal sight distance
  $S = 1.47vt + 1.075\frac{V^2}{a} \rightarrow M = R\left(1 - \cos\left(\frac{28.65S}{R}\right)\right)$
- position of high point – vertical curve
  $R = \frac{G_2 - G_1}{L_{sta.}} \rightarrow X = \frac{-G_1}{R}$
  $BVC_{sta} = PVI_{sta} - L/2_{sta} \rightarrow \text{turning point}_{sta} = BVC_{sta} + X_{sta}$

Transportation, cont.

- intersection crash rate, $R = \dfrac{\#\text{ crashes} \times 10^6}{ADT \times yrs \times 365}$

- tangent slope - vertical curve

  $y' = G_1 + \left(\dfrac{G_2 - G_1}{L_{sta}}\right) x_{sta}$ G_1 & G_2 as %

  give y' as %

- weaving density - $\boxed{\text{HCM pg. 12-23, eq. 12-22}}$ $D = \dfrac{(V/N)}{S}$

  V = volume

  N = # of lanes

  S = speed

- Intersection capacity - $\boxed{\text{HCM pg. 18-41, eq. 18-15}}$ $C = Ns(g/C)$

  N = # of lanes

  S = saturation

  g = green time effective

  C = cycle length

  - S ⇒ saturation flow rate = 3600/hr
    - in formula = $\dfrac{3600}{\text{headway}}$
  - green time effective = green time + yellow time - start up lost time - clearance lost time

- horizontal sight distance on curves

  $HSO = R\left[1 - \cos\dfrac{28.65S}{R}\right]$ R = radius, S = SSD OR $\boxed{\text{GB pg. 3-108, Fig. 3-22b}}$

- compound curves - given bearings, length between and radius_1 - find radius_2
  - calculate $\Delta_1 = \text{bearing}_{\text{between}} \pm \text{bearing}_1$ *   *-draw out
  - calculate $T_1 = R_1 \tan(\Delta_1/2)$
  - T_2 = length between - T_1
  - $\Delta_2 = \text{bearing}_{\text{between}} \pm \text{bearing}_2$ *
  - $R_2 = T_2 / \tan(\Delta_2/2)$

- vertical clearance - @ PVI

$E = \frac{AN}{8}$ E = external distance from PVI to curve
$A = |G_1 - G_2|$
N = length of curve stations

Clearance ⇒ elevation of PVI − E + clearance = elevation of object

- design widths of pavement - ramps too

$\boxed{\text{GB pg. 3-103 Table 3-29}}$ follow chart
don't forget edge conditions

- minimum ramp acceleration lengths

$\boxed{\text{GB pg. 10-110 Table 10-3}}$

- crash cushion (notes pg 92-93)

$V_1 = \frac{M_v V_0}{M_v + M_1}$ V_1 = velocity after impact (ft/s)
M_v = mass of vehicle (lbs)
V_0 = original velocity (ft/s)
M_1 = mass of sand barrel (lb)

- $$SSD = \underbrace{1.47V_{mph}t}_{\text{brake reaction distance}} + \underbrace{\frac{V^2_{mph}}{30\left(\left(\frac{a}{32.2}\right) \pm G\right)}}_{\text{braking distance}}$$

t = 2.5 sec
$a = 11.2\ ft/sec^2$
G = decimal grade
$\left(\frac{a}{32.2}\right)$ can be replaced w/ f

if $G = 0$ $SSD = 1.47V_{mph}t + 1.075\frac{V^2_{mph}}{a}$

Braking or skidding distance

$$D = \frac{V_0^2 - V_f^2}{30\left(\frac{a}{32.2} \pm G\right)}$$

Transportation, cont.

- decision sight distance

  GB pg. 3-7 table 3-3 → based on avoidance maneuver → urban or rural

- passing sight distance

  GB pg. 3-9 table 3-4 → based on passing vehicle speed

- Superelevation transitions - pg. 21

  tangent runout, $T_R = \frac{wp}{SRR}$

  superelevation runoff, $L = \frac{we}{SRR}$

  w = lane width
  p = cross slope
  e = superelevation
  SRR = superelevation runoff rate

  If SRR not given, L from GB pg. 3-64 table 3-17

- spiral curves - pg. 24

  CERM pgs. 79-18 → 79-20

- compound curves - pg. 25-28

- fixed point on vertical curve pg. 37-38

  $$Z = \sqrt{\frac{\text{Elev}A - \text{Elev}C}{\text{Elev}A - \text{Elev}B}} \qquad L = \frac{2w(Z+1)}{Z-1}$$

  w in stations
  L in stations

  If object to left of PVI - B on G_1, C on G_2

  If object to right of PVI - B on G_2 elev $B = (\text{elev})_{pvi} + wG_2$

  C on G_1 elev $C = (\text{elev})_{pvi} + wG_1$

- fixed point located @ turning point along curve

$$L = \frac{2(G_2 - G_1)(Elev_{PVI} - Elev_{TP})}{G_1 G_2}$$

- intersection sight distance - pg. 41 GB pgs. 9-28 → 9-41
  - Case A - no control table 9-3
  - Case B - minor road stop control
    - B1 - left turns - table 9-5
    - B2 - right turns > table 9-7
    - B3 - crossing

$ISD = 1.47V_{major}\,\textcircled{t_g}$ - from tables

pay attention to notes below tables for multi lane highways & approach grades

*add median widths

- minimum ramp terminal spacing

GB pg 10-106
Figure 10-68

- roundabouts - GB pg. 9-167 → 9-176

- demand flow rate $v_p = \frac{V}{PHF \times N \times f_{HV} \times f_p}$

- service flow rate = $SF = MSF \times N \times f_{HV} \times f_p$ HCM Eq. 11-9

  maximum flow rate, MSF - HCM exhibit 11-17

- service volume = $SV = SF \times PHF$ HCM Eq. 11-10

- daily service volume = $DSV = \frac{SV}{K \times D}$ HCM Eq. 11-11

SF & SV → single direction of freeway per hour

DSV → total volumes both directions per day

Transportation, Cont.

- capacity analysis
  - freeways - HCM Chap 11
    LOS criteria is density
  - multi-lane highways (undivided) - HCM Chap 14
    LOS criteria is density
  - pedestrians - Chap 23 HCM
    LOS criteria is flow rate
    need effective walkway width
    platoon adjustments
  - signalized intersections
    HCM Chap 18
    LOS criteria is control delay per vehicle

- Change Interval (yellow)

$$y = t + \frac{V}{2a + 2Gg}$$

y = length of yellow interval (sec)
t = perception/reaction time (1 sec)
V = velocity (ft/s)
a = deceleration (10 fps)
g = 32.2 ft/s²
G = grade %/100

- clearance interval (all-red)

$$r = \frac{W + L}{V}$$ no peds

OR

$$r = \frac{P + L}{V}$$ w/ peds

r = Length of red clearance interval (sec)
W = width of intersection (ft)
P = " "
L = Length of vehicle (20')
V = velocity (fps)

- cycle length - **HCM Chap 18**

$$C = \frac{L \times X_c}{X_c - \sum y_i}$$

L = lost time
X_c = v/c ratio
$\sum y_i = (v/s)_1 + (v/s)_2 \ldots$
v/s = volume to saturation flow rate

- optimum (effective) green time

$$g = \left(\frac{v}{s}\right)\left(\frac{C}{X_c}\right)$$

- phase length = effective green time of the phase + lost time of the phase

  * add all phase lengths should equal cycle length

- minimum cycle length (use $X_c = 1.00$)

$$C = \frac{L \times X_c}{X_c - \Sigma y_i}$$

- intersection delay - $\boxed{\text{HCM Eq. 18-48}}$

$$d_I = \frac{\Sigma d_A v_A}{\Sigma v_A}$$

- pavement design - ESALs - notes pg. 95
  - growth factor, $GF = \left[\frac{(1+r)^n - 1}{r}\right]$ r = growth rate, n = design period (yrs)
  - create table

truck class (1)	AADT (2)	% AADT (3)	days per year (4)	GF (5)	Design Traffic (6)	ESAL factors (7)	ESALs (8)
					2x3x4x5	table	6x7 then sum ESALs

  - ESALs in peak direction & design lane

$W_{18} = D_D D_L \overline{w}_{18}$

D_D = distribution factor

$D_L = 0.90$

$\overline{w}_{18}$ = total design ESALs

- flexible pavement - goal is to design Structural Number $\boxed{\text{CERM eq 76-33}}$

- pavement thickness

$\boxed{\text{CERM eq. 76-29 pg. 76-18}}$ $SN = D_1 a_1 + D_2 a_2 m_2$

for given SN & material characteristics $D_2 = \frac{SN - D_1 a_1}{a_2 m_2}$

Transportation, cont.

- rigid pavement design
  - Similar to flexible design
    - estimate ESALs
    - determine pavement thickness

      CERM pgs. 77-6 → 77-7
      Figure 77.2

- parking lot spaces

  CERM pgs. 74.18 - 74.19

  $\text{area}_{\text{stall}} = \text{width}_{\text{stall}} (L_{\text{stall}} + \frac{1}{2} W_{\text{aisle}})$

  $\# \text{ of stalls} = \frac{\text{area of site}}{\text{total stall area}}$

  \# of accessible parking spaces

  CERM table 74.13 pg. 74.19

- pedestrian facilities

  GB pgs. 4-61 thru 4-65

- turning radii of design vehicles

  GB Section 2.1.2 Table 2-26
  Figures 2-1 thru 2-23