Simplified

$V_c = \phi_c \lambda \beta \sqrt{f'_c}\, b_w d_v$

- $\lambda = 1$ (normal), 0.85 (semi-low), 0.75 (low)
- $\sqrt{f'_c} \le 8$ MPa
- $d_v = \max[0.9d, 0.72h]$

$V_s = [\phi_s A_v f_y d_v \cot\theta] \cdot 1/s$

- $A_v = A_b \cdot$ # of legs in stirrup

$V_{s\,req'd} = V_f - V_c = \phi_s A_v f_y \cdot \dfrac{d_v \cot\theta}{s}$

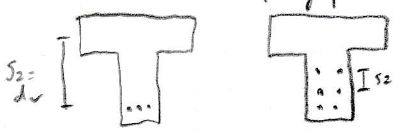
- $d_v \cot\theta / s$ is # stirrups crossing crack

$\therefore S_{req'd} = \dfrac{\phi_s A_v f_y d_v \cot\theta}{V_f - V_c}$

- If special member (is below), $\beta = 0.21$, $\theta = 42$
  - Slab w/ $t \le 350$
  - Beam w/ $t \le 250$
  - Concrete joist
  - Beam cast integrally w/ slab, and depth of beam below slab $< [1/2$ web width or $350]$
- If at least the min transverse reinforcement, $\beta = 0.18$, $\theta = 35$
- If no transverse reinforcement & CA > 20mm, $\beta = \dfrac{230}{1000 + d_v}$, $\theta = 35$
- If no transverse reinforcement & all CA, $\beta = \dfrac{230}{1000 + S_{ze}}$, $\theta = 35$

↳ $S_{ze} = \dfrac{35\, s_z}{15 + CA_{max}} > 0.85\, s_z$ $= 300$ if $A > A_{v\,min}$,

↳ S_z is crack spacing parameter



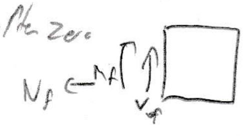
Note:

- $V_{r\,max} = 0.25\, \phi_c f'_c b_w d_v$ (crushing)
- $A_{v\,min} = \dfrac{0.06 \sqrt{f'_c}\, b_w s}{f_y}$ (strength maintained after crack) } Either could define max spacing
- $S_{max} = \min[600, 0.7 d_v]$. $(V_f < 0.125 \lambda \phi_c f'_c b_w d_v)$
- $S_{max} = \min[300, 0.35 d_v]$ $(V_f >$ ")
- Take shear and moment w/ clear span
  - $V_{f\,end} = [w_f l_n]/2$, $V_{f\,int} = L_f l_n / 8$
  - M at support dependent on attached graphs

General

$\beta = \left[\dfrac{0.4}{1 + 1500\, \varepsilon_x}\right] \cdot \left[\dfrac{1300}{1000 + S_{ze}}\right]$

- $\varepsilon_x = \dfrac{\frac{M_f}{d_v} + V_f + 0.5 N_f}{2 E_s A_s}$ ← often zero



- $\theta = 29 + 7000\, \varepsilon_x$

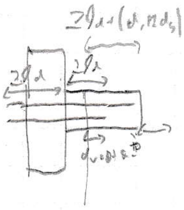
Procedure

1. Shear force and BMD
2. Check if stirrups req'd (and check $V_{r\,max}$)
3. Check max spacing (A_s and $s_{req'd}$)
4. Determine s to resist V_f'
5. Check at several locations
6. Final check

X	X_1	X_2	X_3
V_f'			
M_f'			
A_s			
$S_{req'd}$			

Reinforcing Detailing Procedure

1. Design flexural reinforcement for max moments
2. Select # of bars to cutoff
   - Not more than 50% of A_s @ one location
   - Positive moment steel to support,
   - Negative moment steel to POI
3. Calculate M_r for cutoff locations
4. Find theoretical cutoff points (flexure alone)
   - Where $M_f = M_r$ for continuing steel
   - POI
5. Determine actual cut-off locations
   - All bars must extend past theoretical point by $d_v \cot\theta$ (12.10.3),
   - Supports (12.11.1)
     - → If simply supported, 1/3 of $A_{s,total}$ must continue into support
     - → If continuous, 1/4 of $A_{s,total}$ must continue into support
     - → Bars must extend @ least 150 mm into support, l_{embed} = column width − end cover
     - → longitudinal reinforcement must be capable of resisting T_f due to shear (11.3.9.5)
       - $T_f = (V_f - V_s/2)\cot\theta$
         - ↳ $V_f = w_f L/2$, V_s = stirrups
       - $l_{embed,req'd} = \dfrac{T_f}{\phi_s A_s f_y} l_d$
     - → For negative moment (12.12.1), must be anchored at least l_d
   - Points of inflection (12.12.2)
     - → At least 1/3 of $A_{s,tot}$ must be embedded beyond POI by max$[d, 12d_b, l_n/16]$
6. Additional requirements
   - General anchorage: all bars must extend l_d past M_{max} (12.1.1)
   - Continuing reinforcement must pass theoretical cutoff point by max$[l_d + d, l_d + 12d_b]$
     - → Length of continuing bars = $L_{span} + b_{col} - 2$ cover
     - → Extension of A bars past B = $\frac{1}{2}L_A - x_1$
   - For positive moment bars, develop as follows at zero-moment locations:
     - → $1.3\, M_r/V_f + l_a \geq l_d$
     - → l_a = 1/2 col − cover
   - Lap splice
     - → Min lap splice is 300 mm
     - → 35M + cannot be spliced
     - → Class A splice: $1.0\, l_d$
     - → Class B splice: $1.3\, l_d$
     - → Class A if area of reinforcement provided is at least 2x req'd by analysis at splice location, and less than 1/2 of total reinforcement is spliced w/in required lap length



$$l_d = 1.15\,\frac{k_1 k_2 k_3 k_4}{d_{cs} + K_{tr}} \cdot \frac{f_y}{\sqrt{f'_c}} A_b$$ (Development Length Tension)

- $d_{cs} + K_{tr} \leq 2.5 d_b$
- $K_{tr} = \dfrac{A_{tr} f_{yt}}{10.5\, s n}$ (Stirrup Strength Factor)
  - → A_{tr} = area of stirrups (transverse reinforcement)
  - → f_{yt} = yield strength stirrups
  - → n = # bars developed
  - → s = stirrup spacing
  - → d_{cs} = min[min cover → centre of developed bar, 2/3 c/c bar spacing]
- Note: $l_d \geq 300$

If clear cover ≥ d_b, clear spacing ≥ $1.4 d_b$

$l_d = 0.45 k_1 k_2 k_3 k_4 \dfrac{f_y}{\sqrt{f'_c}} d_b$ (Min transverse reinforcement, slab or wall w/ clear spacing ≥ $2d_b$)

$l_d = 0.6 k_1 k_2 k_3 k_4 \dfrac{f_y}{\sqrt{f'_c}} d_b$ (Other)

- $k_1 = 1.3$ (top bar), 1.0 (else) (Bar location factor)
- $k_2 = 1.0$ (not coated), 1.2 (Bar coating factor)
  - → 1.5 if epoxy coated w/ clear cover < $3d_b$ or clear spacing < $6d_b$
  - → 1.2 for other epoxy
- $k_3 = 1$ (normal), 1.2 (semi-low), 1.3 (low) (Density factor)
- $k_4 = 0.8$ (No. 20 and lower), 1 (25+) (Bar size factor)
- $k_1 k_2 \leq 1.7$

$l_{db} = 0.24 d_b\, f_y/\sqrt{f'_c} \geq 0.044 d_b f_y$ (Basic Development Length Compression)

l_d = Mod factor × l_{db} ≥ 200 mm (Development length Compression)

↳ Mod factor = 0.75 (longitudinal bar in spiral column)

If bundled bars, ↑ l_d of single bar by 1.1 (2 bars), 1.2 (3 bars), 1.33 (4 bars)

If hooked bar in tension, ↓ development length. Basic $l_{hb} = \dfrac{100 d_b}{\sqrt{f'_c}}$ (f_y = 400 MPa)

↳ $l_{dh} = l_{hb}$ × Mod factor ≥ max$[8d_b, 150]$ (Development length Tension Hook)

f_y/400, f_y/400

ACI

All Negative moment terminated @ 0.3 L_n or L_1

- 1/2 Positive moment terminated @ 0.125L

Columns

To determine forces and moment from strain diagrams:

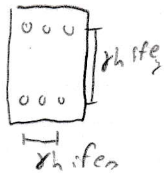
1. Find α and β
2. Solve for a
3. Using similar triangles,
   - $C_r = \alpha \phi_c f'_c \cdot a \cdot b$ (concrete compression force)
   - $F_r = \phi_s f_s A_s$ (steel tension force)
   - $F_r = (\phi_s f_s - \alpha \phi_c f'_c) A_s$ (steel compression force)
4. Axial $= \Sigma F$
   Moment $= \Sigma F$(distance from middle)

To solve column load if given e (interaction)

$P_r e = M_r$, $e = M_r/P_r$, $1/e = P_r/M_r$

Slope of line $= [P_r/A_g] / [M_r/A_g h] = P_r h / M_r = h/e$

1. Draw straight line w/ slope h/e from origin for interaction diagram for proper ρ and γ
   - $\gamma = \gamma h / h$, γh = distance between bars
   - $\rho_g = A_s/A_g$



To solve column if given P (interaction)

1. Set $P_r = P_f$, calculate P_r/A_g
2. Draw horizontal line at P_r/A_g to find the moment $M_r/A_g h$
3. Find $e = M_r/P_r$

If given D, L, and Wind

1. Check different LCs
2. Calculate P_f/A_g and $M_f/A_g h$ for each
3. Verify each w/ interaction diagram

Short column - pure compression

1. Check if short. If short:

$$\frac{k l_u}{r} \leq \frac{25 - 10 M_1/M_2}{\sqrt{P_f/(f'_c A_g)}}, \quad M_1/M_2 \geq -1/2$$

- M_1 = absolute min end moment
  M_2 = absolute max end moment

M_1/M_2 + single curvature, − double

- $r = \sqrt{\frac{I}{A}}$, ~0.3h (rectangular column)
  0.25d (circular column)

l_u = unsupported length
- k=1 conservative
- has to be laterally supported at both ends to be considered short

Short column - pure compression cont.

2. $P_o = \alpha_1 \phi_c f'_c (A_g - A_{st}) + f_y A_{st} \phi_s$ (if unfactored, remove factors)
3. Account for eccentricity
   - $P_r = 0.8 P_{ro}$ (Tied)
   - $P_r = 0.85 P_{ro}$ (Spiral)

Detailing requirements

- $0.01 A_g \leq A_{st} \leq 0.08 A_g$ (recommended upper bound $= 0.04 A_g$)
  ↳ If $0.005 A_g < A_{st} < 0.01 A_g$, $P_r = \frac{P_r}{2}\left[1 + \frac{\rho_t}{0.01}\right]$
- 4 bars req'd (rect), 6 req'd (spiral), 3 req'd (triangular)
- Tie spacing $= \min[16 \cdot d_{\text{smallest longitudinal bar}}, 48 d_{tie}$, smallest xsection dim, 300 mm$]$ — for bundled bars
- Each corner & alternating longitudinal bar is restrained by a tie
- Max longitudinal spacing = 150 (across), 500 mm (end to end)
- Max angle of tie corner = 135° (7.6.4)

Biaxial bending

$$\frac{1}{P_r} = \frac{1}{P_{rx}} + \frac{1}{P_{ry}} - \frac{1}{P_{ro}}, \quad \text{Check if } P_r \geq P_f$$

- P_{rx} = load applied @ e_x, $e_y = 0$
- P_{ry} = load applied @ e_y, $e_x = 0$
- P_{ro}, $e_y = e_x = 0$

$$P_c = \frac{\pi^2 EI}{(kl)^2}$$

k (Table 8.5)

TOP ↓ / BOTTOM →	F	E	E	H
Hinged	0.81	0.91	0.95	1
Elastic (ψ=3.1)	0.77	0.86	0.9	
Elastic (ψ=1.6)	0.74	0.83		
Fixed	0.67			

Moment Magnification Factor, $\delta_b = C_m / \left[1 - \frac{P}{\phi_m P_c}\right]$ (Braced)

- $\phi_m = 0.75$
- $C_m = 0.6 + 0.4 M_1/M_2 \geq 0.4$
  ↳ $M_2 \geq P_f(15 + 0.03h)$
  ↳ $C_m = 1$ if transverse loads present between column ends

Sustained Loads

$$EI = [0.2 E_c I_g + E_s I_{se}]/(1 + \beta_d) = EI_{eff} \text{ or } \frac{0.4}{1+\beta_d} E_c I_g$$

- $\beta_d = \frac{\text{factored DL vert}}{\text{total factored vert load}}$ (Nonsway (Braced))
- $\beta_d = \frac{\text{factored sustained shear}}{\text{total factored shear}}$

Flexure design - Normal Beam

1. Check if doubly-reinforced req'd
   ↳ $d = h - 60$ (one layer), $d' = 60$
   ↳ $d = h - 90$ (2 layer), $d' = 90$

   $K_r = \frac{M_r}{bd^2} \times 10^6$

2. If singley reinforced, use K_r to find ρ

   $A_s = \rho bd$

   $\rho_b = \alpha_1 \beta_1 \frac{\phi_c}{\phi_s}\left[\frac{700}{700+f_y}\right] \frac{f'_c}{f_y}$, $\frac{c_b}{d} = \frac{700}{700+f_y}$

   $M_r = A_s \phi_s f_y (d - a/2) = K_r bd^2$, $A_s = \frac{M_f}{\phi_s f_y jd}$,

   $K_r = \phi_s \rho f_y \left[1 - \frac{\phi_s \rho f_y}{2\phi_c \alpha_1 f'_c}\right]$ $jd = 0.9d$

3. If doubly reinforced, determine tensile steel

   $\rho = 0.6\rho_b$, find K_r
   $M_r = K_r bd^2$
   $A_s = \rho bd$

4. Find compression steel to resist remaining moment

   $M_r = M_f - M_{r_1}$

   $A_{s_2} = \frac{M_{r_2}}{\phi_s f_y (d - d')}$

   $A'_{s_{req}} = A_{s_2}$, $A_{s_{req}} = A_s + A_{s_2}$

5. Choose reinforcement
6. Choose cover, check spacing

   $S_{min} = \max\left[\begin{matrix} 1.4 d \\ 1.4 CA \\ 30 \end{matrix}\right]$, assume $CA = 19$

7. Find actual d and d'
8. Check yielding - assuming yielding, we have:

   $a = \frac{\phi_s (A_s - A_s') f_y}{\phi_c \alpha_1 f'_c b}$

   $\rho < 0.8 \rho_b + \rho'$, $\rho' = \frac{A_s'}{bd}$ (tension), or use c/d check!

   $\varepsilon'_s = (1 - d'/c)\varepsilon_{cu}$ (compression)

9. If both yield, as analysis
10. Check $A_{s_{min}} = 0.2\sqrt{f'_c}\, bh / f_y$

Design - T beam

Positive

1. $d = h - 90$ (2 layer)
2. $A_s = M_f / 0.85 f_y jd$, $jd = 0.9d$
3. Find spacing
4. Find α and β and new d
5. Calculate a
6. Find moment r at max, and for cutoff steel
7. Checked yielding c/d
8. Check $A_{s_{min}} = \frac{0.2\sqrt{f'_c}}{f_y} b_w h$

Negative

1. Determine d (2 layer)
2. Calculate A_s; $jd = 0.8d$
3. Find a
4. Find moments
5. Check yielding
6. Check $A_{s_{min}} = \frac{0.2\sqrt{f'_c}\, b_t h}{f_y}$, $b_t \leq \left\{\begin{matrix} b_f \\ 2.5 b_w \end{matrix}\right\}$

   $A_{flangemin} = 0.004 b' h_f$, $b' \leq \left\{\begin{matrix} l_n / 20 \\ 10.3.3 \end{matrix}\right\}$

9.3.3 for approximate analysis, 10.5.1, 10.5.2, and 10.5.3 satisfied

Slabs

1. Find slab depth w/ 9.8.2.1
2. 9.3.3 for moment
3. Choose cover (Annex A)
4. Verify 7.8, 10.5.1, and 10.5.2 satisfie

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T-beam

$b_f = b'_{T_L} + b'_{T_R} + b_w$ (T section)

$b_f = b'_L + b_w$ (L section)

$b'_T = \min[0.2L_b$ (simple) or $0.1 L_b$ (continuous), $12h_f$, $0.5L_s]$

$b'_L = \min[L/12, 6h_f, 0.5L_s]$

If positive moment, compression zone into web

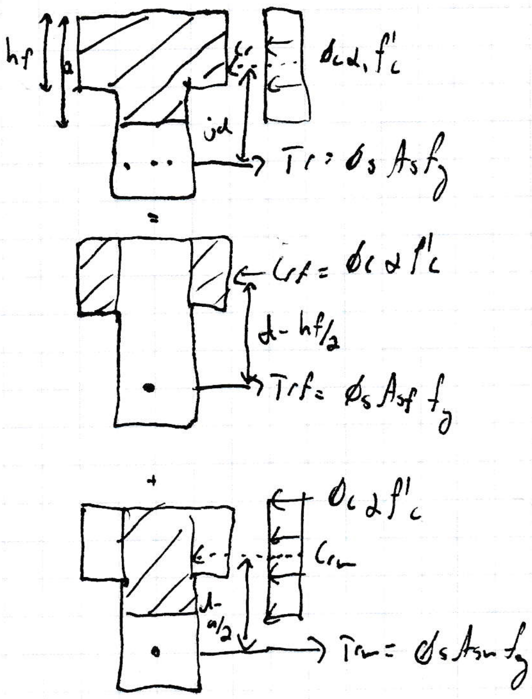
$$A_{sf} = \frac{\phi_c \alpha_1 f'_c (b-b_w) h_f}{\phi_s f_y}$$

$$M_{rf} = \phi_c \alpha_1 f'_c (b-b_w) h_f (d - h_f/2) = \phi_s A_{sf} f_y (d - h_f/2)$$

$$A_{sw} = A_s - A_{sf}$$

$$M_{rw} = \phi_c \alpha_1 f'_c b_w a (d - a/2) = \phi_s A_{sw} f_y (d - a/2)$$

↳ $a = \dfrac{\phi_s A_{sw} f_y}{\phi_c \alpha_1 f'_c b_w}$



$C_{cf} = \alpha_1 \phi_c f'_c (b_f - b_w) h_f$

$C_{cw} = \alpha_1 \phi_c f'_c b_w a$

$T_r = \phi_s A_s f_y$

$$M_r = C_{cw}(d - a/2) + C_{cf}(d - h_f/2) + C'_r(d - d')$$

↑ if doubly reinforced

$$A_{s,min} = \frac{0.2\sqrt{f'_c}}{f_y} b_w h$$

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$m^3 \times kN/m^2$

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Singly Reinforced

$$M_r = A_s \phi_s f_y (d - a/2) = \alpha_1 \phi_c f'_c a b (d - a/2)$$

- $a = \dfrac{\phi_s A_s f_y}{\alpha_1 \phi_c f'_c b}$

Also, $M_r = K_r b d^2$

- $K_r = \phi_s \rho f_y \left[1 - \dfrac{\phi_s \rho f_y}{2 \phi_c \alpha_1 f'_c}\right]$

$\rho < 0.8 \rho_b$

- $\rho_b = \dfrac{A_{sb}}{bd} = \alpha_1 \beta_1 \dfrac{\phi_c}{\phi_s}\left[\dfrac{700}{700 + f_y}\right]\dfrac{f'_c}{f_y}$
- $\rho = \dfrac{A_s}{bd}$

$\dfrac{c}{d} < 0.8 \dfrac{c_b}{d}$

- $\dfrac{c_b}{d} = \dfrac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_y} = \dfrac{0.0035}{0.0035 + \frac{f_y}{E_s = 200000}} = \dfrac{700}{700 + f_y}$
- $c = \dfrac{a}{\beta}$

$\alpha = 0.85 - 0.0015 f'_c \geq 0.67$

$\beta = 0.97 - 0.0025 f'_c \geq 0.67$

Analysis

1. Find α, β, a, c, d, and c_b/d
2. Check if under-reinforced
3. Plug into formula

Design - Beam

Potentially, 9.8.2.1 for h, h/2 for b

1. Check if doubly-reinforced req'd

$\rightarrow d = h - 60$ (One layer), $d' = 60$

$d = h - 90$ (Two layers), $d' = 90$

$K_r = \frac{M_r}{bd^2} \times 10^6$

2. If singly reinforced, use K_r to find ρ

$A_s = \rho b d$

$\rho_b = \alpha_1 \beta_1 \frac{\phi_c}{\phi_s} \left[\frac{700}{700 + f_y}\right] \frac{f'_c}{f_y}$

$a = \frac{\phi_s A_s f_y}{\alpha_1 \phi_c f'_c b}$, $\quad c = a/\beta$

$\alpha = 0.85 - 0.0015 f'_c \geq 0.67$

$\beta = 0.97 - 0.0025 f'_c \geq 0.67$

$c/d < 0.8 \frac{700}{700 + f_y}$

$M_r = A_s \phi_s f_y (d - a/2)$

$= K_r b d^2$, $\quad K_r = \phi_s \rho f_y \left[1 - \frac{\phi_s \rho f_y}{2 \phi_c \alpha f'_c}\right]$

3. If doubly reinforced, determine tensile steel.

$\rho = 0.6 \rho_b$, find K_r

$M_r = K_r b d^2$

$A_s = \rho b d$

4. Find compression steel to resist remaining moment

$M_r = M_f - M_{r_1}$

$A_{s_2} = \frac{M_{r_2}}{\phi_s f_y (d - d')}$

$\therefore A'_{s_{req}} = A_{s_2}$, $\quad A_{s_{req}} = A_{s_1} + A_{s_2}$

5. Determine reinforcement

6. Choose cover and check spacing

$S_{min} = \max \begin{Bmatrix} 1.4d \\ 1.4CA \\ 30 \end{Bmatrix}$

7. Find actual d and d'

8. Check yielding

- Assuming yielding, we have =

$a = \frac{\phi_s (A_s - A_s') f_y}{\phi_c \alpha_1 f'_c b}$

$\rho < 0.8 \rho_b + \rho'$, $\rho' = \frac{A'_s}{bd}$ (Tension), <u>or c/d check</u>

$\varepsilon'_s = (1 - d'/c) \varepsilon_{cu}$ (Compression)

9. If both yield =

$M_{r_1} = \phi_s A'_s f_y (d - d')$

$M_{r_2} = \phi_s (A_s - A'_s) f_y (d - a/2)$

If compression doesn't yield =

$(\phi_c \alpha f'_c b) a^2 + \phi_s (0.0035 E_s A'_s - A_s f_y) a - (0.0035 \phi_s E_s A'_s \beta d') = 0$

- $E_s = 200000$

$C_{rs} = \phi_s (E_s \varepsilon'_s) A'_s$

$C_{rc} = \phi_c \alpha f'_c b a$

$M_r = C_{rs}(d - d') + C_{rc}(d - a/2)$

10. Check $A_{s_{min}} = \frac{0.2 \sqrt{f'_c}}{f_y} bh$

Design - T beam

1. Assume $d = h - 90$ (2 layers)
2. Determine flange width

$b'_T = \min[0.2 L_b \text{ (simple)}, 0.1 L_b \text{ (continuous)}, 12h_f, 0.5 L_s]$

3. Check if T-beam section analysis req'd by subbing $h_f = a$

$M_r = \alpha_1 \phi_c f'_c a h_f (d - h_f/2)$ If not, treat as rectangular beam

4. Find contribution of flange

$$A_{sw} = \frac{\phi_c \alpha_1 f'_c (b - b_w) h_f}{\phi_s f_y}$$

$$M_{rf} = \phi_c \alpha_1 f'_c (b - b_w) h_f (d - h_f/2) = \phi_s A_{sf} f_y (d - h_f/2)$$

5. Check if doubly-reinforced req'd in web

$M_{rw} = M_f - M_{rf}$

$K_{rw} = \frac{M_{rw}}{b_w d^2}$, check if exceeds max

6. Determine tension steel web area

$A_s = \rho b d$

or

$a = \frac{\phi_s A_{sw} f_y}{\phi_c \alpha_1 f'_c b_w}$, $M_{rw} = \phi_s A_{sw} f_y (d - a/2)$

7. Select steel bars
8. Choose concrete cover and check spacing
9. Find a through force equilibrium

$C_{cf} = \alpha_1 \phi_c f'_c (b_f - b_w) h_f$

$C_{cw} = \alpha_1 \phi_c f'_c b_w a$

$T_r = \phi_s A_s f_y$

10. Check $c/d < 0.8 \frac{700}{700 + f_y}$
11. Find $M_r = C_{cw}(d - a/2) + C_{cf}(d - h_f/2)$
12. Check $A_{s_{min}} = \frac{0.2\sqrt{f'_c}}{f_y} b_w h$

13. NEGATIVE MOMENT

Find $K_r = \frac{M_f}{b d^2}$ assuming d = original, + check if $\rho < 0.8\rho_b$

14. If doubly-reinforce not req'd,

$A_s = \rho b d$

15. Determine bar size and quantity

Recheck ρ

16. Check w/ minimum values

$A_{s\,flange\,min} = 0.004 b' h_f$

$b' \le \left\{ \begin{matrix} L_b/20 \\ \cancel{\quad} \end{matrix} \right\}$

10.3.3 requirement

$$A_{s\,min} = \frac{0.2\sqrt{f'_c} b_t h}{f_y}$$

$b_t \le \left\{ \begin{matrix} b_f \\ 2.5 b_w \end{matrix} \right.$

17. If $\rho > 0.8\rho_b$ double reinforce.

Find d' and M_{r_2}

$M_{r_2} = \phi_s A_{s_2} f_y (d - d')$

18. Find A_s' $_{r_1}$

$M_{r_1} = M_f - M_{r_2}$

$K_r = \frac{M_{r_1}}{b d^2}$, ρ from table

$A_s = \rho b d$

19. Check min reinforcement
20. Check given $\rho < 0.8\rho_b + \rho'$ (Tension)

$$a = \frac{\phi_s A_s f_y - \phi_s A'_s f'_c}{\alpha_1 \phi_c f'_c b_w}, \quad c = a/\beta$$

$\varepsilon'_s = (1 - d'/c)\varepsilon_{cu}$

ARUP

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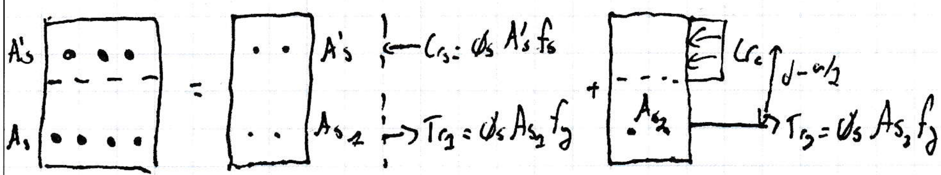
Job Title	
Job #	
Reference	Sheet #
Made by	Date

Doubly Reinforced



Assuming compression steel yields

$$a = \frac{\phi_s (A_s - A'_s) f_y}{\phi_c \alpha_1 f'_c b}$$

$$M_{r1} = \phi_s A'_s f_y (d - d')$$

$$M_{r2} = \phi_s (A_s - A'_s) f_y (d - a/2)$$

$\rho < 0.8\rho_b + \rho'$, $\rho' = \frac{A_s'}{bd}$ (Ductile generally)

$\varepsilon'_s = \left(1 - \frac{d'}{c}\right)\varepsilon_{cu}$ (Compression steel yielding)

If compression steel doesn't yield

$$(\phi_c \alpha_1 f'_c b)\, a^2 + \phi_s (0.0035 E_s A'_s - A_s f_y)\, a - (0.0035\, \phi_s E_s A'_s \beta_1 d') = 0$$

- if compression steel doesn't yield OK as long as tension steel yields
- $T_r = C_{rc} + C_{rs}$ ← new
  - ↳ $C_{rs} = \phi_s f'_s A'_s = \phi_s (E_s \varepsilon'_s) A'_s$
  - ↳ $C_{rc} = \phi_c \alpha_1 f'_c b a$

$$M_r = C_{rs}(d - d') + C_{rc}(d - a/2)$$

In concrete handbook, assuming compression reinforcement yields,

$$M_r = M_{r1} + M_{r2} = (K_r + K_r')\, b d^2$$

- $K_r' = \rho' \phi_s f_y \left[1 - \frac{d'}{d}\right]$

ARUP	Job Title	
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Shear

1. Determine factored shear-force-envelope

2. Check if cross-section is large enough

$V_{r\,max} = 0.25\,\phi_c f'_c b_w d_v$

• d_v = effective shear depth = max$[0.9d,\ 0.72h]$

3. Check if stirrups req'd

• $V_f \geq V_c$

• $V_c = \phi_c \lambda \beta \sqrt{f'_c}\, b_w d_v$

• $h > 750mm$

4. Determine spacing requirements at several points

$(V_s)_{req'd} = V_f - V_c = \dfrac{\phi_s A_v f_y d_v \cot\theta}{s}$

$V_s \rightarrow$

$s_{req'd} = \dfrac{\phi_s A_v f_y d_v \cot\theta}{V_f - V_c}$

A_v = double that of a single leg

5. Find maximum stirrup spacing

$A_{v\,min} = \dfrac{0.06\sqrt{f'_c}\, b_w s}{f_y}$, $s_{max} = \dfrac{A_v f_y}{0.06\sqrt{f'_c}\, b_w}$

s_{max} = min$[600,\ 0.7d_v]$

min$[300,\ 0.35d_v]$ if $V_f > 0.125\,\lambda \phi_c f'_c b_w d_v$

For one-way slab design

1. Use 9.8.2.1 to find slab depth based on clear span
2. Estimate effective depth
   - ~~Slabs one-way~~ • Slabs = 10M bars
   - Cover = A23.3 Annex A (230)
   - $c \geq$ {Table 17 req'mts} (232)
3. Determine loading
   - $1.4 w_D$
   - $1.25 w_D + 1.5 w_L$
4. Determine moment at required location (9.3.3) (57)
5. Determine required A_s
   1. $K_{r\,req'd} = \frac{M_f}{bd^2}$
   2. Linearly interpolate to find ρ
   3. $A_s = \rho b d$
   4. Check $\rho < 0.8\rho_b$, $\rho_b = \alpha_1 \beta_1 \frac{\phi_c}{\phi_s}\left(\frac{700}{700+f_y}\right)\frac{f'_c}{f_y}$ ← might be unnecessary
6. Determine spacing requirement

   $s = \frac{100\,mm^2}{A_{s\,req'd}} \times 1000$ ← mm slab width

7. Check $A_{s\,min}$ and s_{max} (7.8) (49)

   - $A_{s\,min} = 0.002 A_g$, $A_g = bh$
   - $s_{max} = \min[3h, 500]$ (slabs)

8. Temperature and shrinkage

   - $A = A_{s\,min}$
   - $s_{max} = \min[5h, 500]$
   - $s = \frac{100}{A_{s\,min}} \cdot 1000$

9. Check adequacy (10.5.1 & 10.5.2), (

   - ~~$M_r \geq 1.2 M_{cr}$~~, $A_s = \frac{100}{s} 1000$, $\rho = \frac{A_s}{bd}$
   - $K_r = \rho \phi_s f_y \left(1 - \frac{\rho \phi_s f_y}{2\alpha_1 \phi_c f'_c}\right)$, $M_r = K_r b d^2 > M_f$, OK

$\cdot\ a = \dfrac{\phi_s A_s f_y}{\alpha_1 \phi_c f'_c b}$

$\cdot\ \dfrac{c}{d} = \dfrac{a/\beta}{d} < 0.8 \dfrac{700}{700+f_y}$

For beam cross-section (T-beam)

1. 9.8.2.1 to find beam depth using clear span
2. Assume beam width = $h/3 \to h$. $h/2$ good
3. $d = h -$ cover $-$ stirrup dia $- \phi/2$.
   - ↳ if d_b unknown..
     - One layer of steel, $d = h - 60$
     - 2 layers of steel, $d = h - 90$
   - ↳ Check cover requirements
4. Determine loading
   - Check if LLRF

$T_A > 80m^2$ ↳ $0.5 + \sqrt{\frac{20}{A}}$ if assembly occupancy w/ LL > 4.8 or storage, manufacturing, retail, garage, or footbridge

$20m^2$ $\quad 0.3 + \sqrt{\frac{9.8}{B}}$, non-assembly occupancy w/ any ~~...~~ LL

All $\quad 1 \quad$ Assembly occupancy w/ LL < 4.8 kPa

   - Check both load cases

5. Determine moment (9.3.3) (57)
6. Find effective flange width [L or T-beam]

   ↳ $b'_T = \min[0.2 L_{b\,clear}$ (simple) or $0.1 L_{b\,clear}$ (continuous), $12h_f$, $0.5 L_s]$ clear span

   $b'_L = \min[L_{b\,clear}/12,\ 6h_f,\ 0.5 L_s]$

7. Assuming a is within flange, such that $M_r = \alpha \phi_c f'_c h_f b_f (d - h_f/2)$, and letting $M_f = M_r$,

   check $K_r = \dfrac{M_f}{b_f d^2}$

   Using K_r, find ρ and check that $\rho < 0.8 \rho_b$

   Find $A_{s\,req'd} = \rho b_f d$. Determine how many bars

8. Now that b_w known, confirm bar diameter

9. Determine spacing

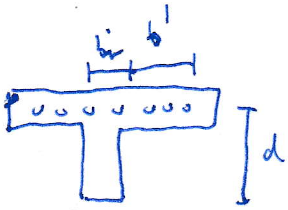
$$s = \frac{b - 2c - 2d_{st} - n d_b}{n-1}, \quad s \geq \begin{Bmatrix} 1.4 d_b \\ 1.4 CA \\ 30 \end{Bmatrix}$$

Also ensure min steel area $A_{s_{min}} = \frac{0.2\sqrt{f'_c}}{f_y} bh$ (10.5.1.2)

10. Check adequacy

Find real d
Find real a, check if within flange
Check c/d for yielding
Check $M_r = \phi_s A_s f_y (d - a/2) > M_f$

11. NEGATIVE MOMENT



Assume $d = d$, find $K_r = \frac{M_f}{bd^2}$ and check if $\rho < 0.8\rho_b$.
↳ If not, either Δ cross-section dims or analyze as doubly reinforced

If not doubly reinforced, find As knowing $A_s = \rho b d$. and determine ~~check if~~ bar size and quantity. Then recheck ρ

Check w/ minimum values, $b \leq \begin{Bmatrix} L/20 \\ 0.1L \end{Bmatrix}$, $A_{s_{min}} = 0.004 b' h_f$

10.5.3.1

$A_{s_{min}} = \frac{0.2\sqrt{f'_c}\, b_t h}{f_y}$

$b_t \leq \begin{Bmatrix} b_f \\ 2 b_w \end{Bmatrix}$ 10.5.3.2

$b' \leq \begin{Bmatrix} 1.5 b_w & (L) \\ 2.5 b_w & (T) \end{Bmatrix}$

If $\rho \geq 0.8\rho_b$, double reinforced