

Reference Formulas

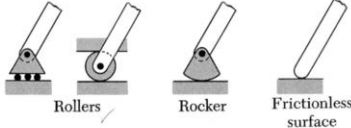

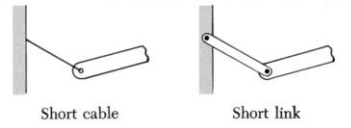

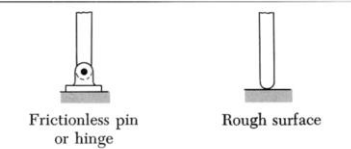



$\sum F_x = 0$	$C^2 = A^2 + B^2 - 2AB\cos\gamma$	$\hat{x} = \frac{\Sigma(\bar{x}A)}{\Sigma A}$
$\sum F_y = 0$	$\frac{A}{\sin\alpha} = \frac{B}{\sin\beta} = \frac{C}{\sin\gamma}$	$Q_y = \bar{x}A = \sum_{i=1}^n \bar{x}_i A_i$
$\sum M = 0$	$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$	$\hat{y} = \frac{\Sigma(\bar{y}A)}{\Sigma A}$
$F_x = F \cos\theta$	$p = 2\pi r = \pi d$	$Q_x = \bar{y}A = \sum_{i=1}^n \bar{y}_i A_i$
$F_y = F \sin\theta$	$A = W \cdot l = t \cdot d$	$I = \bar{I} + Ad^2$
$F = \sqrt{F_x^2 + F_y^2}$	$A = \pi r^2 = \frac{\pi d^2}{4}$	$I = \Sigma I_c + \Sigma Ad^2$
$\tan\theta = \frac{F_y}{F_x}$	$M = Fd$	$r = \sqrt{\frac{I}{A}}$
$g = 9.81 \frac{m}{s^2}$	$F = mg$	$d_x = \hat{x} - \bar{x}$
$\frac{dV}{dx} = -w$	$y = mx + b$	$d_y = \hat{y} - \bar{y}$
$\frac{dM}{dx} = V$	$m = \frac{y_2 - y_1}{x_2 - x_1}$	$x = \frac{V_A}{w}$
$Pa = \frac{N}{m^2}$	$N = \frac{kg \cdot m}{s^2}$	$F = \mu N$
$1 kPa = 1,000 Pa$	$psi = \frac{lb}{in^2}$	$\pi(\text{radians}) = 180^\circ$
$1 kPa = 1 \frac{kN}{m^2}$	$1 kip = 1000 lb$	$ksi = \frac{kip}{in^2}$
$1 MPa = 10^6 Pa$	$1 GPa = 10^9 Pa$	$12 in = 1 ft$
$f_c = \frac{P}{A}$	$F.S = \frac{\text{ultimate}}{\text{allowable}}$	$1 m = 1000 mm$
$f_t = \frac{P}{A} \text{ or } \frac{P}{A_e}$	$f_v = \frac{P}{A} = \frac{P}{td}$	$\varepsilon = \frac{\delta}{L}$
$f_p = \frac{P}{A} = \frac{P}{td}$	$f_v = \tau = \frac{T\rho}{J}$	$f_v = \frac{P}{2A}$
$f_y = \frac{My}{I}$	$f_{v-ave} = \frac{VQ}{Ib}$	$f = E\varepsilon$
$S = \frac{I}{c}$	$f_{v-max} = \frac{3V}{2A}$ for a rectangle	$\delta = \frac{PL}{AE}$
$f_{b-max} = \frac{Mc}{I} = \frac{M}{S}$	$f_{v-max} \cong \frac{V}{A_{web}} = \frac{V}{t_w d}$ for an I beam	$\delta_T = \alpha(\Delta T)L$
$S_{req} \geq \frac{M}{F_b}$	$\varepsilon_y = \varepsilon_z = -\frac{\mu f_x}{E}$	$\varepsilon_T = \alpha(\Delta T)$

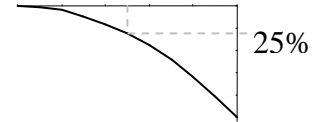
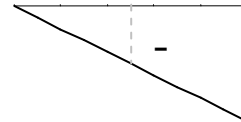
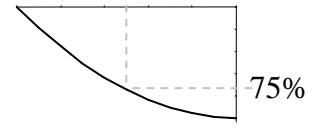
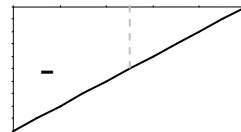
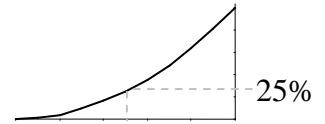
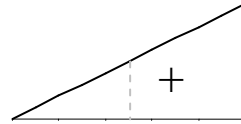
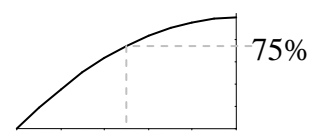
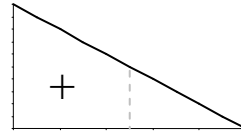
$nF_{connector} \geq \frac{VQ_{connected\ area}}{I} \cdot p$	$V = ZICW/R_w$	$1\ kN/mm^2 = 10^3\ MPa$
$V_{longitudinal} = \frac{V_T Q}{I} \Delta x$	$W = \gamma A$	$w = \gamma A$
$p = w'h$	$W = \gamma V$	$w' = \gamma$
$P = \frac{1}{2} ph$	$\gamma = \frac{\rho\phi}{L}$	$f_v = \tau = G \cdot \frac{\rho\phi}{L}$
$\tau_{max} = \frac{T}{c_1 ab^2}$	$\phi = \frac{TL}{c_2 ab^3 G}$	$\phi = \frac{TL}{JG}$
$\tau_{max} = \frac{T}{\frac{1}{3} ab^2}$	$\phi = \frac{TL}{\frac{1}{3} ab^3 G}$	$\tau_{max} = \frac{T t_{max}}{\frac{1}{3} \Sigma b_i t_i^3}$
$\tau_{max} = \frac{T}{2t\bar{A}}$	$\phi = \frac{TL}{4t\bar{A}^2} \sum_i \frac{s_i}{t_i}$	$\phi = \frac{TL}{\frac{1}{3} G \Sigma b_i t_i^3}$
$\frac{1}{R} = \frac{M}{EI}$	$\Delta = \iint \frac{M(x)}{EI} dx$	$2n = b + 3$
$P_U = P_L \gamma_L + P_D \gamma_D \leq \phi P_n$	1.4D	1.2D + 1.6(L _r or S or R) + (L or 0.5W)
$L_e = Kl$	1.2D + 1.6L + 0.5(L _r or S or R)	1.2D + 1.0W + L + 0.5(L _r or S or R)
$P_{cr} = \frac{\pi^2 EI}{(L_e)^2} = \frac{\pi^2 EA}{\left(\frac{L_e}{r}\right)^2}$	AISC – ASD: $R_a \leq R_n / \Omega$	$\frac{l_e}{r} \geq C_c \quad F_a = \frac{F_{cr}}{F.S.} = \frac{12\pi^2 E}{23\left(\frac{KL}{r}\right)^2}$
$f_{cr} = \frac{\pi^2 E}{\left(\frac{L_e}{r}\right)^2}$	$C_c = \sqrt{\frac{2\pi^2 E}{F_y}}$	$\frac{l_e}{r} < C_c \quad F_a = \left[1 - \frac{\left(\frac{KL}{r}\right)^2}{2C_c^2}\right] \frac{F_y}{F.S.}$
$f_{max} = \frac{P}{A} + \frac{Mc}{I}$	$P_n = F_{cr} A_g$ $\Omega = 1.67$ (bending)	$F.S. = \frac{5}{3} + \frac{3}{8} \cdot \frac{L_e/r}{C_c} - \frac{1}{8} \cdot \left(\frac{L_e/r}{C_c}\right)^3$
$\frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1.0$	$\Omega = 1.5$ (beam shear) $\Omega = 2.00$ (bolt shear)	$\frac{P_u}{\phi_c P_n} \geq 0.2 : \frac{P}{P_n/\Omega} + \frac{8}{9} \left(\frac{M_x}{M_{nx}/\Omega} + \frac{M_y}{M_{ny}/\Omega} \right) \leq 1.0$
$f_{max} = \frac{P}{A} + \frac{M_1 y}{I} + \frac{M_2 z}{I}$	$\Omega = 2.00$ (weld shear) $\Omega = 1.50$ (bearing)	$\frac{P_u}{\phi_c P_n} < 0.2 : \frac{P}{2P_n/\Omega} + \left(\frac{M_x}{M_{nx}/\Omega} + \frac{M_y}{M_{ny}/\Omega} \right) \leq 1.0$
$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1.0$	$\Omega = 1.67$ (compression)	

ACI-318: $A_s f_y = 0.85 f'_c b a$	$a = \frac{A_s f_y}{0.85 f'_c b}$	$\rho = \frac{A_s}{bd}$
$M_u \leq \phi M_n = \phi A_s f_y \left(d - \frac{a}{2} \right)$ $\phi = 0.9$	$\min: A_s = \frac{3\sqrt{f'_c}}{f_y} (b_w d)$, not less than $A_s = \frac{200}{f_y} (b_w d)$	
$R_n = \frac{M_n}{bd^2}$	$T, \min: A_s = \frac{6\sqrt{f'_c}}{f_y} (b_w d)$, not less than $A_s = \frac{3\sqrt{f'_c}}{f_y} (b_f d)$	
<i>slab</i> (<60 ksi): $A_s = 0.002b(t \text{ or } h)$	<i>slab</i> (60 ksi): $A_s = 0.0018b(t \text{ or } h)$	$V_u \leq \phi V_c + \phi V_s \quad \phi = 0.75$
<i>one-way</i> : $V_c = 2\sqrt{f'_c} b_w d$	$V_s = \frac{A_v f_y d}{s}$	$E_c = w^{1.5} 33\sqrt{f'_c}$
<i>two-way</i> : $V_c = 4\sqrt{f'_c} b_w d$	$E_c = 57,000\sqrt{f'_c}$	<i>tied</i> : $\phi_c P_n = \phi_c (0.8 P_o)$ $\phi_c = 0.65$
$G = \Psi = \frac{\sum EI / l_c}{\sum EI / l_b}$	$P_o = 0.85 f'_c (A_g - A_{st}) + f_y A_{st}$	<i>spiral</i> : $\phi_c P_n = \phi_c (0.85 P_o)$ $\phi_c = 0.75$
$l_{dh} = \frac{1200 d_b}{\sqrt{f'_c}}$	(c): $l_d = \frac{0.02 d_b F_y}{\sqrt{f'_c}} \leq 0.0003 d_b F_y$	$\leq \#6: l_d = \frac{d_b F_y}{25\sqrt{f'_c}}$
$\frac{P}{A} \leq q_{net}$	$q_{net} = q_{allowable} - h_f (\gamma_c - \gamma_s)$	$> \#6: l_d = \frac{d_b F_y}{20\sqrt{f'_c}}$
$q_u = \frac{P_u}{A}$	$V_{u2} = P_u - q_u (c + d)(b + d)$	$V_{u1} = BL' q_u$
$volume = \frac{wp_x}{2} = N$	$b_o = 2(c + d) + 2(b + d)$	$V_{u1} \leq \phi 2\sqrt{f'_c} B d$
$p_{max} = \frac{2N}{wx}$	$V_{u2} \leq \phi \left(2 + \frac{4}{\beta_c} \right) \sqrt{f'_c} b_o d \leq \phi 4\sqrt{f'_c} b_o d$	$M_u = q_u \frac{BL_m^2}{2}$
$SF = \frac{M_{resist}}{M_{overturning}} \geq 1.5$	$P_u \leq \phi_b P_n = \phi_b (0.85 f'_c A_1) \sqrt{A_2 / A_1}$ $\phi_p = 0.65$	$SF = \frac{F_{horizontal+resist}}{F_{sliding}} \geq 1.5$
Wood: $F' = C_D C_M C_F \dots \times F_{tabulated}$	$K_{cE} = 0.3 \text{ sawn}, 0.418 \text{ glulam}$	$P_a = F' A$
$F'_c = F_c^* C_p = (F_c C_D) C_p$	$F_{cE} = \frac{K_{cE} E}{\left(l_e / d \right)^2}$	$\left[\frac{f_c}{F'_c} \right]^2 + \frac{f_{bx}}{F'_{bx} \left[1 - f_c / F_{cEx} \right]} \leq 1.0$

AISC-LRFD: $\phi_b = 0.9$ $M_u \leq \phi_b M_n = 0.9 F_y Z$	$k = Z/S$	$Z = \frac{M_p}{f_y}$
$M_{ult} = M_p = f_y \sum A_i y_i = f_y Z$	$L_p = 1.76 r_y \sqrt{\frac{E}{F_y}}$	$M_{max} = \frac{w_{equivalent} L^2}{8}$
$V_u \leq \phi_v (0.6 F_{yw} A_w) \quad \phi_v = 1.0$	$I_{req'd} \geq \frac{\Delta_{loobig}}{\Delta_{limit}} I_{trial}$	$F_e = \frac{\pi^2 E}{(KL/r)^2}$
$P_u \leq \phi_c F_{cr} A_g \quad \phi_c = 0.90$	$F_e \geq 0.44 F_y \quad F_{cr} = \left[0.658^{\frac{F_y}{F_e}} \right] F_y$	
$P_{n(max-end)} = (N + 2.5k) F_{yw} t_w \quad \phi = 1.0$	$F_e < 0.44 F_y \quad F_{cr} = 0.877 F_e$	
$P_{n(max-interior)} = (N + 5k) F_{yw} t_w \quad \phi = 1.0$		
$R_u \leq \phi_t F_y A_g \quad \phi_t = 0.9$	$\frac{P_u}{\phi_c P_n} \geq 0.2 : \frac{P_u}{\phi_c P_n} + \frac{8}{9} \left(\frac{M_{ux}}{\phi_b M_{nx}} + \frac{M_{uy}}{\phi_b M_{ny}} \right) \leq 1.0$	
$R_u \leq \phi_t F_u A_e \quad \phi_t = 0.75$		
$R_u \leq \phi 0.6 F_{EXX} Tl \quad \phi = 0.75$		
$C_m = 0.6 - 0.4 \left(\frac{M_1}{M_2} \right)$		$\frac{P_u}{\phi_c P_n} < 0.2 : \frac{P_u}{2\phi_c P_n} + \left(\frac{M_{ux}}{\phi_b M_{nx}} + \frac{M_{uy}}{\phi_b M_{ny}} \right) \leq 1.0$
$A_n = A_g - A_{of\ holes} + t \sum \frac{s}{4g}$	$B_1 = \frac{C_m}{1 - (P_u/P_{e1})} \leq 1.0$	$P_{e1} = \frac{\pi^2 EA}{(KL/r)^2}$
$A_e = A_n U$	$R_u \leq \phi (0.6 F_u A_{nv} + U_{bs} F_u A_{nt}) \leq 0.6 F_y A_{gv} + U_{bs} F_u A_{nt} \quad \phi = 0.75$	
Masonry: plain: $F_b = \frac{1}{3} f'_m$	$A_s f_s = \frac{f_m b (kd)}{2}$	$M_m = \frac{f_m b d^2 jk}{2}$
plain: $F_v = 1.5 \sqrt{f'_m} \leq 120 \text{psi}$	$F_v = 3.0 \sqrt{f'_m}$ when $M/(Vd) \geq 0.25$ $F_v = 2.0 \sqrt{f'_m}$ when $M/(Vd) \geq 1.0$	$f_v \leq V/A_{mv}$
$F_v = F_{vm} + F_{vs}$	$F_{vm} = \frac{1}{2} \left[\left(4.0 - 1.75 \left(\frac{M}{Vd} \right) \right) \sqrt{f'_m} \right] + 0.25 \frac{P}{A_n}$	$F_{vs} = 0.5 \left(\frac{A_v F_s d}{A_{nv} s} \right)$
$f_b - f_a \leq F_t$	$h/r \leq 99 \quad P_a = \left[0.25 f'_m A_n + 0.65 A_{st} F_s \right] \left[1 - \left(\frac{h}{140r} \right)^2 \right]$	
$f_a + f_b \leq F_b$	$h/r > 99 \quad P_a = \left[0.25 f'_m A_n + 0.65 A_{st} F_s \right] \left(\frac{70r}{h} \right)^2$	
$e_1 = \frac{M}{P}$	$h/r \leq 99 \quad F_a = 0.25 f'_m \left[1 - \left(\frac{h}{140r} \right)^2 \right]$	$h/r > 99 \quad F_a = 0.25 f'_m \left(\frac{70r}{h} \right)^2$

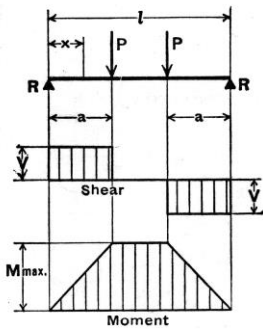
Reference Diagrams

Support or Connection	Reaction
 <p>Rollers Rocker Frictionless surface</p>	
 <p>Short cable Short link</p>	
 <p>Frictionless pin or hinge Rough surface</p>	
 <p>Fixed support</p>	



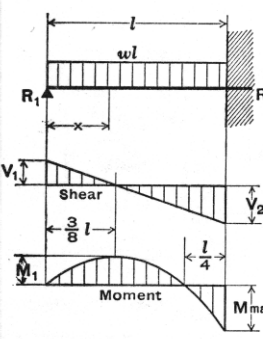
Reference Beam Diagrams

9. SIMPLE BEAM—TWO EQUAL CONCENTRATED LOADS SYMMETRICALLY PLACED



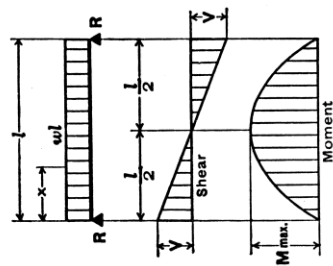
$\text{Total Equiv. Uniform Load} \dots = \frac{8 Pa}{l}$
 $R = V \dots = P$
 $M \text{ max. (between loads)} \dots = Pa$
 $M_x \text{ (when } x < a) \dots = Px$
 $\Delta \text{ max. (at center)} \dots = \frac{Pa}{24EI} (3l^2 - 4a^2)$
 $\Delta x \text{ (when } x < a) \dots = \frac{Px}{6EI} (3la - 3a^2 - x^2)$
 $\Delta x \text{ (when } x > a \text{ and } < (l-a)) \dots = \frac{Pa}{6EI} (3lx - 3x^2 - a^2)$

12. BEAM FIXED AT ONE END, SUPPORTED AT OTHER—UNIFORMLY DISTRIBUTED LOAD



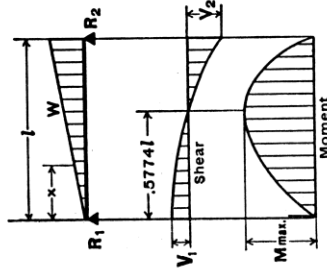
$\text{Total Equiv. Uniform Load} \dots = wl$
 $R_1 = V_1 \dots = \frac{3wl}{8}$
 $R_2 = V_2 \text{ max.} \dots = \frac{5wl}{8}$
 $V_x \dots = R_1 - wx$
 $M \text{ max.} \dots = \frac{wl^2}{8}$
 $M_1 \text{ (at } x = \frac{3}{8} l) \dots = \frac{9}{128} wl^2$
 $M_x \dots = R_1 x - \frac{wx^2}{2}$
 $\Delta \text{ max. (at } x = \frac{l}{16} (1 + \sqrt{33}) = .4215l) \dots = \frac{wl^4}{185EI}$
 $\Delta x \dots = \frac{wx}{48EI} (l^3 - 3lx^2 + 2x^3)$

1. SIMPLE BEAM—UNIFORMLY DISTRIBUTED LOAD



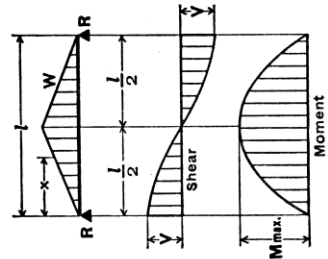
Total Equiv. Uniform Load = wl
 $R = V$ = $\frac{wl}{2}$
 V_x = $w(\frac{l}{2} - x)$
 M max. (at center) = $\frac{wl^2}{8}$
 M_x = $\frac{wx}{2}(l-x)$
 Δ max. (at center) = $\frac{5wl^4}{384EI}$
 Δ_x = $\frac{wx}{24EI}(l^3 - 2lx^2 + x^3)$

2. SIMPLE BEAM—LOAD INCREASING UNIFORMLY TO ONE END



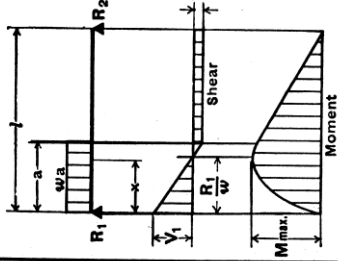
Total Equiv. Uniform Load = $\frac{16W}{9\sqrt{3}}$ $W = \frac{wl}{2}$
 $R_1 = V_1$ = $\frac{W}{3}$
 $R_2 = V_2$ max. = $\frac{2W}{3}$
 V_x = $\frac{W}{3} - \frac{Wx^2}{l^2}$
 M max. (at $x = \frac{l}{\sqrt{3}} = .5774l$) = $\frac{2Wl}{9\sqrt{3}} = .1283Wl$
 M_x = $\frac{Wx}{3/2}(l^2 - x^2)$
 Δ max. (at $x = l\sqrt{\frac{8}{15}} = .5193l$) = $.01304 \frac{Wl^3}{EI}$
 Δ_x = $\frac{Wx}{180EI^2}(3x^4 - 10l^2x^2 + 7l^4)$

3. SIMPLE BEAM—LOAD INCREASING UNIFORMLY TO CENTER



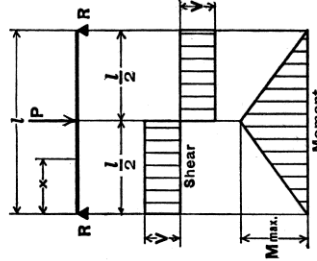
Total Equiv. Uniform Load = $\frac{4W}{3}$ $W = \frac{wl}{2}$
 $R = V$ = $\frac{W}{2}$
 V_x (when $x < \frac{l}{2}$) = $\frac{W}{2l^2}(l^2 - 4x^2)$
 M max. (at center) = $\frac{Wl}{6}$
 M_x (when $x < \frac{l}{2}$) = $Wx(\frac{1}{2} - \frac{2x^2}{3l^2})$
 Δ max. (at center) = $\frac{Wl^3}{60EI}$
 Δ_x (when $x < \frac{l}{2}$) = $\frac{Wx}{480EI^2}(5l^2 - 4x^2)^2$

5. SIMPLE BEAM—UNIFORM LOAD PARTIALLY DISTRIBUTED AT ONE END



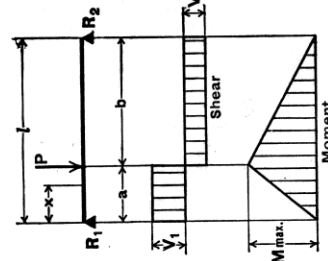
$R_1 = V_1$ max. = $\frac{wa}{2l}(2l-a)$
 $R_2 = V_2$ = $\frac{wa^2}{2l}$
 V_x (when $x < a$) = $R_1 - wx$
 M max. (at $x = \frac{R_1}{w}$) = $\frac{R_1^2}{2w}$
 M_x (when $x < a$) = $R_1x - \frac{wx^2}{2}$
 M_x (when $x > a$) = $R_2(l-x)$
 Δ max. (when $x < a$) = $\frac{wx}{24EI}(a^2(2l-a)^2 - 2ax^2(2l-a) + lx^3)$
 Δ_x (when $x > a$) = $\frac{24EI}{(4xl - 2x^2 - a^2)}$

7. SIMPLE BEAM—CONCENTRATED LOAD AT CENTER



Total Equiv. Uniform Load = $2P$
 $R = V$ = $\frac{P}{2}$
 M max. (at point of load) = $\frac{Pl}{4}$
 M_x (when $x < \frac{l}{2}$) = $\frac{Px}{2}$
 Δ max. (at point of load) = $\frac{Pl^3}{48EI}$
 Δ_x (when $x < \frac{l}{2}$) = $\frac{Px}{48EI}(3l^2 - 4x^2)$

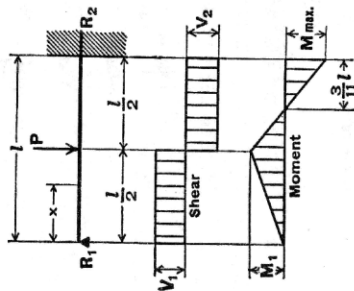
8. SIMPLE BEAM—CONCENTRATED LOAD AT ANY POINT



Total Equiv. Uniform Load = $\frac{8Pab}{l^2}$
 $R_1 = V_1$ (max. when $a < b$) = $\frac{Pb}{l}$
 $R_2 = V_2$ (max. when $a > b$) = $\frac{Pa}{l}$
 M max. (at point of load) = $\frac{Pab}{l}$
 M_x (when $x < a$) = $\frac{Pbx}{l}$
 Δ max. (at $x = \sqrt{\frac{a(a+2b)}{3}}$ when $a > b$) = $\frac{Pab}{27EI} \sqrt{3a(a+2b)}$
 Δ_a (at point of load) = $\frac{Pa^2b^2}{3EI}$
 Δ_x (when $x < a$) = $\frac{Pbx}{6EI} (l^2 - b^2 - x^2)$

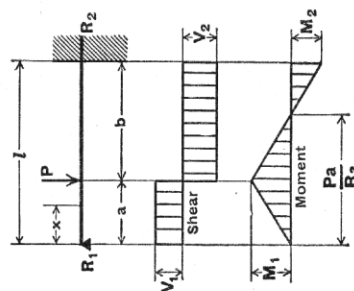
13. BEAM FIXED AT ONE END, SUPPORTED AT OTHER—
CONCENTRATED LOAD AT CENTER

Total Equiv. Uniform Load = $\frac{3P}{2}$
 $R_1 = V_1$ = $\frac{5P}{16}$
 $R_2 = V_2$ max. = $\frac{11P}{16}$
 M max. (at fixed end) = $\frac{3Pl}{16}$
 M_1 (at point of load) = $\frac{5Pl}{16}$
 M_x (when $x < \frac{l}{2}$) = $\frac{5Px}{16}$
 M_x (when $x > \frac{l}{2}$) = $P \left(\frac{l}{2} - \frac{11x}{16} \right)$
 Δ max. (at $x = l \sqrt{\frac{1}{5}} = .4472l$) = $\frac{Pl^3}{48EI} \sqrt{5} = .009317 \frac{Pl^3}{EI}$
 Δ_x (at point of load) = $\frac{7Pl^3}{768EI}$
 Δ_x (when $x < \frac{l}{2}$) = $\frac{Px}{96EI} (3l^2 - 5x^2)$
 Δ_x (when $x > \frac{l}{2}$) = $\frac{P}{96EI} (x-l)^2 (11x-2l)$



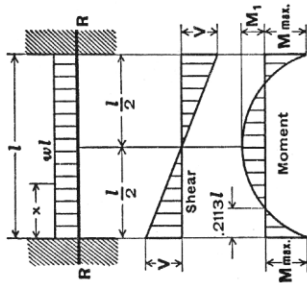
14. BEAM FIXED AT ONE END, SUPPORTED AT OTHER—
CONCENTRATED LOAD AT ANY POINT

$R_1 = V_1$ = $\frac{Pb^2}{2l^3} (a+2l)$
 $R_2 = V_2$ = $\frac{Pa}{2l^3} (3l^2 - a^2)$
 M_1 (at point of load) = R_1a
 M_2 (at fixed end) = $\frac{Pab}{2l^2} (a+l)$
 M_x (when $x < a$) = R_1x
 M_x (when $x > a$) = $R_1x - P(x-a)$
 Δ max. (when $a < .414l$ at $x = \frac{l^2+a^2}{3l^2-a^2}$) = $\frac{Pa}{3EI} \frac{(l^2-a^2)^3}{(3l^2-a^2)^2}$
 Δ max. (when $a > .414l$ at $x = l \sqrt{\frac{a}{2l+a}}$) = $\frac{Pab^2}{6EI} \sqrt{\frac{a}{2l+a}}$
 Δa (at point of load) = $\frac{Pa^2b^3}{12EI l^3} (3l+a)$
 Δ_x (when $x < a$) = $\frac{Pb^2x}{12EI l^3} (3a/2 - 2lx^2 - ax^2)$
 Δ_x (when $x > a$) = $\frac{Pa}{12EI l^3} (l-x)^2 (3l^2x - a^2x - 2a^2l)$



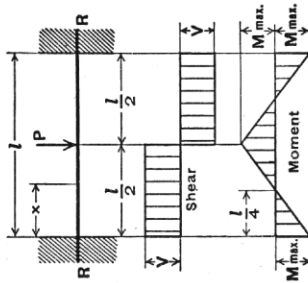
15. BEAM FIXED AT BOTH ENDS—UNIFORMLY DISTRIBUTED
LOADS

Total Equiv. Uniform Load = $\frac{2wl}{3}$
 $R = V$ = $\frac{wl}{2}$
 V_x = $w \left(\frac{l}{2} - x \right)$
 M max. (at ends) = $\frac{wl^2}{12}$
 M_1 (at center) = $\frac{24}{24}$
 M_x = $\frac{w}{12} (6lx - l^2 - 6x^2)$
 Δ max. (at center) = $\frac{384EI}{wl^4}$
 Δ_x = $\frac{wx^2}{24EI} (l-x)^2$



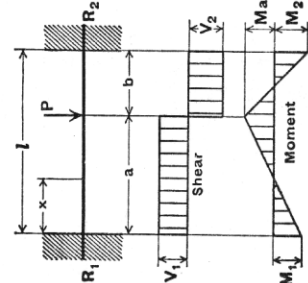
16. BEAM FIXED AT BOTH ENDS—CONCENTRATED LOAD AT
CENTER

Total Equiv. Uniform Load = P
 $R = V$ = $\frac{P}{2}$
 M max. (at center and ends) = $\frac{Pl}{8}$
 M_x (when $x < \frac{l}{2}$) = $\frac{P}{8} (4x - l)$
 Δ max. (at center) = $\frac{Pl^3}{192EI}$
 Δ_x (when $x < \frac{l}{2}$) = $\frac{Px^2}{48EI} (3l - 4x)$

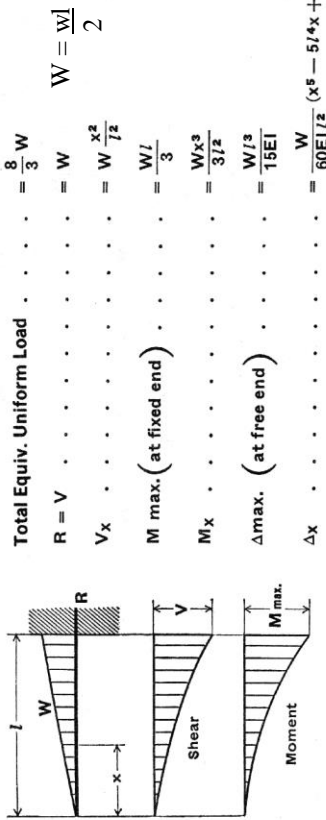


17. BEAM FIXED AT BOTH ENDS—CONCENTRATED LOAD AT
ANY POINT

$R_1 = V_1$ (max. when $a < b$) = $\frac{Pb^2}{l^3} (3a+b)$
 $R_2 = V_2$ (max. when $a > b$) = $\frac{Pa^2}{l^3} (a+3b)$
 M_1 (max. when $a < b$) = $\frac{Pab^2}{l^2}$
 M_2 (max. when $a > b$) = $\frac{Pa^2b}{l^2}$
 M_a (at point of load) = $\frac{2Pa^2b^2}{l^3}$
 M_x (when $x < a$) = $R_1x - \frac{Pabx^2}{l^2}$
 Δ max. (when $a > b$ at $x = \frac{2a}{3a+b}$) = $\frac{2Pa^2b^2}{3EI (3a+b)^2}$
 Δa (at point of load) = $\frac{Pa^2b^3}{3EI l^3}$
 Δ_x (when $x < a$) = $\frac{Pb^2x^2}{6EI l^3} (3a-l - 3ax - bx)$

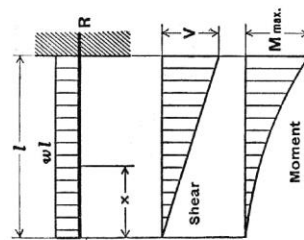


18. CANTILEVER BEAM—LOAD INCREASING UNIFORMLY TO FIXED END



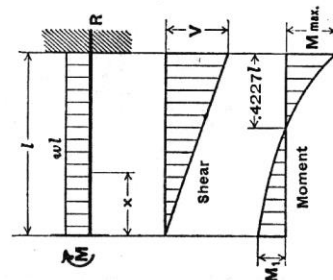
Total Equiv. Uniform Load $\frac{8}{3} W$
 $R = V$ W $W = \frac{Wl}{2}$
 V_x $\frac{Wx^2}{l^2}$
 M max. (at fixed end) $\frac{Wl}{3}$
 M_x $\frac{Wx^3}{3l^2}$
 Δ max. (at free end) $\frac{Wl^3}{15EI}$
 Δ_x $\frac{W}{60EI l^2} (x^5 - 5l^4x + 4l^5)$

19. CANTILEVER BEAM—UNIFORMLY DISTRIBUTED LOAD



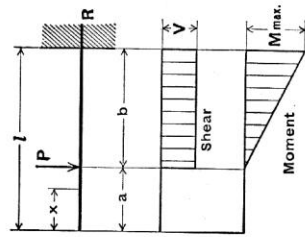
Total Equiv. Uniform Load $4wl$
 $R = V$ wl
 V_x $w(x-l)$
 M max. (at fixed end) $\frac{wl^2}{2}$
 M_x $\frac{wx^2}{2}$
 Δ max. (at free end) $\frac{wl^4}{8EI}$
 Δ_x $\frac{w}{24EI} (x^4 - 4l^3x + 3l^4)$

20. BEAM FIXED AT ONE END, FREE TO DEFLECT VERTICALLY BUT NOT ROTATE AT OTHER—UNIFORMLY DISTRIBUTED LOAD



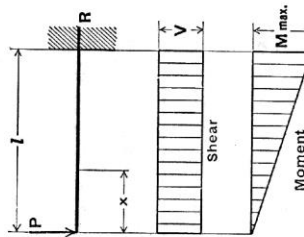
Total Equiv. Uniform Load $\frac{8}{3} wl$
 $R = V$ wl
 V_x $w(x-l)$
 M max. (at fixed end) $\frac{wl^2}{3}$
 M_1 (at deflected end) $\frac{wl^2}{6}$
 M_x $\frac{w}{6} (l^2 - 3x^2)$
 Δ max. (at deflected end) $\frac{wl^4}{24EI}$
 Δ_x $\frac{w}{24EI} (l^2 - x^2)^2$

21. CANTILEVER BEAM—CONCENTRATED LOAD AT ANY POINT



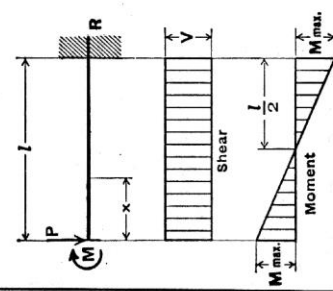
Total Equiv. Uniform Load $\frac{8Pb}{l}$
 $R = V$ P
 M max. (at fixed end) Pb
 M_x (when $x > a$) $P(x-a)$
 Δ max. (at free end) $\frac{Pb^2}{6EI} (3l-b)$
 Δ_a (at point of load) $\frac{Pb^3}{3EI}$
 Δ_x (when $x < a$) $\frac{Pb^2}{6EI} (3l-3x-b)$
 Δ_x (when $x > a$) $\frac{P(l-x)^2}{6EI} (3b-l+x)$

22. CANTILEVER BEAM—CONCENTRATED LOAD AT FREE END



Total Equiv. Uniform Load $8P$
 $R = V$ P
 M max. (at fixed end) Pl
 M_x Px
 Δ max. (at free end) $\frac{Pl^3}{3EI}$
 Δ_x $\frac{P}{6EI} (2l^3 - 3l^2x + x^3)$

23. BEAM FIXED AT ONE END, FREE TO DEFLECT VERTICALLY BUT NOT ROTATE AT OTHER—CONCENTRATED LOAD AT DEFLECTED END



Total Equiv. Uniform Load $4P$
 $R = V$ P
 M max. (at both ends) $\frac{Pl}{2}$
 M_x $P(\frac{l}{2} - x)$
 Δ max. (at deflected end) $\frac{Pl^3}{12EI}$
 Δ_x $\frac{P(l-x)^2}{12EI} (l+2x)$

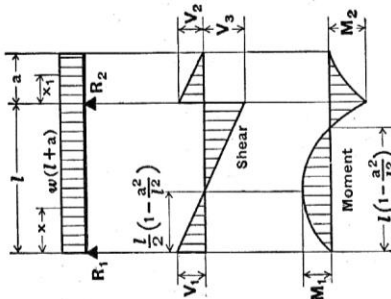
24. BEAM OVERHANGING ONE SUPPORT—UNIFORMLY DISTRIBUTED LOAD

$$R_1 = V_1 = \frac{w}{2l} (l^2 - a^2)$$

$$R_2 = V_2 + V_3 = \frac{w}{2l} (l + a)^2$$

$$V_2 = \frac{wa}{2}$$

$$V_3 = \frac{w}{2l} (l^2 + a^2)$$



$$V_x \text{ (between supports)} = R_1 - wx$$

$$V_{x_1} \text{ (for overhang)} = w(a - x_1)$$

$$M_1 \text{ (at } x = \frac{l}{2} [1 - \frac{a^2}{l^2}])} = \frac{w}{8l^2} (l + a)^2 (l - a)^2$$

$$M_2 \text{ (at } R_2) = \frac{wa^2}{2}$$

$$M_x \text{ (between supports)} = \frac{wx}{2l} (l^2 - a^2 - xl)$$

$$M_{x_1} \text{ (for overhang)} = \frac{w}{2} (a - x_1)^2$$

$$\Delta x \text{ (between supports)} = \frac{wx}{24EI} (4 - 2lx^2 + lx^3 - 2a^2l + 2a^2x^2)$$

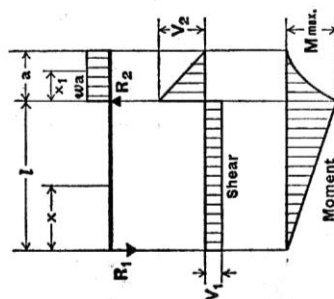
$$\Delta x_1 \text{ (for overhang)} = \frac{wx_1}{24EI} (4a^2l - l^3 + 6a^2x_1 - 4ax_1^2 + x_1^3)$$

25. BEAM OVERHANGING ONE SUPPORT—UNIFORMLY DISTRIBUTED LOAD ON OVERHANG

$$R_1 = V_1 = \frac{wa^2}{2l}$$

$$R_2 = V_2 + V_3 = \frac{wa}{2l} (2l + a)$$

$$V_2 = \frac{wa}{2}$$



$$V_{x_1} \text{ (for overhang)} = w(a - x_1)$$

$$M \text{ max. (at } R_2) = \frac{wa^2}{2}$$

$$M_x \text{ (between supports)} = \frac{wa^2x}{2l}$$

$$M_{x_1} \text{ (for overhang)} = \frac{w}{2} (a - x_1)^2$$

$$\Delta \text{ max. (between supports at } x = \frac{l}{\sqrt{3}}) = \frac{wa^3}{18\sqrt{3}EI} = .03208 \frac{wa^3}{EI}$$

$$\Delta \text{ max. (for overhang at } x_1 = a) = \frac{wa^3}{24EI} (4l + 3a)$$

$$\Delta x \text{ (between supports)} = \frac{wa^2x}{12EI} (l^2 - x^2)$$

$$\Delta x_1 \text{ (for overhang)} = \frac{wx_1}{24EI} (4a^2l + 6a^2x_1 - 4ax_1^2 + x_1^3)$$

26. BEAM OVERHANGING ONE SUPPORT—CONCENTRATED LOAD AT END OF OVERHANG

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

$$R_2 = V_2 + V_3 = \frac{P}{l} (l + a)$$

$$V_2 = \frac{P}{l}$$

$$M \text{ max. (at } R_2) = Pa$$

$$M_x \text{ (between supports)} = \frac{Pax}{l}$$

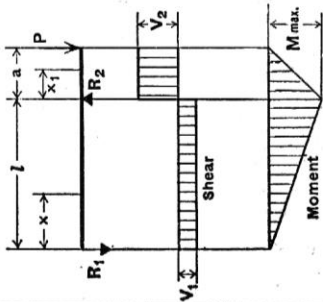
$$M_{x_1} \text{ (for overhang)} = P(a - x_1)$$

$$\Delta \text{ max. (between supports at } x = \frac{l}{\sqrt{3}}) = \frac{Pa l^2}{9\sqrt{3}EI} = .06415 \frac{Pa l^2}{EI}$$

$$\Delta \text{ max. (for overhang at } x_1 = a) = \frac{Pa^2}{3EI} (l + a)$$

$$\Delta x \text{ (between supports)} = \frac{Pax}{6EI} (l^2 - x^2)$$

$$\Delta x_1 \text{ (for overhang)} = \frac{Px_1}{6EI} (2al + 3ax_1 - x_1^2)$$



27. BEAM OVERHANGING ONE SUPPORT—UNIFORMLY DISTRIBUTED LOAD BETWEEN SUPPORTS

$$\text{Total Equiv. Uniform Load} = wl$$

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

$$V_x = \frac{wl}{2} (l - x)$$

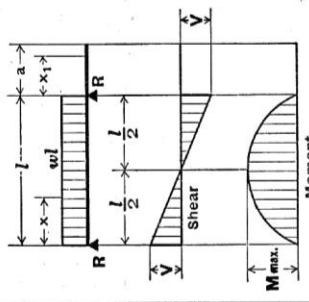
$$M \text{ max. (at center)} = \frac{wl^2}{8}$$

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

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

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

$$\Delta x_1 = \frac{wl^3x_1}{24EI}$$



28. BEAM OVERHANGING ONE SUPPORT—CONCENTRATED LOAD AT ANY POINT BETWEEN SUPPORTS

$$\text{Total Equiv. Uniform Load} = \frac{8Pab}{l^2}$$

$$R_1 = V_1 \text{ (max. when } a < b) = \frac{Pb}{l}$$

$$R_2 = V_2 \text{ (max. when } a > b) = \frac{Pa}{l}$$

$$M \text{ max. (at point of load)} = \frac{Pab}{l}$$

$$M_x \text{ (when } x < a) = \frac{Pbx}{l}$$

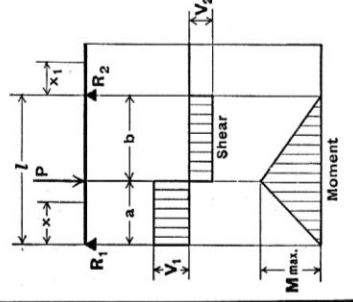
$$\Delta \text{ max. (at } x = \frac{a(a+2b)}{3} \text{ when } a > b) = \frac{Pab(a+2b)\sqrt{3a(a+2b)}}{27EI}$$

$$\Delta a \text{ (at point of load)} = \frac{Pa^2b^2}{3EI}$$

$$\Delta x \text{ (when } x < a) = \frac{6EI}{l^2} (l^2 - b^2 - x^2)$$

$$\Delta x \text{ (when } x > a) = \frac{6EI}{l^2} (2lx - x^2 - a^2)$$

$$\Delta x_1 = \frac{Pabx_1}{6EI} (l + a)$$



Reference Diagrams

Table 7-1 Available Shear Strength of Bolts, kips												
Nominal Bolt Diameter, d , in.					$\frac{5}{8}$		$\frac{3}{4}$		$\frac{7}{8}$		1	
Nominal Bolt Area, in. ²					0.307		0.442		0.601		0.785	
ASTM Desig.	Thread Cond.	F_{nv}/Ω (ksi)		Load- ing	r_n/Ω		ϕr_n		r_n/Ω		ϕr_n	
		ASD	LRFD		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Group A	N	27.0	40.5	S	8.29	12.4	11.9	17.9	16.2	24.3	21.2	31.8
				D	16.6	24.9	23.9	35.8	32.5	48.7	42.4	63.6
Group A	X	34.0	51.0	S	10.4	15.7	15.0	22.5	20.4	30.7	26.7	40.0
				D	20.9	31.3	30.1	45.1	40.9	61.3	53.4	80.1
Group B	N	34.0	51.0	S	10.4	15.7	15.0	22.5	20.4	30.7	26.7	40.0
				D	20.9	31.3	30.1	45.1	40.9	61.3	53.4	80.1
Group B	X	42.0	63.0	S	12.9	19.3	18.6	27.8	25.2	37.9	33.0	49.5
				D	25.8	38.7	37.1	55.7	50.5	75.7	65.9	98.9
A307	-	13.5	20.3	S	4.14	6.23	5.97	8.97	8.11	12.2	10.6	15.9
				D	8.29	12.5	11.9	17.9	16.2	24.4	21.2	31.9
Nominal Bolt Diameter, d , in.					$1\frac{1}{8}$		$1\frac{1}{4}$		$1\frac{3}{8}$		$1\frac{1}{2}$	
Nominal Bolt Area, in. ²					0.994		1.23		1.48		1.77	
ASTM Desig.	Thread Cond.	F_{nv}/Ω (ksi)		Load- ing	r_n/Ω		ϕr_n		r_n/Ω		ϕr_n	
		ASD	LRFD		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Group A	N	27.0	40.5	S	26.8	40.3	33.2	49.8	40.0	59.9	47.8	71.7
				D	53.7	80.5	66.4	99.6	79.9	120	95.6	143
Group A	X	34.0	51.0	S	33.8	50.7	41.8	62.7	50.3	75.5	60.2	90.3
				D	67.6	101	83.6	125	101	151	120	181
Group B	N	34.0	51.0	S	33.8	50.7	41.8	62.7	50.3	75.5	60.2	90.3
				D	67.6	101	83.6	125	101	151	120	181
Group B	X	42.0	63.0	S	41.7	62.6	51.7	77.5	62.2	93.2	74.3	112
				D	83.5	125	103	155	124	186	149	223
A307	-	13.5	20.3	S	13.4	20.2	16.6	25.0	20.0	30.0	23.9	35.9
				D	26.8	40.4	33.2	49.9	40.0	60.1	47.8	71.9
ASD	LRFD	For end loaded connections greater than 38 in., see AISC Specification Table J3.2 footnote b.										
$\Omega = 2.00$	$\phi = 0.75$											

Available Strength of Fillet Welds
per inch of weld (ϕS)

Weld Size (in.)	E60XX (k/in.)	E70XX (k/in.)
$\frac{3}{16}$	3.58	4.18
$\frac{1}{4}$	4.77	5.57
$\frac{5}{16}$	5.97	6.96
$\frac{3}{8}$	7.16	8.35
$\frac{7}{16}$	8.35	9.74
$\frac{1}{2}$	9.55	11.14
$\frac{5}{8}$	11.93	13.92
$\frac{3}{4}$	14.32	16.70

(not considering increase in throat with
submerged arc weld process)

Reference Diagrams

Group A Bolts		Table 7-3 (continued)										Group B Bolts	
		Slip-Critical Connections										Group B Bolts	
		Available Shear Strength, kips (Class A Faying Surface, $\mu = 0.30$)										Group B Bolts	
A325, A325M F1858 A354 Grade BC A449		Available Shear Strength, kips (Class A Faying Surface, $\mu = 0.30$)										A490, A490M F2280 A354 Grade BD	
Hole Type	Loading	Nominal Bolt Diameter, d , in.										Nominal Bolt Diameter, d , in.	
		5/8		3/4		7/8		1		1 1/8		1 1/2	
		Minimum Group A Bolt Pretension, kips										Minimum Group B Bolt Pretension, kips	
		19		28		39		51		64		64	
Hole Type	Loading	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
STD/SSLT	S	4.29	6.44	6.33	9.49	8.81	13.2	11.5	17.3	10.8	16.3	15.8	23.7
	D	8.59	12.9	12.7	19.0	17.6	26.4	23.1	34.6	10.8	16.3	15.8	23.7
OVS/SSLP	S	3.66	5.47	5.39	8.07	7.51	11.2	9.82	14.7	4.62	6.92	6.74	10.1
	D	7.32	10.9	10.8	16.1	15.0	22.5	19.6	29.4	9.25	13.8	13.5	20.2
LSL	S	3.01	4.51	4.44	6.64	6.18	9.25	8.08	12.1	3.80	5.70	5.54	8.31
	D	6.02	9.02	8.87	13.3	12.4	18.5	16.2	24.2	7.60	11.4	11.1	16.6
		Nominal Bolt Diameter, d , in.										Nominal Bolt Diameter, d , in.	
		1 1/8		1 1/4		1 3/8		1 1/2		1 1/4		1 3/8	
		Minimum Group A Bolt Pretension, kips										Minimum Group B Bolt Pretension, kips	
		56		71		85		103		80		102	
Hole Type	Loading	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
STD/SSLT	S	12.7	19.0	16.0	24.1	19.2	28.8	23.3	34.9	18.1	27.1	23.1	34.6
	D	25.3	38.0	32.1	48.1	38.4	57.6	46.6	69.8	36.2	54.2	46.1	69.2
OVS/SSLP	S	10.8	16.1	13.7	20.5	16.4	24.5	19.8	29.7	15.4	23.1	19.6	29.4
	D	21.6	32.3	27.4	40.9	32.7	49.0	39.7	59.4	30.8	46.1	39.3	58.8
LSL	S	8.87	13.3	11.2	16.8	13.5	20.2	16.3	24.4	12.7	19.0	16.2	24.2
	D	17.7	26.6	22.5	33.7	26.9	40.3	32.6	48.9	25.3	38.0	32.3	48.4

STD = standard hole
OVS = oversized hole
SSLT = short-slotted hole transverse to the line of force
SSLP = short-slotted hole parallel to the line of force
LSL = long-slotted hole transverse or parallel to the line of force

Note: Slip-critical bolt values assume no more than one filler has been provided or bolts have been added to distribute loads in the fillers. See AISC Specification Sections J3.8 and J5 for provisions when fillers are present. For Class B faying surfaces, multiply the tabulated available strength by 1.67.

S = single shear
D = double shear

Group B Bolts		Table 7-3 (continued)										Group A Bolts	
		Slip-Critical Connections										Group A Bolts	
		Available Shear Strength, kips (Class A Faying Surface, $\mu = 0.30$)										Group A Bolts	
A490, A490M F2280 A354 Grade BD		Available Shear Strength, kips (Class A Faying Surface, $\mu = 0.30$)										A325, A325M F1858 A354 Grade BC A449	
Hole Type	Loading	Nominal Bolt Diameter, d , in.										Nominal Bolt Diameter, d , in.	
		5/8		3/4		7/8		1		1 1/8		1 1/2	
		Minimum Group B Bolt Pretension, kips										Minimum Group A Bolt Pretension, kips	
		24		35		49		64		80		103	
Hole Type	Loading	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
STD/SSLT	S	5.42	8.14	7.91	11.9	11.1	16.6	14.5	21.7	12.7	19.0	16.0	24.1
	D	10.8	16.3	15.8	23.7	22.1	33.2	28.9	43.4	25.3	38.0	32.1	48.1
OVS/SSLP	S	4.62	6.92	4.62	6.92	4.62	6.92	4.62	6.92	3.66	5.47	3.66	5.47
	D	9.25	13.8	9.25	13.8	9.25	13.8	9.25	13.8	7.32	10.9	7.32	10.9
LSL	S	3.80	5.70	3.80	5.70	3.80	5.70	3.80	5.70	3.01	4.51	3.01	4.51
	D	7.60	11.4	7.60	11.4	7.60	11.4	7.60	11.4	6.02	9.02	6.02	9.02
		Nominal Bolt Diameter, d , in.										Nominal Bolt Diameter, d , in.	
		1 1/8		1 1/4		1 3/8		1 1/2		1 1/8		1 1/4	
		Minimum Group B Bolt Pretension, kips										Minimum Group A Bolt Pretension, kips	
		80		102		121		148		56		71	
Hole Type	Loading	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n	r_n/Ω	ϕr_n
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
STD/SSLT	S	18.1	27.1	23.1	34.6	27.3	41.0	33.4	50.2	12.7	19.0	16.0	24.1
	D	36.2	54.2	46.1	69.2	54.7	82.0	66.9	100	25.3	38.0	32.1	48.1
OVS/SSLP	S	15.4	23.1	19.6	29.4	23.3	34.9	28.5	42.6	10.8	16.1	13.7	20.5
	D	30.8	46.1	39.3	58.8	46.6	69.7	57.0	85.3	21.6	32.3	27.4	40.9
LSL	S	12.7	19.0	16.2	24.2	19.2	28.8	23.3	34.9	8.87	13.3	11.2	16.8
	D	25.3	38.0	32.3	48.4	38.3	57.4	46.9	70.2	17.7	26.6	22.5	33.7

STD = standard hole
OVS = oversized hole
SSLT = short-slotted hole transverse to the line of force
SSLP = short-slotted hole parallel to the line of force
LSL = long-slotted hole transverse or parallel to the line of force

Note: Slip-critical bolt values assume no more than one filler has been provided or bolts have been added to distribute loads in the fillers. See AISC Specification Sections J3.8 and J5 for provisions when fillers are present. For Class B faying surfaces, multiply the tabulated available strength by 1.67.

S = single shear
D = double shear

Reference Diagrams

Table 7-4 (continued)
Available Bearing Strength at Bolt Holes
Based on Bolt Spacing
kips/in. thickness

Hole Type	Bolt Spacing, s , in.	F_u , ksi	Nominal Bolt Diameter, d , in.															
			$5/8$		$3/4$		$7/8$		1		$1\ 1/4$		$1\ 3/8$		$1\ 1/2$			
			r_n/Ω	LRFD	r_n/Ω	LRFD	r_n/Ω	LRFD	r_n/Ω	LRFD	r_n/Ω	LRFD	r_n/Ω	LRFD	r_n/Ω	LRFD	r_n/Ω	LRFD
STD	$2\ 2/3\ d_b$	58	34.1	51.1	41.3	62.0	46.6	72.9	55.8	83.7	58.3	83.7	58.3	83.7	58.3	83.7	58.3	83.7
SSLT	3 in.	65	38.2	57.3	46.3	69.5	54.4	81.7	62.6	93.8	65.1	93.8	65.1	93.8	65.1	93.8	65.1	93.8
SSLP	$2\ 2/3\ d_b$	58	27.6	41.3	34.8	52.2	42.1	63.1	47.1	70.7	58.3	70.7	58.3	70.7	58.3	70.7	58.3	70.7
	3 in.	65	30.9	46.3	39.0	56.5	47.1	70.7	52.8	79.2	65.1	79.2	65.1	79.2	65.1	79.2	65.1	79.2
OVS	$2\ 2/3\ d_b$	58	43.5	65.3	52.2	78.3	60.9	91.4	68.3	102	68.3	102	68.3	102	68.3	102	68.3	102
	3 in.	65	48.8	73.1	58.5	87.8	68.3	102	88.1	98.7	88.1	98.7	88.1	98.7	88.1	98.7	88.1	98.7
LSLP	$2\ 2/3\ d_b$	58	29.7	44.6	37.0	55.5	44.2	66.3	49.3	74.0	65.1	74.0	65.1	74.0	65.1	74.0	65.1	74.0
	3 in.	65	33.3	50.0	41.4	62.2	49.6	74.3	55.3	82.9	65.1	82.9	65.1	82.9	65.1	82.9	65.1	82.9
LSLT	$2\ 2/3\ d_b$	58	43.5	65.3	52.2	78.3	60.9	91.4	68.3	102	68.3	102	68.3	102	68.3	102	68.3	102
	3 in.	65	48.8	73.1	58.5	87.8	68.3	102	88.1	98.7	88.1	98.7	88.1	98.7	88.1	98.7	88.1	98.7
STD, SSLT, SSLP, OVS, LSLP	$s \geq s_{full}$	58	3.62	5.44	4.35	6.53	5.08	7.61	5.80	8.70	65.1	8.70	65.1	8.70	65.1	8.70	65.1	8.70
	$s \geq s_{full}$	65	4.06	6.09	4.88	7.31	5.69	8.53	6.50	9.75	88.1	9.75	88.1	9.75	88.1	9.75	88.1	9.75
LSP	3 in.	65	43.5	65.3	39.2	58.7	28.3	42.4	17.4	26.1	65.1	26.1	65.1	26.1	65.1	26.1	65.1	26.1
LST	$2\ 2/3\ d_b$	58	28.4	42.6	34.4	51.7	40.5	60.7	46.5	69.8	65.1	69.8	65.1	69.8	65.1	69.8	65.1	69.8
	3 in.	65	31.8	47.7	38.6	57.9	45.4	68.0	52.1	78.2	65.1	78.2	65.1	78.2	65.1	78.2	65.1	78.2
STD, SSLT, SSLP, OVS, LSLP	$s \geq s_{full}$	58	36.3	54.4	43.5	65.3	50.8	76.1	56.2	84.3	65.1	84.3	65.1	84.3	65.1	84.3	65.1	84.3
	$s \geq s_{full}$	65	40.6	60.9	48.8	73.1	56.9	85.3	63.0	94.5	88.1	94.5	88.1	94.5	88.1	94.5	88.1	94.5
LSP	$s \geq s_{full}$	58	43.5	65.3	52.2	78.3	60.9	91.4	68.3	102	68.3	102	68.3	102	68.3	102	68.3	102
	$s \geq s_{full}$	65	48.8	73.1	58.5	87.8	68.3	102	88.1	98.7	88.1	98.7	88.1	98.7	88.1	98.7	88.1	98.7
LST	$s \geq s_{full}$	58	36.3	54.4	43.5	65.3	50.8	76.1	56.2	84.3	65.1	84.3	65.1	84.3	65.1	84.3	65.1	84.3
	$s \geq s_{full}$	65	40.6	60.9	48.8	73.1	56.9	85.3	63.0	94.5	88.1	94.5	88.1	94.5	88.1	94.5	88.1	94.5
Spacing for full bearing strength s_{full}^a , in.			1 ^{15/16}	2 ^{5/16}	2 ^{7/16}	2 ^{1/2}	2 ^{3/8}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}
Minimum Spacing ^a = $2\ 2/3d$, in.			1 ^{1/16}	2	2 ^{5/16}	2 ^{5/16}	2 ^{5/16}	2 ^{5/16}	2 ^{5/16}	2 ^{1/16}	3 ^{1/16}	3 ^{1/16}	3 ^{1/16}	3 ^{1/16}	3 ^{1/16}	3 ^{1/16}	3 ^{1/16}	3 ^{1/16}

STD = standard hole
 SSLT = short-slotted hole oriented transverse to the line of force
 SSLP = short-slotted hole oriented parallel to the line of force
 OVS = oversized hole
 LSLP = long-slotted hole oriented parallel to the line of force
 LSLT = long-slotted hole oriented transverse to the line of force

Note: Spacing indicated is from the center of the hole or slot to the center of the adjacent hole or slot in the line of force. Hole deformation is considered. When hole deformation is not considered, see ASC Specification Section J3.10.

^a Decimal value has been rounded to the nearest sixteenth of an inch.

Table 7-4
Available Bearing Strength at Bolt Holes
Based on Bolt Spacing
kips/in. thickness

Hole Type	Bolt Spacing, s , in.	F_u , ksi	Nominal Bolt Diameter, d , in.															
			$5/8$		$3/4$		$7/8$		1		$1\ 1/4$		$1\ 3/8$		$1\ 1/2$			
			r_n/Ω	LRFD	r_n/Ω	LRFD	r_n/Ω	LRFD	r_n/Ω	LRFD	r_n/Ω	LRFD	r_n/Ω	LRFD	r_n/Ω	LRFD	r_n/Ω	LRFD
STD	$2\ 2/3\ d_b$	58	34.1	51.1	41.3	62.0	46.6	72.9	55.8	83.7	58.3	83.7	58.3	83.7	58.3	83.7	58.3	83.7
SSLT	3 in.	65	38.2	57.3	46.3	69.5	54.4	81.7	62.6	93.8	65.1	93.8	65.1	93.8	65.1	93.8	65.1	93.8
SSLP	$2\ 2/3\ d_b$	58	27.6	41.3	34.8	52.2	42.1	63.1	47.1	70.7	58.3	70.7	58.3	70.7	58.3	70.7	58.3	70.7
	3 in.	65	30.9	46.3	39.0	56.5	47.1	70.7	52.8	79.2	65.1	79.2	65.1	79.2	65.1	79.2	65.1	79.2
OVS	$2\ 2/3\ d_b$	58	43.5	65.3	52.2	78.3	60.9	91.4	68.3	102	68.3	102	68.3	102	68.3	102	68.3	102
	3 in.	65	48.8	73.1	58.5	87.8	68.3	102	88.1	98.7	88.1	98.7	88.1	98.7	88.1	98.7	88.1	98.7
LSP	$2\ 2/3\ d_b$	58	29.7	44.6	37.0	55.5	44.2	66.3	49.3	74.0	65.1	74.0	65.1	74.0	65.1	74.0	65.1	74.0
	3 in.	65	33.3	50.0	41.4	62.2	49.6	74.3	55.3	82.9	65.1	82.9	65.1	82.9	65.1	82.9	65.1	82.9
LST	$2\ 2/3\ d_b$	58	43.5	65.3	52.2	78.3	60.9	91.4	68.3	102	68.3	102	68.3	102	68.3	102	68.3	102
	3 in.	65	48.8	73.1	58.5	87.8	68.3	102	88.1	98.7	88.1	98.7	88.1	98.7	88.1	98.7	88.1	98.7
STD, SSLT, SSLP, OVS, LSLP	$s \geq s_{full}$	58	3.62	5.44	4.35	6.53	5.08	7.61	5.80	8.70	65.1	8.70	65.1	8.70	65.1	8.70	65.1	8.70
	$s \geq s_{full}$	65	4.06	6.09	4.88	7.31	5.69	8.53	6.50	9.75	88.1	9.75	88.1	9.75	88.1	9.75	88.1	9.75
LSP	3 in.	65	43.5	65.3	39.2	58.7	28.3	42.4	17.4	26.1	65.1	26.1	65.1	26.1	65.1	26.1	65.1	26.1
LST	$2\ 2/3\ d_b$	58	28.4	42.6	34.4	51.7	40.5	60.7	46.5	69.8	65.1	69.8	65.1	69.8	65.1	69.8	65.1	69.8
	3 in.	65	31.8	47.7	38.6	57.9	45.4	68.0	52.1	78.2	65.1	78.2	65.1	78.2	65.1	78.2	65.1	78.2
STD, SSLT, SSLP, OVS, LSLP	$s \geq s_{full}$	58	36.3	54.4	43.5	65.3	50.8	76.1	56.2	84.3	65.1	84.3	65.1	84.3	65.1	84.3	65.1	84.3
	$s \geq s_{full}$	65	40.6	60.9	48.8	73.1	56.9	85.3	63.0	94.5	88.1	94.5	88.1	94.5	88.1	94.5	88.1	94.5
LSP	$s \geq s_{full}$	58	43.5	65.3	52.2	78.3	60.9	91.4	68.3	102	68.3	102	68.3	102	68.3	102	68.3	102
	$s \geq s_{full}$	65	48.8	73.1	58.5	87.8	68.3	102	88.1	98.7	88.1	98.7	88.1	98.7	88.1	98.7	88.1	98.7
LST	$s \geq s_{full}$	58	36.3	54.4	43.5	65.3	50.8	76.1	56.2	84.3	65.1	84.3	65.1	84.3	65.1	84.3	65.1	84.3
	$s \geq s_{full}$	65	40.6	60.9	48.8	73.1	56.9	85.3	63.0	94.5	88.1	94.5	88.1	94.5	88.1	94.5	88.1	94.5
Spacing for full bearing strength s_{full}^a , in.			1 ^{15/16}	2 ^{5/16}	2 ^{7/16}	2 ^{1/2}	2 ^{3/8}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}	2 ^{1/2}
Minimum Spacing ^a = $2\ 2/3d$, in.			1 ^{1/16}	2	2 ^{5/16}	2 ^{5/16}	2 ^{5/16}	2 ^{5/16}	2 ^{5/16}	2 ^{1/16}	3 ^{1/16}	3 ^{1/16}	3 ^{1/16}	3 ^{1/16}	3 ^{1/16}	3 ^{1/16}	3 ^{1/16}	3 ^{1/16}

STD = standard hole
 SSLT = short-slotted hole oriented transverse to the line of force
 SSLP = short-slotted hole oriented parallel to the line of force
 OVS = oversized hole
 LSLP = long-slotted hole oriented parallel to the line of force
 LSLT = long-slotted hole oriented transverse to the line of force

Note: Spacing indicated is from the center of the hole or slot to the center of the adjacent hole or slot in the line of force. Hole deformation is considered. When hole deformation is not considered, see ASC Specification Section J3.10.

^a Decimal value has been rounded to the nearest sixteenth of an inch.

Reference Diagrams

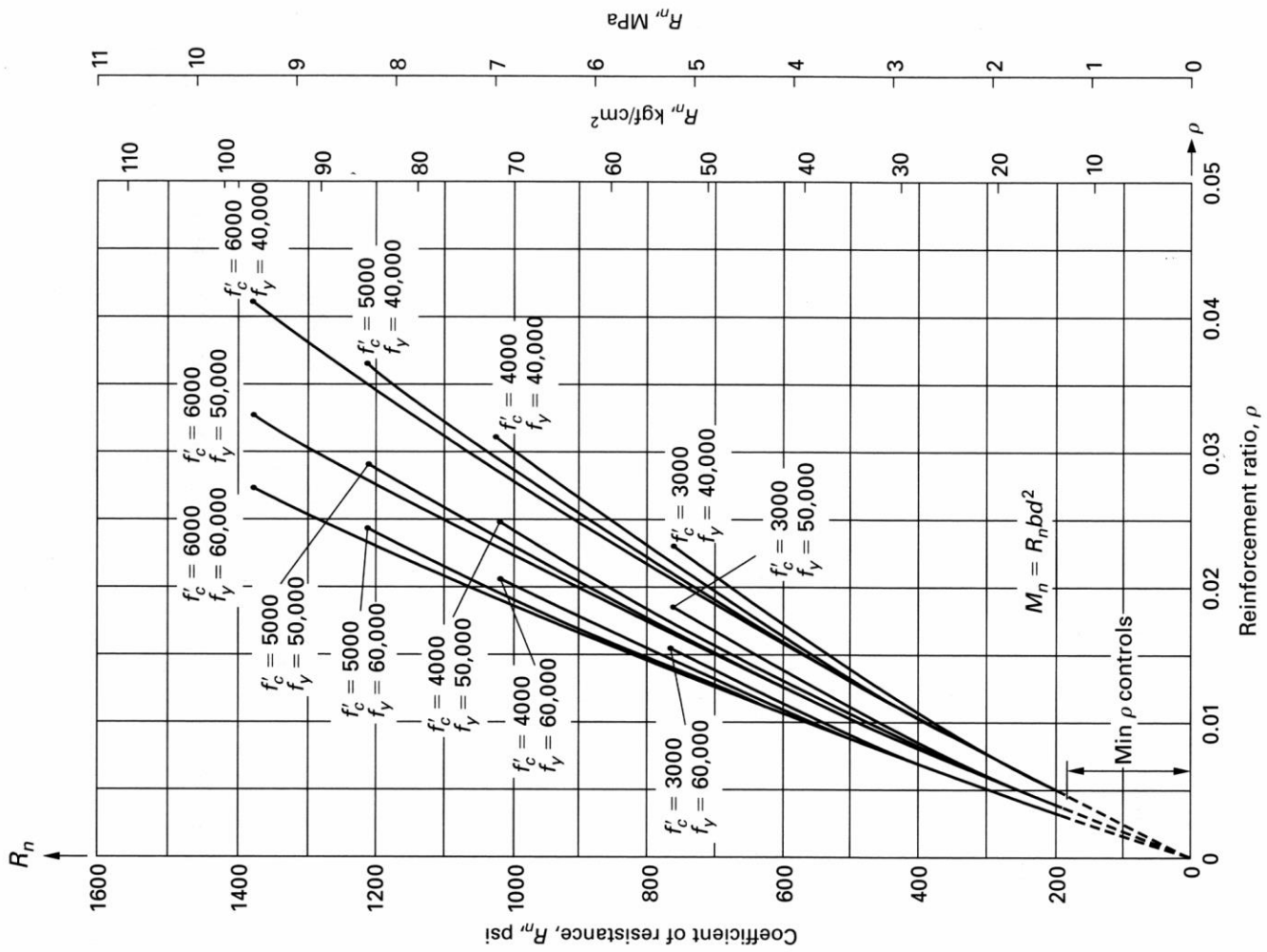
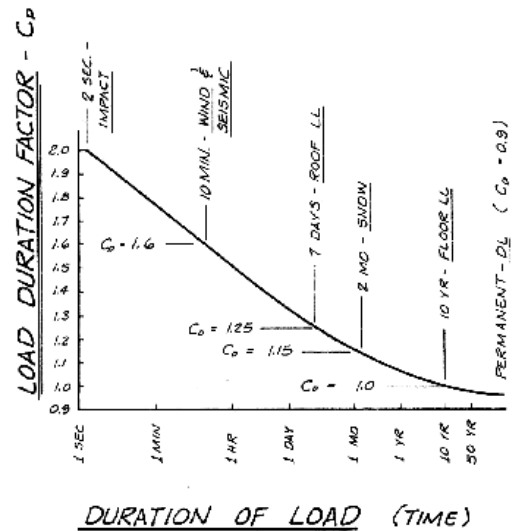


Figure 3.8.1 Strength curves (R_n vs ρ) for singly reinforced rectangular sections. Upper limit of curves is at ρ_{max} . (tensile strain of 0.004)

TABLE 13.6 Areas Provided By Spaced Reinforcement

Bar Spacing (in.)	Area Provided (in. ² /ft width)									
	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11
3		0.44	0.80	1.24	1.76	2.40	3.16	4.00		
3.5		0.38	0.69	1.06	1.51	2.06	2.71	3.43	4.35	
4		0.33	0.60	0.93	1.32	1.80	2.37	3.00	3.81	4.68
4.5		0.29	0.53	0.83	1.17	1.60	2.11	2.67	3.39	4.16
5		0.26	0.48	0.74	1.06	1.44	1.89	2.40	3.05	3.74
5.5		0.24	0.44	0.68	0.96	1.31	1.72	2.18	2.77	3.40
6		0.22	0.40	0.62	0.88	1.20	1.58	2.00	2.54	3.12
7		0.19	0.34	0.53	0.75	1.03	1.35	1.71	2.18	2.67
8		0.16	0.30	0.46	0.66	0.90	1.18	1.50	1.90	2.34
9		0.15	0.27	0.41	0.59	0.80	1.05	1.33	1.69	2.08
10		0.13	0.24	0.37	0.53	0.72	0.95	1.20	1.52	1.87
11		0.12	0.22	0.34	0.48	0.65	0.86	1.09	1.38	1.70
12		0.11	0.20	0.31	0.44	0.60	0.79	1.00	1.27	1.56
13		0.10	0.18	0.29	0.40	0.55	0.73	0.92	1.17	1.44
14		0.09	0.17	0.27	0.38	0.51	0.68	0.86	1.09	1.34
15		0.09	0.16	0.25	0.35	0.48	0.63	0.80	1.01	1.25
16		0.08	0.15	0.23	0.33	0.45	0.59	0.75	0.95	1.17
18		0.07	0.13	0.21	0.29	0.40	0.53	0.67	0.85	1.04
24		0.05	0.10	0.15	0.22	0.30	0.39	0.50	0.63	0.78



Reference Diagrams

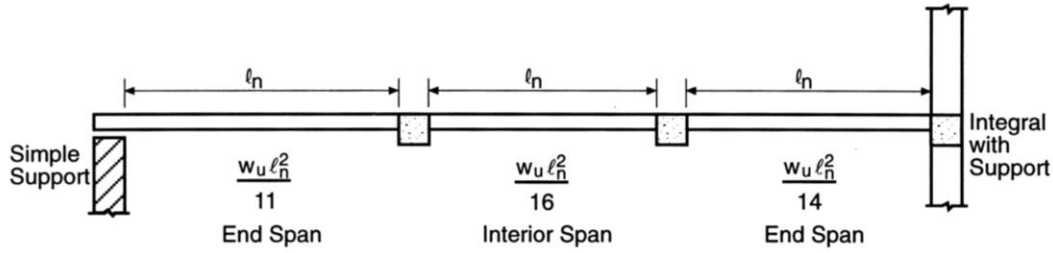


Figure 2-3 Positive Moments—All Cases

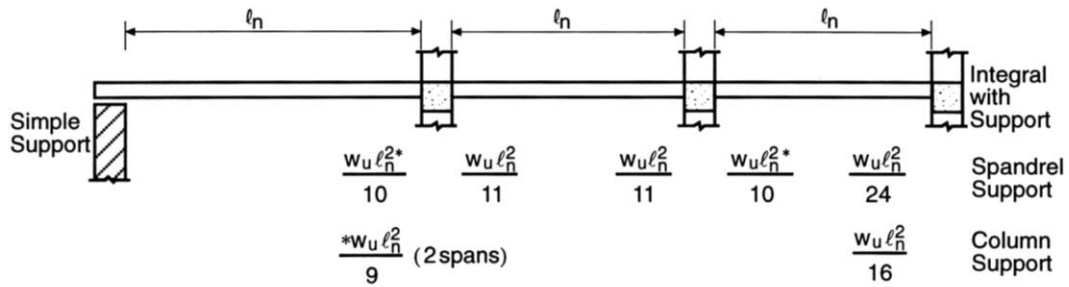


Figure 2-4 Negative Moments—Beams and Slabs

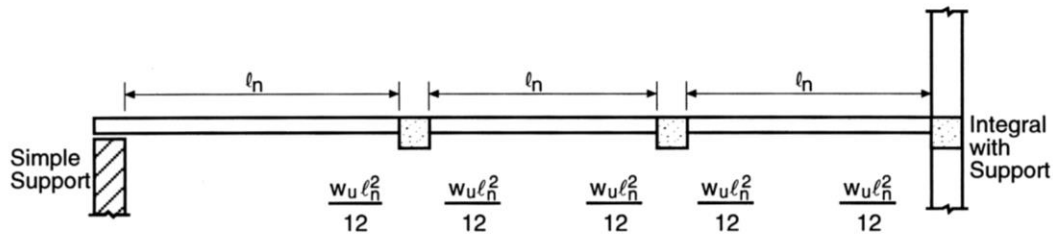


Figure 2-5 Negative Moments—Slabs with spans ≤ 10 ft

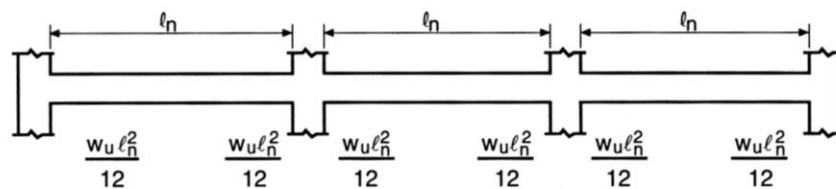


Figure 2-6 Negative Moments—Beams with Stiff Columns ($\Sigma K_c / \Sigma K_b > 8$)

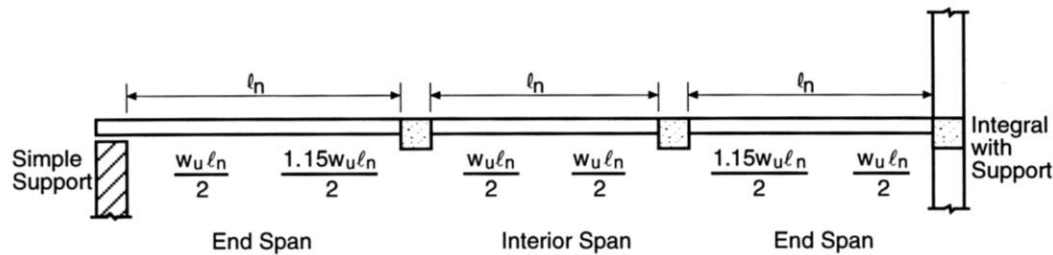


Figure 2-7 End Shears—All Cases

Reference Diagrams

Table 14 Column Stability Factor C_p

			" C_p "			$F_c' = C_p \cdot F_c^*$ $F_{CE} = \frac{.30 E}{(l/d)^2}$ for sawed posts $F_{CE} = \frac{.418 E}{(l/d)^2}$ for glu-lam posts		
$\frac{F_{CE}}{F_c^*}$	Sawed C_p	Glu-Lam C_p	$\frac{F_{CE}}{F_c^*}$	Sawed C_p	Glu-Lam C_p	$\frac{F_{CE}}{F_c^*}$	Sawed C_p	Glu-Lam C_p
0.00	0.000	0.000	0.40	0.360	0.377	0.80	0.610	0.667
0.01	0.010	0.010	0.41	0.367	0.386	0.81	0.614	0.672
0.02	0.020	0.020	0.42	0.375	0.394	0.82	0.619	0.678
0.03	0.030	0.030	0.43	0.383	0.403	0.83	0.623	0.683
0.04	0.040	0.040	0.44	0.390	0.411	0.84	0.628	0.688
0.05	0.049	0.050	0.45	0.398	0.420	0.85	0.632	0.693
0.06	0.059	0.060	0.46	0.405	0.428	0.86	0.637	0.698
0.07	0.069	0.069	0.47	0.412	0.436	0.87	0.641	0.703
0.08	0.079	0.079	0.48	0.419	0.444	0.88	0.645	0.708
0.09	0.088	0.089	0.49	0.427	0.453	0.89	0.649	0.713
0.10	0.098	0.099	0.50	0.434	0.461	0.90	0.653	0.718
0.11	0.107	0.109	0.51	0.441	0.469	0.91	0.658	0.722
0.12	0.117	0.118	0.52	0.448	0.477	0.92	0.661	0.727
0.13	0.126	0.128	0.53	0.454	0.484	0.93	0.665	0.731
0.14	0.136	0.138	0.54	0.461	0.492	0.94	0.669	0.735
0.15	0.145	0.147	0.55	0.468	0.500	0.95	0.673	0.740
0.16	0.154	0.157	0.56	0.474	0.508	0.96	0.677	0.744
0.17	0.164	0.167	0.57	0.481	0.515	0.97	0.680	0.748
0.18	0.173	0.176	0.58	0.487	0.523	0.98	0.684	0.752
0.19	0.182	0.186	0.59	0.494	0.530	0.99	0.688	0.756
0.20	0.191	0.195	0.60	0.500	0.538	1.00	0.691	0.760
0.21	0.200	0.205	0.61	0.506	0.545	1.01	0.694	0.764
0.22	0.209	0.214	0.62	0.512	0.552	1.02	0.698	0.767
0.23	0.218	0.224	0.63	0.518	0.559	1.03	0.701	0.771
0.24	0.227	0.233	0.64	0.524	0.566	1.04	0.704	0.774
0.25	0.235	0.242	0.65	0.530	0.573	1.05	0.708	0.778
0.26	0.244	0.252	0.66	0.536	0.580	1.06	0.711	0.781
0.27	0.253	0.261	0.67	0.542	0.587	1.07	0.714	0.784
0.28	0.261	0.270	0.68	0.548	0.593	1.08	0.717	0.788
0.29	0.270	0.279	0.69	0.553	0.600	1.09	0.720	0.791
0.30	0.278	0.288	0.70	0.559	0.607	1.10	0.723	0.794
0.31	0.287	0.297	0.71	0.564	0.613	1.11	0.726	0.797
0.32	0.295	0.306	0.72	0.569	0.619	1.12	0.729	0.800
0.33	0.304	0.315	0.73	0.575	0.626	1.13	0.731	0.803
0.34	0.312	0.324	0.74	0.580	0.632	1.14	0.734	0.806
0.35	0.320	0.333	0.75	0.585	0.638	1.15	0.737	0.809
0.36	0.328	0.342	0.76	0.590	0.644	1.16	0.740	0.811
0.37	0.336	0.351	0.77	0.595	0.650	1.17	0.742	0.814
0.38	0.344	0.360	0.78	0.600	0.655	1.18	0.745	0.817
0.39	0.352	0.368	0.79	0.605	0.661	1.19	0.747	0.819

(continued)

Reference Diagrams

Table 14 Column Stability Factor C_p . (Continued)

C_p			$F_c' = C_p \cdot F_c^*$ $F_{CE} = \frac{.30 E}{(l/d)^2}$ for sawed posts $F_{CE} = \frac{.418 E}{(l/d)^2}$ for glu-lam posts								
$\frac{F_{CE}}{F_c^*}$	Sawed C_p	Glu-Lam C_p	$\frac{F_{CE}}{F_c^*}$	Sawed C_p	Glu-Lam C_p	$\frac{F_{CE}}{F_c^*}$	Sawed C_p	Glu-Lam C_p	$\frac{F_{CE}}{F_c^*}$	Sawed C_p	Glu-Lam C_p
2.00	0.867	0.921	2.40	0.894	0.940	3.40	0.930	0.962	4.40	0.948	0.972
2.02	0.869	0.922	2.45	0.897	0.941	3.45	0.931	0.963	4.45	0.949	0.973
2.04	0.870	0.924	2.50	0.899	0.943	3.50	0.932	0.963	4.50	0.949	0.973
2.06	0.872	0.925	2.55	0.901	0.944	3.55	0.933	0.964	4.55	0.950	0.974
2.08	0.874	0.926	2.60	0.904	0.946	3.60	0.934	0.965	4.60	0.950	0.974
2.10	0.875	0.927	2.65	0.906	0.947	3.65	0.936	0.965	4.65	0.951	0.974
2.12	0.876	0.928	2.70	0.908	0.949	3.70	0.937	0.966	4.70	0.952	0.975
2.14	0.878	0.929	2.75	0.910	0.950	3.75	0.938	0.966	4.75	0.952	0.975
2.16	0.879	0.930	2.80	0.912	0.951	3.80	0.938	0.967	4.80	0.953	0.975
2.18	0.881	0.931	2.85	0.914	0.952	3.85	0.939	0.968	4.85	0.953	0.975
2.20	0.882	0.932	2.90	0.916	0.953	3.90	0.940	0.968	4.90	0.954	0.976
2.22	0.883	0.932	2.95	0.917	0.954	3.95	0.941	0.969	5.00	0.955	0.976
2.24	0.885	0.933	3.00	0.919	0.955	4.00	0.942	0.969	6.00	0.963	0.981
2.26	0.886	0.934	3.05	0.920	0.956	4.05	0.943	0.969	8.00	0.973	0.986
2.28	0.887	0.935	3.10	0.922	0.957	4.10	0.944	0.970	10.0	0.979	0.989
2.30	0.888	0.936	3.15	0.923	0.958	4.15	0.944	0.970	20.0	0.990	0.995
2.32	0.889	0.937	3.20	0.925	0.959	4.20	0.945	0.971	40.0	0.995	0.997
2.34	0.891	0.937	3.25	0.926	0.960	4.25	0.946	0.971	60.0	0.997	0.998
2.36	0.892	0.938	3.30	0.927	0.961	4.30	0.947	0.972	100.0	0.998	0.999
2.38	0.893	0.939	3.35	0.929	0.961	4.35	0.947	0.972	200.0	0.999	0.999

Table developed and permission for use granted by Professor Ed Lebert, Dept. of Architecture, University of Washington.

Table 3.7.1

Total Areas for Various Numbers of Reinforcing Bars

Bar Size	Nominal Diameter (in.)	Weight (lb/ft)	Number of Bars									
			1	2	3	4	5	6	7	8	9	10
#3	0.375	0.376	0.11	0.22	0.33	0.44	0.55	0.66	0.77	0.88	0.99	1.10
#4	0.500	0.668	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00
#5	0.625	1.043	0.31	0.62	0.93	1.24	1.55	1.86	2.17	2.48	2.79	3.10
#6	0.750	1.502	0.44	0.88	1.32	1.76	2.20	2.64	3.08	3.52	3.96	4.40
#7	0.875	2.044	0.60	1.20	1.80	2.40	3.00	3.60	4.20	4.80	5.40	6.00
#8	1.000	2.670	0.79	1.58	2.37	3.16	3.95	4.74	5.53	6.32	7.11	7.90
#9	1.128	3.400	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
#10	1.270	4.303	1.27	2.54	3.81	5.08	6.35	7.62	8.89	10.16	11.43	12.70
#11	1.410	5.313	1.56	3.12	4.68	6.24	7.80	9.36	10.92	12.48	14.04	15.60
#14 ^a	1.693	7.65	2.25	4.50	6.75	9.00	11.25	13.50	15.75	18.00	20.25	22.50
#18 ^a	2.257	13.60	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00	40.00

^a #14 and #18 bars are used primarily as column reinforcement and are rarely used in beams.

Reference Diagrams

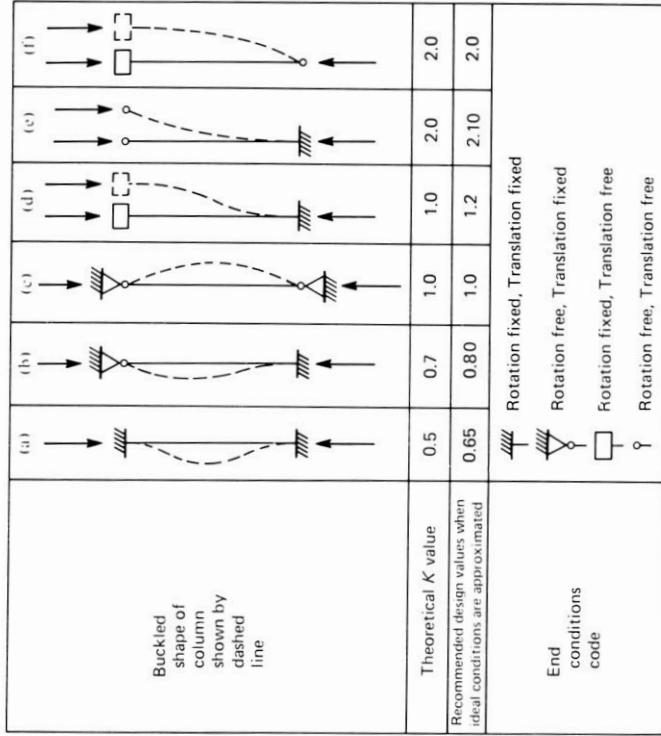
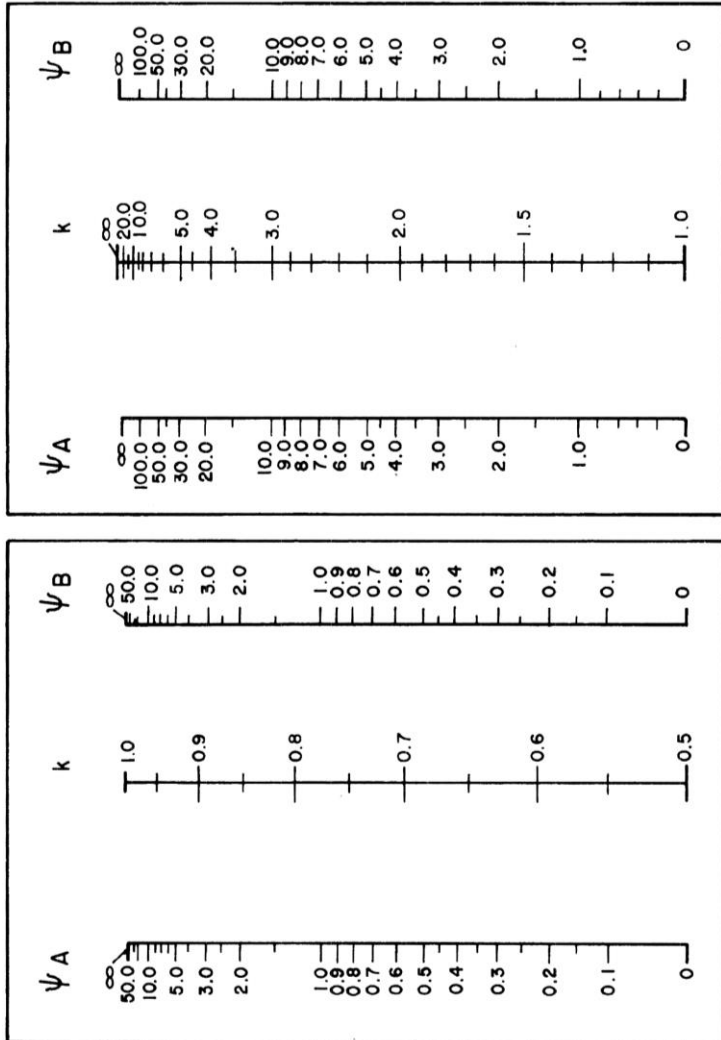


Table 3-8 ACI Provisions for Shear Design*

Required area of stirrups, A_v^{**}	$V_u \leq \frac{\phi V_c}{2}$	$\phi V_c \geq V_u > \frac{\phi V_c}{2}$	$V_u > \phi V_c$
Required	none	$\frac{50b_w s}{f_y}$	$\frac{(V_u - \phi V_c)s}{\phi f_y d}$
Recommended Minimum†	—	$\frac{A_v f_y}{50b_w}$	$\frac{\phi A_v f_y d}{V_u - \phi V_c}$
Stirrup spacing, s	—	—	4 in.
Maximum †† (ACI 11.5.4)	—	$\frac{d}{2}$ or 24 in.	$\frac{d}{2}$ or 24 in. for $(V_u - \phi V_c) \leq \phi 4\sqrt{f_c} b_w d$ $\frac{d}{4}$ or 12 in. for $(V_u - \phi V_c) > \phi 4\sqrt{f_c} b_w d$

*Members subjected to shear and flexure only; $\phi V_c = \phi 2\sqrt{f_c} b_w d$, $\phi = 0.75$ (ACI 11.5.2)

** $A_v = 2 \times A_b$ for U stirrups; $f_y \leq 60$ ksi (ACI 11.5.2)

†A practical limit for minimum spacing is $d/4$

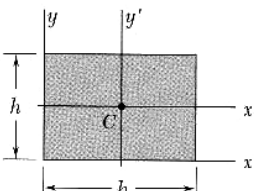
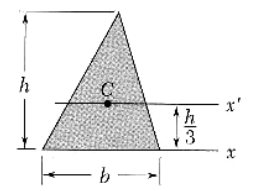
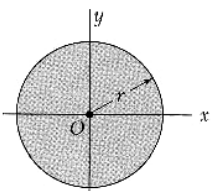
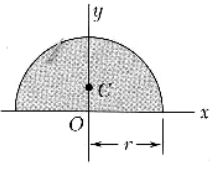
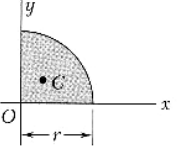
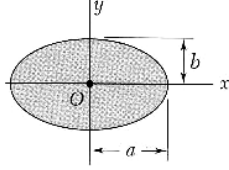
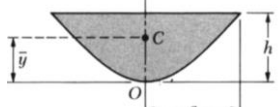
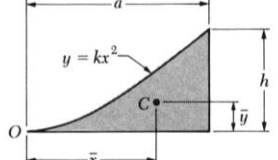
††Maximum spacing based on minimum shear reinforcement ($= A_v f_y / 50b_w$) must also be considered (ACI 11.5.5.3).

Maximum Reinforcement Ratio ρ for Singly Reinforced Rectangular Beams

(tensile strain = 0.005) for which ϕ is permitted to be 0.9

f_y	$f_c = 3000$ psi $\beta_1 = 0.85$	$f_c = 3500$ psi $\beta_1 = 0.85$	$f_c = 4000$ psi $\beta_1 = 0.85$	$f_c = 5000$ psi $\beta_1 = 0.80$	$f_c = 6000$ psi $\beta_1 = 0.75$
40,000 psi	0.0203	0.0237	0.0271	0.0319	0.0359
50,000 psi	0.0163	0.0190	0.0217	0.0255	0.0287
60,000 psi	0.0135	0.0158	0.0181	0.0213	0.0239
f_y	$f_c = 20$ MPa $\beta_1 = 0.85$	$f_c = 25$ MPa $\beta_1 = 0.85$	$f_c = 30$ MPa $\beta_1 = 0.85$	$f_c = 35$ MPa $\beta_1 = 0.81$	$f_c = 40$ MPa $\beta_1 = 0.77$
300 MPa	0.0181	0.0226	0.0271	0.0301	0.0327
350 MPa	0.0155	0.0194	0.0232	0.0258	0.0281
400 MPa	0.0135	0.0169	0.0203	0.0226	0.0245
500 MPa	0.0108	0.0135	0.0163	0.0181	0.0196

Reference Geometry

<p>Rectangle</p>		$\bar{I}_{x'} = \frac{1}{12}bh^3$ $\bar{I}_{y'} = \frac{1}{12}b^3h$ $I_x = \frac{1}{3}bh^3$ $I_y = \frac{1}{3}b^3h$ $J_C = \frac{1}{12}bh(b^2 + h^2)$	<p>Area = bh $\bar{x} = b/2$ $\bar{y} = h/2$</p>
<p>Triangle</p>		$\bar{I}_{x'} = \frac{1}{36}bh^3$ $I_x = \frac{1}{12}bh^3$ $\bar{I}_{y'} = \frac{1}{36}b^3h$	<p>Area = $bh/2$ $\bar{x} = b/3$ $\bar{y} = h/3$</p>
<p>Circle</p>		$\bar{I}_x = \bar{I}_y = \frac{1}{4}\pi r^4$ $J_O = \frac{1}{2}\pi r^4$	<p>Area = $\pi r^2 = \pi d^2/4$ $\bar{x} = 0$ $\bar{y} = 0$</p>
<p>Semicircle</p>		$\bar{I}_x = 0.1098r^4$ $\bar{I}_y = \pi r^4/8$	<p>Area = $\pi r^2/2 = \pi d^2/8$ $\bar{x} = 0$ $\bar{y} = 4r/3\pi$</p>
<p>Quarter circle</p>		$\bar{I}_x = 0.0549r^4$ $\bar{I}_y = 0.0549r^4$	<p>Area = $\pi r^2/4 = \pi d^2/16$ $\bar{x} = 4r/3\pi$ $\bar{y} = 4r/3\pi$</p>
<p>Ellipse</p>		$\bar{I}_x = \frac{1}{4}\pi ab^3$ $\bar{I}_y = \frac{1}{4}\pi a^3b$ $J_O = \frac{1}{4}\pi ab(a^2 + b^2)$	<p>Area = πab $\bar{x} = 0$ $\bar{y} = 0$</p>
<p>Parabolic area</p>		$\bar{I}_x = 16ah^3/175$ $\bar{I}_y = 4a^3h/15$	<p>Area = $4ah/3$ $\bar{x} = 0$ $\bar{y} = 3h/5$</p>
<p>Parabolic spandrel</p>		$\bar{I}_x = 37ah^3/2100$ $\bar{I}_y = a^3h/80$	<p>Area = $ah/3$ $\bar{x} = 3a/4$ $\bar{y} = 3h/10$</p>