Reference Formulas

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

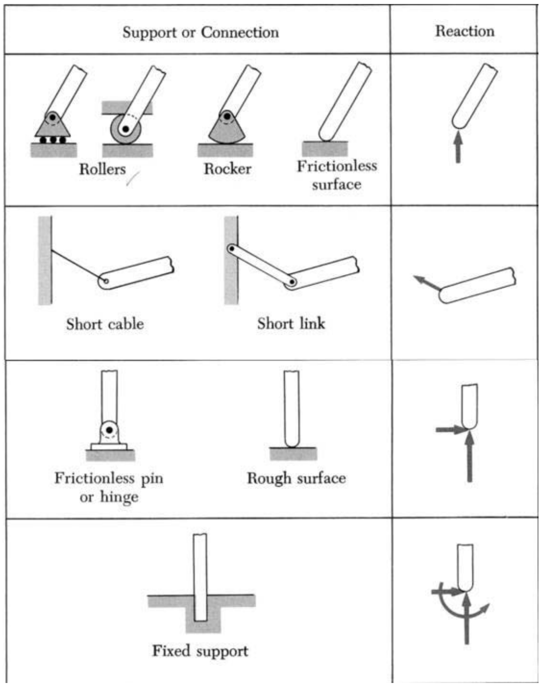
$nF_{connector} \ge \frac{VQ_{connected\ area}}{I} \cdot p$	$V = ZICW/R_W$	$1\ kN/mm^2 = 10^3\ MPa$
$V_{longitudinal} = \frac{V_T Q}{I}\Delta x$	$W = \gamma t A$	$w = \gamma A$
$p = w'h$	$W = \gamma V$	$w' = \gamma t$
$P = \frac{1}{2} ph$	$\gamma = \frac{\rho\phi}{L}$	$f_v = \tau = G \cdot \frac{\rho\phi}{L}$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

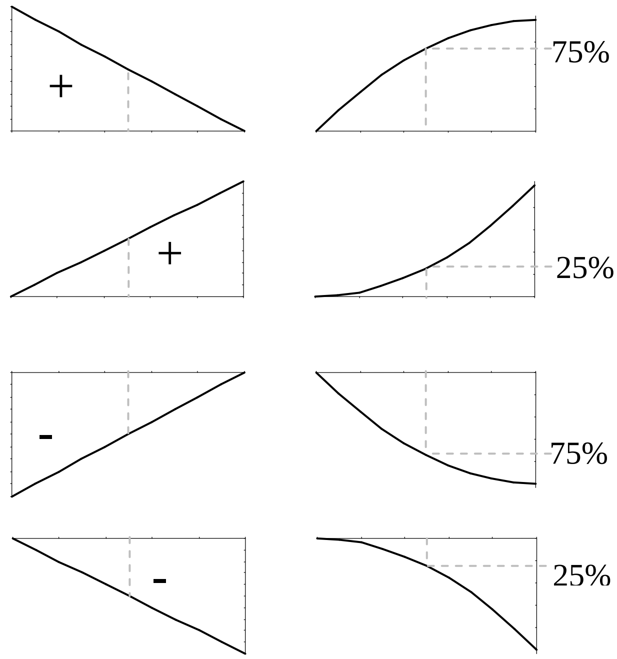
ACI-318: $A_s f_y = 0.85 f_c' ba$	$a = \frac{A_s f_y}{0.85 f_c' b}$	$\rho = \frac{A_s}{bd}$
$M_u \le \phi M_n = \phi A_s f_y \left(d - \frac{a}{2}\right)$ $\phi = 0.9$	*min:* $A_s = \frac{3\sqrt{f_c'}}{f_y}(b_w d)$, *not less than* $A_s = \frac{200}{f_y}(b_w d)$	
$R_n = \frac{M_n}{bd^2}$	*T, min:* $A_s = \frac{6\sqrt{f_c'}}{f_y}(b_w d)$, *not less than* $A_s = \frac{3\sqrt{f_c'}}{f_y}(b_f d)$	
slab (<60 ksi): $A_s = 0.002b(t \text{ or } h)$	*slab (60 ksi):* $A_s = 0.0018b(t \text{ or } h)$	$V_u \le \phi V_c + \phi V_s \quad \phi = 0.75$
one-way: $V_c = 2\sqrt{f_c'} b_w d$	$V_s = \frac{A_v f_y d}{s}$	$E_c = w_c^{1.5} 33\sqrt{f_c'}$
two-way: $V_c = 4\sqrt{f_c'} b_w d$	$E_c = 57{,}000\sqrt{f_c'}$	*tied:* $\phi_c P_n = \phi_c(0.8P_o)$ $\phi_c = 0.65$
$G = \Psi = \frac{\Sigma EI/l_c}{\Sigma EI/l_b}$	$P_o = 0.85 f_c'(A_g - A_{st}) + f_y A_{st}$	*spiral:* $\phi_c P_n = \phi_c(0.85P_o)$ $\phi_c = 0.75$
$l_{dh} = \frac{1200 d_b}{\sqrt{f_c'}}$	*(c):* $l_d = \frac{0.02 d_b F_y}{\sqrt{f_c'}} \le 0.0003 d_b F_y$	$\le$#6 : $l_d = \frac{d_b F_y}{25\sqrt{f_c'}}$
$\frac{P}{A} \le q_{net}$	$q_{net} = q_{allowable} - h_f(\gamma_c - \gamma_s)$	>#6 : $l_d = \frac{d_b F_y}{20\sqrt{f_c'}}$
$q_u = \frac{P_u}{A}$	$V_{u2} = P_u - q_u(c+d)(b+d)$	$V_{u1} = BL' q_u$
$volume = \frac{wpx}{2} = N$	$b_o = 2(c+d) + 2(b+d)$	$V_{u1} \le \phi 2\sqrt{f_c'} Bd$
$p_{\max} = \frac{2N}{wx}$	$V_{u2} \le \phi\left(2 + \frac{4}{\beta_c}\right)\sqrt{f_c'} b_o d \le \phi 4\sqrt{f_c'} b_o d$	$M_u = q_u \frac{BL_m^2}{2}$
$SF = \frac{M_{resist}}{M_{overturning}} \ge 1.5$	$\text{P}_u \le \phi_b \text{P}_n = \phi_b(0.85 f_c' A_1)\sqrt{A_2/A_1}$ $\phi_p = 0.65$	$SF = \frac{F_{horizontal\text{-}resist}}{F_{sliding}} \ge 1.5$

Wood: $F' = C_D C_M C_F \ldots \times F_{tabulated}$	K_{cE} = 0.3 sawn, 0.418 glulam	$P_a = F_c' A$
$F_c' = F_c^* C_p = (F_c C_D) C_p$	$F_{cE} = \frac{K_{cE} E}{\left(l_e/d\right)^2}$	$\left[\frac{f_c}{F_c'}\right]^2 + \frac{f_{bx}}{F_{bx}'\left[1 - f_c/F_{cEx}\right]} \le 1.0$

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

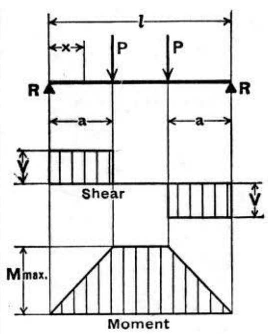
Reference Diagrams





Reference Beam Diagrams

9. SIMPLE BEAM—TWO EQUAL CONCENTRATED LOADS SYMMETRICALLY PLACED



Total Equiv. Uniform Load . . . . . . $= \frac{8Pa}{l}$

$R = V$ . . . . $= P$

M max. (between loads) . . . . . $= Pa$

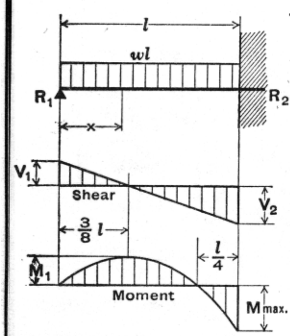
M_x (when $x < a$) . . . . . $= Px$

Δmax. (at center) . . . . $= \frac{Pa}{24EI}(3l^2 - 4a^2)$

Δx (when $x < a$) . . . . $= \frac{Px}{6EI}(3la - 3a^2 - x^2)$

Δx (when $x > a$ and $< (l - a)$) . . $= \frac{Pa}{6EI}(3lx - 3x^2 - a^2)$

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



Total Equiv. Uniform Load . . . . . . $= wl$

$R_1 = V_1$ . . . . $= \frac{3wl}{8}$

$R_2 = V_2$ max. . . . . $= \frac{5wl}{8}$

V_x . . . . $= R_1 - wx$

M max. . . . . $= \frac{wl^2}{8}$

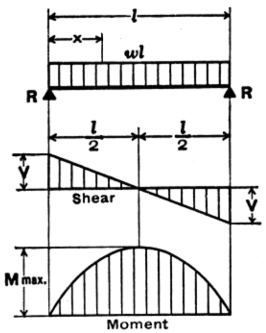
M_1 (at $x = \frac{3}{8}l$) . . . . $= \frac{9}{128}wl^2$

M_x . . . . $= R_1x - \frac{wx^2}{2}$

Δmax. (at $x = \frac{l}{16}(1 + \sqrt{33}) = .4215l$) . $= \frac{wl^4}{185EI}$

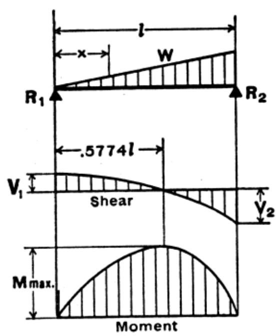
Δx . . . . $= \frac{wx}{48EI}(l^3 - 3lx^2 + 2x^3)$

1. SIMPLE BEAM—UNIFORMLY DISTRIBUTED LOAD



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

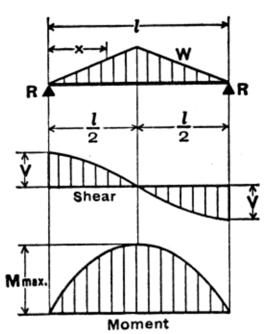
2. SIMPLE BEAM—LOAD INCREASING UNIFORMLY TO ONE END



Total Equiv. Uniform Load		$= \frac{16W}{9\sqrt{3}} = 1.0264W$
$R_1 = V_1$		$= \frac{W}{3}$
$R_2 = V_2$ max.		$= \frac{2W}{3}$
V_x		$= \frac{W}{3} - \frac{Wx^2}{l^2}$
M max.	$\left(\text{at } x = \frac{l}{\sqrt{3}} = .5774l\right)$	$= \frac{2Wl}{9\sqrt{3}} = .1283\,Wl$
M_x		$= \frac{Wx}{3l^2}(l^2 - x^2)$
Δmax.	$\left(\text{at } x = l\sqrt{1 - \sqrt{\frac{8}{15}}} = .5193l\right)$	$= .01304\,\frac{Wl^3}{EI}$
Δx		$= \frac{Wx}{180EIl^2}(3x^4 - 10l^2x^2 + 7l^4)$

$W = \frac{wl}{2}$

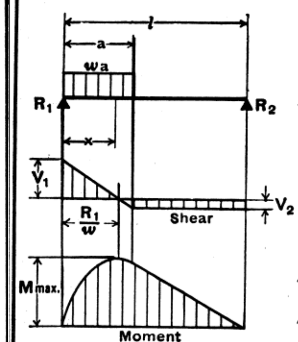
3. SIMPLE BEAM—LOAD INCREASING UNIFORMLY TO CENTER



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

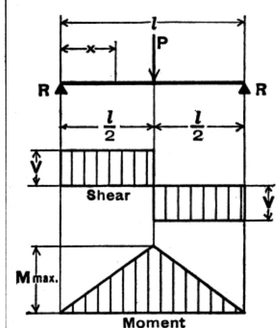
$W = \frac{wl}{2}$

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



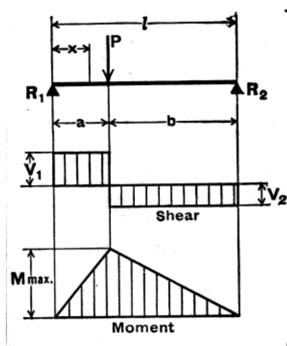
$R_1 = V_1$ max.		$= \frac{wa}{2l}(2l - a)$
$R_2 = V_2$		$= \frac{wa^2}{2l}$
V_x	(when $x < a$)	$= R_1 - wx$
M max.	$\left(\text{at } x = \frac{R_1}{w}\right)$	$= \frac{R_1^2}{2w}$
M_x	(when $x < a$)	$= R_1x - \frac{wx^2}{2}$
M_x	(when $x > a$)	$= R_2(l - x)$
Δx	(when $x < a$)	$= \frac{wx}{24EIl}\left(a^2(2l-a)^2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

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	$\left(\text{when } x < \frac{l}{2}\right)$	$= \frac{Px}{2}$
Δmax.	(at point of load)	$= \frac{Pl^3}{48EI}$
Δx	$\left(\text{when } x < \frac{l}{2}\right)$	$= \frac{Px}{48EI}(3l^2 - 4x^2)$

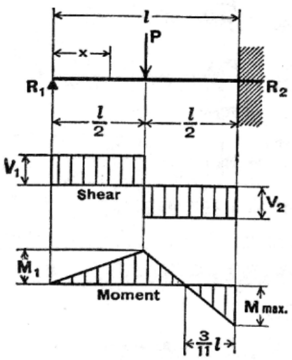
8. SIMPLE BEAM—CONCENTRATED LOAD AT ANY POINT



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 $x < a$)	$= \frac{Pbx}{l}$
Δmax.	$\left(\text{at } x = \sqrt{\frac{a(a+2b)}{3}} \text{ when } a > b\right)$	$= \frac{Pab(a+2b)\sqrt{3a(a+2b)}}{27EIl}$
Δa	(at point of load)	$= \frac{Pa^2b^2}{3EIl}$
Δx	(when $x < a$)	$= \frac{Pbx}{6EIl}(l^2 - b^2 - x^2)$

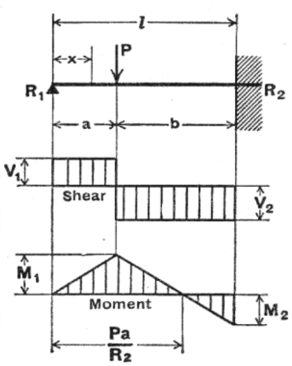
Δx

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



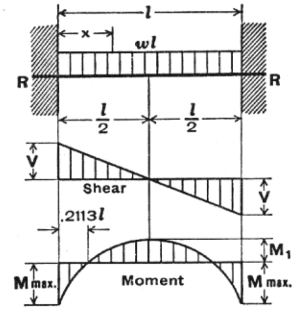
Total Equiv. Uniform Load	$= \frac{3P}{2}$
$R_1 = V_1$	$= \frac{5P}{16}$
$R_2 = V_2$ max.	$= \frac{11P}{16}$
M max. (at fixed end)	$= \frac{3Pl}{16}$
M_1 (at point of load)	$= \frac{5Pl}{32}$
M_x $\left(\text{when } x < \frac{l}{2}\right)$	$= \frac{5Px}{16}$
M_x $\left(\text{when } x > \frac{l}{2}\right)$	$= P\left(\frac{l}{2} - \frac{11x}{16}\right)$
Δmax. $\left(\text{at } x = l\sqrt{\frac{1}{5}} = .4472l\right)$	$= \frac{Pl^3}{48EI\sqrt{5}} = .009317\frac{Pl^3}{EI}$
Δx (at point of load)	$= \frac{7Pl^3}{768EI}$
Δx $\left(\text{when } x < \frac{l}{2}\right)$	$= \frac{Px}{96EI}(3l^2 - 5x^2)$
Δx $\left(\text{when } x > \frac{l}{2}\right)$	$= \frac{P}{96EI}(x-l)^2(11x - 2l)$

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



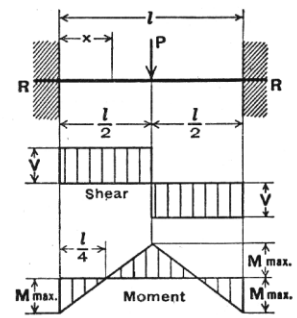
$R_1 = V_1$	$= \frac{Pb^2}{2l^3}(a + 2l)$
$R_2 = V_2$	$= \frac{Pa}{2l^3}(3l^2 - a^2)$
M_1 (at point of load)	$= R_1 a$
M_2 (at fixed end)	$= \frac{Pab}{2l^2}(a + l)$
M_x (when $x < a$)	$= R_1 x$
M_x (when $x > a$)	$= R_1 x - P(x - a)$
Δmax. $\left(\text{when } a < .414l \text{ at } x = l\frac{l^2+a^2}{3l^2-a^2}\right)$	$= \frac{Pa}{3EI}\frac{(l^2 - a^2)^3}{(3l^2 - a^2)^2}$
Δmax. $\left(\text{when } a > .414l \text{ at } x = l\sqrt{\frac{a}{2l+a}}\right)$	$= \frac{Pab^2}{6EI}\sqrt{\frac{a}{2l+a}}$
Δa (at point of load)	$= \frac{Pa^2b^3}{12EIl^3}(3l + a)$
Δx (when $x < a$)	$= \frac{Pb^2x}{12EIl^3}(3al^2 - 2lx^2 - ax^2)$
Δx (when $x > a$)	$= \frac{Pa}{12EIl^3}(l-x)^2(3l^2x - a^2x - 2a^2l)$

15. BEAM FIXED AT BOTH ENDS—UNIFORMLY DISTRIBUTED LOADS



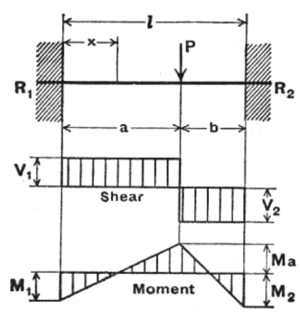
Total Equiv. Uniform Load	$= \frac{2wl}{3}$
$R = V$	$= \frac{wl}{2}$
V_x	$= w\left(\frac{l}{2} - x\right)$
M max. (at ends)	$= \frac{wl^2}{12}$
M_1 (at center)	$= \frac{wl^2}{24}$
M_x	$= \frac{w}{12}(6lx - l^2 - 6x^2)$
Δmax. (at center)	$= \frac{wl^4}{384EI}$
Δx	$= \frac{wx^2}{24EI}(l - x)^2$

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



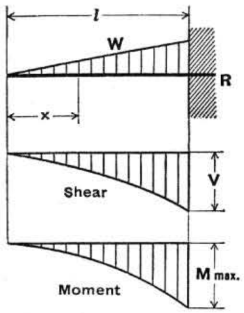
Total Equiv. Uniform Load	$= P$
$R = V$	$= \frac{P}{2}$
M max. (at center and ends)	$= \frac{Pl}{8}$
M_x $\left(\text{when } x < \frac{l}{2}\right)$	$= \frac{P}{8}(4x - l)$
Δmax. (at center)	$= \frac{Pl^3}{192EI}$
Δx $\left(\text{when } x < \frac{l}{2}\right)$	$= \frac{Px^2}{48EI}(3l - 4x)$

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 $a > b$)	$= \frac{Pa^2b}{l^2}$
Ma (at point of load)	$= \frac{2Pa^2b^2}{l^3}$
M_x (when $x < a$)	$= R_1 x - \frac{Pab^2}{l^2}$
Δmax. $\left(\text{when } a > b \text{ at } x = \frac{2al}{3a+b}\right)$	$= \frac{2Pa^3b^2}{3EI(3a+b)^2}$
Δa (at point of load)	$= \frac{Pa^3b^3}{3EIl^3}$
Δx (when $x < a$)	$= \frac{Pb^2x^2}{6EIl^3}(3al - 3ax - bx)$

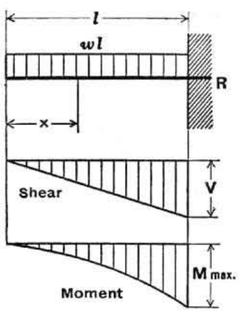
18. CANTILEVER BEAM—LOAD INCREASING UNIFORMLY TO FIXED END



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

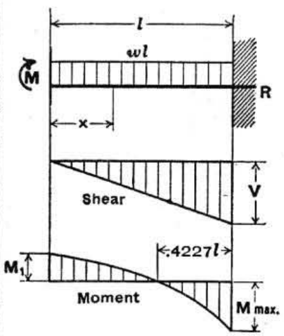
$W = \frac{wl}{2}$

19. CANTILEVER BEAM—UNIFORMLY DISTRIBUTED LOAD



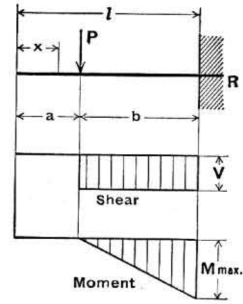
Total Equiv. Uniform Load	$= 4wl$
R = V	$= wl$
V_x	$= wx$
M max. (at fixed end)	$= \frac{wl^2}{2}$
M_x	$= \frac{wx^2}{2}$
Δmax. (at free end)	$= \frac{wl^4}{8EI}$
Δx	$= \frac{w}{24EI}(x^4 - 4l^3x + 3l^4)$

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



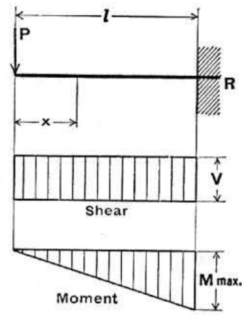
Total Equiv. Uniform Load	$= \frac{8}{3} wl$
R = V	$= wl$
V_x	$= wx$
M max. (at fixed end)	$= \frac{wl^2}{3}$
M_1 (at deflected end)	$= \frac{wl^2}{6}$
M_x	$= \frac{w}{6}(l^2 - 3x^2)$
Δmax. (at deflected end)	$= \frac{wl^4}{24EI}$
Δx	$= \frac{w(l^2 - x^2)^2}{24EI}$

21. CANTILEVER BEAM—CONCENTRATED LOAD AT ANY POINT



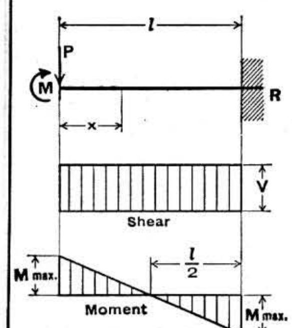
Total Equiv. Uniform Load	$= \frac{8Pb}{l}$
R = V	$= P$
M max. (at fixed end)	$= Pb$
M_x (when x > a)	$= P(x - a)$
Δmax. (at free end)	$= \frac{Pb^2}{6EI}(3l - b)$
Δa (at point of load)	$= \frac{Pb^3}{3EI}$
Δx (when x < a)	$= \frac{Pb^2}{6EI}(3l - 3x - b)$
Δx (when x > a)	$= \frac{P(l - x)^2}{6EI}(3b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

22. CANTILEVER BEAM—CONCENTRATED LOAD AT FREE END



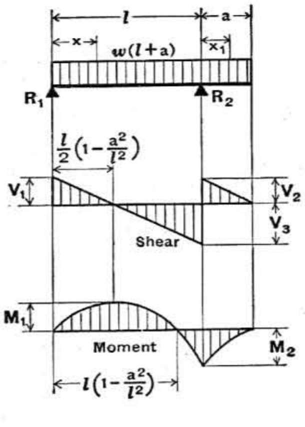
Total Equiv. Uniform Load	$= 8P$
R = V	$= P$
M max. (at fixed end)	$= Pl$
M_x	$= Px$
Δmax. (at free end)	$= \frac{Pl^3}{3EI}$
Δx	$= \frac{P}{6EI}(2l^3 - 3l^2x + x^3)$

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	$= P\left(\frac{l}{2} - x\right)$
Δmax. (at deflected end)	$= \frac{Pl^3}{12EI}$
Δx	$= \frac{P(l - x)^2}{12EI}(l + 2x)$

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 . . . . $= wa$

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

V_x (between supports) . . . $= R_1 - wx$

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

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

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

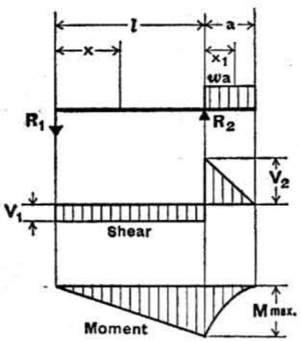
M_x (between supports) . . . $= \frac{wx}{2l}(l^2 - a^2 - xl)$

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

Δx (between supports) . . . $= \frac{wx}{24EIl}(l^4 - 2l^2x^2 + lx^3 - 2a^2l^2 + 2a^2x^2)$

Δx_1 (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



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

$R_2 = V_1 + V_2$ . . . . $= \frac{wa}{2l}(2l + a)$

V_2 . . . . $= wa$

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

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

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

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

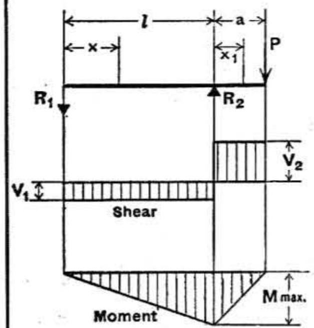
Δmax. $\left(\text{between supports at } x = \frac{l}{\sqrt{3}}\right)$ $= \frac{wa^2l^2}{18\sqrt{3}EI} = .03208\ \frac{wa^2l^2}{EI}$

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

Δx (between supports) . . . $= \frac{wa^2x}{12EIl}(l^2 - x^2)$

Δx_1 (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



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

$R_2 = V_1 + V_2$ . . . . $= \frac{P}{l}(l + a)$

V_2 . . . . $= P$

M max. (at R_2) . . . . $= Pa$

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

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

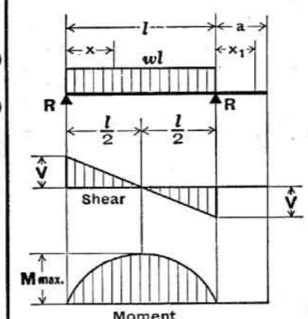
Δmax. $\left(\text{between supports at } x = \frac{l}{\sqrt{3}}\right)$ $= \frac{Pal^2}{9\sqrt{3}EI} = .06415\ \frac{Pal^2}{EI}$

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

Δx (between supports) . . . $= \frac{Pax}{6EIl}(l^2 - x^2)$

Δx_1 (for overhang) . . . . . $= \frac{Px_1}{6EI}(2al + 3ax_1 - x_1^2)$

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



Total Equiv. Uniform Load . . . $= wl$

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

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

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

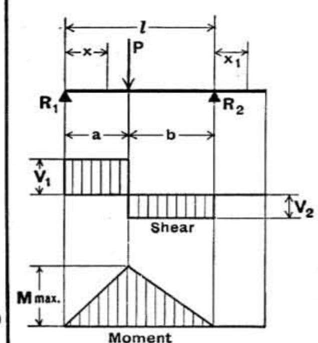
M_x . . . . $= \frac{wx}{2}(l - x)$

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

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

Δx_1 . . . . $= \frac{wl^3x_1}{24EI}$

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



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 $x < a$) . . . . . $= \frac{Pbx}{l}$

Δmax. $\left(\text{at } x = \sqrt{\frac{a(a+2b)}{3}} \text{ when } a > b\right)$ $= \frac{Pab(a + 2b)\sqrt{3a(a + 2b)}}{27EIl}$

Δa (at point of load) . . . $= \frac{Pa^2b^2}{3EIl}$

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

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

Δx_1 . . . . $= \frac{Pabx_1}{6EIl}(l + a)$

Reference Diagrams

Table 7-1
Available Shear Strength of Bolts, kips

Nominal Bolt Diameter, d, in.					5/8		3/4		7/8		1	
Nominal Bolt Area, in.²					0.307		0.442		0.601		0.785	
ASTM Desig.	Thread Cond.	F_{nv}/Ω (ksi)	ϕF_{nv} (ksi)	Load-ing	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
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
	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
	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 1/8		1 1/4		1 3/8		1 1/2	
Nominal Bolt Area, in.²					0.994		1.23		1.48		1.77	
ASTM Desig.	Thread Cond.	F_{nv}/Ω (ksi)	ϕF_{nv} (ksi)	Load-ing	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
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
	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
	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.)
3/16	3.58	4.18
¼	4.77	5.57
5/16	5.97	6.96
3/8	7.16	8.35
7/16	8.35	9.74
½	9.55	11.14
5/8	11.93	13.92
¾	14.32	16.70

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

Reference Diagrams

Group A Bolts

A325, A325M
F1858
A354 Grade BC
A449

Table 7-3
Slip-Critical Connections
Available Shear Strength, kips
(Class A Faying Surface, $\mu = 0.30$)

Group A Bolts

Hole Type	Loading	Nominal Bolt Diameter, d, in.							
		5/8		3/4		7/8		1	
		Minimum Group A Bolt Pretension, kips							
		19		28		39		51	
		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
STD/SSLT	S	4.29	6.44	6.33	9.49	8.81	13.2	11.5	17.3
	D	8.59	12.9	12.7	19.0	17.6	26.4	23.1	34.6
OVS/SSLP	S	3.66	5.47	5.39	8.07	7.51	11.2	9.82	14.7
	D	7.32	10.9	10.8	16.1	15.0	22.5	19.6	29.4
LSL	S	3.01	4.51	4.44	6.64	6.18	9.25	8.08	12.1
	D	6.02	9.02	8.87	13.3	12.4	18.5	16.2	24.2

Hole Type	Loading	Nominal Bolt Diameter, d, in.							
		1 1/8		1 1/4		1 3/8		1 1/2	
		Minimum Group A Bolt Pretension, kips							
		56		71		85		103	
		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
STD/SSLT	S	12.7	19.0	16.0	24.1	19.2	28.8	23.3	34.9
	D	25.3	38.0	32.1	48.1	38.4	57.6	46.6	69.8
OVS/SSLP	S	10.8	16.1	13.7	20.5	16.4	24.5	19.8	29.7
	D	21.6	32.3	27.4	40.9	32.7	49.0	39.7	59.4
LSL	S	8.87	13.3	11.2	16.8	13.5	20.2	16.3	24.4
	D	17.7	26.6	22.5	33.7	26.9	40.3	32.6	48.9

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

S = single shear
D = double shear

Hole Type	ASD	LRFD
STD and SSLT	$\Omega = 1.50$	$\phi = 1.00$
OVS and SSLP	$\Omega = 1.76$	$\phi = 0.85$
LSL	$\Omega = 2.14$	$\phi = 0.70$

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.

Table 7-3 (continued)
Slip-Critical Connections
Available Shear Strength, kips
(Class A Faying Surface, $\mu = 0.30$)

Group B Bolts

A490, A490M
F2280
A354 Grade BD

Group B Bolts

Hole Type	Loading	Nominal Bolt Diameter, d, in.							
		5/8		3/4		7/8		1	
		Minimum Group B Bolt Pretension, kips							
		24		35		49		64	
		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
STD/SSLT	S	5.42	8.14	7.91	11.9	11.1	16.6	14.5	21.7
	D	10.8	16.3	15.8	23.7	22.1	33.2	28.9	43.4
OVS/SSLP	S	4.62	6.92	6.74	10.1	9.44	14.1	12.3	18.4
	D	9.25	13.8	13.5	20.2	18.9	28.2	24.7	36.9
LSL	S	3.80	5.70	5.54	8.31	7.76	11.6	10.1	15.2
	D	7.60	11.4	11.1	16.6	15.5	23.3	20.3	30.4

Hole Type	Loading	Nominal Bolt Diameter, d, in.							
		1 1/8		1 1/4		1 3/8		1 1/2	
		Minimum Group B Bolt Pretension, kips							
		80		102		121		148	
		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
STD/SSLT	S	18.1	27.1	23.1	34.6	27.3	41.0	33.4	50.2
	D	36.2	54.2	46.1	69.2	54.7	82.0	66.9	100
OVS/SSLP	S	15.4	23.1	19.6	29.4	23.3	34.9	28.5	42.6
	D	30.8	46.1	39.3	58.8	46.6	69.7	57.0	85.3
LSL	S	12.7	19.0	16.2	24.2	19.2	28.7	23.4	35.1
	D	25.3	38.0	32.3	48.4	38.3	57.4	46.9	70.2

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

S = single shear
D = double shear

Hole Type	ASD	LRFD
STD and SSLT	$\Omega = 1.50$	$\phi = 1.00$
OVS and SSLP	$\Omega = 1.76$	$\phi = 0.85$
LSL	$\Omega = 2.14$	$\phi = 0.70$

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.

Reference Diagrams

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	5/8 r_n/Ω ASD	5/8 ϕr_n LRFD	3/4 r_n/Ω ASD	3/4 ϕr_n LRFD	7/8 r_n/Ω ASD	7/8 ϕr_n LRFD	1 r_n/Ω ASD	1 ϕr_n LRFD
STD SSLT	$2\frac{2}{3} d_b$	58	34.1	51.1	41.3	62.0	48.6	72.9	55.8	83.7
		65	38.2	57.3	46.3	69.5	54.4	81.7	62.6	93.8
	3 in.	58	43.5	65.3	52.2	78.3	60.9	91.4	67.4	101
		65	48.8	73.1	58.5	87.8	68.3	102	75.6	113
SSLP	$2\frac{2}{3} d_b$	58	27.6	41.3	34.8	52.2	42.1	63.1	47.1	70.7
		65	30.9	46.3	39.0	58.5	47.1	70.7	52.8	79.2
	3 in.	58	43.5	65.3	52.2	78.3	60.9	91.4	58.7	88.1
		65	48.8	73.1	58.5	87.8	68.3	102	65.8	98.7
OVS	$2\frac{2}{3} d_b$	58	29.7	44.6	37.0	55.5	44.2	66.3	49.3	74.0
		65	33.3	50.0	41.4	62.2	49.6	74.3	55.3	82.9
	3 in.	58	43.5	65.3	52.2	78.3	60.9	91.4	60.9	91.4
		65	48.8	73.1	58.5	87.8	68.3	102	68.3	102
LSLP	$2\frac{2}{3} d_b$	58	3.62	5.44	4.35	6.53	5.08	7.61	5.80	8.70
		65	4.06	6.09	4.88	7.31	5.69	8.53	6.50	9.75
	3 in.	58	43.5	65.3	39.2	58.7	28.3	42.4	17.4	26.1
		65	48.8	73.1	43.9	65.8	31.7	47.5	19.5	29.3
LSLT	$2\frac{2}{3} d_b$	58	28.4	42.6	34.4	51.7	40.5	60.7	46.5	69.8
		65	31.8	47.7	38.6	57.9	45.4	68.0	52.1	78.2
	3 in.	58	36.3	54.4	43.5	65.3	50.8	76.1	56.2	84.3
		65	40.6	60.9	48.8	73.1	56.9	85.3	63.0	94.5
STD, SSLT, SSLP, OVS, LSLP	$s \ge s_{full}$	58	43.5	65.3	52.2	78.3	60.9	91.4	69.6	104
		65	48.8	73.1	58.5	87.8	68.3	102	78.0	117
LSLT	$s \ge s_{full}$	58	36.3	54.4	43.5	65.3	50.8	76.1	58.0	87.0
		65	40.6	60.9	48.8	73.1	56.9	85.3	65.0	97.5
Spacing for full bearing strength s_{full}[a], in.		STD, SSLT, LSLT	$1\frac{15}{16}$		$2\frac{5}{16}$		$2\frac{11}{16}$		$3\frac{1}{16}$	
		OVS	$2\frac{1}{16}$		$2\frac{7}{16}$		$2\frac{13}{16}$		$3\frac{1}{4}$	
		SSLP	$2\frac{1}{8}$		$2\frac{1}{2}$		$2\frac{7}{8}$		$3\frac{5}{16}$	
		LSLP	$2\frac{13}{16}$		$3\frac{3}{8}$		$3\frac{15}{16}$		$4\frac{1}{2}$	
Minimum Spacing[a] = $2\frac{2}{3}d$, in.			$1\frac{11}{16}$		2		$2\frac{5}{16}$		$2\frac{11}{16}$	

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

ASD	LRFD	
$\Omega = 2.00$	$\phi = 0.75$	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 AISC *Specification* Section J3.10. [a] Decimal value has been rounded to the nearest sixteenth of an inch.

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	1 1/8 r_n/Ω ASD	1 1/8 ϕr_n LRFD	1 1/4 r_n/Ω ASD	1 1/4 ϕr_n LRFD	1 3/8 r_n/Ω ASD	1 3/8 ϕr_n LRFD	1 1/2 r_n/Ω ASD	1 1/2 ϕr_n LRFD
STD SSLT	$2\frac{2}{3} d_b$	58	63.1	94.6	70.3	105	77.6	116	84.8	127
		65	70.7	106	78.8	118	86.9	130	95.1	143
	3 in.	58	63.1	94.6	—	—	—	—	—	—
		65	70.7	106	—	—	—	—	—	—
SSLP	$2\frac{2}{3} d_b$	58	52.2	78.3	59.5	89.2	66.7	100	74.0	111
		65	58.5	87.8	66.6	99.9	74.8	112	82.9	124
	3 in.	58	52.2	78.3	—	—	—	—	—	—
		65	58.5	87.8	—	—	—	—	—	—
OVS	$2\frac{2}{3} d_b$	58	54.4	81.6	61.6	92.4	68.9	103	76.1	114
		65	60.9	91.4	69.1	104	77.2	116	85.3	128
	3 in.	58	54.4	81.6	—	—	—	—	—	—
		65	60.9	91.4	—	—	—	—	—	—
LSLP	$2\frac{2}{3} d_b$	58	6.53	9.79	7.25	10.9	7.98	12.0	8.70	13.1
		65	7.31	11.0	8.13	12.2	8.94	13.4	9.75	14.6
	3 in.	58	6.53	9.79	—	—	—	—	—	—
		65	7.31	11.0	—	—	—	—	—	—
LSLT	$2\frac{2}{3} d_b$	58	52.6	78.8	58.6	87.9	64.6	97.0	70.7	106
		65	58.9	88.4	65.7	98.5	72.4	109	79.2	119
	3 in.	58	52.6	78.8	—	—	—	—	—	—
		65	58.9	88.4	—	—	—	—	—	—
STD, SSLT, SSLP, OVS, LSLP	$s \ge s_{full}$	58	78.3	117	87.0	131	95.7	144	104	157
		65	87.8	132	97.5	146	107	161	117	176
LSLT	$s \ge s_{full}$	58	65.3	97.9	72.5	109	79.8	120	87.0	131
		65	73.1	110	81.3	122	89.4	134	97.5	146
Spacing for full bearing strength s_{full}[a], in.		STD, SSLT, LSLT	$3\frac{7}{16}$		$3\frac{13}{16}$		$4\frac{3}{16}$		$4\frac{9}{16}$	
		OVS	$3\frac{11}{16}$		$4\frac{1}{16}$		$4\frac{7}{16}$		$4\frac{13}{16}$	
		SSLP	$3\frac{3}{4}$		$4\frac{1}{8}$		$4\frac{1}{2}$		$4\frac{7}{8}$	
		LSLP	$5\frac{1}{16}$		$5\frac{5}{8}$		$6\frac{3}{16}$		$6\frac{3}{4}$	
Minimum Spacing[a] = $2\frac{2}{3}d$, in.			3		$3\frac{5}{16}$		$3\frac{11}{16}$		4	

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

ASD	LRFD	
$\Omega = 2.00$	$\phi = 0.75$	— indicates spacing less than minimum spacing required per AISC *Specification* Section J3.3. 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 AISC *Specification* Section J3.10. [a] Decimal value has been rounded to the nearest sixteenth of an inch.

Reference Diagrams

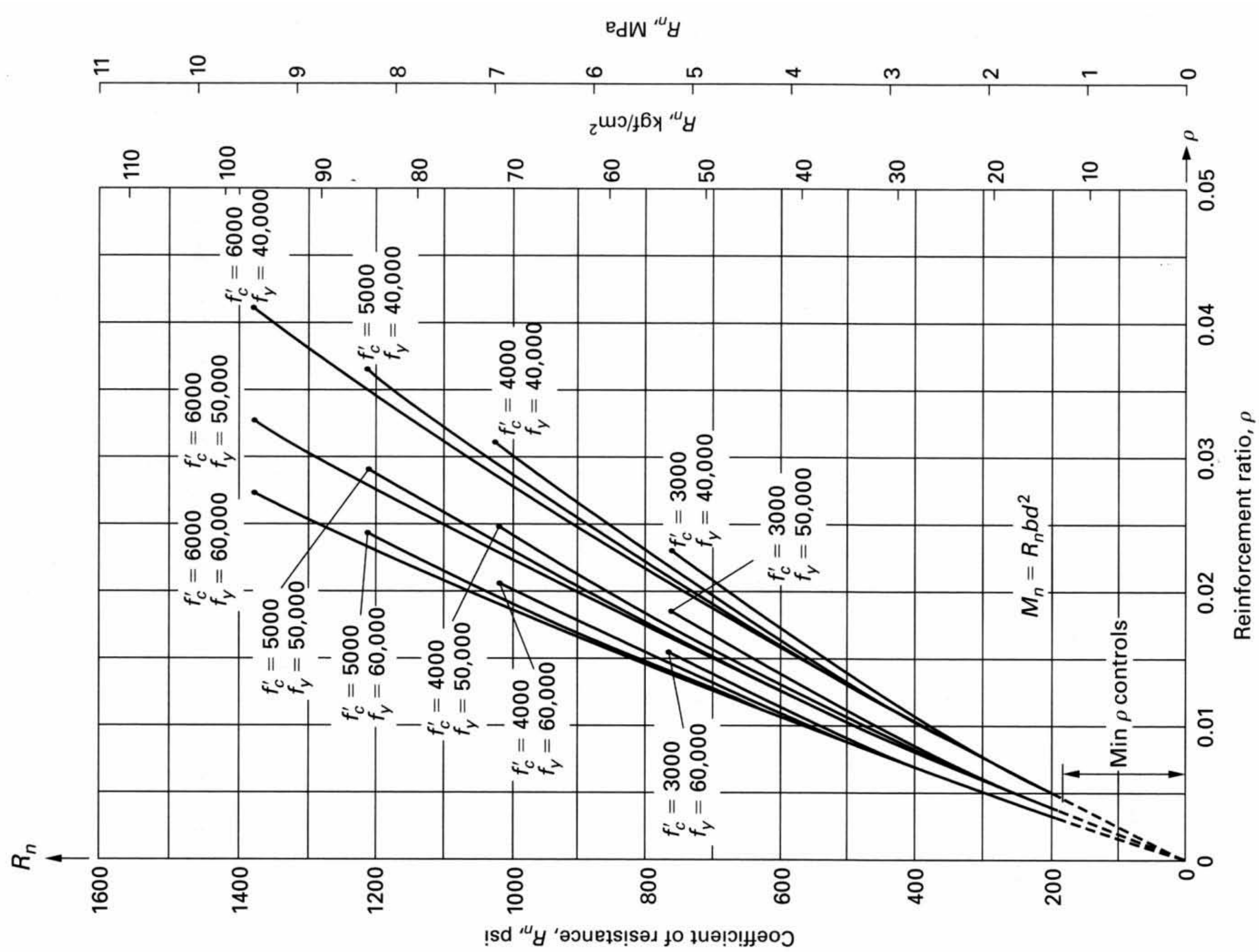
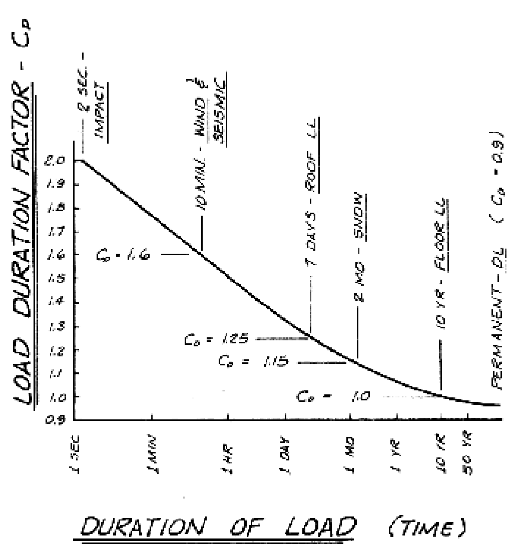


Figure 3.8.1 Strength curves (R_n vs ρ) for singly reinforced rectangular sections. Upper limit of curves is at ρ_{max}. (tensile strain of 0.004)

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

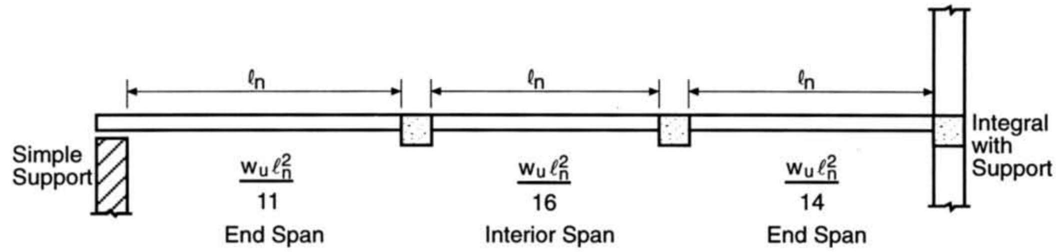


Figure 2-3 Positive Moments—All Cases

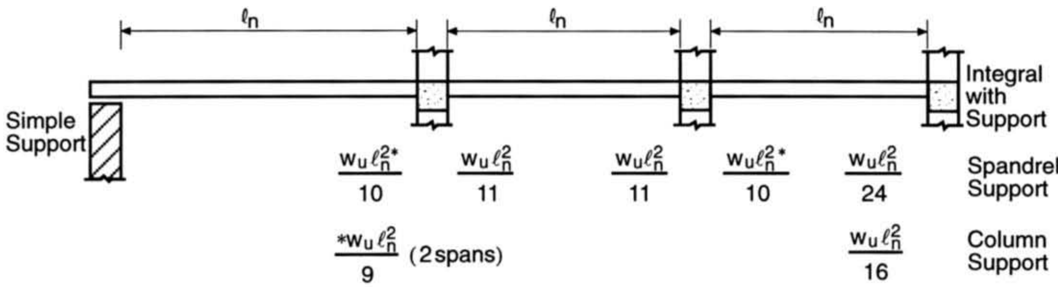


Figure 2-4 Negative Moments—Beams and Slabs

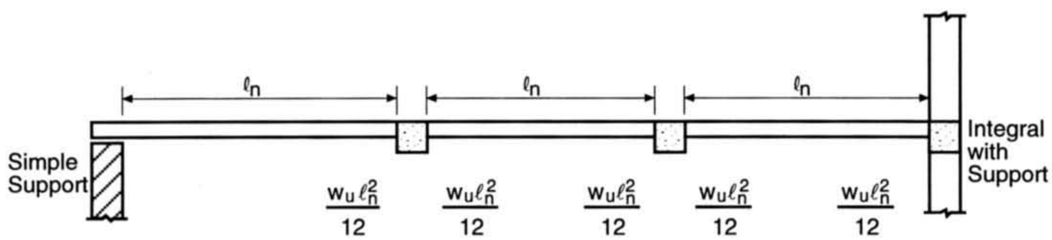


Figure 2-5 Negative Moments—Slabs with spans ≤ 10 ft

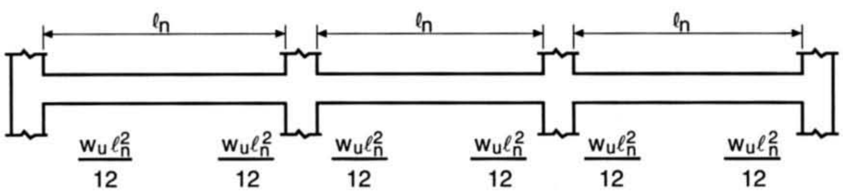


Figure 2-6 Negative Moments—Beams with Stiff Columns ($\Sigma K_c/\Sigma K_b > 8$)

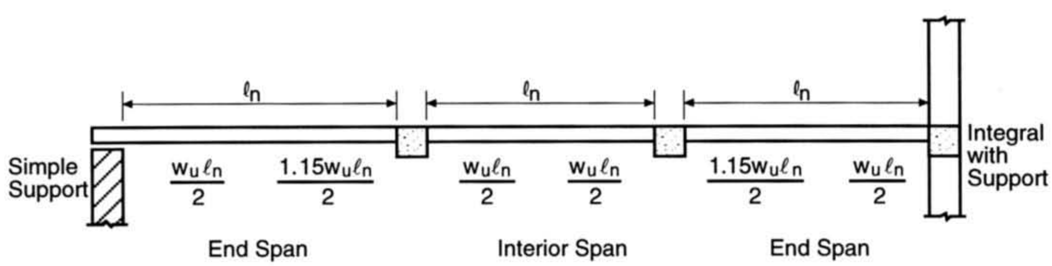


Figure 2-7 End Shears—All Cases

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	$\frac{F_{CE}}{F_C^*}$	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	1.20	0.750	0.822
0.01	0.010	0.010	0.41	0.367	0.386	0.81	0.614	0.672	1.22	0.755	0.826
0.02	0.020	0.020	0.42	0.375	0.394	0.82	0.619	0.678	1.24	0.760	0.831
0.03	0.030	0.030	0.43	0.383	0.403	0.83	0.623	0.683	1.26	0.764	0.836
0.04	0.040	0.040	0.44	0.390	0.411	0.84	0.628	0.688	1.28	0.769	0.840
0.05	0.049	0.050	0.45	0.398	0.420	0.85	0.632	0.693	1.30	0.773	0.844
0.06	0.059	0.060	0.46	0.405	0.428	0.86	0.637	0.698	1.32	0.777	0.848
0.07	0.069	0.069	0.47	0.412	0.436	0.87	0.641	0.703	1.34	0.781	0.852
0.08	0.079	0.079	0.48	0.419	0.444	0.88	0.645	0.708	1.36	0.785	0.855
0.09	0.088	0.089	0.49	0.427	0.453	0.89	0.649	0.713	1.38	0.789	0.859
0.10	0.098	0.099	0.50	0.434	0.461	0.90	0.653	0.718	1.40	0.793	0.862
0.11	0.107	0.109	0.51	0.441	0.469	0.91	0.658	0.722	1.42	0.796	0.865
0.12	0.117	0.118	0.52	0.448	0.477	0.92	0.661	0.727	1.44	0.800	0.868
0.13	0.126	0.128	0.53	0.454	0.484	0.93	0.665	0.731	1.46	0.803	0.871
0.14	0.136	0.138	0.54	0.461	0.492	0.94	0.669	0.735	1.48	0.807	0.874
0.15	0.145	0.147	0.55	0.468	0.500	0.95	0.673	0.740	1.50	0.810	0.877
0.16	0.154	0.157	0.56	0.474	0.508	0.96	0.677	0.744	1.52	0.813	0.879
0.17	0.164	0.167	0.57	0.481	0.515	0.97	0.680	0.748	1.54	0.816	0.882
0.18	0.173	0.176	0.58	0.487	0.523	0.98	0.684	0.752	1.56	0.819	0.884
0.19	0.182	0.186	0.59	0.494	0.530	0.99	0.688	0.756	1.58	0.822	0.887
0.20	0.191	0.195	0.60	0.500	0.538	1.00	0.691	0.760	1.60	0.825	0.889
0.21	0.200	0.205	0.61	0.506	0.545	1.01	0.694	0.764	1.62	0.827	0.891
0.22	0.209	0.214	0.62	0.512	0.552	1.02	0.698	0.767	1.64	0.830	0.893
0.23	0.218	0.224	0.63	0.518	0.559	1.03	0.701	0.771	1.66	0.832	0.895
0.24	0.227	0.233	0.64	0.524	0.566	1.04	0.704	0.774	1.68	0.835	0.897
0.25	0.235	0.242	0.65	0.530	0.573	1.05	0.708	0.778	1.70	0.837	0.899
0.26	0.244	0.252	0.66	0.536	0.580	1.06	0.711	0.781	1.72	0.840	0.901
0.27	0.253	0.261	0.67	0.542	0.587	1.07	0.714	0.784	1.74	0.842	0.903
0.28	0.261	0.270	0.68	0.548	0.593	1.08	0.717	0.788	1.76	0.844	0.904
0.29	0.270	0.279	0.69	0.553	0.600	1.09	0.720	0.791	1.78	0.846	0.906
0.30	0.278	0.288	0.70	0.559	0.607	1.10	0.723	0.794	1.80	0.849	0.908
0.31	0.287	0.297	0.71	0.564	0.613	1.11	0.726	0.797	1.82	0.851	0.909
0.32	0.295	0.306	0.72	0.569	0.619	1.12	0.729	0.800	1.84	0.853	0.911
0.33	0.304	0.315	0.73	0.575	0.626	1.13	0.731	0.803	1.86	0.855	0.912
0.34	0.312	0.324	0.74	0.580	0.632	1.14	0.734	0.806	1.88	0.857	0.914
0.35	0.320	0.333	0.75	0.585	0.638	1.15	0.737	0.809	1.90	0.858	0.915
0.36	0.328	0.342	0.76	0.590	0.644	1.16	0.740	0.811	1.92	0.860	0.916
0.37	0.336	0.351	0.77	0.595	0.650	1.17	0.742	0.814	1.94	0.862	0.918
0.38	0.344	0.360	0.78	0.600	0.655	1.18	0.745	0.817	1.96	0.864	0.919
0.39	0.352	0.368	0.79	0.605	0.661	1.19	0.747	0.819	1.98	0.868	0.920

(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
2.00	0.867	0.921
2.02	0.869	0.922
2.04	0.870	0.924
2.06	0.872	0.925
2.08	0.874	0.926
2.10	0.875	0.927
2.12	0.876	0.928
2.14	0.878	0.929
2.16	0.879	0.930
2.18	0.881	0.931
2.20	0.882	0.932
2.22	0.883	0.932
2.24	0.885	0.933
2.26	0.886	0.934
2.28	0.887	0.935
2.30	0.888	0.936
2.32	0.889	0.937
2.34	0.891	0.937
2.36	0.892	0.938
2.38	0.893	0.939

$\frac{F_{CE}}{F_C^*}$	Sawed C_p	Glu-Lam C_p
2.40	0.894	0.940
2.45	0.897	0.941
2.50	0.899	0.943
2.55	0.901	0.944
2.60	0.904	0.946
2.65	0.906	0.947
2.70	0.908	0.949
2.75	0.910	0.950
2.80	0.912	0.951
2.85	0.914	0.952
2.90	0.916	0.953
2.95	0.917	0.954
3.00	0.919	0.955
3.05	0.920	0.956
3.10	0.922	0.957
3.15	0.923	0.958
3.20	0.925	0.959
3.25	0.926	0.960
3.30	0.927	0.961
3.35	0.929	0.961

$\frac{F_{CE}}{F_C^*}$	Sawed C_p	Glu-Lam C_p
3.40	0.930	0.962
3.45	0.931	0.963
3.50	0.932	0.963
3.55	0.933	0.964
3.60	0.934	0.965
3.65	0.936	0.965
3.70	0.937	0.966
3.75	0.938	0.966
3.80	0.938	0.967
3.85	0.939	0.968
3.90	0.940	0.968
3.95	0.941	0.969
4.00	0.942	0.969
4.05	0.943	0.969
4.10	0.944	0.970
4.15	0.944	0.970
4.20	0.945	0.971
4.25	0.946	0.971
4.30	0.947	0.972
4.35	0.947	0.972

$\frac{F_{CE}}{F_C^*}$	Sawed C_p	Glu-Lam C_p
4.40	0.948	0.972
4.45	0.949	0.973
4.50	0.949	0.973
4.55	0.950	0.974
4.60	0.950	0.974
4.65	0.951	0.974
4.70	0.952	0.975
4.75	0.952	0.975
4.80	0.953	0.975
4.85	0.953	0.975
4.90	0.954	0.976
5.00	0.955	0.976
6.00	0.963	0.981
8.00	0.973	0.986
10.0	0.979	0.989
20.0	0.990	0.995
40.0	0.995	0.997
60.0	0.997	0.998
100.0	0.998	0.999
200.0	0.999	0.999

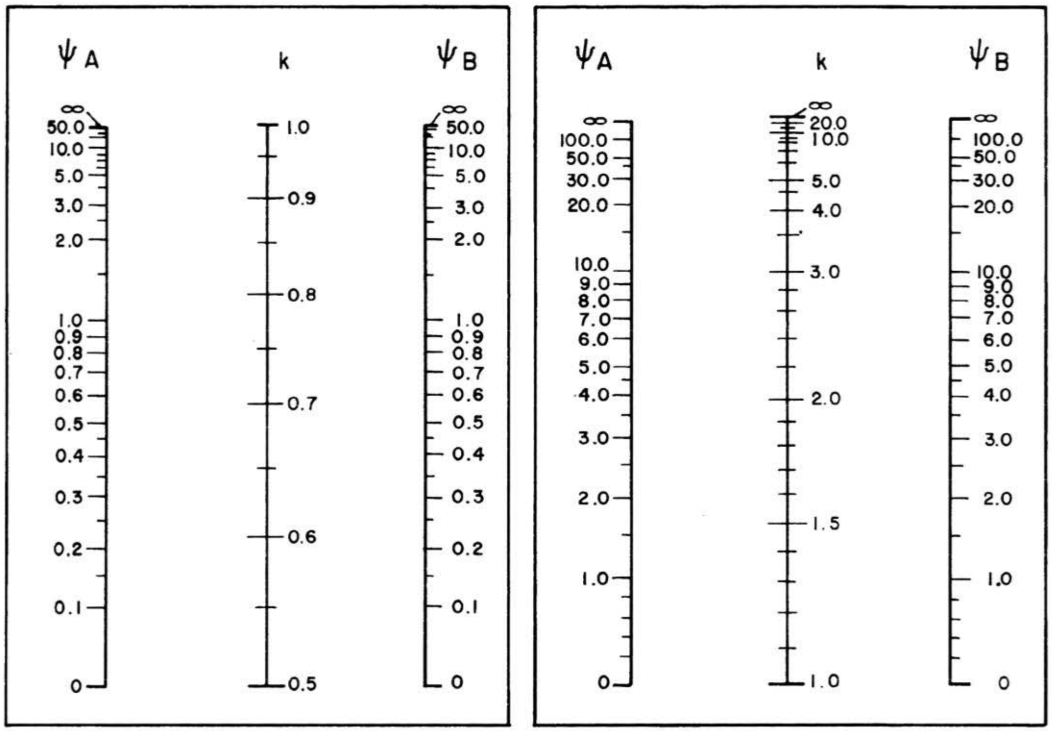
Table developed and permission for use granted by Professor Ed Lebert, Dept. of Architecture, University of Washington.

Table 3.7.1
Total Areas for Various Numbers of Reinforcing Bars

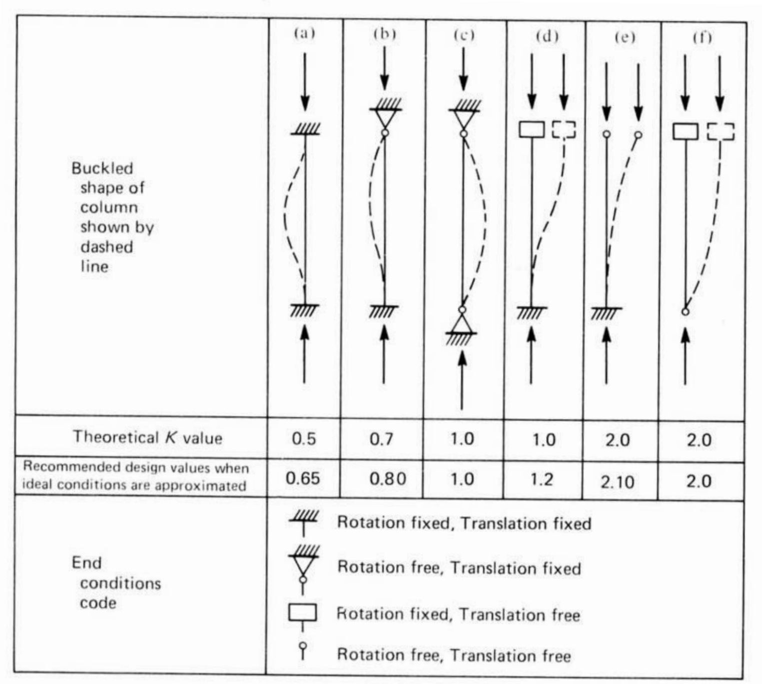
Bar Size	*Nominal Diameter (in.)*	*Weight (lb/ft)*	*Number of Bars* 1	2	3	4	5	6	7	8	9	10
#3	0.375	0.376	0.11	0.22	0.33	0.44	0.55	0.66	0.77	0.88	0.99	1.10
#4	0.500	0.668	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00
#5	0.625	1.043	0.31	0.62	0.93	1.24	1.55	1.86	2.17	2.48	2.79	3.10
#6	0.750	1.502	0.44	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



(a) Nonsway Frames (b) Sway Frames



Maximum Reinforcement Ratio ρ for Singly Reinforced Rectangular Beams (tensile strain = 0.005) for which ϕ is permitted to be 0.9

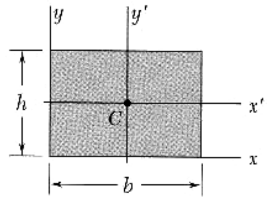
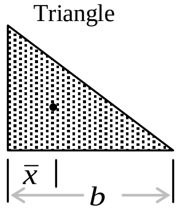
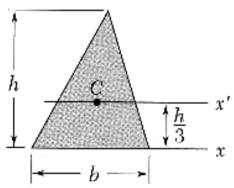
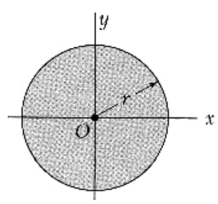
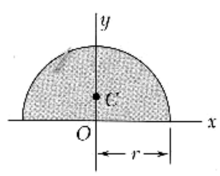
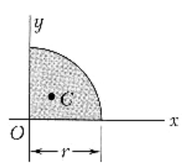
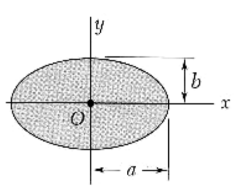
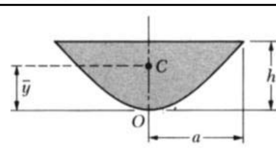
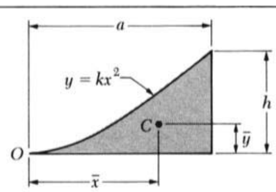
f_y	$f'_c = 3000$ psi $\beta_1 = 0.85$	$f'_c = 3500$ psi $\beta_1 = 0.85$	$f'_c = 4000$ psi $\beta_1 = 0.85$	$f'_c = 5000$ psi $\beta_1 = 0.80$	$f'_c = 6000$ psi $\beta_1 = 0.75$
40,000 psi	0.0203	0.0237	0.0271	0.0319	0.0359
50,000 psi	0.0163	0.0190	0.0217	0.0255	0.0287
60,000 psi	0.0135	0.0158	0.0181	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

Table 3-8 ACI Provisions for Shear Design*

		$V_u \le \frac{\phi V_c}{2}$	$\phi V_c \ge V_u > \frac{\phi V_c}{2}$	$V_u > \phi V_c$
Required area of stirrups, A_v**		none	$\frac{50 b_w s}{f_y}$	$\frac{(V_u - \phi V_c)s}{\phi f_y d}$
Stirrup spacing, s	Required	—	$\frac{A_v f_y}{50 b_w}$	$\frac{\phi A_v f_y d}{V_u - \phi V_c}$
	Recommended Minimum†	—	—	4 in.
	Maximum†† (ACI 11.5.4)	—	$\frac{d}{2}$ or 24 in.	$\frac{d}{2}$ or 24 in. for $(V_u - \phi V_c) \le \phi 4\sqrt{f'_c}\, b_w d$
				$\frac{d}{4}$ 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 11.3.1.1)
**$A_v = 2 \times A_b$ for U stirrups; $f_y \le 60$ ksi (ACI 11.5.2)
†A practical limit for minimum spacing is d/4
††Maximum spacing based on minimum shear reinforcement ($= A_v f_y / 50 b_w$) must also be considered (ACI 11.5.5.3).

Reference Geometry

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