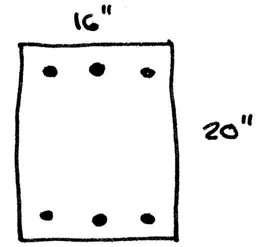
1.1 $A_s = 6.0\ in^2$ $A_g = 16 \times 20 = 320\ in^2$

$f_y = 40{,}000\ psi$ $A_c = 320 - 6 = 314\ in^2$

$f_c' = 4{,}000\ psi$

$E_s = 29{,}000{,}000\ psi$ $E_c = 3{,}600{,}000$

$n = \dfrac{29{,}000{,}000}{3{,}600{,}000} = 8$




a) $f_c = 1200\ psi$, $f_y = 40{,}000\ psi$

$P = 1200(314 + 8 \times 6)$
$= 434{,}000\ lbs$

$P_s = 1200(8 \times 6) = 57{,}600\ lbs$
$P_s = 13.3\%$ of $P$

$f_y = 60{,}000\ psi$
a) Same

b) $\epsilon_y = \dfrac{40{,}000}{29{,}000{,}000} = 0.00140$

for slow loading $f_c = 3000\ psi$

$P = 3000(314) + 40{,}000(6) =$
$= 1{,}182{,}000\ lbs$

$P_s = 40{,}000(6) = 240{,}000\ lb$
$= 20.3\%\ P$

$\epsilon_y = \dfrac{60{,}000}{29{,}000} = 0.00207$

$f_c = 3300\ psi$

$P = 3300(314) + 60{,}000(6)$
$= 1{,}396{,}000\ lbs$

$P_s = 60{,}000(6) = 360{,}000\ lb$
$= 25.6\%\ P$

c) $f_c = 3400\ psi$

$P_u = 3400(314) + 40{,}000(6)$
$= 1{,}308{,}000\ lb$

$P_s = 240{,}000\ lb$ $(18.3\%\ P_u)$

$P_u = 3400(314) + 60{,}000(6)$
$= 1{,}428{,}000\ lb$

$P_s = 360{,}000\ lb$ $(25.2\%\ P_u)$

*Comments:*

1. *There is no difference in performance at $f_c = 1200\ psi$*
2. *As the strain increases, the steel with $f_y = 60{,}000\ psi$ contributes more to the total load and the column has a higher total load.*
3. *For the same cost, $f_y = 60{,}000\ psi$ provides a 9% increase in capacity.*

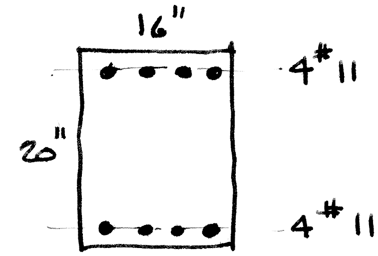
1.2

$A_s = 8(1.56) = 12.48 \text{ in}^2$

$A_g = 320 \text{ in}^2 \qquad A_c = 307.5 \text{ in}^2$

$n = 8 \qquad E_s = 29{,}000{,}000 \text{ psi}$

$E_c = 3{,}600{,}000 \text{ psi}$




$f_y = 40{,}000 \text{ psi}$

$f_y = 60{,}000 \text{ psi}$

a)

$P = 1200(307.5 + 8(12.48)) =$

$= 489{,}000 \text{ lb}$

$P_s = 1200(8)(12.48) = 120{,}000 \text{ lb}$

(24.5% P)

· Same as $f_y = 40{,}000$

b) $\epsilon_y = 0.00140$, $f_c = 3000 \text{psi}$

$P = 3000(307.5) + 40{,}000(12.48)$

$= 1{,}424{,}000 \text{ lb}$

$P_s = 40{,}000(12.48) = 500{,}000 \text{ lb}$

(35.1 % of P)

$\epsilon_y = 0.00207 \qquad f_c = 3300 \text{psi}$

$P = 3300(307.5) + 60{,}000(12.48)$

$= 1{,}766{,}000 \text{ lb}$

$P_s = 60{,}000(12.48) = 750{,}000$

(42.5% of P)

c) $f_c = 3400 \text{psi}$ both cases

$P_u = 3400(307.5) + 40{,}000(12.48)$

$= 1{,}547{,}000 \text{ lb}$

$P_s = 500{,}000 \text{ lb}$

(32.3% of $P_u$)

$P_u = 3400(307.5) + 60{,}000(12.48)$

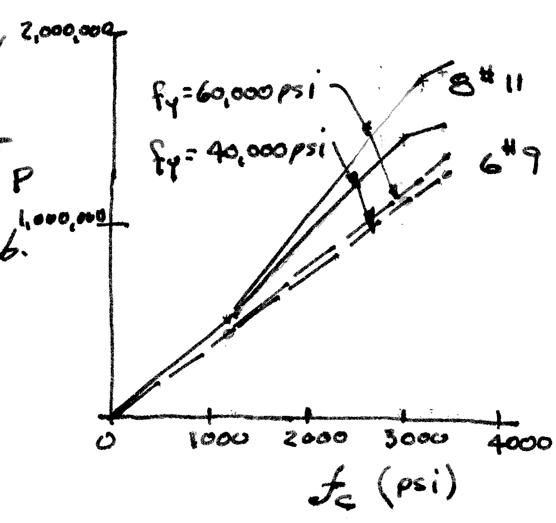
$= 1{,}797{,}000 \text{ lb}$

$P_s = 750{,}000 \text{ lb}$

(41.7% of $P_u$)

Comments

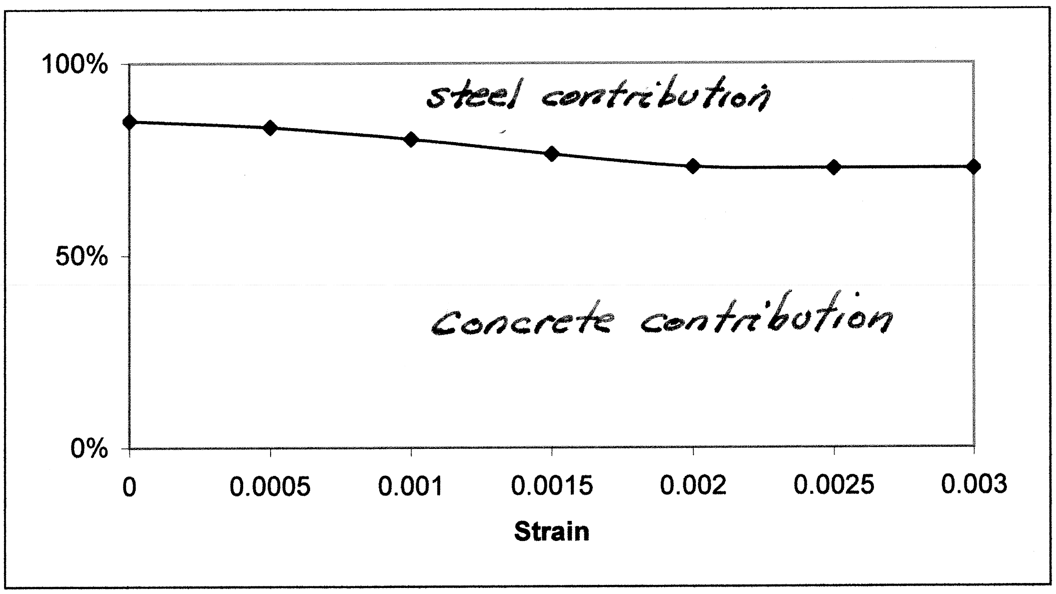
1. There is no strength difference at $f_c = 1200$ psi
2. There is a 16% strength increase at ultimate using $f_y = 60{,}000$ psi, This occurs at virtually no cost increase
3. The higher steel ratio produces a stronger column - compare to prob. 1.1



1. 3

| | | |
|---|---|---|
| $A_s$ = | 10.12 | $in^2$ |
| $A_c$ = | 474 | $in^2$ |
| $f_y$ = | 60000 | psi |
| $f'_c$ = | 4000 | psi |

| $\epsilon_c = \epsilon_s$ | $f_c$ (psi) | $P_c$ (kips) | $f_s$ (psi) | $P_s$ (kips) | $P_{total}$ (kips) | $P_c/P_{total}$ | $P_s/P_{total}$ |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 85.0% | 15.0% |
| 0.0005 | 1600 | 758.4 | 15000 | 151.8 | 910.2 | 83.3% | 16.7% |
| 0.001 | 2600 | 1232.4 | 30000 | 303.6 | 1536 | 80.2% | 19.8% |
| 0.0015 | 3100 | 1469.4 | 45000 | 455.4 | 1924.8 | 76.3% | 23.7% |
| 0.002 | 3300 | 1564.2 | 57000 | 576.84 | 2141.04 | 73.1% | 26.9% |
| 0.0025 | 3400 | 1611.6 | 60000 | 607.2 | 2218.8 | 72.6% | 27.4% |
| 0.003 | 3400 | 1611.6 | 60000 | 607.2 | 2218.8 | 72.6% | 27.4% |



1.4 A 20 x 24 in. column is made of the same concrete as Examples 1.1 and 1.2 but reinforced with six No. 11 (No. 36) bars with $f_y$ = 60 ksi. For this column section, determine (a) the axial load the section will carry at a concrete stress of 1400 psi, (b) the load on the section when the steel begins to yield, (c) the maximum load if the section is loaded slowly and (d) the maximum load if the section is loaded rapidly. The area of one No. 11 (No. 36) bar is 1.56 in$^2$. Determine the percent of the load carried by the steel and the concrete for each combination.

▶ Reinforcement Areas

Given Properties

$f'_c := 4000psi$ $\quad f_y := 60000psi$ $\quad f_c := 1400psi$ $\quad n := 8$ $\quad E_s := 29000000psi$

Column Properties

$b := 20in$ $\quad h := 24in$ $\quad A_{st} := 6 \cdot A_{s11} = 9.36\,in^2$ $\quad$ The total area of steel $A_{st}$ is six no. 11 bars

**Part (a)** Compute the axial capacity of the section loaded below the elastic limit.

**Solution:** The axial capacity is based on the gross area of the column plus the effective area of the steel. Since we count the holes where the steel is removed, the additional effective area of the steel is (n-1)$A_{st}$.

$A_g := b \cdot h$ $\quad A_g = 480\,in^2$ $\quad A_{st} = 9.36\,in^2$ $\quad$ Reinforcement ratio = $\dfrac{A_{st}}{A_g} = 0.0195$

$P := f_c \cdot \left[A_g + (n-1) \cdot A_{st}\right]$ $\quad P = 764\,kip$

$P_c := f_c \cdot \left(A_g - A_{st}\right)$ $\quad P_c = 659\,kip$

$P_s := f_c \cdot n \cdot A_{st}$ $\quad P_s = 105\,kip$ $\quad 100 \cdot \dfrac{P_c}{P} = 86.3$ $\quad 100 \dfrac{P_s}{P} = 13.7$

**Part (b)**: Compute the capacity of the column when the steel begins to yield $\varepsilon := 0.002069$ or 2/10 of one percent

Examining Figure 1.16, we are **beyond the elastic portion of the concrete** stress strain curve, but we are at the elastic limit of the steel.

$f_s := \varepsilon \cdot E_s$ $\quad f_s = 60001\,psi$

From Figure 1.16 $\quad f_c := 3100psi$ for slow loading

Since the problem is nonlinear, we must break out the concrete and steel areas. We can no longer use the elastic equation from 1.1. $\quad A_c := A_g - A_{st}$

$P := f_c \cdot A_c + f_s \cdot A_{st}$ $\quad P = 2021\,kip$

$P_c := f_c \cdot A_c$ $\quad P_c = 1459\,kip$

$P_s := f_s \cdot A_{st}$ $\quad P_s = 562\,kip$ $\quad 100 \cdot \dfrac{P_c}{P} = 72.2$ $\quad 100 \dfrac{P_s}{P} = 27.8$

**Part (c)**: Compute the maximum load capacity of the section

Examining Figure 1.16, we are **beyond the elastic portion of the concrete** stress strain curve, but we are in the plastic range of the steel.