DTY Tutoring, inc.
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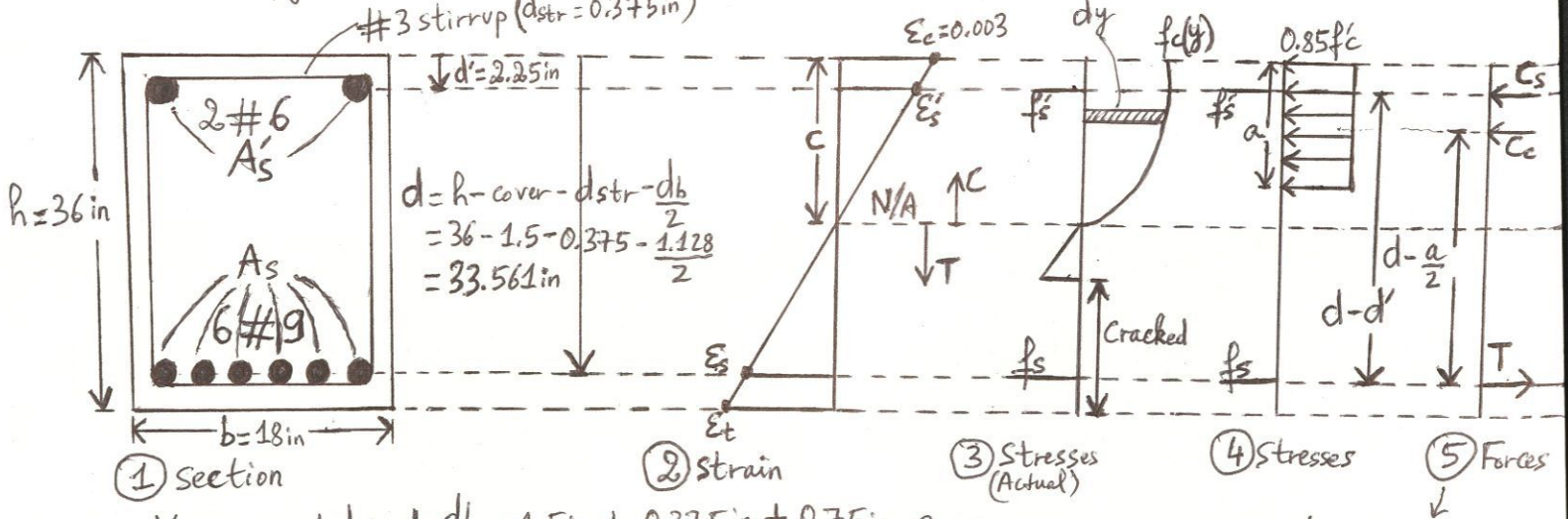
Date: 13th February 2019

$f'_c = 4\,ksi$ Cover = 1.5 in $E_s = 29{,}000\,ksi$
$f_y = 60\,ksi$ $\varepsilon_y = 0.002$



$d = h - \text{cover} - d_{str} - \frac{d_b}{2} = 36 - 1.5 - 0.375 - \frac{1.128}{2} = 33.561\,in$

$d' = \text{cover} + d_{str} + \frac{d_b}{2} = 1.5in + 0.375in + \frac{0.75in}{2} = 2.25in$

$\#9 \rightarrow A_b = 1in^2$; $A_s = (1in^2)(6) = 6in^2$

$\#6 \rightarrow A_b = 0.44in^2$; $A'_s = (0.44in^2)(2) = 0.88in^2$

$T = A_s f_y = (6in^2)(60ksi) = 360\,kips$

$C_c = 0.85 f'_c\, a\, b = 0.85(4ksi)(a)(18in) = (61.2a)\,kips$; $a = \beta_1 c = 0.85c \Rightarrow c = \frac{a}{0.85}$

$\pm \rightarrow \sum F_x = 0$

$T = C_c + C_s$

Assuming both tension and compression steel yields

$\varepsilon'_s \geq \varepsilon_y$ & $\varepsilon_s \geq \varepsilon_y$; $f'_s = f_s$ & $f_s = f_y$

$C'_s = A'_s f'_s = A'_s f_y = (0.88in^2)(60ksi) = 52.8\,kips$

from ⑤; $T = C_c + C_s \Rightarrow 360\,kips = (61.2a)\,kips + (52.8\,kips) \Rightarrow a = 5.0196in$

$c = \frac{a}{0.85} = \frac{5.0196}{0.85} = 5.905in$

Check strain

$\varepsilon'_s = \varepsilon_c\left(\frac{c - d'}{c}\right) = (0.003)\left[\frac{(5.905 - 2.25)}{5.905}\right] = 1.86 \times 10^{-3} = 0.00186 < \varepsilon_y$

Assumption $\varepsilon'_s \geq \varepsilon_y$ not valid

$\varepsilon_s = \frac{\varepsilon_c(d - c)}{c} = (0.003)\left[\frac{(33.561 - 5.905)}{5.905}\right] = 0.0141 > \varepsilon_y \Rightarrow$ Assumption $\varepsilon_s > \varepsilon_y$ is correct

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Compression steel did not yield because $\varepsilon_s' < \varepsilon_y$, therefore

$$f_s' = (E_s)(\varepsilon_s') \neq f_y$$

$$\varepsilon_s' = \varepsilon_c\left(\frac{c-d'}{c}\right) = 0.003\left[\frac{\left(\frac{a}{0.85}\right) - 2.25\,in}{\left(\frac{a}{0.85}\right)}\right] = \frac{0.003a - 0.0057375}{a}$$

$$f_s' = (29{,}000\,ksi)\left[\frac{0.003a - 0.0057375}{a}\right] = \left(\frac{87a - 166.3875}{a}\right) kips$$

$T = 360\,kips$

$C_c = (61.2a)\,kips$; $C_s = A_s' f_s' = (0.88\,in^2)\left[\frac{87a - 166.3875}{a}\right] = \frac{76.56a - 146.421}{a}$

$$T = C_c + C_s \Rightarrow 360\,kips = (61.2a)\,kips + \left(\frac{76.56a - 146.421}{a}\right) kips$$

$$a = 5.10\,in \Rightarrow c = \frac{a}{0.85} = \frac{5.10}{0.85} = 6\,in$$

Check strains again

$$\varepsilon_s' = \varepsilon_c\left(\frac{c-d'}{c}\right) = 0.003\left[\frac{6 - 2.25}{6}\right] = 1.875 \times 10^{-3} = 0.001875 < \varepsilon_y$$

Assumption $\varepsilon_s' < \varepsilon_y$ is valid

$$\varepsilon_s = \varepsilon_c\left(\frac{d-c}{c}\right) = 0.003\left[\frac{33.561 - 6\,in}{6\,in}\right] = 0.0138 > \varepsilon_y$$

→ Assumption $\varepsilon_s > \varepsilon_y$ is still valid

Compute ultimate moment capacity

$+\circlearrowleft \sum M_{N(@T)} = 0$ from ⑤

$$M_N = C_c\left(d - \frac{a}{2}\right) + C_s(d - d') = 61.2(5.10in)\left[33.561 - \frac{5.10\,in}{2}\right] + \frac{76.56(5.10) - 146.421}{5.10}\left[33.561 - 2.25\right]$$

$$M_N = 11{,}177.38\,kips\text{-}in\left(\frac{1\,ft}{12\,in}\right) = 931.45\,kips\text{-}ft$$

$$\phi M_N = (0.9)(931.45) = 838.3\,kips\text{-}ft$$