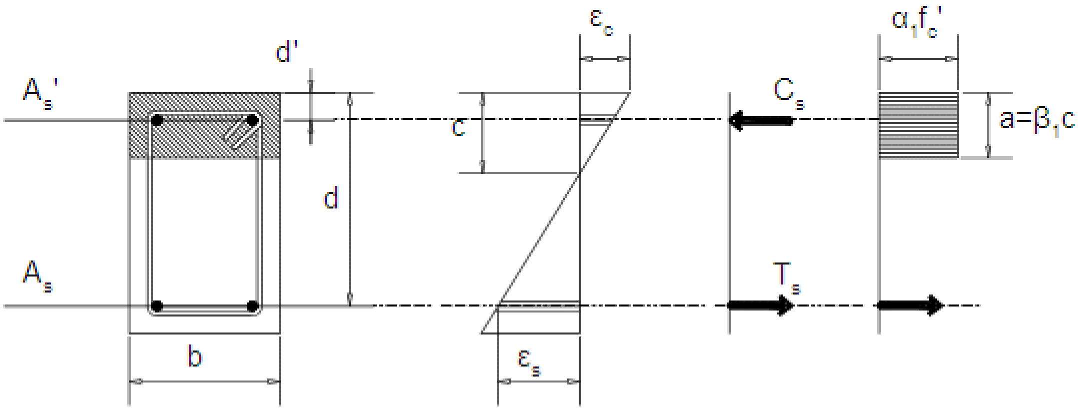
REINFORCED CONCRETE BEAM DESIGN (NZS 3101-95)



Material Properties

Concrete strength,

$f\_c := 30\ MPa$

Concrete stress block factors,

$\alpha\_1 :=$ if $0.85 - 0.004\cdot\left(\frac{f\_c}{MPa} - 55\right) < 0.75$
    0.75
  else
    if $0.85 - 0.004\cdot\left(\frac{f\_c}{MPa} - 55\right) \geq 0.85$
      0.85
    else
      $0.85 - 0.004\cdot\left(\frac{f\_c}{MPa} - 55\right)$ --> $\alpha\_1 = 0.85$

$\beta\_1 :=$ if $0.85 - 0.008\cdot\left(\frac{f\_c}{MPa} - 30\right) < 0.65$
    0.65
  else
    if $0.85 - 0.008\cdot\left(\frac{f\_c}{MPa} - 30\right) \geq 0.85$
      0.85
    else
      $0.85 - 0.008\cdot\left(\frac{f\_c}{MPa} - 30\right)$ --> $\beta\_1 = 0.85$

Steel bars yield strength,

$f\_y := 400\ MPa$

$f\_ys := 240\ MPa$

Modulus of elasticity of steel reinforcement,

$E\_s := 200000\ MPa$

Beam Dimensions

Width,

$b\_w := 400\ mm$

Depth,

$h := 400\ mm$

Concrete cover,

$c\_v := 30\ mm$

Main bars diameter,

$D\_b := 22\ mm$

Strirrup bars diameter,

$d\_b := 10\ mm$

Effective depth,

Tension steel (assumed as one layer),

$d := h - c\_v - d\_b - \frac{D\_b}{2}$ --> $d = 349\ mm$

adjust and overwrites for steel bars if more than one layer,

$d := 300\ mm$

Compression steel,

$d\_p := \left(c\_v + d\_b + \frac{D\_b}{2}\right)$ --> $d\_p = 51\ mm$

adjust and overwrites for steel bars if more than one layer,

$d\_p := 51\ mm$

D e s i g n f o r F l e x u r e

Factored negative or positive moment,

$M\_u := 300\ kN\ m$

Strength reduction factors for bending,

$\varphi\_b := 0.85$

Depth of the compression block,

$a := d - \sqrt{d^2 - \frac{2 \cdot M\_u}{\alpha\_1 \cdot f\_c \cdot \varphi\_b \cdot b\_w}}$ --> $a = 155.792\ mm$

Neutral axes depth at balanced conditions,

$c\_b := \frac{600\ MPa}{600\ MPa + f\_y} \cdot d$ --> $c\_b = 180\ mm$

Maximum allowed depth of the compression block,

$a\_max := 0.75 \cdot \beta\_1 \cdot c\_b$ --> $a\_max = 114.75\ mm$

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b_type := if a < a_max
             "CASE 1 - Singly Reinfoced Beams"
          else
             "CASE 2 - Doubly Reinforced Beams"
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--> b_type = "CASE 2 - Doubly Reinforced Beams"

CASE 1

$a < a\_max = 0$

"(1) TRUE" area of tensile steel reinforcement,

$A\_s := \frac{M\_u}{\varphi\_b \cdot f\_y \cdot \left(d - \frac{a}{2}\right)}$ --> $A\_s = 3972.705\ mm^2$

Number of bars required,

$N\_b := \frac{A\_s}{\frac{1}{4} \cdot \pi \cdot D\_b^2}$ --> $N\_b = 10.451$ bars

CASE 2

$a > a\_max = 1$

"(1) TRUE" compression reinforcement is required, Compressive force developed in the concrete alone,

$C := \alpha\_1 \cdot f\_c \cdot b\_w \cdot a\_max$ --> $C = 1170.45\ kN$

Moment resisted by the concrete and bottom steel,

$M\_c := C \cdot \left(d - \frac{a\_max}{2}\right) \cdot \varphi\_b$ --> $M\_c = 241.383\ kN\ m$

Moment resisted by compression steel and tensile steel,

$M\_s := M\_u - M\_c$ --> $M\_s = 58.617\ kN\ m$

Compression steel required,

$c := \frac{a}{\beta\_1}$ --> $c = 183.285\ mm$

$f\_sp1 := 0.003 \cdot E\_s \cdot \left(\frac{c - d\_p}{c}\right)$ --> $f\_sp1 = 433.047\ MPa$

$f\_sp := \min\left(\begin{pmatrix} f\_y \\ f\_sp1 \end{pmatrix}\right)$ --> $f\_sp = 400\ MPa$

$A\_sp := \frac{M\_s}{(f\_sp - \alpha\_1 \cdot f\_c) \cdot (d - d\_p) \cdot \varphi\_b}$ --> $A\_sp = 739.521\ mm^2$

Number of bars required,

$N\_b := \frac{A\_sp}{\frac{1}{4} \cdot \pi \cdot D\_b^2}$ --> $N\_b = 1.945$ bars

Required tensile steel for balancing the compression in concrete,

$A\_s1 := \frac{M\_c}{f\_y \cdot \left(d - \frac{a\_max}{2}\right) \cdot \varphi\_b}$ --> $A\_s1 = 2926.125\ mm^2$

Tensile steel for balancing the compression in steel,

$A\_s2 := \frac{M\_s}{f\_y \cdot (d - d\_p) \cdot \varphi\_b}$ --> $A\_s2 = 692.377\ mm^2$

$A\_s := A\_s1 + A\_s2$ --> $A\_s = 3618.502\ mm^2$

Number of bars required,

$N\_b := \frac{A\_s}{\frac{1}{4} \cdot \pi \cdot D\_b^2}$ --> $N\_b = 9.519$ bars

Minimum and maximum tensile reinforcement,

$A\_smin := \max\left(\begin{pmatrix} \frac{\sqrt{f\_c\ MPa}}{4 \cdot f\_y} \cdot b\_w \cdot d \\ \frac{4}{3} \cdot A\_s \\ 0.004 \cdot b\_w \cdot d \end{pmatrix}\right)$ --> $A\_smin = 4824.669\ mm^2$

Beam flexural tensile steel is limited to a maximum,

$A\_smax := \min\left(\begin{pmatrix} 0.025 \cdot b\_w \cdot d \\ \frac{f\_c + 10\ MPa}{6 \cdot f\_y} \cdot b\_w \cdot d \end{pmatrix}\right)$ --> $A\_smax = 2000\ mm^2$

D e s i g n f o r S h e a r

Shear force,

$V := 200\ kN$

Strength reduction factor for shear,

$\varphi\_s := 0.65$

Shear capacity provided by the concrete,

$v\_b := \left(0.07 + 10 \cdot \frac{A\_s}{b\_w \cdot d}\right) \cdot \sqrt{f\_c\ MPa}$ --> $v\_b = 2.035\ MPa$

$v\_c := v\_b$ --> $v\_c = 2.035\ MPa$

Checked,

$\sqrt{f\_c} < \sqrt{70\ MPa} = 1$

Checked,

$\left(0.08 \cdot \sqrt{f\_c\ MPa} < v\_b\right) \wedge \left(v\_b < 0.2 \cdot \sqrt{f\_c\ MPa}\right) = 0$

Average shear stress is computed for a rectangular beam,

$v := \frac{V}{b\_w \cdot d}$ --> $v = 1.667\ MPa$

Average shear stress is limited to a maximum,

$v\_max := \min\left(\begin{pmatrix} 1.1 \cdot \sqrt{f\_c\ MPa} \\ 0.2 \cdot f\_c \\ 9.0\ MPa \end{pmatrix}\right)$ --> $v\_max = 6\ MPa$

Checked,

$v < v\_max = 1$

Shear reinforcement per unit length,

$$
\begin{aligned}
A\_v := &\ \text{if } v < \varphi\_s \cdot \left(\frac{v\_c}{2}\right) \\
&\quad 0.00 \frac{mm^2}{mm} \\
&\ \text{else} \\
&\quad \text{if } \left(\varphi\_s \cdot \left(\frac{v\_c}{2}\right) < v\right) \wedge \left(v \le \varphi\_s \cdot (v\_c + 0.35\ MPa)\right) \\
&\quad\quad \frac{0.35\ MPa \cdot b\_w\ mm}{f\_ys} \\
&\quad \text{else} \\
&\quad\quad \frac{(v - \varphi\_s \cdot v\_c) \cdot b\_w\ mm}{\varphi\_s \cdot f\_ys}
\end{aligned}
$$

--> $A\_v = 0.882\ mm^2$

$s := 1.0\ mm$

$\frac{A\_v}{s} = 0.882 \frac{mm^2}{mm}$

Stirrups legs,

$n\_s := 2$ legs

$A\_sv := n\_s \cdot \frac{1}{4} \cdot \pi \cdot d\_b^2$ --> $A\_sv = 157.08\ mm^2$

Stirrups spacing required,

$S\_sp := \frac{A\_sv \cdot s}{A\_v}$ --> $S\_sp = 178.134\ mm$