

### Coupling beam: SW1 - SW3

Requirement to place diagonal reinforcement (ACI 318S-14, 18.10.7.1, 18.10.7.2)

Diagonally reinforced coupling beams are restricted to beams having aspect ratio  $L/h < 4$

$$(\ell_n/h) < 4$$

$$1.1 < 4.0 \quad \checkmark$$

Ultimate limit state for shear (ACI 318S-14, 18.10.7.4 (a))

Coupling beams reinforced with two intersecting groups of diagonally placed bars symmetrical about the midspan shall satisfy

$$V_u \leq \phi \cdot V_n$$

$$211.0 \text{ kN} \leq 227.6 \text{ kN} \quad \checkmark$$

Where:

$$V_n = 2 \cdot A_{vd} \cdot f_y \cdot \sin \alpha \leq 0.83 \sqrt{f'_c} A_{cw}$$

$A_{vd}$ : Total area of reinforcement in each group of diagonal bars.

$$A_{vd} : \underline{516.13} \text{ mm}^2$$

$\alpha$ : Angle between the diagonal bars and the longitudinal axis of the coupling beam.

$$\alpha : \underline{38.14}$$

$f_y$ : Specified yield strength for reinforcement.

$$f_y : \underline{420.00} \text{ MPa}$$

$V_u$ : Factored shear force at section.

$$V_u : \underline{211.0} \text{ kN}$$

$A_{cw}$ : Area of concrete section of a coupling beam resisting shear.

$$A_{cw} : \underline{403713.75} \text{ mm}^2$$

$f'_c$ : Specified compressive strength of concrete.

$$f'_c : \underline{25.00} \text{ MPa}$$

$\Phi$ : Strength reduction factor.

$$\Phi : \underline{0.85}$$

Layout of the longitudinal reinforcement at lateral faces (ACI 318S-14, 9.7.2.3)

For beams with  $h$  exceeding 900 mm, longitudinal skin reinforcement shall be uniformly distributed on both side faces of the beam  $\checkmark$

Maximum spacing of the longitudinal reinforcement in lateral faces (ACI 318S-14, 9.7.2.3)

The spacing of skin reinforcement shall not exceed 's', where  $c_c$  is the clear cover from the skin reinforcement to the side face

$$s \leq \text{MIN} \left( 380 \left( \frac{280}{f_s} \right) - 2.5c_c, 300 \left( \frac{280}{f_s} \right) \right)$$

$$22 \text{ cm} \leq 28 \text{ cm} \quad \checkmark$$

Where:

$$f_s = \frac{2}{3} f_y$$

$s$ : Skin reinforcement spacing

$$s : \underline{22} \text{ cm}$$

$c_c$ : Clear cover from the skin reinforcement to the side face

$$c_c : \underline{4.0} \text{ cm}$$

Minimum spacing of the longitudinal reinforcement in lateral faces (ACI 318S-14, 25.2.2)

Reinforcement in the upper layers shall be placed directly above reinforcement in the bottom layer with a clear spacing between layers of at least 25mm

$$s \geq 25 \text{ mm}$$

$$21 \text{ cm} \geq 3 \text{ cm} \quad \checkmark$$

Ratio of the longitudinal reinforcement in lateral faces (ACI 318S-14, 18.10.7.4 (c))

Additional longitudinal and transverse reinforcement shall be distributed around the beam perimeter with total area in each direction of at least  $0.002 \cdot b_w \cdot s$

$$A_s \geq 0.002 \cdot b_w \cdot s$$

$$141.94 \text{ mm}^2 \geq 129.14 \text{ mm}^2 \quad \checkmark$$

Where:

$A_s$ : Longitudinal reinforcement total area

$$A_s : \underline{141.94} \text{ mm}^2$$

$b_w$ : Web width of the coupling beam

$$b_w : \underline{30.0} \text{ cm}$$

$s$ : Maximum spacing of longitudinal reinforcement

$$s : \underline{22} \text{ cm}$$

### Maximum spacing of the longitudinal reinforcement in lateral faces (ACI 318S-14, 18.10.7.4 (c))

Additional longitudinal and transverse reinforcement shall be distributed around the beam perimeter with spacing not exceeding 300mm

$$s \leq 300\text{mm}$$

$$22 \text{ cm} \leq 30 \text{ cm} \quad \checkmark$$

**s**: Maximum spacing of longitudinal reinforcement

$$s : \underline{22} \text{ cm}$$

### Stirrup spacing (ACI 318S-14, 18.10.7.4 (c))

Additional longitudinal and transverse reinforcement shall be distributed around the beam perimeter with spacing not exceeding 300mm

$$s \leq 300\text{mm}$$

$$23 \text{ cm} \leq 30 \text{ cm} \quad \checkmark$$

**s**: Transverse reinforcement spacing

$$s : \underline{23} \text{ cm}$$

### Ratio of transverse reinforcement (ACI 318S-14, 18.10.7.4 (c))

Additional longitudinal and transverse reinforcement shall be distributed around the beam perimeter with total area in each direction of at least  $0.002 \cdot b_w \cdot s$

$$A_s \geq 0.002 \cdot b_w \cdot s$$

$$141.94 \text{ mm}^2 \geq 138.00 \text{ mm}^2 \quad \checkmark$$

Where:

**A<sub>s</sub>**: Transverse reinforcement total area

$$A_s : \underline{141.94} \text{ mm}^2$$

**b<sub>w</sub>**: Web width of the coupling beam

$$b_w : \underline{30.0} \text{ cm}$$

**s**: Transverse reinforcement spacing

$$s : \underline{23} \text{ cm}$$

### Minimum spacing of the longitudinal reinforcement of the diagonal element (ACI 318S-14, 25.2.1)

For parallel reinforcement in a horizontal layer, clear spacing shall be at least the greatest of

$$s \geq s_{\min}$$

$$5 \text{ cm} \geq 3 \text{ cm} \quad \checkmark$$

Where:

**s<sub>min</sub>**: Maximum value of  $s_1, s_2, s_3$

$$s_1 = d_b$$

$$s_1 : \underline{1} \text{ cm}$$

$$s_2 = 25\text{mm}$$

$$s_2 : \underline{3} \text{ cm}$$

$$s_3 = \frac{4}{3} \cdot d_{\text{agg}}$$

$$s_3 : \underline{3} \text{ cm}$$

Where:

**d<sub>b</sub>**: Nominal bar diameter.

$$d_b : \underline{12.7} \text{ mm}$$

**d<sub>agg</sub>**: Nominal maximum size of coarse aggregate.

$$d_{\text{agg}} : \underline{20.0} \text{ mm}$$

### Distance between longitudinal reinforcement layers of the diagonal element (ACI 318S-14, 25.2.2)

Reinforcement in the upper layers shall be placed directly above reinforcement in the bottom layer with a clear spacing between layers of at least 25mm

$$s \geq 25\text{mm}$$

$$7 \text{ cm} \geq 3 \text{ cm} \quad \checkmark$$

### Layout of the longitudinal reinforcement of the diagonal element (ACI 318S-14, 18.10.7.4 (b))

Each group of diagonal bars shall consist of a minimum of four bars provided in two or more layers

$$n \geq 4$$

$$4 \geq 4 \quad \checkmark$$

**n**: Number of longitudinal bars of the diagonal reinforcement

$$n : \underline{4}$$

Length of the diagonal element that is embedded in the wall (ACI 318S-14, 18.10.7.4 (b))

The diagonal bars shall be embedded into the wall at least 1.25 times the development length for  $f_y$  in tension

$$l_{dw} \geq 1.25 \cdot l_d$$

$$63.5 \text{ cm} \geq 63.5 \text{ cm} \quad \checkmark$$

$l_{dw}$ : Length of diagonal reinforcement embedded into the wall

$$l_{dw} : \underline{63.5} \text{ cm}$$

$l_d$ : Development length.

$$l_d : \underline{50.8} \text{ cm}$$

$$l_d = \left( \frac{f_y \Psi_t \Psi_e}{2.1 \lambda \sqrt{f'_c}} \right) d_b \geq 300 \text{ mm}$$

Where:

$f_y$ : Specified yield strength for reinforcement.

$$f_y : \underline{420.00} \text{ MPa}$$

$f'_c$ : Specified compressive strength of concrete.

$$f'_c : \underline{25.00} \text{ MPa}$$

$d'_b$ : Nominal bar diameter.

$$d'_b : \underline{12.7} \text{ mm}$$

$\Psi_t$ : Factor used to modify development length for casting location in tension.

$$\Psi_t : \underline{1}$$

$\Psi_e$ : Factor used to modify development length based on reinforcement coating.

$$\Psi_e : \underline{1}$$

$\lambda$ : Modification factor to reflect the reduced mechanical properties of lightweight concrete relative to normalweight concrete of the same compressive strength.

$$\lambda : \underline{1}$$

Dimensions of the transverse reinforcement of the diagonal element (ACI 318S-14, 18.10.7.4 (c))

Each group of diagonal bars shall be enclosed by rectilinear transverse reinforcement having out-to-out dimensions of at least  $b_w/2$  in the direction parallel to  $b_w$  and  $b_w/5$  along the other sides

$$b_{diag} \geq b_w / 2$$

$$15.0 \text{ cm} \geq 15.0 \text{ cm} \quad \checkmark$$

$$h_{diag} \geq b_w / 5$$

$$12.0 \text{ cm} \geq 6.0 \text{ cm} \quad \checkmark$$

Where:

$b_{diag}$ : Out-to-out dimension of the transverse reinforcement, parallel to  $b_w$

$$b_{diag} : \underline{15.0} \text{ cm}$$

$h_{diag}$ : Out-to-out dimension of the transverse reinforcement, not parallel to  $b_w$

$$h_{diag} : \underline{12.0} \text{ cm}$$

$b_w$ : Web width of the coupling beam

$$b_w : \underline{30.0} \text{ cm}$$

Volumetric ratio of the transverse reinforcement of the diagonal element (ACI 318S-14, 18.10.7.4 (c))

The transverse reinforcement shall be in accordance with  $A_{sh}$  not less than  $A_{sh,min}$

In the X-axis:

$$A_{sh} \geq A_{sh,min}$$

$$258.06 \text{ mm}^2 \geq 250.00 \text{ mm}^2 \quad \checkmark$$

In the Y-axis:

$$A_{sh} \geq A_{sh,min}$$

$$258.06 \text{ mm}^2 \geq 200.00 \text{ mm}^2 \quad \checkmark$$

Where:

$A_{sh,min}$ : Maximum value of  $A_1$ ,  $A_2$

$$A_1 = 0.3 \frac{s \cdot b_c \cdot f'_c}{f_{yt}} \left[ \left( \frac{A_g}{A_{ch}} - 1 \right) \right]$$

$$A_{1x} : \underline{250.00} \text{ mm}^2$$

$$A_{1y} : \underline{200.00} \text{ mm}^2$$

$$A_2 = 0.09 \frac{s \cdot b_c \cdot f'_c}{f_{yt}}$$

$$A_{2x} : \underline{48.21} \text{ mm}^2$$

$$A_{2y} : \underline{38.57} \text{ mm}^2$$

Where:

$s$ : Center-to-center spacing of transverse reinforcement.

$$s : \underline{6} \text{ cm}$$

$b_c$ : Cross-sectional dimension of member core measured to the outside edges of the transverse reinforcement composing area  $A_{sh}$ .

$$b_{cx} : \underline{15.0} \text{ cm}$$

$$b_{cy} : \underline{12.0} \text{ cm}$$

$f_y$ : Specified yield strength for reinforcement.

$$f_y : \underline{420.00} \text{ MPa}$$

$f'_c$ : Specified compressive strength of concrete.

$$f'_c : \underline{25.00} \text{ MPa}$$

$A_g$ : Gross area of concrete section.

$$A_g : \underline{46000.00} \text{ mm}^2$$

**A<sub>ch</sub>**: Cross-sectional area measured to the outside edges of transverse reinforcement.

$$A_{ch} : \underline{18000.00} \text{ mm}^2$$

**A<sub>sh</sub>**: Total cross-sectional area of transverse reinforcement, including crossties, within spacing *s* and perpendicular to dimension, *b<sub>c</sub>*.

#### Spacing of the transverse reinforcement of the diagonal element (ACI 318S-14, 18.10.7.4 (c))

The spacing of the transverse reinforcement, measured parallel to the diagonal bars, shall satisfy

$$s_0 \leq s_{0,max}$$

$$6 \text{ cm} \leq 8 \text{ cm} \quad \checkmark$$

Where:

**s<sub>0,max</sub>**: Minimum of *s<sub>01</sub>* and *s<sub>02</sub>*

$$s_{01} = 6 \cdot d_b$$

$$s_{01} : \underline{8} \text{ cm}$$

$$s_{02} = 100 + \left( \frac{350 - h_x}{3} \right) \rightarrow \begin{cases} s_{02} \geq 100 \text{ mm} \\ s_{02} \leq 150 \text{ mm} \end{cases}$$

$$s_{02} : \underline{14} \text{ cm}$$

Where:

**d<sub>b</sub>**: Diameter of the smallest diagonal bar

$$d_b : \underline{12.7} \text{ mm}$$

**h<sub>x</sub>**: Maximum center-to-center spacing of longitudinal bars laterally supported by corners of crossties or hoop legs.

$$h_x : \underline{22} \text{ cm}$$

#### Spacing of the crossties and hooks of the diagonal element (ACI 318S-14, 18.10.7.4 (c))

The transverse reinforcement shall have spacing of crossties or legs of hoops measured perpendicular to the diagonal bars not exceeding 350 mm

$$h_x \leq 350 \text{ mm}$$

$$22 \text{ cm} \leq 35 \text{ cm} \quad \checkmark$$

**h<sub>x</sub>**: Maximum center-to-center spacing of longitudinal bars laterally supported by corners of crossties or hoop legs.

$$h_x : \underline{22} \text{ cm}$$