

# Shear Wall Detailing for Ductility Class

According to **Eurocode**: EN 1998-1

## Shear wall dimensions

Length -  $l_w = 4000$  mm

Web thickness -  $b_{wo} = 300$  mm

Total height -  $h_w = 19000$  mm

Clear storey height -  $h_s = 3820$  mm

Number of storeys -  $n_s = 6$

Confined zone dimensions

$b_c = 300$  mm,  $h_c = 875$  mm

Cross section area

Area of confined boundary element

$$A_f = b_c \cdot h_c = 300 \cdot 875 = 262500 \text{ mm}^2$$

Web area

$$A_w = (l_w - 2 \cdot h_c) \cdot b_{wo} = (4000 - 2 \cdot 875) \cdot 300 = 675000 \text{ mm}^2$$

Total area

$$A_c = A_w + 2 \cdot A_f = 675000 + 2 \cdot 262500 = 1200000 \text{ mm}^2$$

Maximum seismic axial load -  $N_{Ed} = 2254$  kN

## Concrete [EN 1992-1-1, Table 3.1]

Characteristic compressive cylinder strength

$$f_{ck} = 25 \text{ MPa}$$

Partial safety factor -  $\gamma_c = 1.5$ ,  $\alpha_{ct} = 1$ ,  $\alpha_{cc} = 1$

Mean value of axial tensile strength

$$f_{ctm} = 0.3 \cdot f_{ck}^{\frac{2}{3}} = 0.3 \cdot 25^{\frac{2}{3}} = 2.564964 \text{ MPa}$$

Characteristic axial tensile strength

$$f_{ctk,005} = 0.7 \cdot f_{ctm} = 0.7 \cdot 2.564964 = 1.795475 \text{ MPa}$$

Design compressive cylinder strength

$$f_{cd} = \frac{\alpha_{cc} \cdot f_{ck}}{\gamma_c} = \frac{1 \cdot 25}{1.5} = 16.666667 \text{ MPa}$$

Unconfined concrete ultimate strain

$$\varepsilon_{cu2} = 0.0035$$

Ultimate compressive strain -  $\varepsilon_{c2} = 0.002$

## Longitudinal reinforcement

Characteristic yield strength -  $f_{yk} = 500$  MPa

Selected steel class **B500B**

Partial safety factor -  $\gamma_s = 1.15$

$$f_{yd} = \frac{f_{yk}}{\gamma_s} = \frac{500}{1.15} = 434.782609 \text{ MPa}$$

Modulus of elasticity -  $E_s = 200000$  MPa

## Reinforcement for each confined boundary element

Bar diameter -  $d_{bL} = 25$  mm

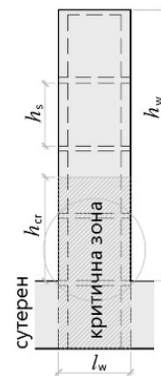
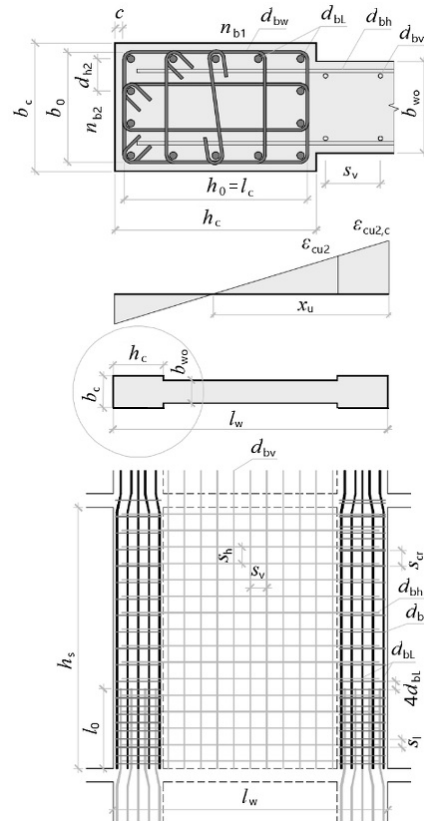
Minimum bar diameter -  $d_{bL,min} = 12$  mm

Bar count -  $n_b = 13$

Bar count along " $h_0$ " -  $n_{b1} = 6$

$$\text{Bar count along "b}_0\text{" - } n_{b2} = \text{ceiling}\left(\frac{n_b}{2} - n_{b1} + 2\right) = \text{ceiling}\left(\frac{13}{2} - 6 + 2\right) = 3$$

Reinforcement area



[BS EN 1992-1-1, § 9.5.2 (1)/NA.1]

$$A_{s1} = \frac{\pi \cdot d_{bL}^2}{4} = \frac{3.141593 \cdot 25^2}{4} = 490.873852 \text{ mm}^2$$

$$A_s = n_b \cdot A_{s1} = 13 \cdot 490.873852 = 6381.360078 \text{ mm}^2$$

Reinforcement ratio

$$\rho_L = \frac{A_s}{A_f} = \frac{6381.360078}{262500} = 0.02430994$$

Design check:  $0.005 \leq \rho_L = 0.02430994 \leq 0.04$ . The check is satisfied! ✓ [§ 5.4.3.4.2 (8)]

### Vertical web reinforcement

Bar diameter -  $d_{bv} = 10$  mm

Bar spacing -  $s_v = 250$  mm

Maximum bar spacing [EN 1992-1-1, § 9.6.2 (3)]

$$s_{v,max} = \min(3 \cdot b_{wo}; 400) = \min(3 \cdot 300; 400) = 400 \text{ mm}$$

$$\text{Single bar area - } A_{sv1} = \frac{\pi \cdot d_{bv}^2}{4} = \frac{3.141593 \cdot 10^2}{4} = 78.539816 \text{ mm}^2$$

$$\text{Reinforcement ratio - } \rho_v = \frac{2 \cdot A_{sv1}}{s_v \cdot b_{wo}} = \frac{2 \cdot 78.539816}{250 \cdot 300} = 0.002094395$$

Minimum reinforcement ratio -  $\rho_{v,min} = 0.002$  [EN 1992-1-1, § 9.6.2 (1)]

Minimum reinforcement ratio for zones with compressive strain > 0.002 [§ 5.4.3.4.2 (11)]

$$\rho_{v,min} = 0.005$$

### Horizontal web reinforcement

Bar diameter -  $d_{bh} = 12$  mm

Bar spacing -  $s_h = 150$  mm

Maximum bar spacing -  $s_{h,max} = 400$  mm [EN 1992-1-1, § 9.6.3 (2)]

$$\text{Single bar area - } A_{sh1} = \frac{\pi \cdot d_{bh}^2}{4} = \frac{3.141593 \cdot 12^2}{4} = 113.097336 \text{ mm}^2$$

$$\text{Reinforcement ratio - } \rho_h = \frac{2 \cdot A_{sh1}}{s_h \cdot b_{wo}} = \frac{2 \cdot 113.097336}{150 \cdot 300} = 0.005026548$$

Minimum reinforcement ratio [EN 1992-1-1, § 9.6.3 (1)]

$$\rho_{h,min} = \max(0.25 \cdot \rho_v; 0.001) = \max(0.25 \cdot 0.002094395; 0.001) = 0.001$$

### Transverse reinforcement in confined boundary elements

Characteristic yield strength -  $f_{ywk} = 500$  MPa

$$\text{Design yield strength - } f_{ywd} = \frac{f_{ywk}}{\gamma_s} = \frac{500}{1.15} = 434.782609 \text{ MPa}$$

Concrete cover to hoops -  $c = 42$  mm

Hoop diameter -  $d_{bw} = 8$  mm

Minimum diameter [EN 1992-1-1, § 9.5.3 (1)]

$$d_{bw,min} = \max(6; 0.25 \cdot d_{bL}) = \max(6; 0.25 \cdot 25) = 6.25 \text{ mm}$$

Hoop diameter check:

$$d_{bw} = 8 \geq d_{bw,min} = 6.25 \text{ mm. The check is satisfied! } \checkmark$$

**Critical region height** [§ 5.4.3.4.2 (1)]

$$h_{cr-} = \max\left(l_w; \frac{h_w}{6}\right) = \max\left(4000; \frac{19000}{6}\right) = 4000 \text{ mm}$$

Must not be greater than

$$h_{cr,max} = \min(2 \cdot l_w; h_s) = \min(2 \cdot 4000; 3820) = 3820 \text{ mm, for number of storeys } n_s = 6 \leq 6$$

$$h_{cr} = \min(h_{cr-}; h_{cr,max}) = \min(4000; 3820) = 3820 \text{ mm}$$

**Shear wall dimensions check** [§ 5.1.2 (1)]

$$\frac{l_w}{b_{wo}} = \frac{4000}{300} = 13.333333 \geq 4. \text{ The check is satisfied! } \checkmark$$

$$\text{Minimum thickness - } b_{w,min} = \max\left(150; \frac{h_s}{20}\right) = \max\left(150; \frac{3820}{20}\right) = 191 \text{ mm} \quad \text{[§ 5.4.1.2.3 (1)]}$$

$b_{wo} = 300 \text{ mm} \geq b_{w,min} = 191 \text{ mm}$ . The check is satisfied! ✓

Confined boundary element length

[§ 5.4.3.4.2 (6)]

$$l_c = h_c - (d_{bw} + 2 \cdot c) = 875 - (8 + 2 \cdot 42) = 783 \text{ mm}$$

Minimum confined boundary element length

$$l_{c,min} = \max(0.15 \cdot l_w; 1.5 \cdot b_c) = \max(0.15 \cdot 4000; 1.5 \cdot 300) = 600 \text{ mm}$$

$$l_c = 783 \text{ mm} \geq l_{c,min} = 600 \text{ mm}. \text{ The check is satisfied! } \checkmark$$

Minimum confined boundary element thickness

[§ 5.4.3.4.2 (10)]

$$\text{For } l_c = 783 \text{ mm} \leq \max(2 \cdot b_c; 0.2 \cdot l_w) = \max(2 \cdot 300; 0.2 \cdot 4000) = 800 \text{ mm:}$$

$$b_{c,min} = \max\left(\frac{h_s}{15}; 200\right) = \max\left(\frac{3820}{15}; 200\right) = 254.666667 \text{ mm}$$

$$b_c = 300 \text{ mm} \geq b_{c,min} = 254.666667 \text{ mm}. \text{ The check is satisfied! } \checkmark$$

**Check for normalized axial load**

[§ 5.4.3.4.1 (2)]

$$v_d = \frac{N_{Ed}}{A_c \cdot f_{cd}} \cdot 10^3 = \frac{2254}{1200000 \cdot 16.666667} \cdot 10^3 = 0.1127$$

$$v_d = 0.1127 \leq 0.4. \text{ The check is satisfied! } \checkmark$$

**Design anchorage length**

$\eta_1 = 1$  - when good conditions are provided

$\eta_2 = 1$  - for  $d_{bL} = 25 \leq 32 \text{ mm}$

$$f_{ctd} = \frac{\alpha_{ct} \cdot f_{ctk,005}}{\gamma_c} = \frac{1 \cdot 1.795475}{1.5} = 1.196983 \text{ MPa}$$

$$f_{bd} = 2.25 \cdot \eta_1 \cdot \eta_2 \cdot f_{ctd} = 2.25 \cdot 1 \cdot 1 \cdot 1.196983 = 2.693212 \text{ MPa}$$

[EN 1992-1-1, § 8.4.2 (2)]

$$\sigma_{sd} = f_{yd} = 434.782609 \text{ MPa}$$

$$l_{b,rqd} = \frac{d_{bL}}{4} \cdot \frac{\sigma_{sd}}{f_{bd}} = \frac{25}{4} \cdot \frac{434.782609}{2.693212} = 1008.977825 \text{ mm}$$

[EN 1992-1-1, § 8.4.3 (2)]

$$\alpha_1 = 1, \alpha_2 = 1, \alpha_3 = 1, \alpha_5 = 1, \alpha_6 = 1.5$$

[EN 1992-1-1, Table 8.2]

$$l_{0-} = \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_5 \cdot \alpha_6 \cdot l_{b,rqd} = 1 \cdot 1 \cdot 1 \cdot 1 \cdot 1.5 \cdot 1008.977825 = 1513.466738 \text{ mm}$$

[EN 1992-1-1, § 8.7.3 (1)]

$$l_{0,min} = \max(0.3 \cdot \alpha_6 \cdot l_{b,rqd}; 15 \cdot d_{bL}; 200) = \max(0.3 \cdot 1.5 \cdot 1008.977825; 15 \cdot 25; 200) = 454.040021 \text{ mm}$$

$$l_0 = \text{round}(\max(l_{0-}; l_{0,min})) = \text{round}(\max(1513.466738; 454.040021)) = 1513 \text{ mm}$$

Confined core dimensions (between centerlines of hoops)

$$b_0 = b_c - (d_{bw} + 2 \cdot c) = 300 - (8 + 2 \cdot 42) = 208 \text{ mm}$$

$$h_0 = h_c - (d_{bw} + 2 \cdot c) = 875 - (8 + 2 \cdot 42) = 783 \text{ mm}$$

Maximum bar spacing

$$d_{b1} = \frac{h_c - 2 \cdot (d_{bw} + c) - d_{bL}}{n_{b1} - 1} = \frac{875 - 2 \cdot (8 + 42) - 25}{6 - 1} = 150 \text{ mm}$$

$$d_{b2} = \frac{b_c - 2 \cdot (d_{bw} + c) - d_{bL}}{n_{b2} - 1} = \frac{300 - 2 \cdot (8 + 42) - 25}{3 - 1} = 87.5 \text{ mm}$$

Maximum distance between consecutive longitudinal bars engaged by hoops

$$d_{h,max} = 200 \text{ mm}$$

[§ 5.4.3.4.2 (9)]

Distance between bars engaged by hoops

$$n_{h1} = \max\left(\text{floor}\left(\frac{d_{h,max}}{d_{b1}}\right); 1\right) = \max\left(\text{floor}\left(\frac{200}{150}\right); 1\right) = 1$$

$$n_{h2} = \max\left(\text{floor}\left(\frac{d_{h,max}}{d_{b2}}\right); 1\right) = \max\left(\text{floor}\left(\frac{200}{87.5}\right); 1\right) = 2$$

Distance between bars engaged by hoops

$$d_{h1} = n_{h1} \cdot d_{b1} = 1 \cdot 150 = 150$$

$$d_{h2} = n_{h2} \cdot d_{b2} = 2 \cdot 87.5 = 175$$

Distance between bars engaged by hoops

$$n_{h1} = \text{round}\left(\frac{(n_{b1} - 1) \cdot d_{b1}}{d_{h1}}\right) = \text{round}\left(\frac{(6 - 1) \cdot 150}{150}\right) = 5$$

$$n_{h2} = \text{round}\left(\frac{(n_{b2}-1) \cdot d_{b2}}{d_{h2}}\right) = \text{round}\left(\frac{(3-1) \cdot 87.5}{175}\right) = 1$$

Hoop spacing in the critical region

$$s_{cr} = \min\left(\frac{b_0}{2}; 8 \cdot d_{bL}; 175\right) = \min\left(\frac{208}{2}; 8 \cdot 25; 175\right) = 104 \text{ mm} \quad [\S 5.4.3.4.2 (9)]$$

Hoop spacing in lap zone

$$s_l = \min\left(100; \frac{b_c}{4}\right) = \min\left(100; \frac{300}{4}\right) = 75 \text{ mm} \quad [\S 5.6.3 (3), c)]$$

Hoop spacing outside lap zone

$$s = \min(b_c; 20 \cdot d_{bL}; 400) = \min(300; 20 \cdot 25; 400) = 300 \text{ mm} \quad [\text{EN 1992-1-1}, \S 9.5.3 (3)]$$

### Transverse reinforcement in the lap zone

Required area of one leg

$$A_{st} = s_l \cdot \frac{d_{bL}}{50} \cdot \frac{f_{yd}}{f_{ywd}} = 75 \cdot \frac{25}{50} \cdot \frac{434.782609}{434.782609} = 37.5 \text{ mm}^2 \quad [\S 5.6.3 (4)]$$

Provided area of one leg

$$A_{sw1} = \frac{\pi \cdot d_{bw}^2}{4} = \frac{3.141593 \cdot 8^2}{4} = 50.265482 \text{ mm}^2$$

Design check:  $A_{sw1} = 50.265482 \text{ mm}^2 \geq A_{st} = 37.5 \text{ mm}^2$ . The check is satisfied! ✓

Check for bar diameters > 20 mm:

Number of legs in the outer 1/3 of lap zone

$$n_w = \text{round}\left(\frac{2 \cdot l_0}{3 \cdot s_l}\right) = \text{round}\left(\frac{2 \cdot 1513}{3 \cdot 75}\right) = 13$$

Total area of legs in the outer 1/3 of lap zone

$$\Sigma A_{sw} = A_{sw1} \cdot n_w = 50.265482 \cdot 13 = 653.451272$$

Design check:  $\Sigma A_{sw} = 653.451272 \text{ mm}^2 \geq A_{s1} = 490.873852 \text{ mm}^2 \quad [\text{EN 1992-1-1} \S 8.7.4.1 (3)]$

An additional hoop is required for compressed bars

at  $4 \cdot d_{bL} = 4 \cdot 25 = 100 \text{ mm}$  from the end of the lap zone. [EN 1992-1-1 § 8.7.4.2 (1)]

### Detailing for local ductility in the critical region

Total length of confining links

$$\Sigma l_i = (n_{h1} + 1) \cdot b_0 + (n_{h2} + 1) \cdot h_0 = (5 + 1) \cdot 208 + (1 + 1) \cdot 783 = 2814$$

Mechanical volumetric ratio of confining hoops within the critical region

$$\omega_d = \frac{A_{sw1} \cdot \Sigma l_i}{b_0 \cdot h_0 \cdot s_{cr}} \cdot \frac{f_{ywd}}{f_{cd}} = \frac{50.265482 \cdot 2814}{208 \cdot 783 \cdot 104} \cdot \frac{434.782609}{16.666667} = 0.2178507$$

The minimum value is 0.08.

[§ 5.4.3.2.2 (8)]

Design check:  $\omega_d = 0.2178507 \geq 0.08 = 0.08$ . The check is satisfied! ✓

Sum of the squares of the distances between consecutive engaged bars

$$\Sigma b_{2i} = 2 \cdot (n_{h1} \cdot d_{h1}^2 + n_{h2} \cdot d_{h2}^2) = 2 \cdot (5 \cdot 150^2 + 1 \cdot 175^2) = 286250$$

Confinement effectiveness factors for bars and links

$$\alpha_n = 1 - \frac{\Sigma b_{2i}}{6 \cdot b_0 \cdot h_0} = 1 - \frac{286250}{6 \cdot 208 \cdot 783} = 0.7070664$$

$$\alpha_s = \left(1 - \frac{s_{cr}}{2 \cdot b_0}\right) \cdot \left(1 - \frac{s_{cr}}{2 \cdot h_0}\right) = \left(1 - \frac{104}{2 \cdot 208}\right) \cdot \left(1 - \frac{104}{2 \cdot 783}\right) = 0.7001916$$

$$\alpha = \alpha_n \cdot \alpha_s = 0.7070664 \cdot 0.7001916 = 0.495082$$

### Analysis results

Fundamental period of first vibration mode -  $T_1 = \underline{0.6795}$  s

Upper limit period of constant spectral acceleration -  $T_C = \underline{0.4}$  s

Basic behavior factor value -  $q_0 = \underline{3}$

Design bending moment -  $M_{Ed} = \underline{9591}$  kNm

Bending moment capacity -  $M_{Rd} = \underline{13268}$  kNm

(The above values refer to the section above the base)

### Curvature ductility factor

$$\mu_{\Phi} = 2 \cdot q_0 \cdot \frac{M_{Ed}}{M_{Rd}} - 1 = 2 \cdot 3 \cdot \frac{9591}{13268} - 1 = 3.337202 - 1 = 3.337202 \text{ - for } T_1 \geq T_C \quad [\S 5.2.3.4 (3)]$$

For steel class B, ductility factor is increased by 50% -  $\mu_{\Phi} = 5.005803$  [§ 5.2.3.4 (4)]

$$\text{Design value of steel yield strain - } \varepsilon_{sy,d} = \frac{f_{yd}}{E_s} = \frac{434.782609}{200000} = 0.002173913$$

Mechanical ratio of vertical web reinforcement

$$\omega_v = \rho_v \cdot \frac{f_{yd}}{f_{cd}} = 0.002094395 \cdot \frac{434.782609}{16.666667} = 0.05463639$$

$$\text{Design check: } \alpha \omega_d \geq \alpha \omega_{d,min} = 30 \cdot \mu_{\Phi} \cdot (v_d + \omega_v) \cdot \varepsilon_{sy,d} \cdot b_c / b_0 - 0.035 \quad [\S 5.4.3.4.2 (4)]$$

$$\alpha \omega_d = \alpha \cdot \omega_d = 0.495082 \cdot 0.2178507 = 0.1078539$$

$$\alpha \omega_{d,min} = 30 \cdot \mu_{\Phi} \cdot (v_d + \omega_v) \cdot \varepsilon_{sy,d} \cdot \frac{b_c}{b_0} - 0.035 = 30 \cdot 5.005803 \cdot (0.1127 + 0.05463639) \cdot 0.002173913 \cdot \frac{300}{208} - 0.035 = 0.04379262$$

The required curvature ductility is provided:  $\alpha \omega_d = 0.1078539 \geq \alpha \omega_{d,min} = 0.04379262$  . ✓

Ultimate strain of confined concrete

$$\varepsilon_{cu2,c} = 0.0035 + 0.1 \cdot \alpha \omega_d = 0.0035 + 0.1 \cdot 0.1078539 = 0.01428539$$

Neutral axis depth at ultimate curvature

$$x_u = (v_d + \omega_v) \cdot l_w \cdot \frac{b_c}{b_0} = (0.1127 + 0.05463639) \cdot 4000 \cdot \frac{300}{208} = 965.402273 \text{ mm}$$

Confined boundary element length

$$l_{c,req} = x_u \cdot \left( 1 - \frac{\varepsilon_{cu2}}{\varepsilon_{cu2,c}} \right) = 965.402273 \cdot \left( 1 - \frac{0.0035}{0.01428539} \right) = 728.873416 \text{ mm}$$

Design check:  $l_c = 783 \text{ mm} \geq l_{c,req} = 728.873416 \text{ mm}$ . The check is satisfied! ✓

NOTE: All references are according to EN 1998-1, unless noted otherwise.

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