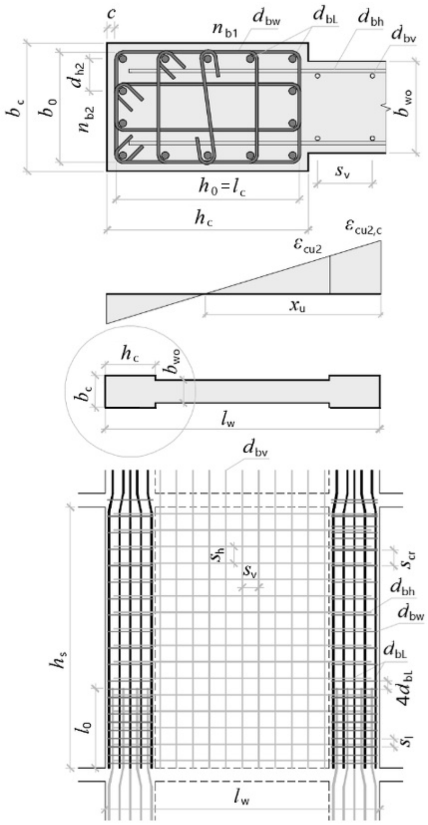
Shear Wall Detailing for Ductility Class

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

$A_f = b_c \cdot h_c = 300 \cdot 875 = 262500$ mm²

Web area

$A_w = (l_w - 2 \cdot h_c) \cdot b_{wo} = (4000 - 2 \cdot 875) \cdot 300 = 675000$ mm²

Total area

$A_c = A_w + 2 \cdot A_f = 675000 + 2 \cdot 262500 = 1200000$ mm²

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

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

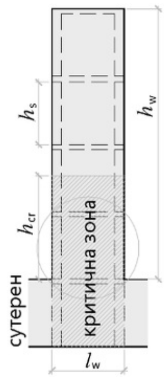
Characteristic compressive cylinder strength

$f_{ck} = 25$ MPa

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

Mean value of axial tensile strength

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



Characteristic axial tensile strength

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

Design compressive cylinder strength

$f_{cd} = \frac{\alpha_{cc} \cdot f_{ck}}{\gamma_c} = \frac{1 \cdot 25}{1.5} = 16.666667$ 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 - $\gamma_s = 1.15$

Design yield strength - $f_{yd} = \frac{f_{yk}}{\gamma_s} = \frac{500}{1.15} = 434.782609$ 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 [BS EN 1992-1-1, § 9.5.2 (1)/NA.1]

Bar count - $n_b = 13$

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

Bar count along "b_0" - $n_{b2} = \mathbf{ceiling}\left(\frac{n_b}{2} - n_{b1} + 2\right) = \mathbf{ceiling}\left(\frac{13}{2} - 6 + 2\right) = 3$

Reinforcement area

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

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

Reinforcement ratio

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

Design check: $0.005 \le \rho_L = 0.02430994 \le 0.04$. 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)]

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

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

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)]

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

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)]

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

Transverse reinforcement in confined boundary elements

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

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

Concrete cover to hoops - $c = 42$ mm

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

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

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

Hoop diameter check:

$d_{bw} = 8 \ge d_{bw,min} = 6.25$ mm. The check is satisfied! ✓

Critical region height [§ 5.4.3.4.2 (1)]

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

Must not be greater than

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

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

Shear wall dimensions check [§ 5.1.2 (1)]

$\frac{l_w}{b_{wo}} = \frac{4000}{300} = 13.333333 \ge 4$. The check is satisfied! ✓

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

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

Confined boundary element length [§ 5.4.3.4.2 (6)]

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

Minimum confined boundary element length

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

$l_c = 783$ mm ≥ $l_{c,min} = 600$ mm. The check is satisfied! ✓

Minimum confined boundary element thickness [§ 5.4.3.4.2 (10)]

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

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

$b_c = 300$ mm ≥ $b_{c,min} = 254.666667$ mm. The check is satisfied! ✓

Check for normalized axial load [§ 5.4.3.4.1 (2)]

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

$v_d = 0.1127$ ≤ 0.4. The check is satisfied! ✓

Design anchorage length

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

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

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

$f_{bd} = 2.25 \cdot \eta_1 \cdot \eta_2 \cdot f_{ctd} = 2.25 \cdot 1 \cdot 1 \cdot 1.196983 = 2.693212$ MPa [EN 1992-1-1, § 8.4.2 (2)]

$\sigma_{sd} = f_{yd} = 434.782609$ 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]

$l_{0\_} = \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_5 \cdot \alpha_6 \cdot l_{b,rqd} = 1 \cdot 1 \cdot 1 \cdot 1 \cdot 1.5 \cdot 1008.977825 = 1513.466738$ mm [EN 1992-1-1, § 8.7.3 (1)]

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

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

Confined core dimensions (between centerlines of hoops)

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

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

$d_{h,max} = 200$ mm [§ 5.4.3.4.2 (9)]

Distance between bars engaged by hoops

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

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

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

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

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

Hoop spacing in the critical region

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

Hoop spacing in lap zone

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

Hoop spacing outside lap zone

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

Transverse reinforcement in the lap zone

Required area of one leg

$$A_{st} = s_l\cdot\frac{d_{bL}}{50}\cdot\frac{f_{yd}}{f_{ywd}} = 75\cdot\frac{25}{50}\cdot\frac{434.782609}{434.782609} = 37.5 \text{ mm}^2$$ [§ 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: $A_{sw1} = 50.265482$ mm² ≥ $A_{st} = 37.5$ mm². The check is satisfied! ✓

Check for bar diameters > 20 mm:

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

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

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: $\Sigma A_{sw} = 653.451272$ mm² ≥ $A_{s1} = 490.873852$ mm² [EN 1992-1-1 § 8.7.4.1 (3)]

An additional hoop is required for compressed bars

at $4\cdot d_{bL} = 4\cdot 25 = 100$ 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

$$\Sigma b2_i = 2\cdot(n_{h1}\cdot d_{h1}^2 + n_{h2}\cdot d_{h2}^2) = 2\cdot(5\cdot 150^2 + 1\cdot 175^2) = 286250$$

Confinement effectiveness factors for bars and links

$$\alpha_n = 1 - \frac{\Sigma b2_i}{6\cdot b_0\cdot h_0} = 1 - \frac{286250}{6\cdot 208\cdot 783} = 0.7070664$$

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

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

Analysis results

Fundamental period of first vibration mode - $T_1 = 0.6795$ s

Upper limit period of constant spectral acceleration - $T_C = 0.4$ s

Basic behavior factor value - $q_0 = 3$

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

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

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

Curvature ductility factor

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

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

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

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

Design check: $\alpha\omega_d \geq \alpha\omega_{d\_min} = 30 \cdot \mu_{\Phi} \cdot (v_d + \omega_v) \cdot \varepsilon_{sy\_d} \cdot b_c / b_0 - 0.035$ [§ 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: $l_c = 783$ mm $\geq l_{c,req} = 728.873416$ mm. The check is satisfied! ✓

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

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