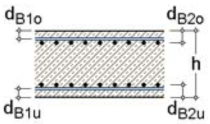
POS. 1: WALL DESIGN

axial force- and shear design calculation (EC 2 (1.11), NA: Deutschland)

wall design calculation (only axial force) (4H-BETON version: 11/2007-4q)



wall thickness
h = 24.0 cm
edge distances of longit. reinf.
d_{B1o} = 2.5 cm, d_{B2o} = 3.0 cm
d_{B1u} = 2.5 cm, d_{B2u} = 3.0 cm
transformation of design values
acc. to T.Baumann, 1972
material
C20/25
BSt 500 (A)
γ_s = 1.15, γ_c = 1.50

detailing of reinforcement orthogonal
B1 and B2 axially parallel
min./max./transverse reinforcement
min a_s acc. to 9.6.2 for reinf. direction B2
max ρ_0 = 8.00%
no secondary reinforcement direction
initial reinforcement
a_{s0B1o} = 1.88 cm²/m, a_{s0B2o} = 1.88 cm²/m
a_{s0B1u} = 1.88 cm²/m, a_{s0B2u} = 1.88 cm²/m

verifications in ultimate limit states are executed with stress-strain relation for concrete acc. to 3.1.7 (figure 3.3)
with $f_{cd} = \alpha_c f_{ck} / \gamma_c$ = 11.3 MN/m2 and reinforcement stress-strain relation acc. to 3.2.7 (fig. 3.8) with $f_{yd} = f_{yk} / \gamma_s$ = 434.8 MN/m2
and $f_{td} = f_{tk} / \gamma_s$ = 456.5 MN/m2 !
verifications in serviceability limit states are executed with stress-strain relation for concrete acc. to 3.1.5 (figure 3.2)
with $f_c = f_{cm}$ = 28.0 MN/m2 and reinforcement stress-strain relation acc. to 3.2.7 (figure 3.8) with $f_y = f_{yk}$, f_t = 525.0 MN/m2 and ε_{uk} = 25‰ !

design calculation values and minimum reinforcement areas (EC 2, 6.1)
output of the design relevant results for each reinforcement direction B1 top(o)/bottom(u) resp. B2 top(o)/bottom(u).

bwr	γ -	n_{bwr} kN/m	ε_{c2u} ‰	ε_{s2u} ‰	ε_{s1u} ‰	ε_{c1u} ‰	a_{sB1o} cm²/m	a_{sB1u} cm²/m	a_{sB2o} cm²/m	a_{sB2u} cm²/m	note
1	: $n_{xx,Ed}$ = 24.30 kN/m, $n_{yy,Ed}$ = -456.00 kN/m, $n_{xy,Ed}$ = 98.00 kN/m										
B1	---	122.30	25.00	25.00	25.00	25.00	1.34	1.34			
B2	---	-554.00	-2.20	-2.20	-2.20	-2.20			1.80	1.80	6) 14) 15)
2	: $n_{xx,Ed}$ = 35.10 kN/m, $n_{yy,Ed}$ = -700.30 kN/m, $n_{xy,Ed}$ = 154.40 kN/m										
B1	---	189.50	25.00	25.00	25.00	25.00	**2.08**	**2.08**			
B2	---	-854.70	-2.20	-2.20	-2.20	-2.20			1.80	1.80	6) 14) 15)

n_{bwr}: design normal force transformed in the respective reinforcement direction (n_{xx}, n_{yy}, n_{xy} in kN/m)
ε_{c2u} = -3.50‰: concr. strain in state of failure (fibre 2), ε_{s1u} = 25.00‰: reinforcement strain in state of failure (fibre 1)

6) $e_d/h < 0.30 \Rightarrow$ symmetrical reinforcement
14) $e_d/h < 0.1 \Rightarrow \varepsilon_{c2}$ = -2.2‰ !
15) minimum reinforcement acc. to 9.6.2

verification of principle concrete compressive stresses ($\nu = 1.00 \cdot \eta_1$)
1: n_d = -475.23 kN/m $\Rightarrow$ $|\sigma_{Rd}|$ = 1.98 MN/m² < 11.33 MN/m² = $\nu \cdot f_{cd}$ $\Rightarrow$ verification executed !
2: n_d = -731.40 kN/m $\Rightarrow$ $|\sigma_{Rd}|$ = 3.05 MN/m² < 11.33 MN/m² = $\nu \cdot f_{cd}$ $\Rightarrow$ verification executed !

$\Rightarrow$ **longitudinal reinforcement: min a_{sB1o} = 2.08 cm²/m   min a_{sB2o} = 1.88 cm²/m**
(incl. initial reinf.) **min a_{sB1u} = 2.08 cm²/m   min a_{sB2u} = 1.88 cm²/m**

design action effects
verification notations: R = crack limitation S = fatigue design σ = stress verification

bwr	$n_{xx,Ed}$ / n_{bwr} kN/m	$n_{yy,Ed}$ kN/m	$n_{xy,Ed}$ kN/m
R	25.50	-501.00	109.80
B1	135.30		
B2	-610.80		
S	24.30	-456.00	98.10

bwr	$n_{xx,Ed}$ / n_{bwr} kN/m	$n_{yy,Ed}$ kN/m	$n_{xy,Ed}$ kN/m
B1	122.40		
B2	-554.10		
S	25.80	-512.50	112.70
B1	138.50		

bwr	$n_{xx,Ed}$ / n_{bwr} kN/m	$n_{yy,Ed}$ kN/m	$n_{xy,Ed}$ kN/m
B2	-625.20		
σ	24.30	-456.00	98.10
B1	122.40		
B2	-554.10		

crack control (EC 2, 7.3: 7.3.2 minimum reinforcement, 7.3.3 without direct calculation)

cracking in bending restraint (intrinsically imposed)
factor for progress of hardening $k_{z,t}$ = 1.00
formation of first crack: n_{cr} = 0.00 kN/m
crack width w_k = 0.30 mm
sel. diameter d_{sB1o} = 8 mm d_{sB2o} = 8 mm
d_{sB1u} = 8 mm d_{sB2u} = 8 mm
design action effects see above
reinforcement: a_{sB1o} = 2.08 a_{sB2o} = 1.88
in cm^2/m a_{sB1u} = 2.08 a_{sB2u} = 1.88

minimum reinforcement:
coeff. - stress distribution k_c = 0.40
coeff. - self-equil. stresses k = 0.80
concr. tens. str. (restr.) $f_{ct,eff}$ = 2.21 N/mm^2
($a_{stB1o,min}$ = 2.69 cm^2/m $a_{stB2o,min}$ = 2.69 cm^2/m
$a_{stB1u,min}$ = 2.69 cm^2/m $a_{stB2u,min}$ = 2.69 cm^2/m)
crack control:
concr. tens. strength (load) $f_{ct,eff}$ = f_{ctm} = 2.21 N/mm^2
σ_{sB1o} = 311.0 N/mm^2 σ_{sB2o} = 0.0 N/mm^2
σ_{sB1u} = 311.0 N/mm^2 σ_{sB2u} = 0.0 N/mm^2
($a_{stB1o,ste}$ = 2.18 cm^2/m ($\Rightarrow d_{so}$ = 8.2 mm > 8)
$a_{stB1u,ste}$ = 2.18 cm^2/m ($\Rightarrow d_{su}$ = 8.2 mm > 8)
$a_{stB2o,ste}$ = 1.88 cm^2/m (d_{so} = 8 mm)
$a_{stB2u,ste}$ = 1.88 cm^2/m (d_{su} = 8 mm))
additional reinforcement:
Δa_{stB1o} = 0.62 cm^2/m Δa_{stB2o} = 0.81 cm^2/m
Δa_{stB1u} = 0.62 cm^2/m Δa_{stB2u} = 0.81 cm^2/m

$\Rightarrow$ incl. anti-crack reinforcement: min a_{sB1o} = 2.69 cm^2/m min a_{sB2o} = 2.69 cm^2/m
min a_{sB1u} = 2.69 cm^2/m min a_{sB2u} = 2.69 cm^2/m

fatigue design (EC 2, 6.8.5 + 6.8.7(1))

for steel: $U_{s1} = \gamma_{F,fat}\ \gamma_{Ed,fat}\ \Delta\sigma_{s,equ} \leq U_{s2} = \Delta\sigma_{Rsk}(N^*)/\gamma_{s,fat}$ = 73.91 N/mm^2
damage equivalent stress range $\Delta\sigma_{s,equ} = \sigma_{s,O} - \sigma_{s,U}$
partial safety factors $\gamma_{F,fat}$ = 1.00, $\gamma_{Ed,fat}$ = 1.00, $\gamma_{s,fat} = \gamma_s$ = 1.15
allowable stress range $\Delta\sigma_{Rsk}(N^*)$ = 85.0 N/mm^2
for conc.: $U_{c1} = |\sigma_{cd,max,equ}|/f_{cd,fat} + 0.43\ \mathrm{sqrt}(1 - \sigma_{cd,min,equ}/\sigma_{cd,max,equ}) \leq 1.0$
design value of compression strength $f_{cd,fat}$ = 10.43 N/mm^2 at t_0 = 28 d
material safety $\gamma_{c,fat} = \gamma_c$ = 1.50
design action effects see above
reinforcement: a_{sB1o} = 2.69 cm^2/m a_{sB2o} = 2.69 cm^2/m a_{sB1u} = 2.69 cm^2/m a_{sB2u} = 2.69 cm^2/m

fatigue design for steel:
initial state:
$\Delta\sigma_{s0B1o,equ}$ = 257.31 - 227.40 = 29.91 N/mm^2
$\Delta\sigma_{s0B1u,equ}$ = 257.31 - 227.40 = 29.91 N/mm^2
$\Delta\sigma_{s0B2o,equ}$ = -14.83 - -16.79 = 1.96 N/mm^2
$\Delta\sigma_{s0B2u,equ}$ = -14.83 - -16.79 = 1.96 N/mm^2
= end state

concrete fatigue design:
$\sigma_{cdB1,min,equ}$ = 0.00 N/mm^2
$\sigma_{cdB1,max,equ}$ = 0.00 N/mm^2
U_{c1B1} = 0.00
$\sigma_{cdB2,min,equ}$ = 2.28 N/mm^2
$\sigma_{cdB2,max,equ}$ = 2.57 N/mm^2
U_{c1B2} = 0.39 < 1.00
$\Rightarrow$ verification executed !

$\Rightarrow$ no additional fatigue reinforcement !

limitation of steel tension and concrete compression stresses (EC 2, 7.2)

permitted tensile stress of reinf. $\sigma_s = 0.80 \cdot f_{yk}$ = 400.0 N/mm^2
permitted concrete compression stress $\sigma_c = 0.60 \cdot f_{ck}$ = -12.0 N/mm^2
design action effects see above
reinforcement: a_{sB1o} = 2.69 cm^2/m a_{sB2o} = 2.69 cm^2/m a_{sB1u} = 2.69 cm^2/m a_{sB2u} = 2.69 cm^2/m

maximal reinforcement tensile stresses
initial state:
σ_{0sB1o} = 227.4 N/mm^2 σ_{0sB2o} = -14.8 N/mm^2
σ_{0sB1u} = 227.4 N/mm^2 σ_{0sB2u} = -14.8 N/mm^2
= end state

minimal concrete compression stress
initial state:
σ_{0cB1} = 1.5 N/mm^2
σ_{0cB2} = -2.3 N/mm^2
= end state

$\Rightarrow$ no additional stress reinforcement !

fire protection for compression members - analysis of utilization factor α_1

the utilization factor is calculated for the decisive design calculation values in ULS (bending design).
ratio between design value in fire case and design value in ULS $S_{fi,d,t}/S_{Ed}$ = 0.70
permitted utilization factor $\alpha_{1,zul}$ = 1.00
utilization factor:
$\alpha_1 = S_{fi,d,t}/S_{Rd}$ = **0.540** < 1.00
$\Rightarrow$ fire resistance class REI 90
EC 2, table 5.4: min. wall thickness d = 131 mm min. centre distance u = 23 mm

total reinforc.: **total a_{sB1o} = 2.69 cm²/m** **a_{sB2o} = 2.69 cm²/m**
total a_{sB1u} = 2.69 cm²/m **a_{sB2u} = 2.69 cm²/m**

additional reinforcement: **Δa_{sB1o} = 0.81 cm²/m** **Δa_{sB2o} = 0.81 cm²/m**
Δa_{sB1u} = 0.81 cm²/m **Δa_{sB2u} = 0.81 cm²/m**

cross-section data

gross area of concrete: a_c = 24.0 dm²/m, second moment of area: i_{cs} = 11.5 dm⁴/m
moment of resistance: w_{cs} = 9.6 dm³/m, distance of centre of gravity from upper edge: z_s = 12.0 cm
total area of longitudinal reinforcement: $\Sigma(\min a_s)$ = 10.77 cm²/m $\Rightarrow$ ρ_s = 0.45% < 8.00%

material properties for design calculation

concrete	f_{ck}	α	ε_{c2}	ε_{c2u}	n_c	E_{cm}	f_{ctm}
	MN/m²	-	‰	‰	-	MN/m²	MN/m²
C20/25	20.0	0.850	-2.00	-3.50	2.00	29962.0	2.210

design value of compression strength $f_{cd} = \alpha_c f_{ck} / \gamma_c$
strain at reaching the maximum strength ε_{c2}, ult. compr. strain ε_{c2u}
concr. comp. stress $\sigma_c = f_{cd} (1-(1-\varepsilon_c/\varepsilon_{c2})^n)$ for $0 \geq \varepsilon_c > \varepsilon_{c2}$ and $\sigma_c = f_{cd}$ for $\varepsilon_{c2} \geq \varepsilon_c > \varepsilon_{c2u}$
modulus of elasticity E_{cm}, mean value of axial tensil strength f_{ctm}

reinforcem.	f_{yk}	f_{tk}	ε_{su}	E_s
	MN/m²	MN/m²	‰	MN/m²
BSt 500 (A)	500.0	525.0	25.00	200000.0

design yield strength $f_{yd} = f_{yk} / \gamma_s$
design tensile strength $f_{td} = f_{tk} / \gamma_s$
ult. tensile strain ε_{su}, modulus of elasticity E_s