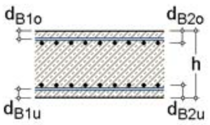
POS. 3: FOLDED STRUCTURE DESIGN

bending and shear design calculation (EC 2 (1.11), NA: Deutschland)

folded structure design (bending with/without axial force) (4H-BETON version: 11/2007-4q)



thickness
h = 90.0 cm
edge distances of longit. reinf.
d_{B1o} = 3.5 cm, d_{B2o} = 4.0 cm
d_{B1u} = 3.5 cm, d_{B2u} = 4.0 cm
transformation of design values
acc. to B.Thürlimann, 1983
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 (9.2.1.1; 9.6.2 for both reinf. dir.)
max ρ_0 = 8.00%
no secondary reinforcement direction
initial reinforcement
a_{s0B1o} = 3.77 cm²/m, a_{s0B2o} = 3.77 cm²/m
a_{s0B1u} = 3.77 cm²/m, a_{s0B2u} = 3.77 cm²/m
$a_{s0bü}$ = 0.00 cm²/m²

verifications in ultimate limit states are executed with stress-strain relation for concrete acc. to 3.1.7 (figure 3.3)
with fcd = αc fck / γc = 11.3 MN/m2 and reinforcement stress-strain relation acc. to 3.2.7 (fig. 3.8) with fyd = fyk / γs = 434.8 MN/m2
and ftd = ftk / γs = 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 fc = fcm = 28.0 MN/m2 and reinforcement stress-strain relation acc. to 3.2.7 (figure 3.8) with fy = fyk, ft = 525.0 MN/m2 and εuk = 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).
1mn: minimal design moment in reinforcement direction 1, 1mx: maximal design moment in reinforcement direction 1
2mn: minimal design moment in reinforcement direction 2, 2mx: maximal design moment in reinforcement direction 2

bwr	γ	n_{bwr}	m_{bwr}	ε_{c2u}	ε_{s2u}	ε_{s1u}	ε_{c1u}	z	a_{sB1o}	a_{sB1u}	a_{sB2o}	a_{sB2u}	note
	-	kN/m	kNm/m	‰	‰	‰	‰	cm	cm²/m	cm²/m	cm²/m	cm²/m	
1 : n_{xx} = 40.40, n_{yy} = 116.30, n_{xy} = 135.20, m_{xx} = 94.50, m_{yy} = -34.60, m_{xy} = -57.40													
1mn	---	175.60	37.10	25.00	25.00	25.00	25.00	83.0	0.94	2.90			
	---	-94.80	37.10	-3.50	-2.64	17.82	18.68	80.6	**6.75**	6.75			15)
1mx	---	175.60	151.90	-0.74	0.30	25.00	26.04	85.6	----	5.87			
	---	-94.80	151.90	-1.23	-0.17	25.00	26.06	85.1	----	2.85			
2mn	---	251.50	-92.00	25.00	25.00	25.00	25.00	82.0			5.21	0.30	
	---	-18.90	-92.00	-0.85	0.35	25.00	26.20	85.0			2.16	----	
2mx	---	251.50	22.80	25.00	25.00	25.00	25.00	82.0			2.15	3.36	
	---	-18.90	22.80	-0.45	0.74	25.00	26.18	85.5			----	0.37	
2 : n_{xx} = 23.20, n_{yy} = 86.50, n_{xy} = 79.90, m_{xx} = 48.80, m_{yy} = -33.60, m_{xy} = -23.60													
1mn	---	103.10	25.20	25.00	25.00	25.00	25.00	83.0	0.46	1.79			
	---	-56.70	25.20	-0.57	0.46	25.00	26.03	85.8	**6.75**	6.75			15)
1mx	---	103.10	72.40	-0.44	0.59	25.00	26.03	86.0	----	3.01			
	---	-56.70	72.40	-0.83	0.22	25.00	26.05	85.5	----	1.21			
2mn	---	166.40	-57.20	25.00	25.00	25.00	25.00	82.0			3.35	0.29	
	---	6.60	-57.20	-0.61	0.58	25.00	26.19	85.3			1.54	----	
2mx	---	166.40	-10.00	25.00	25.00	25.00	25.00	82.0			2.09	1.56	
	---	6.60	-10.00	-0.21	0.96	25.00	26.17	85.8			0.33	----	
minimum values:													
B1u			298.41	-1.62	-0.54	25.00	26.08	----	----	**7.06**			9)
B2o			-298.41	-1.63	-0.39	25.00	26.24	----			**7.10**	----	9)
B2u			298.41	-1.63	-0.39	25.00	26.24	----			----	**7.10**	9)

n_{bwr}, m_{bwr}: design values transformed in the respective reinforcement direction (n_{xx}, n_{yy}, n_{xy} in kN/m, m_{xx}, m_{yy}, m_{xy} in kNm/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)
z: lever arm of internal forces

9) minimum reinforcement acc. to 9.3.1.1
15) minimum reinforcement acc. to 9.6.2

⇒ **longitudinal reinforcement:** min a_{sB1o} = 6.75 cm²/m, min a_{sB2o} = 7.10 cm²/m
(incl. initial reinf.) min a_{sB1u} = 7.06 cm²/m, min a_{sB2u} = 7.10 cm²/m

shear design calculation (EC 2, 6.2 + 6.3)
design calc. as 'slab', material quality as flexural reinf., z from bending design
angle of reinforcement $\alpha = 90.0°$, angle of compr. strut $\theta_{gew} = 0°$
design carried out for each reinforcement direction with subsequently summation of portions.
the minimum value of V_{Rdct} is limited acc. to design code ($V_{Rdct} \geq \min V_{Rdct}$).

design calculation of shear force (EC 2, 6.2)

	$v_{x,Ed}$ kN/m	$v_{y,Ed}$ kN/m	v_{Ed} kN/m	ρ_l %	z cm	v_{Rdct} kN/m	θ °	cot θ	v_{Rdmax} kN/m	AB	a_l cm	$a_{s,büv}$ cm²/m²	note
1	182.30	-133.70	182.30	0.08	80.6	254.92	18.4	3.00	2055.14	1	120.9	0.00	min V_{Rdct}
			133.70	0.08	85.0	245.09	18.4	3.00	2167.93	1	127.5	0.00	min V_{Rdct}
2	105.00	-90.30	105.00	0.08	85.5	250.53	18.4	3.00	2181.24	1	128.3	0.00	min V_{Rdct}
			90.30	0.08	85.3	242.16	18.4	3.00	2175.05	1	127.9	0.00	min V_{Rdct}

v_{Ed}: design shear force (je reinforcement direction), ρ_l reinf. ratio of longit. tension reinf. refering to static height, z = inner lever arm
v_{Rdct}: design value of shear resistance without shear reinforcement, θ: angle of compr. strut
v_{Rdmax}: design value of maximal shear resistance, a_l: shift rule
AB: range of utilization see NA-DE

$\Rightarrow$ **shear reinforcement:** min $a_{s,bü}$ = 0.00 cm²/m²

design action effects

verification notations: R = crack limitation S = fatigue design σ = stress verification D = verification of impermeability

bwr	$n_{xx,Ed}$ / n_{bwr} kN/m	$n_{yy,Ed}$ kN/m	$n_{xy,Ed}$ kN/m	$m_{xx,Ed}$ / m_{bwr} kNm/m	$m_{yy,Ed}$ kNm/m	$m_{xy,Ed}$ kNm/m
R	27.40	87.90	92.80	61.60	-29.80	-34.70
1mn	120.20			26.90		
	-65.40			26.90		
1mx	120.20			96.30		
	-65.40			96.30		
2mn	180.70			-64.50		
	-4.90			-64.50		
2mx	180.70			4.90		
	-4.90			4.90		
S	23.20	86.50	79.90	48.80	-33.60	-23.60
1mn	103.10			25.20		
	-56.70			25.20		
1mx	103.10			72.40		
	-56.70			72.40		
2mn	166.40			-57.20		
	6.60			-57.20		
2mx	166.40			-10.00		
	6.60			-10.00		
S	29.30	86.20	98.10	67.90	-26.40	-40.10
1mn	127.40			27.80		
	-68.80			27.80		
1mx	127.40			108.00		
	-68.80			108.00		
2mn	184.30			-66.50		
	-11.90			-66.50		
2mx	184.30			13.70		
	-11.90			13.70		
σ	29.30	86.20	98.10	67.90	-26.40	-40.30
1mn	127.40			27.60		
	-68.80			27.60		
1mx	127.40			108.20		
	-68.80			108.20		
2mn	184.30			-66.70		
	-11.90			-66.70		
2mx	184.30			13.90		
	-11.90			13.90		
D	-25.40	-83.20	82.30	53.10	-35.60	-26.00
1mn	56.90			27.10		
	-107.70			27.10		
1mx	56.90			79.10		
	-107.70			79.10		
2mn	-0.90			-61.60		
	-165.50			-61.60		
2mx	-0.90			-9.60		
	-165.50			-9.60		

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} = 6.75 a_{sB2o} = 7.10
in cm^2/m a_{sB1u} = 7.06 a_{sB2u} = 7.10

minimum reinforcement:
coeff. - stress distribution k_c = 0.40
coeff. - self-equil. stresses k = 0.52
concr. tens. str. (restr.) $f_{ct,eff}$ = 2.21 N/mm^2
($a_{stB1o,min}$ = 6.56 cm^2/m $a_{stB2o,min}$ = 6.56 cm^2/m
$a_{stB1u,min}$ = 6.56 cm^2/m $a_{stB2u,min}$ = 6.56 cm^2/m)

crack control:
concr. tens. strength (load) $f_{ct,eff}$ = f_{ctm} = 2.21 N/mm^2
σ_{sB1o} = 41.0 N/mm^2 σ_{sB2o} = 238.1 N/mm^2
σ_{sB1u} = 247.9 N/mm^2 σ_{sB2u} = 135.7 N/mm^2
($a_{stB1o,ste}$ = 6.75 cm^2/m ($\Rightarrow d_{so}$ = 60.0 mm > 8)
$a_{stB1u,ste}$ = 7.06 cm^2/m ($\Rightarrow d_{su}$ = 12.9 mm > 8)
$a_{stB2o,ste}$ = 7.10 cm^2/m ($\Rightarrow d_{so}$ = 14.0 mm > 8)
$a_{stB2u,ste}$ = 7.10 cm^2/m ($\Rightarrow d_{su}$ = 43.2 mm > 8))
verification not required !

$\Rightarrow$ no additional anti-crack reinforcement !

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} = 6.75 cm^2/m a_{sB2o} = 7.10 cm^2/m a_{sB1u} = 7.06 cm^2/m a_{sB2u} = 7.10 cm^2/m

fatigue design for steel:
initial state:
$\Delta\sigma_{s0B1o,equ}$ = -1.82 - -4.67 = 2.85 N/mm^2
$\Delta\sigma_{s0B1u,equ}$ = 272.73 - 195.49 = 77.23 N/mm^2
$\Delta\sigma_{s0B2o,equ}$ = 134.39 - 106.28 = 28.11 N/mm^2
$\Delta\sigma_{s0B2u,equ}$ = 153.36 - 100.03 = 53.33 N/mm^2
end state:
$\Delta\sigma_{sB1o,equ}$ = -1.95 - -4.82 = 2.86 N/mm^2
U_{s1B1o} = 2.86 < U_{s2} = 73.91
$\Delta\sigma_{sB1u,equ}$ = 259.64 - 186.11 = 73.54 N/mm^2
U_{s1B1u} = 73.54 < U_{s2} = 73.91 $\Rightarrow$ $\Delta a_{sB1u,fat}$ = 0.36 cm^2/m
$\Delta\sigma_{sB2o,equ}$ = 134.39 - 106.28 = 28.11 N/mm^2
U_{s1B2o} = 28.11 < U_{s2} = 73.91
$\Delta\sigma_{sB2u,equ}$ = 153.36 - 100.03 = 53.33 N/mm^2
U_{s1B2u} = 53.33 < U_{s2} = 73.91

concrete fatigue design:
$\sigma_{cdB1,min,equ}$ = 1.94 N/mm^2
$\sigma_{cdB1,max,equ}$ = 2.91 N/mm^2
U_{c1B1} = 0.53 < 1.00
$\sigma_{cdB2,min,equ}$ = 0.00 N/mm^2
$\sigma_{cdB2,max,equ}$ = 0.37 N/mm^2
U_{c1B2} = 0.46 < 1.00
$\Rightarrow$ verification executed !

$\Rightarrow$ incl. fatigue reinforcement: min a_{sB1o} = 6.75 cm^2/m min a_{sB2o} = 7.10 cm^2/m
min a_{sB1u} = 7.41 cm^2/m min a_{sB2u} = 7.10 cm^2/m

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} = 6.75 cm^2/m a_{sB2o} = 7.10 cm^2/m a_{sB1u} = 7.41 cm^2/m a_{sB2u} = 7.10 cm^2/m

maximal reinforcement tensile stresses
initial state:
σ_{0sB1o} = 45.1 N/mm^2 σ_{0sB2o} = 244.4 N/mm^2
σ_{0sB1u} = 260.0 N/mm^2 σ_{0sB2u} = 153.7 N/mm^2
= end state

minimal concrete compression stress
initial state:
σ_{0cB1} = -2.9 N/mm^2
σ_{0cB2} = -1.8 N/mm^2
= end state

$\Rightarrow$ no additional stress reinforcement !

verification of impermeability

DAfStb-Richtlinie: Wasserundurchlässige Bauwerke aus Beton

design action effects see above

reinforcement: a_{sB1o} = 6.75 cm²/m a_{sB2o} = 7.10 cm²/m a_{sB1u} = 7.41 cm²/m a_{sB2u} = 7.10 cm²/m

minimal allowable height of compression zone zul x_D = 60.0 mm

verification of minimum height of compression zone:

for service class A and stress class 1

1mx: x_{min} = 62.0 mm > 60.0 mm ⇒ **verification executed**

2mn: x_{min} = 82.5 mm > 60.0 mm ⇒ **verification executed**

⇒ Δa_{sDB1u} = 51.47 cm²/m

⇒ incl. impermeability reinf.: min a_{sB1o} = 6.75 cm²/m min a_{sB2o} = 7.10 cm²/m
min a_{sB1u} = 58.88 cm²/m min a_{sB2u} = 7.10 cm²/m

total reinforc.: total a_{sB1o} = 6.75 cm²/m a_{sB2o} = 7.10 cm²/m
total a_{sB1u} = 58.88 cm²/m a_{sB2u} = 7.10 cm²/m

degree of utilization: U = 0.73

additional reinforcement: Δa_{sB1o} = 2.98 cm²/m Δa_{sB2o} = 3.33 cm²/m
Δa_{sB1u} = 55.11 cm²/m Δa_{sB2u} = 3.33 cm²/m

cross-section data

gross area of concrete: a_c = 90.0 dm²/m, second moment of area: i_{cs} = 607.5 dm⁴/m

moment of resistance: w_{cs} = 135.0 dm³/m, distance of centre of gravity from upper edge: z_s = 45.0 cm

total area of longitudinal reinforcement: Σ(min a_s) = 79.83 cm²/m ⇒ ρ_s = 0.89% < 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