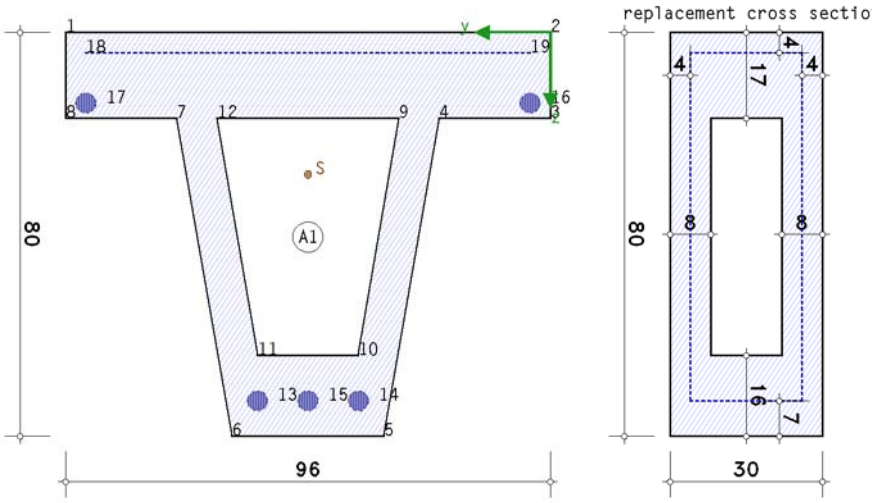
POS. 16: POLYGONALER CROSS SECTION

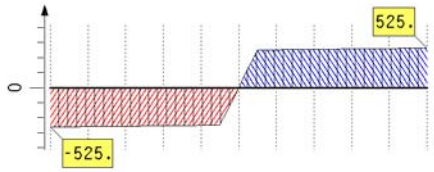
reinforced concrete design EC 2 (1.11), NA: Deutschland 4H-EC2QB Version: 10/2023-1b

1. input protocol



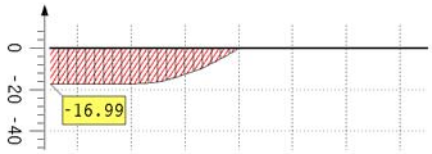
1.1. building material

reinforcing steel B500A, concrete C30/37
stress-strain line of reinforcing steel: EC 2-1-1, 3.2.7 (bilinear)



σ in N/mm²
ε in ‰
max ε = 25.00
max σ = 525.00

stress-strain line of concrete: EC 2-1-1, 3.1.7 (parabola-rectangle diagram)



σ in N/mm²
ε in ‰
min ε = -3.50
min σ = -16.99

1.2. material safety factors

design situation: basic combination
design resistance: concrete γ_c = 1.50, reinforcement γ_s = 1.15

1.3. cross section

polygon: data A_{s0}, A_{s1}, Rng apply to the entire group in each case. Rng 0 (design): reinforcement is ignored.

no	y cm	z cm	Typ	Grp/Ac -/cm²	A_{s0} cm²	A_{s1} cm²	Rng
1	96.0	0.0	B				
2	0.0	0.0	B				
3	0.0	17.0	B				
4	22.0	17.0	B				
5	33.0	80.0	B				
6	63.0	80.0	B				
7	74.0	17.0	B				
8	96.0	17.0	B				
9	30.0	17.0	A	1			
10	38.0	64.0	A	1			
11	58.0	64.0	A	1			
12	66.0	17.0	A	1			
13	58.0	73.0	E	1	4.91	10.00	1
14	38.0	73.0	E	1			
15	48.0	73.0	E	1			
16	4.0	14.0	E	2	4.91	10.00	3
17	92.0	14.0	E	2			
18	92.0	4.0	L	3	4.91	20.00	2

no	y	z	Typ	Grp/Ac	As0	As1	Rng
	cm	cm		-/cm²	cm²	cm²	
19	4.0	4.0	L	3			

Typ: B concrete outer edge, A large opening, P point opening, E single reinforcement bar, L line-distributed reinforcement
y,z: coordinates relative to origin; Grp: reinforcement group, no. of large recess; A_c: area of point opening
A_{s0}: basic/minimum reinforcement of one group; A_{s1}: maximum reinforcement of one group; Rng: design sequence of reinforcement groups

replacement cross section (rectangle) for shear design:
h = 80.0 cm, b = 30.0 cm, h_o = 17.0 cm, h_u = 16.0 cm, b_l = 8.0 cm, b_r = 8.0 cm
axis distances: d_o = 4.0 cm, d_u = 7.0 cm, d_l = 4.0 cm, d_r = 4.0 cm
max. reinforcement ratio ρ_s = 8.00%

1.4. durability and concrete cover

minimum strength class, concrete cover
due to reinforcement corrosion XC3 ⇒ C20/25, c_{min} = 20 mm (≥ Ø$_s$!!), Δc = 15 mm, $c_{nom} = c_{min}+\Delta c$ = 35 mm
due to concrete attack XA1 ⇒ C25/30
minimum concrete quality C25/30 with f_{ck} = 25.0 N/mm² < 30.0 N/mm² ok

1.5. design parameters

1.5.1. bending/shear design

1.5.1.1. bending design
minimum reinforcement for beams
minimum center of compression normal force

1.5.1.2. shear design
reinforcing steel like flexural reinforcemant
shear force
angle of the shear force reinforcement α = 90°
minimum compression strut angle
with minimum reinforcement (beam)
inner lever arm $z = 0.9 \cdot d \le d-2 \cdot c_{v,l} \le d-c_{v,l}-3$ cm
with concrete cover to longitudinal reinforcement in the compress. zone $c_{v,l}$ = 3.0 cm
limit the design value of the shear force resistance without shear force reinforcement $V_{Rd,c}$
torsion
effective thickness of a wall t_{eff} acc. to design code

1.5.1.3. design calculation values
lc 1: Import lc 1
N_{Ed} = 1.85 kN, $M_{y,Ed}$ = 281.60 kNm, $V_{z,Ed}$ = -22.69 kN, $M_{z,Ed}$ = -20.31 kNm, $V_{y,Ed}$ = -4.06 kN
$T_{t,Ed}$ = 17.24 kNm
lc 2: Import lc 2
N_{Ed} = 29.13 kN, $M_{y,Ed}$ = -101.24 kNm, $V_{z,Ed}$ = 157.67 kN, $M_{z,Ed}$ = 241.20 kNm, $V_{y,Ed}$ = 89.10 kN
$T_{t,Ed}$ = 8.20 kNm
lc 3: Import lc 3
N_{Ed} = 23.83 kN, $M_{y,Ed}$ = -85.92 kNm, $V_{z,Ed}$ = 135.17 kN

2. note

shear design: in the case of biaxial loading, each direction is examined separately

3. bending/shear design

material properties
bending design:
concrete acc. to EC 2, 3.1.7(1): C30/37, ε_{c2} = -2.00‰, ε_{cu2} = -3.50‰, f_{cd} = 17.00 N/mm²
σ-ε line acc. to EC 2, 3.2.7(2a): B500A, ε_{ud} = 25.0‰, f_{yd} = 434.78 N/mm², f_{td} = 456.52 N/mm², E_s = 200000.0 N/mm²
shear design:
σ-ε line acc. to EC 2, 3.2.7(2a): B500A, ε_{ud} = 25.00‰, f_{yd} = 434.78 N/mm², f_{td} = 456.52 N/mm², E_s = 200000.0 N/mm²

3.1. results table

design calculation values
lc	N_{Ed}	$M_{y,Ed}$	$V_{z,Ed}$	$M_{z,Ed}$	$V_{y,Ed}$	$T_{t,Ed}$	
	kN	kNm	kN	kNm	kN	kNm	
1	1.85	281.60	-22.69	-20.31	-4.06	17.24	
2	29.13	-101.24	157.67	241.20	89.10	8.20	
3	23.83	-85.92	135.17	0.00	0.00	0.00	
		107.59		0.00			min reinf.
		0.00		93.43			min reinf.
		-198.50		0.00			min reinf.

N,M_y,V_z,M_z,V_y,T_t: design calculation values

reinforcement and interim results

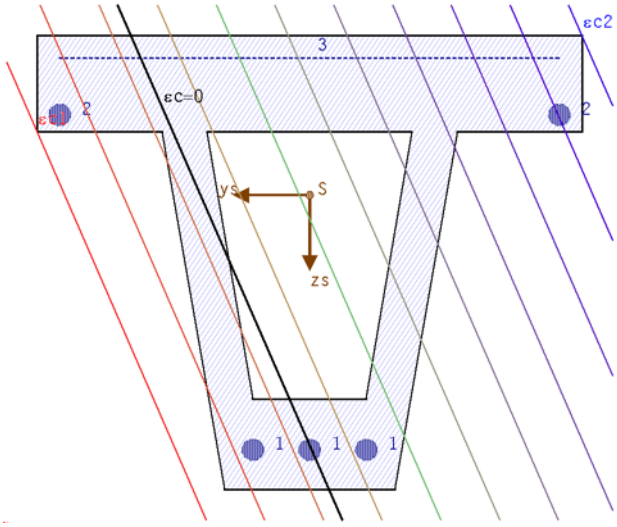
lc	A_{s1} cm²	A_{s3} cm²	a_{sbV} cm²/m	a_{sbT} cm²/m	A_{sT} cm²	$U_{y,vt}$	$U_{z,vt}$	
1	8.65	---	3.06	0.83	7.06	0.270	0.311	
2	10.00	13.77	4.83	0.58	2.38	0.369	0.379	
3	10.00	2.76	3.06	---	---	---	---	
	2.97	---						min reinf.
	10.00	1.74						min reinf.
	10.00	5.41						min reinf.

A_S: flexural reinforcement; a_{sbV}: shear reinforcement; a_{sbT},A_{sT}: torsional reinforcement; $U_{y,vt}$,$U_{z,vt}$: interaction shear force with torsion

3.2. lc 2 (decisive)

3.2.1. bending design (EC 2, 6.1)

design calculation values: N_{Ed} = 29.13 kN, $M_{y,Ed}$ = -101.24 kNm, $M_{z,Ed}$ = 241.20 kNm
limit strains: ε_{c1} = -3.500‰, ε_{s1} = -2.482‰, ε_{s2} = 15.247‰, ε_{c2} = 16.349‰, α_k = 203.50°
design aid values: d = 89.6 cm, z = 43.9 cm, x = 16.72 cm
reinforcement (bending/normal force): A_{s1} = 10.00 cm², A_{s2} = 0.00 cm², A_{s3} = 13.77 cm²
limit strains



limit strains: ε_{c1} = -3.500‰, ε_{s1} = -2.482‰, ε_{s2} = 15.247‰, ε_{c2} = 16.349‰, α_k = 203.50°

3.2.2. shear design (EC 2, 6.2+6.3) - separately for $V_{y,Ed}$+T_{Ed} and $V_{z,Ed}$+T_{Ed}

shear force in y-direction
design shear force $V_{y,Ed}$ = 89.10 kN
design aid values: ρ_{ly} = 2.00%, z_y' = 20.0 cm, $V_{y,Rd,c}$ = 60.02 kN, Θ_y = 25.22°, $V_{y,Rd,max}$ = 324.38 kN,
AB$_y$ = 1 for $V_{y,Ed}/V_{y,Rd,max}$ = 0.275, $\Delta F_{ys,Ed}$ = 94.59 kN
reinforcement $a_{sbv,y}$ = 4.83 cm²/m
torsion in y-direction
design moment T_{Ed} = 8.20 kN
design aid values: $V_{y,Ed,T+V}$ = 27.29 kN, Θ_y = 25.22°, $T_{y,Rd,max}$ = 87.19 kNm
reinforcement: $a_{sbt,y}$ = 0.56 cm²/m, $A_{st,y}$ = 2.38 cm²
shear force with torsion in y-direction
torsional crack moment $T_{y,Rd,c}$ = 6.53 kNm, torsional shear force $V_{y,Ed,T}$ = 200.92 kN
for $T_{Ed} > T_{y,Rd,c}$ and $V_{y,Ed,T} > V_{y,Rd,c}$ ⇒ verification: $(T_{Ed}/T_{y,Rd,max})+(V_{y,Ed}/V_{y,Rd,max})$ = 0.369 < 1 ok
shear force in z-direction
design shear force $V_{z,Ed}$ = 157.67 kN
design aid values: ρ_{lz} = 1.95%, z_z' = 68.4 cm, $V_{z,Rd,c}$ = 68.16 kN, Θ_z = 25.94°, $V_{z,Rd,max}$ = 548.89 kN,
AB$_z$ = 1 for $V_{z,Ed}/V_{z,Rd,max}$ = 0.287, $\Delta F_{zs,Ed}$ = 162.06 kN
reinforcement $a_{sbv,z}$ = 2.58 cm²/m
torsion in z-direction
design moment T_{Ed} = 8.20 kN
design aid values: $V_{z,Ed,T+V}$ = 97.47 kN, Θ_z = 25.94°, $T_{z,Rd,max}$ = 88.98 kNm
reinforcement $a_{sbt,z}$ = 0.58 cm²/m, $A_{st,z}$ = 2.30 cm²
shear force with torsion in z-direction
torsional crack moment $T_{z,Rd,c}$ = 5.61 kNm, torsional shear force $V_{z,Ed,T}$ = 388.30 kN
for $T_{Ed} > T_{z,Rd,c}$ and $V_{z,Ed,T} > V_{z,Rd,c}$ ⇒ verification: $(T_{Ed}/T_{z,Rd,max})+(V_{z,Ed}/V_{z,Rd,max})$ = 0.379 < 1 ok
reinforcement total
a_{sbv} = 4.83 cm²/m, a_{sbt} = 0.58 cm²/m, A_{st} = 2.38 cm²
messages for calculation run
shear design: longitudinal reinforcement considered

3.3. result

resulting reinforcement: A_{s1} = 10.00 cm², A_{s2} = 0.00 cm², A_{s3} = 13.77 cm²
a_{sbV} = 4.83 cm²/m, a_{sbT} = 0.83 cm²/m, A_{sT} = 7.06 cm²
utilization: $U_{y,vt}$ = 0.369 < 1 ok, $U_{z,vt}$ = 0.379 < 1 ok

4. final result

maximum reinforcement: A_{s1} = 10.00 cm², A_{s2} = 0.00 cm², A_{s3} = 13.77 cm²
a_{sbV} = 4.83 cm²/m, a_{sbT} = 0.83 cm²/m, A_{sT} = 7.06 cm²
maximum utilization: $U_{y,vt}$ = 0.369 < 1 ok, $U_{z,vt}$ = 0.379 < 1 ok

design resistance ensured

5. regulations

EN 1990, Eurocode 0: Grundlagen der Tragwerksplanung;
Deutsche Fassung EN 1990:2002 + A1:2005 + A1:2005/AC:2010, Ausgabe Dezember 2010
EN 1990/NA, Nationaler Anhang zur EN 1990, Ausgabe Dezember 2010

EN 1992-1-1, Eurocode 2: Bemessung und Konstruktion von Stahlbeton- und Spannbetonbauteilen -
Teil 1-1: Allgemeine Bemessungsregeln und Regeln for den Hochbau;
Deutsche Fassung EN 1992-1-1:2004 + AC:2010, Ausgabe Januar 2011
EN 1992-1-1/NA, Nationaler Anhang zur EN 1992-1-1, Ausgabe April 2013