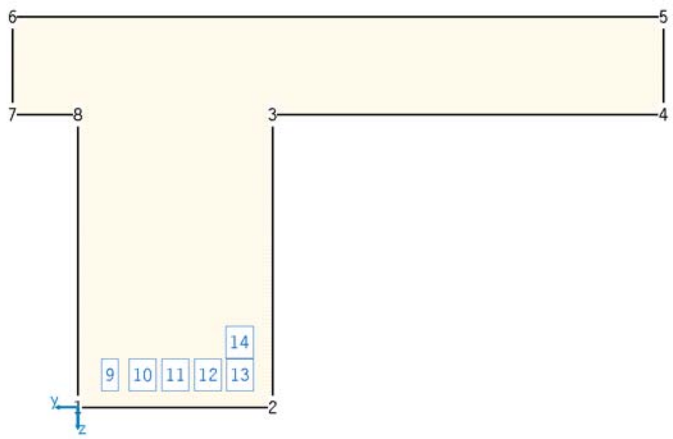
POS. 38: POLYGONAL CROSS SECTION (REINFORCED CONCRETE)

bending and shear design incl. verif. of serviceability (EC 2 (1.11), NA: Deutschland)

biaxial bending with/abs. axial force (4H-BETON version: 11/2007-4l)

polygonal cross section



min./max. reinforcement

min A_s (9.2.1.1, 9.5.2), max ρ_0 = 8.00 %

reinforcement groups

Nr	rank	min A_s	max A_s	A_{si} / A_{s1}
	-	cm²	cm²	-
1	1	0.00	100.00	1.00

min A_s: initial reinforcement per group
max A_s: highest reinforcement amount per group
A_{si}/A_{s1}: reinforcement group factor ref. to group 1

material

C25/30
BSt 500 (A)
γ_s = 1.15, γ_c = 1.50
exposure class X0

point coordinates and group assignment

Pkt	y	z	A_p/Nr	
	cm	cm	cm2 / -	
1	0.0	0.0	----	B
2	-30.0	0.0	----	B
3	-30.0	-45.0	----	B
4	-90.0	-45.0	----	B
5	-90.0	-60.0	----	B
6	10.0	-60.0	----	B
7	10.0	-45.0	----	B
8	0.0	-45.0	----	B
9	-5.0	-5.0	1	E
10	-10.0	-5.0	1	E
11	-15.0	-5.0	1	E
12	-20.0	-5.0	1	E
13	-25.0	-5.0	1	E
14	-25.0	-10.0	1	E

A_p: cross section area of a punctual opening, Nr: number of the assigned reinforcement group (reinforcement)
B: concrete cr. section, A_c: opening c, P: punctual opening, E: point reinforcement, L: line reinforcement

design calculation and verifications

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 = 14.2 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 = 33.0 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)

load application in concrete centroid at y_s = -28.2 cm, z_s = -38.3 cm !

	γ	N_{Ed}	M_{yEd}	M_{zEd}	ε_{c2u}	ε_{s2u}	ε_{s1u}	ε_{c1u}	α_{ku}	d	z	x
	-	kN	kNm	kNm	‰	‰	‰	‰	°	cm	cm	cm
1	---	0.00	280.00	130.00	-3.50	0.21	2.56	8.80	163.26	49.4	43.1	28.5
			0.00	84.73	-3.50	-1.90	2.77	21.80	180.00	35.0	37.0	19.5

ε_{c2u}: concr. strain in state of failure (fibre 2), ε_{s1u}: reinforcement strain in state of failure (fibre 1),
α_{ku}: dir. angle of cross section principal strain, d: static height, z: lever arm of internal forces, x: height of concr. compr. zone

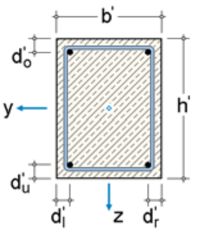
	A_{sb1}	note
	cm²	
1	**24.64**	
	23.22	8)

8) minimum reinforcement acc. to 9.2.1.1

⇒ **longitudinal reinforcement: min A_s = 24.6 cm²**

shear design calculation (EC 2, 6.2 + 6.3) - separated into coordinate directions
minimum reinforcement acc. to 9.2.2(5), material quality as flexural reinf.
$z = 0.9$ d (10.3.4(2), d in each direction), $c_{v,D} = 3.0$ cm, D = compression reinf.
angle of compr. strut $\theta_{gew} = 0°$, tension reinforcement $A_{sl,gew} = 25.0$ cm^2
P.Mark: Querkraftbemessung bei schiefer Biegung ohne Normalkraft (z from bending design).
the minimum value of V_{Rdct} is limited acc. to design code ($V_{Rdct} \geq$ min V_{Rdct}).

equivalent cross section:
($A'_c = 18.0$ dm^2)



h' = 60.0 cm
b' = 30.0 cm
d'o = 5.0 cm
d'u = 5.0 cm
d'l = 5.0 cm
d'r = 5.0 cm

design calculation of shear force (EC 2, 6.2)

	V_{yEd} kN	V_{zEd} kN	z_y cm	V_{yRdct} kN	θ_y °	V_{yRdmax} kN	z_z cm	V_{zRdct} kN	θ_z °	V_{zRdmax} kN	$a_{s,büV}$ cm^2/m	note
1	40.00	15.00	0.0	0.00	0.0	0.00	43.4	84.38	18.4	414.64	2.46*	min. reinf.

z: decisive 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, *) P.Mark: inter. result not related to direction

⇒ **shear reinforcement: min $a_{s,bü}$ = 2.46 cm^2/m**

fatigue design (EC 2, 6.8.6 + 6.8.7(2))
for steel: $U_{s1} = \Delta\sigma_s \leq U_{s2} = 70.0$ N/mm^2
stress range $\Delta\sigma_s = \sigma_{s,O} - \sigma_{s,U}$
for conc.: $U_{c1} = |\sigma_{cd,max}|/f_{cd,fat} \leq 0.5 + 0.45\,|\sigma_{cd,min}|/f_{cd,fat} \leq 0.9$
design value of compression strength $f_{cd,fat} = 15.00$ N/mm^2 at $t_0 = 28$ d
material safety $\gamma_{c,fat} = \gamma_c = 1.50$
load: $N_{s1} = 0.00$ kN $M_{ys1} = 80.00$ kNm $M_{zs1} = 130.00$ kNm
$N_{s2} = 0.00$ kN $M_{ys2} = 50.00$ kNm $M_{zs2} = 100.00$ kNm
reinforcement (initial state): $A_s = 24.64$ cm^2

fatigue design for steel:

Nr	$\sigma_{s,O}$ N/mm^2	$\sigma_{s,U}$ N/mm^2	$\Delta\sigma_s$ N/mm^2	U_{s1} N/mm^2	$\Delta A_{s,fat}$ cm^2
1	349.47	279.57	69.89	69.89	12.45

concrete fatigue design:
$\sigma_{cd,min} = 26.87$ N/mm^2
$\sigma_{cd,max} = 29.66$ N/mm^2
$U_{c1} = 1.98 > 1.31 > 0.9$ ⇒ verification **not** complied !

⇒ **incl. fatigue reinforcement: min A_s = 37.1 cm^2**

limitation of steel tension and concrete compression stresses (EC 2, 7.2)
permitted tensile stress of reinf. $\sigma_s = 1.60 \cdot f_{yk} = 800.0$ N/mm^2
permitted concrete compression stress $\sigma_c = 0.60 \cdot f_{ck} = -15.0$ N/mm^2
stress forces and moments: $N_\sigma = 0.00$ kN $M_{y\sigma} = 280.00$ kNm $M_{z\sigma} = 130.00$ kNm
reinforcement (initial state): $A_s = 37.09$ cm^2

⇒ **error - max A_s reached !**

cross-section data
gross area of concrete: $A_c = 28.5$ dm^2 second moment of areae: $I_{cys} = 64.8$ dm^4, $I_{czs} = 204.3$ dm^4
centroid coordinates: $y_s = -28.2$ cm, $z_s = -38.3$ cm
total area of longitudinal reinforcement: Σ(min A_s) = 37.1 cm^2 ⇒ $\rho_s = 1.30\% < 8.00\%$

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
C25/30	25.0	0.850	-2.00	-3.50	2.00	31475.8	2.565

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

symbols: positive result values marked with -1.0 or **** in tables
refer to incorrect resp. not computable conditions !