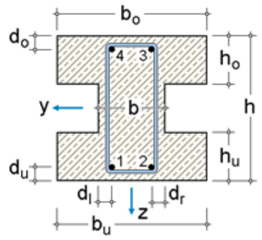
POS. 35: I-SECTION (REINFORCED CONCRETE 2-ACHS.)

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)



I-section

h = 100.0 cm b = 40.0 cm
h_o = 20.0 cm b_o = 160.0 cm
h_u = 30.0 cm b_u = 60.0 cm

edge distances of longit. reinf.

d_o = 6.0 cm d_u = 6.0 cm
d_l = 6.0 cm d_r = 6.0 cm

material

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

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
	-	cm^2	cm^2
1	1	0.00	100.00
2	1	0.00	100.00
3	1	0.00	100.00
4	1	0.00	100.00

min A_s: initial reinforcement per group
max A_s: highest reinforcement amount per group

verifications in ultimate limit states are executed with stress-strain relation for concrete acc. to 3.1.7 (figure 3.3)
with $f_{cd} = \alpha_c f_{ck} / \gamma_c$ = 14.2 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 $f_c = f_{cm}$ = 33.0 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)

	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	---	-55.00	387.00	256.00	-2.77	0.30	25.00	26.99	94.50	101.1	86.3	10.1
			305.43	0.00	-1.10	0.57	25.00	26.67	90.00	94.0	76.3	3.9

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}	A_{sb2}	A_{sb3}	A_{sb4}	note
	cm^2	cm^2	cm^2	cm^2	
1	**4.37**	**4.37**	**4.37**	**4.37**	
	3.26	3.26	3.26	3.26	8)

8) minimum reinforcement acc. to 9.2.1.1

⇒ **longitudinal reinforcement: min A_s = 4.4/4.4/4.4/4.4 cm^2**

shear design calculation (EC 2, 6.2 + 6.3) - separated into V_{yEd} +T_{Ed} and V_{zEd} +T_{Ed}
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 θ_{gew} = 0°, torsion: $t_{eff} = A_c/U_c > 2 \cdot \min(d_o, d_u)$
the minimum value of V_{Rdct} is limited acc. to design code ($V_{Rdct} \geq \min V_{Rdct}$).
only web design; connection of compression/tension boom has to be designed separately.

design calculation of shear force (EC 2, 6.2)

	V_{yEd}	V_{zEd}	z_y	V_{yRdct}	θ_y	V_{yRdmax}	z_z	V_{zRdct}	θ_z	V_{zRdmax}	$a_{s,bü V}$	note
	kN	kN	cm	kN	°	kN	cm	kN	°	kN	cm^2/m	
1	0.00	186.00	0.0	0.00	0.0	0.00	84.6	122.43	31.6	1603.24	3.28	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

design calculation of torsion (EC 2, 6.3)

	T_{Ed}	V_{yEdT+V}	θ_y	V_{zEdT+V}	θ_z	T_{Rdmax}	$a_{s,büT}$	$A_{s,T}$	note
	kNm	kN	°	kN	°	kNm	cm^2/m	cm^2	
1	135.00	0.00	0.0	328.93	31.6	208.85	4.32	25.57	

stirrup reinforcement $a_{s,büT}$ per leg, longit. reinf. for torsion $A_{s,T}$ uniformly distributed along the perimeter

design calculation of shear force and torsion (EC 2, 6.3(4))

1: $(T_{Ed}/T_{Rdmax}) + (V_{zEd}/V_{zRdmax})$ = **0.43 < 1.0** ⇒ verification executed !

⇒ **shear reinforcement:** min $a_{s,büV}$ = 3.28 cm^2/m
torsion: min $a_{s,büT}$ = 4.32 cm^2/m **(1-shear)**
Σ (2-shear) min $a_{s,bü}$ = 11.93 cm^2/m
torsion: min $A_{s,T}$ = 25.6 cm^2 (uniformly distributed along the perimeter)

crack control (EC 2, 7.3: 7.3.2 minimum reinforcement, 7.3.3 without direct calculation)
cracking in bending restraint (self induced)
factor for the concrete hardening process $k_{z,t}$ = 1.00
axial force in the centre of gravity at formation of first crack N_{cr} = 0.00 kN
crack width w_k = 0.30 mm
crack forces and moments: N_r = 400.00 kN M_{yr} = 100.00 kNm M_{zr} = 300.00 kNm
reinforcement (initial state): A_s = 4.37/4.37/4.37/4.37 cm^2

Nr	d_s	k_c	k	$A_{s,min}$	d_{sgr}	σ_s	ΔA_{sr}
	mm	-	-	cm^2	mm	N/mm^2	cm^2
1	20	0.40	0.74	3.55	60.0	56.1	9.50
2	20	0.40	0.74	3.55	41.6	149.0	9.50
3	20	0.40	0.74	3.55	20.0	223.0	9.50
4	20	0.40	0.74	3.55	54.5	130.2	9.50

concr. tens. str. (restr.) $f_{ct,eff}$ = 2.56 N/mm^2 concr. tens. strength (load) $f_{ct,eff} = f_{ctm}$ = 2.56 N/mm^2
k_c: coeff. - stress distribution, k: coeff. - concr. tens. stress, As,min: min. reinf. from restraint
d_s: selected bar diameter, d_{sgr}: existing bar diameter
σ_s: steel tensile stress, ΔA_{sr}: reinf. increase from load and restraint

⇒ **incl. anti-crack reinforcement:** min A_s = 13.9/13.9/13.9/13.9 cm^2

fatigue design (EC 2, 6.8.5 + 6.8.7(1))
for steel: $U_{s1} = \gamma_{F,fat}\ \gamma_{Ed,fat}\ \Delta\sigma_{s,equ} \leq U_{s2} = \Delta\sigma_{Rsk}(N^*)/\gamma_{s,fat}$ = 152.17 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 $\Delta\sigma_{Rsk}(N^*)$ = 175.0 N/mm^2
shear force : $\Delta\sigma_{Rskv}(N^*)$ = 107.0 N/mm^2 ⇒ $U_{s2v} = \Delta\sigma_{Rskv}(N^*)/\gamma_{s,fat}$ = 93.04 N/mm^2
for conc.: $U_{c1} = |\sigma_{cd,max,equ}|/f_{cd,fat}$ + 0.43 sqrt(1 - $\sigma_{cd,min,equ}/\sigma_{cd,max,equ}$) ≤ 1.0
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} = 187.00 kNm M_{zs1} = 256.00 kNm V_{ys1} = 0.00 kN V_{zs1} = 186.00 kN
N_{s2} = -10.00 kN M_{ys2} = 210.00 kNm M_{zs2} = 145.00 kNm V_{ys2} = 225.00 kN V_{zs2} = 200.00 kN
reinforcement (initial state): A_s = 13.87/13.87/13.87/13.87 cm^2 $a_{s,büV}$ = 3.28 cm^2/m

fatigue design for steel:

Nr	$\sigma_{s,O}$	$\sigma_{s,U}$	$\Delta\sigma_{s,equ}$	U_{s1}	$\Delta A_{s,fat}$
	N/mm^2	N/mm^2	N/mm^2	N/mm^2	cm^2
1	81.10	62.85	18.25	18.25	0.00
2	101.16	91.24	9.92	9.92	0.00
3	69.41	6.47	62.94	62.94	0.00
4	31.09	-3.68	34.77	34.77	0.00

reinforcement (shear force):
$\Delta\sigma_{sv,equy}$ = 93.04 - 0.00 = 93.04 N/mm^2 = U_{s2v}
$\Delta\sigma_{sv,equz}$ = 27.37 - 25.46 = 1.92 N/mm^2
U_{s1vz} = 1.92 < U_{s2v} = 93.04
⇒ $\Delta a_{sbü,fat}$ = 46.58 cm^2/m

concrete fatigue design:
$\sigma_{cd,min,equ}$ = 2.18 N/mm^2
$\sigma_{cd,max,equ}$ = 7.98 N/mm^2
U_{c1} = 0.90 < 1.00 ⇒ verification executed !
verif. of compression strut for decisive $V_{s1,2}$:
$\sigma_{cdv,min,equ}$ = 0.00 N/mm^2
$\sigma_{cdv,max,equ}$ = 2.41 N/mm^2
U_{c1v} = 0.24 < 0.50 ⇒ verification executed !

⇒ **incl. fatigue reinforcement:** min A_s = 13.9/13.9/13.9/13.9 cm^2
min $a_{s,büV}$ = 49.86 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 $\sigma_c = 0.60 \cdot f_{ck}$ = -15.0 N/mm^2
stress forces and moments: N_σ = 85.00 kN $M_{y\sigma}$ = 387.00 kNm $M_{z\sigma}$ = 256.00 kNm
reinforcement (initial state): A_s = 13.87/13.87/13.87/13.87 cm^2

maximal reinforcement tensile stresses

Nr	σ_{0s} N/mm²	σ_s N/mm²	$\Delta A_{s\sigma}$ cm²
1	161.6	161.6	0.00
2	183.8	183.8	0.00
3	21.3	21.3	0.00
4	-0.9	0.0	0.00

σ_{0s}: initial state, σ_s: end state
$\Delta A_{s\sigma}$: reinforcement increase from steel and concrete design

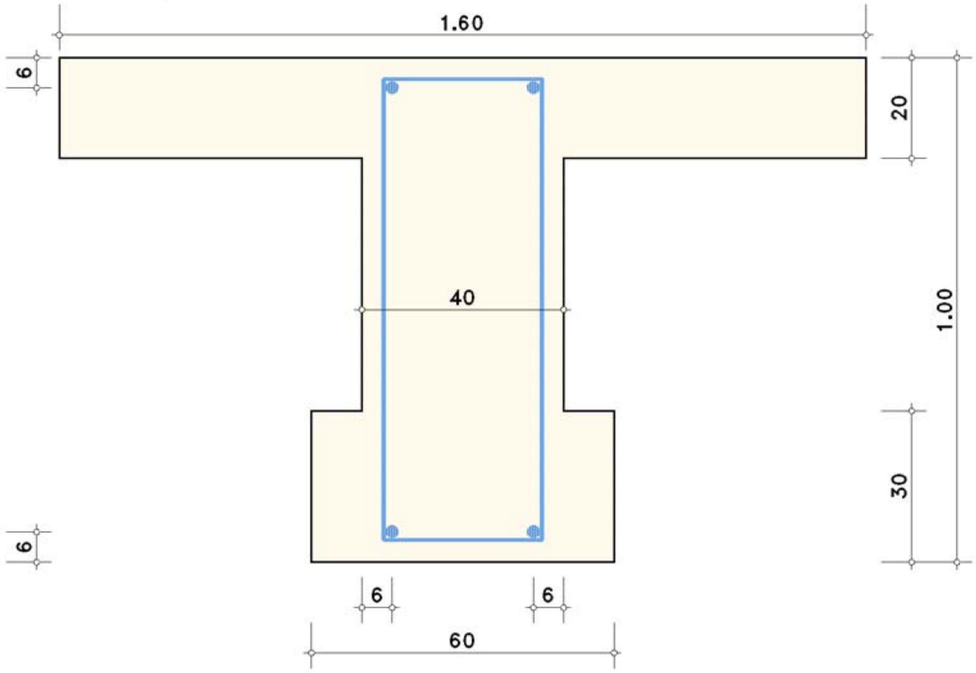
minimal concrete compression stress
initial state:
σ_{0c} = -9.4 N/mm²
end state:
σ_c = -9.4 N/mm² > -15.0

⇒ no additional stress reinforcement !

total reinforc.: total A_s = 13.9/13.9/13.9/13.9 cm²
total $a_{s,büV}$ = 49.86 cm²/m
total $a_{s,büT}$ = 4.32 cm²/m, $A_{s,T}$ = 25.6 cm²
degree of utilization: U = 0.35

selected:
longitudinal, E1: 1 Ø 25 = 4.9 cm² < 13.9 cm²
E2: 1 Ø 25 = 4.9 cm² < 13.9 cm²
E3: 1 Ø 25 = 4.9 cm² < 13.9 cm²
E4: 1 Ø 25 = 4.9 cm² < 13.9 cm²
stirrups, 2-shear: Ø 8 / 30 cm = 3.35 cm²/m < 58.51 cm²/m

reinforcement drawing:
scale 1 : 15
reinforcement only hinted!



cross-section data
gross area of concrete: A_c = 70.0 dm² second moment of areae: I_{cys} = 723.0 dm⁴, I_{czs} = 763.3 dm⁴
centroid coordinates (from centre of upper edge): y_s = 0.0 cm, z_s = 39.3 cm
total area of longitudinal reinforcement: $\Sigma(\min A_s)$ = 55.5 cm² ⇒ ρ_s = 0.79% < 8.00%

material properties for design calculation

concrete	f_{ck} MN/m²	α -	ε_{c2} ‰	ε_{c2u} ‰	n_c -	E_{cm} MN/m²	f_{ctm} 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} MN/m²	f_{tk} MN/m²	ε_{su} ‰	E_s 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