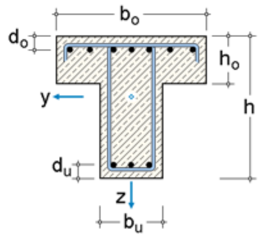
POS. 19: T-BEAM (REINFORCED CONCRETE 1-ACHS.)

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

uniaxial bending with/without axial force (4H-BETON version: 11/2007-4I)



T-beam-cross section
$h = 75.0$ cm, $b_u = 25.0$ cm
$h_o = 10.0$ cm, $b_o = 145.0$ cm
edge distances of longit. reinf.
$d_o = 3.8$ cm, $d_u = 6.6$ cm
material
C25/30
BSt 500 (A)
$\gamma_s = 1.15$, $\gamma_c = 1.50$
exposure class X0

detailing of reinforcement
preferably in tension face ($\varepsilon_{s1u} = 25.00‰$)
min./max. reinforcement
min A_s (9.2.1.1, 9.5.2), max $\rho_0 = 8.00\%$
initial reinforcement
$A_{s0o} = 0.00$ cm^2, $A_{s0u} = 0.00$ cm^2
$a_{s0bü} = 0.00$ cm^2/m

verifications in ultimate limit states are executed with stress-strain relation for concrete acc. to 3.1.7 (figure 3.3)
with $f_{cd} = \alpha_c f_{ck} / \gamma_c = 14.2$ 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 $\varepsilon_{uk} = 25‰$!

design calculation values and minimum reinforcement areas (EC 2, 6.1)

	γ	N_{Ed}	M_{Ed}	ε_{c2u}	ε_{s2u}	ε_{s1u}	ε_{c1u}	ξ	ζ	d	A_{so}	A_{su}	note
	-	kN	kNm	‰	‰	‰	‰	-	-	cm	cm^2	cm^2	
1	---	-125.00	500.00	-2.29	-0.78	25.00	27.63	0.08	0.97	68.4	----	**15.61**	
			84.94	-0.72	0.71	25.00	27.48	----	----	----	----	2.51	9)

$\varepsilon_{c2u} = -3.50‰$: concr. strain in state of failure (fibre 2), $\varepsilon_{s1u} = 25.00‰$: reinforcement strain in state of failure (fibre 1)
$x = \xi$ d: height of conc. compr. zone, $z = \zeta$ d: lever arm of internal forces, $d = h - d_1$: effective depth

9) minimum reinforcement acc. to 9.2.1.1

⇒ **longitudinal reinforcement: min A_{so} = 0.0 cm^2 min A_{su} = 15.6 cm^2**

shear design calculation (EC 2, 6.2 + 6.3)
minimum reinforcement acc. to 9.2.2(5), material quality as flexural reinf.
$z = 0.9$ d (6.2.3(1)), $c_{v,D} = 3.0$ cm, D = compression reinf.
angle of reinforcement $\alpha = 90.0°$, angle of compr. strut $\theta_{gew} = 0°$
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_{Ed}	ρ_l	z	V_{Rdct}	θ	cot θ	V_{Rdmax}	AB	a_l	$a_{s,bü}$	note
	kN	%	cm	kN	°		kN		cm	cm^2/m	
1	50.00	0.91	61.6	88.41	18.4	3.00	490.56	1	92.3	2.05	minimum reinforcement

ρ_l: ratio of longit. reinf. related to static height, 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, a_l: shift rule
AB: range of utilization see NA-DE

⇒ **shear reinforcement: min $a_{s,bü}$ = 2.05 cm^2/m**

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
crack width $w_k = 0.30$ mm
sel. diameter $d_{so} = 20$ mm $d_{su} = 20$ mm
crack forces and moments:
$N_r = 25.00$ kN $M_r = 275.00$ kNm
initial state: $A_{so} = 0.00$ cm^2 $A_{su} = 15.61$ cm^2

minimum reinforcement:
coeff. - stress distribution $k_c = 0.55 / 0.26$
coeff. - self-equil. stresses $k = 0.80$
concr. tens. str. (restr.) $f_{ct,eff} = 2.56$ N/mm^2
tension zones $A_{cto} = 6.2$ dm^2 $A_{ctu} = 12.5$ dm^2
($A_{sto,min} = 1.6$ cm^2 $A_{stu,min} = 6.6$ cm^2)
crack control:
concr. tens. strength (load) $f_{ct,eff} = f_{ctm} = 2.56$ N/mm^2
effective slab width $b_{eff} = 36.4$ cm
$\sigma_{so} = 0.0$ N/mm^2 $\sigma_{su} = 284.9$ N/mm^2

($A_{sto,ste}$ = 0.0 cm² (d_{so} = 20 mm)
$A_{stu,ste}$ = 15.6 cm² (⇒ d_{su} = 27.9 mm > 20))
additional reinforcement:
max A_{sto} = 1.6 cm² ⇒ ΔA_{sto} = 1.6 cm²

⇒ incl. anti-crack reinforcement: min A_{so} = 1.6 cm² min A_{su} = 15.6 cm²

fatigue design (EC 2, 6.8.5 + 6.8.7(1))
for steel: $U_{s1} = \gamma_{F,fat}\ \gamma_{Ed,fat}\ \Delta\sigma_{s,equ} \le U_{s2} = \Delta\sigma_{Rsk}(N^*)/\gamma_{s,fat}$ = 152.17 N/mm²
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/mm²
shear force : $\Delta\sigma_{Rskv}(N^*)$ = 107.0 N/mm² ⇒ $U_{s2v} = \Delta\sigma_{Rskv}(N^*)/\gamma_{s,fat}$ = 93.04 N/mm²
for conc.: $U_{c1} = |\sigma_{cd,max,equ}|/f_{cd,fat} + 0.43\ \mathrm{sqrt}(1 - \sigma_{cd,min,equ}/\sigma_{cd,max,equ}) \le 1.0$
design value of compression strength $f_{cd,fat}$ = 15.00 N/mm² at t_0 = 28 d
material safety $\gamma_{c,fat} = \gamma_c$ = 1.50
load: N_{s1} = 0.00 kN M_{s1} = 500.00 kNm V_{s1} = 50.00 kN
N_{s2} = 10.00 kN M_{s2} = 355.00 kNm V_{s2} = 45.00 kN
reinforcement (initial state): A_{so} = 1.56 cm² A_{su} = 15.61 cm² $a_{s,büV}$ = 2.05 cm²/m

fatigue design for steel:
initial state:
$\Delta\sigma_{s0o,equ}$ = -31.15 - -45.08 = 13.93 N/mm²
$\Delta\sigma_{s0u,equ}$ = 490.71 - 350.17 = 140.54 N/mm²
= end state
reinforcement (shear force):
$\Delta\sigma_{sv,equ}$ = 228.53 - 205.68 = 22.85 N/mm²
U_{s1v} = 22.85 < U_{s2v} = 93.04

concrete fatigue design:
$\sigma_{cd,min,equ}$ = 7.90 N/mm²
$\sigma_{cd,max,equ}$ = 10.97 N/mm²
U_{c1} = 0.96 < 1.00 ⇒ verification executed !
verification of compression strut:
$\sigma_{cdv,min,equ}$ = 0.97 N/mm²
$\sigma_{cdv,max,equ}$ = 1.08 N/mm²
U_{c1v} = 0.10 < 0.54 ⇒ verification executed !

⇒ 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/mm²
permitted concrete compression stress $\sigma_c = 0.60 \cdot f_{ck}$ = -15.0 N/mm²
stress forces and moments: N_σ = 0.00 kN, M_σ = 500.00 kNm
reinforcement (initial state): A_{so} = 1.56 cm² A_{su} = 15.61 cm²

maximal reinforcement tensile stresses
initial state:
σ_{0so} = -45.1 N/mm² σ_{0su} = 490.7 N/mm²
end state:
σ_{so} = -43.6 N/mm² < 400.0 N/mm²
σ_{su} = 399.0 N/mm² < 400.0 N/mm²
⇒ $\Delta A_{s\sigma u}$ = 3.7 cm²

minimal concrete compression stress
initial state:
σ_{0c} = -11.0 N/mm²
end state:
σ_c = -10.1 N/mm² > -15.0 N/mm²

⇒ incl. stress reinforcement: min A_{so} = 1.6 cm² min A_{su} = 19.3 cm²

total reinforc.: total A_{so} = 1.6 cm² A_{su} = 19.3 cm²
total $a_{s,büV}$ = 2.05 cm²/m
degree of utilization: U = 0.82

selected:

longitudinal, top : 2 Ø 10 = **1.6 cm²** ≥ 1.6 cm²
bottom:4 Ø 20 + 2 Ø 20 = 18.8 cm² < 19.3 cm²
stirrups, 2-shear: Ø 8 / 30 cm = **3.35 cm²/m** > 2.05 cm²/m

anchorage lengths top ($A_{sb,min}$ = 0.00 cm² $A_{s,exis}$ = 1.57 cm²):
l_b: basic size of anchorage length, $l_{b,min}$: minimum value of anchorage length, $l_{b,net}$: anchorage length
curt. of longit. tension reinf.: anch. l. at $l_{b,dir}$: direct end support, $l_{b,ind}$: indirect end support, $l_{b,Zwi}$: intermediate support
with hooks: l_b = 57.7 cm, $l_{b,min}$ = 12.1 cm, $l_{b,net}$ = 12.1 cm
$l_{b,dir}$ = 8.1 cm, $l_{b,ind}$ = 12.1 cm, $l_{b,Zwi}$ = 6.0 cm
without: l_b = 57.7 cm, $l_{b,min}$ = 17.3 cm, $l_{b,net}$ = 17.3 cm
$l_{b,dir}$ = 11.5 cm, $l_{b,ind}$ = 17.3 cm, $l_{b,Zwi}$ = 6.0 cm

anchorage lengths bottom ($A_{sb,min}$ = 15.61 cm² $A_{s,exis}$ = 18.85 cm²):

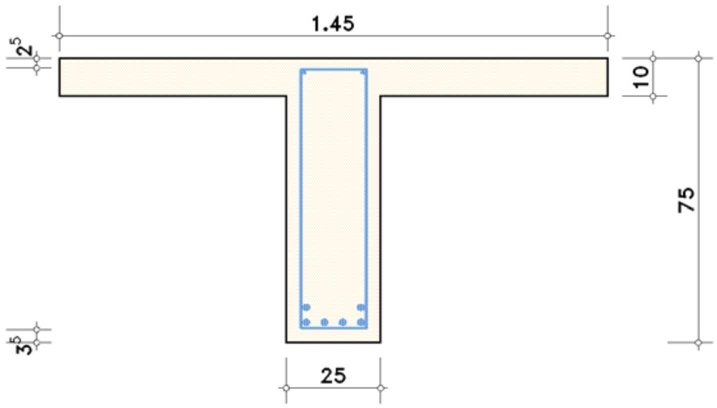
l_b: basic size of anchorage length, $l_{b,min}$: minimum value of anchorage length, $l_{b,net}$: anchorage length
curt. of longit. tension reinf.: anch. l. at $l_{b,dir}$: direct end support, $l_{b,ind}$: indirect end support, $l_{b,Zwi}$: intermediate support

with hooks:	l_b = 80.7 cm,	$l_{b,min}$ = 20.0 cm,	$l_{b,net}$ = 46.8 cm
	$l_{b,dir}$ = 31.2 cm,	$l_{b,ind}$ = 46.8 cm,	$l_{b,Zwi}$ = 12.0 cm
without:	l_b = 80.7 cm,	$l_{b,min}$ = 24.2 cm,	$l_{b,net}$ = 66.9 cm
	$l_{b,dir}$ = 44.6 cm,	$l_{b,ind}$ = 66.9 cm,	$l_{b,Zwi}$ = 12.0 cm

reinforcement drawing:

scale 1 : 20

cvo = 2.5 cm
cvu = 3.5 cm



cross-section data

gross area of concrete: A_c = 30.8 dm², second moment of area: I_{cs} = 166.2 dm⁴
moment of resistance: W_{cs} = 33.1 dm³, distance of centre of gravity from upper edge: z_s = 24.8 cm
total area of longitudinal reinforcement: $\Sigma(\min A_s)$ = 20.9 cm² $\Rightarrow$ ρ_s = 0.68% < 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