Project data

Project name	Anchoring with shear lug
Project number	01-2025
Author	IDEA StatiCa
Description	Concrete and reinforcement
Date	1/1/2025
Design code	EN

Summary results

Check item	
Detail1	✓

Materials

Concrete

Name	f_{ck} [MPa]	$f_{ctk,0.05}$ [MPa]	f_{ctm} [MPa]	E_{cm} [MPa]	ν [-]	φ_{perm}	φ_{pres}
C25/30	25.0	1.8	2.6	31475.8	0.20	2.5	2.5
	ε_{c2} = 20.0 1e-4, ε_{cu2} = 500.0 1e-4, Diagram type: Parabolic φ_{perm}: 2.50 φ_{pres}: 2.50						

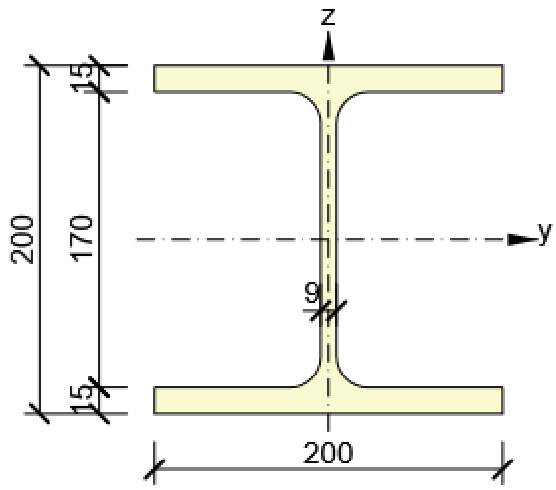
Reinforcement

Name	f_{yk} [MPa]	k [-]	E_s [MPa]	Unit mass [kg/m^3]	ε_{uk} [1e-4]	Surface
B 500B	500.0	1.08	200000.0	7850	500.0	Ribbed
	ε_{st} = 500.0 1e-4, ε_{sc} = 500.0 1e-4,					

Steel

Name	E [MPa]
S 355	210000.0

Cross-sections

Name	Material	Master	Picture
	S 355	Detail1: BP1	

Detail1

Geometry

Overview table

Name	Type	Properties	Position
CB 1	Solid Block	Shape: General; H: 0.80 m; Material: C25/30	
BP1	Base plate	W: 0.30 m; T: 0.03 m; D: 0.30 m; Material: S 355; : Load; Shear force transfer: Shear lug; - Cross-section: 3; - Edge of base plate: 1; - X - position: 0.28 m; - Y - position: 0.33 m; - Length of shear lug: 0.15 m; - Rotation of shear lug: 0.0 °	M: CB 1, Edge 1, Surface 6; X: 0.00 m; Y: 0.00 m
SS1	Surface support	X; Y; Z; Direction - Local	M: CB 1, Surface: 100000005; Geometry type: Whole surface
AN1	Anchorage - Load	L1: 0.03 m; L2: 0.40 m; Φ: 30 mm; Material: 8.8; Anchor type:	M: CB 1, Edge: 1, Surface: 100000006; X: 0.38 m
AN2	Anchorage - Load	L1: 0.03 m; L2: 0.40 m; Φ: 30 mm; Material: 8.8; Anchor type:	M: CB 1, Edge: 1, Surface: 6; X: 0.78 m
AN3	Anchorage - Load	L1: 0.03 m; L2: 0.40 m; Φ: 30 mm; Material: 8.8; Anchor type:	M: CB 1, Edge: 1, Surface: 6; X: 0.38 m
AN4	Anchorage - Load	L1: 0.03 m; L2: 0.40 m; Φ: 30 mm; Material: 8.8; Anchor type:	M: CB 1, Edge: 1, Surface: 6; X: 0.78 m

Loads

Load case LE1 - Permanent

Point loads

Name	Fx [kN]	Fy [kN]	Fz [kN]	Direction	Master	Position [X;Y;Z] [mm]
PL2	0.0			Global		-
PL3	0.0			Global		-
PL4	0.0			Global		-

Point loads

Name	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]	Direction	Master	Position [X;Z] [mm]
FL1	1.7	10.3	-15.6	0.1	0.1	0.1	Global	BP1	425;157
FL1	3.5	10.3	-15.7	-0.2	0.1	0.0	Global	BP1	392;157
FL1	0.2	-5.8	-1.1	0.0	0.0	0.0	Global	BP1	392;157
FL1	2.8	-5.8	1.2	0.0	0.0	0.0	Global	BP1	358;157
FL1	-0.2	-5.7	4.4	0.0	0.0	0.0	Global	BP1	358;157
FL1	3.1	-5.7	3.8	0.1	0.0	0.0	Global	BP1	325;157
FL1	-0.8	-7.1	2.7	0.0	0.0	0.0	Global	BP1	325;157
FL1	2.8	-7.1	2.2	0.1	0.0	0.0	Global	BP1	292;157
FL1	-1.0	-6.3	0.8	0.0	0.0	0.0	Global	BP1	292;157
FL1	2.3	-6.3	0.5	0.0	0.0	0.0	Global	BP1	258;157
FL1	-1.5	-5.3	-1.1	0.0	0.0	0.0	Global	BP1	258;157
FL1	1.6	-5.3	-1.4	0.0	0.0	0.0	Global	BP1	225;157
FL1	-1.9	-5.1	-3.2	0.1	0.0	0.0	Global	BP1	225;157
FL1	1.1	-5.1	-4.0	0.0	0.0	0.0	Global	BP1	192;157
FL1	-1.7	-5.8	-2.9	0.0	0.0	0.0	Global	BP1	192;157
FL1	1.1	-5.8	-1.6	0.0	0.0	0.0	Global	BP1	158;157
FL1	-4.2	4.7	4.0	-0.1	0.0	0.0	Global	BP1	158;157
FL1	-2.4	4.7	6.3	0.0	0.0	0.1	Global	BP1	125;157
FL1	1.7	15.5	-23.6	0.2	-0.1	0.0	Global	BP1	425;117
FL1	3.5	15.5	-23.7	-0.3	-0.1	-0.1	Global	BP1	392;117
FL1	0.2	1.8	-8.3	0.1	0.0	0.0	Global	BP1	392;117
FL1	2.8	1.8	-6.0	-0.1	0.0	0.0	Global	BP1	358;117
FL1	-0.2	4.0	-2.2	0.0	0.0	0.0	Global	BP1	358;117
FL1	3.1	4.0	-2.9	0.0	0.0	0.0	Global	BP1	325;117
FL1	-0.8	3.5	-1.2	0.0	0.0	0.0	Global	BP1	325;117
FL1	2.8	3.5	-1.7	0.0	0.0	0.0	Global	BP1	292;117
FL1	-1.0	3.3	-0.6	0.0	0.0	0.0	Global	BP1	292;117
FL1	2.3	3.3	-0.9	0.0	0.0	0.0	Global	BP1	258;117
FL1	-1.5	3.7	-0.3	0.0	0.0	0.0	Global	BP1	258;117
FL1	1.6	3.7	-0.6	0.0	0.0	0.0	Global	BP1	225;117
FL1	-1.9	3.6	-0.2	0.0	0.0	0.0	Global	BP1	225;117
FL1	1.1	3.6	-1.0	0.0	0.0	0.0	Global	BP1	192;117
FL1	-1.7	2.4	0.9	0.0	0.0	0.0	Global	BP1	192;117
FL1	1.1	2.4	2.2	0.0	0.0	0.0	Global	BP1	158;117
FL1	-4.2	10.1	10.4	-0.2	0.0	-0.1	Global	BP1	158;117
FL1	-2.4	10.1	12.7	0.1	0.0	0.0	Global	BP1	125;117
FL1	2.4	-13.9	20.4	-0.2	-0.1	0.0	Global	BP1	425;533
FL1	4.1	-13.9	19.4	0.3	-0.1	-0.1	Global	BP1	392;533
FL1	-2.1	-2.0	5.7	0.0	0.0	0.0	Global	BP1	392;533
FL1	0.0	-2.0	4.0	0.1	0.0	0.0	Global	BP1	358;533
FL1	-1.1	-2.2	2.2	0.0	0.0	0.0	Global	BP1	358;533
FL1	-0.2	-2.2	2.8	0.0	0.0	0.0	Global	BP1	325;533
FL1	-0.7	0.3	3.1	0.0	0.0	0.0	Global	BP1	325;533

Name	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]	Direction	Master	Position [X;Z] [mm]
FL1	-1.3	0.3	3.7	0.0	0.0	0.0	Global	BP1	292;533
FL1	3.7	5.0	6.9	-0.1	0.0	0.0	Global	BP1	292;533
FL1	0.0	5.0	6.5	0.1	0.0	0.0	Global	BP1	258;533
FL1	2.7	9.2	4.0	-0.1	0.0	0.0	Global	BP1	258;533
FL1	-4.0	9.2	2.2	0.0	0.0	0.0	Global	BP1	225;533
FL1	4.1	11.2	2.5	-0.1	0.0	0.0	Global	BP1	225;533
FL1	-4.0	11.2	0.2	0.0	0.0	0.0	Global	BP1	192;533
FL1	5.9	9.8	10.5	-0.2	0.0	0.1	Global	BP1	192;533
FL1	-2.3	9.8	18.8	0.1	-0.1	0.0	Global	BP1	158;533
FL1	9.6	35.4	45.3	-0.7	-0.2	0.2	Global	BP1	158;533
FL1	2.3	32.1	46.5	0.4	-0.2	0.1	Global	BP1	125;533
FL1	2.4	-9.0	12.9	-0.1	0.1	0.1	Global	BP1	425;493
FL1	4.1	-9.0	11.9	0.2	0.1	0.0	Global	BP1	392;493
FL1	-2.1	3.9	1.4	0.0	0.0	0.0	Global	BP1	392;493
FL1	0.0	3.9	-0.3	0.0	0.0	0.0	Global	BP1	358;493
FL1	-1.1	0.4	-2.9	0.0	0.0	0.0	Global	BP1	358;493
FL1	-0.2	0.4	-2.3	0.0	0.0	0.0	Global	BP1	325;493
FL1	-0.7	-1.7	-1.9	0.0	0.0	0.0	Global	BP1	325;493
FL1	-1.3	-1.7	-1.3	0.0	0.0	0.0	Global	BP1	292;493
FL1	3.7	-6.1	-2.3	0.1	0.0	0.0	Global	BP1	292;493
FL1	0.0	-6.1	-2.7	0.0	0.0	0.0	Global	BP1	258;493
FL1	2.7	-10.6	-5.1	0.1	0.0	0.0	Global	BP1	258;493
FL1	-4.0	-10.6	-6.9	0.0	0.0	0.1	Global	BP1	225;493
FL1	4.1	-12.6	-9.8	0.2	0.0	0.1	Global	BP1	225;493
FL1	-4.0	-12.6	-12.1	-0.1	-0.1	0.1	Global	BP1	192;493
FL1	5.9	-14.3	-5.6	0.1	0.0	0.1	Global	BP1	192;493
FL1	-2.3	-14.3	2.8	0.0	0.0	0.0	Global	BP1	158;493
FL1	16.9	26.5	26.5	-0.5	0.2	0.0	Global	BP1	158;493
FL1	4.0	26.5	37.5	0.2	0.2	-0.2	Global	BP1	125;493
FL1	2.9	-1.1	2.3	0.0	0.0	0.0	Global	BP1	287;137
FL1	2.9	1.5	2.8	0.0	0.0	0.0	Global	BP1	287;168
FL1	2.8	-1.7	1.3	0.0	0.0	0.0	Global	BP1	287;168
FL1	2.8	1.1	2.0	0.0	0.0	0.0	Global	BP1	287;200
FL1	2.5	-1.6	2.6	0.0	0.0	0.0	Global	BP1	287;200
FL1	2.5	0.9	3.7	0.0	0.0	0.0	Global	BP1	287;231
FL1	1.0	-1.3	1.6	0.0	0.0	0.0	Global	BP1	287;231
FL1	1.0	0.6	1.7	0.0	0.0	0.0	Global	BP1	287;262
FL1	0.3	-1.0	1.1	0.0	0.0	0.0	Global	BP1	287;262
FL1	0.3	0.3	0.8	0.0	0.0	0.0	Global	BP1	287;294
FL1	-0.1	-0.7	0.3	0.0	0.0	0.0	Global	BP1	287;294
FL1	-0.1	0.1	0.2	0.0	0.0	0.0	Global	BP1	287;325
FL1	-0.7	-0.5	-0.4	0.0	0.0	0.0	Global	BP1	287;325
FL1	-0.7	-0.1	-0.6	0.0	0.0	0.0	Global	BP1	287;356
FL1	-1.9	-0.4	-1.1	0.0	0.0	0.0	Global	BP1	287;356

Name	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]	Direction	Master	Position [X;Z] [mm]
FL1	-1.9	-0.5	-1.8	0.0	0.0	0.0	Global	BP1	287;388
FL1	-2.5	-0.1	-3.3	0.0	0.0	0.0	Global	BP1	287;388
FL1	-2.5	-1.0	-2.8	0.0	0.0	0.0	Global	BP1	287;419
FL1	-1.3	0.3	-5.4	0.0	0.0	0.0	Global	BP1	287;419
FL1	-1.3	-1.6	-3.1	0.0	0.0	0.0	Global	BP1	287;450
FL1	-2.7	0.8	-4.2	0.0	0.0	0.0	Global	BP1	287;450
FL1	-2.7	-1.8	-2.2	0.0	0.0	0.0	Global	BP1	287;482
FL1	-1.3	1.4	-3.2	0.0	0.0	0.0	Global	BP1	287;482
FL1	-1.3	-0.5	-1.5	0.0	0.0	0.0	Global	BP1	287;513
FL1	-1.7	-1.1	-0.7	0.0	0.0	0.0	Global	BP1	263;137
FL1	-1.7	1.5	-0.3	0.0	0.0	0.0	Global	BP1	263;168
FL1	-2.2	-1.7	0.8	0.0	0.0	0.0	Global	BP1	263;168
FL1	-2.2	1.1	1.4	0.0	0.0	0.0	Global	BP1	263;200
FL1	-1.9	-1.6	0.1	0.0	0.0	0.0	Global	BP1	263;200
FL1	-1.9	0.9	1.1	0.0	0.0	0.0	Global	BP1	263;231
FL1	-2.3	-1.3	0.0	0.0	0.0	0.0	Global	BP1	263;231
FL1	-2.3	0.6	0.1	0.0	0.0	0.0	Global	BP1	263;262
FL1	-2.0	-1.0	-0.7	0.0	0.0	0.0	Global	BP1	263;262
FL1	-2.0	0.3	-1.1	0.0	0.0	0.0	Global	BP1	263;294
FL1	-1.6	-0.7	-1.5	0.0	0.0	0.0	Global	BP1	263;294
FL1	-1.6	0.1	-1.6	0.0	0.0	0.0	Global	BP1	263;325
FL1	-1.4	-0.5	-2.2	0.0	0.0	0.0	Global	BP1	263;325
FL1	-1.4	-0.1	-2.4	0.0	0.0	0.0	Global	BP1	263;356
FL1	-1.6	-0.4	-3.2	0.0	0.0	0.0	Global	BP1	263;356
FL1	-1.6	-0.5	-3.8	0.0	0.0	0.0	Global	BP1	263;388
FL1	-0.8	-0.1	-5.1	0.0	-0.1	0.0	Global	BP1	263;388
FL1	-0.8	-1.0	-4.7	0.0	0.0	0.0	Global	BP1	263;419
FL1	1.9	0.3	-8.4	0.0	-0.1	0.0	Global	BP1	263;419
FL1	1.9	-1.6	-6.2	0.0	0.1	0.0	Global	BP1	263;450
FL1	1.8	0.8	-5.2	0.0	0.0	0.0	Global	BP1	263;450
FL1	1.8	-1.8	-3.2	0.0	0.0	0.0	Global	BP1	263;482
FL1	2.1	1.4	-6.7	0.0	-0.1	0.0	Global	BP1	263;482
FL1	2.1	-0.5	-5.0	0.0	0.1	0.0	Global	BP1	263;513
FL1	4.3	1.4	-9.1	0.0	-0.1	0.0	Global	BP1	292;11
FL1	4.3	2.4	-8.0	0.0	0.1	0.0	Global	BP1	292;34
FL1	4.1	0.2	-3.6	0.0	0.0	0.0	Global	BP1	292;34
FL1	4.1	1.6	-3.3	0.0	0.0	0.0	Global	BP1	292;57
FL1	4.6	-0.2	-2.5	0.0	0.0	0.0	Global	BP1	292;57
FL1	4.6	1.4	-2.2	0.0	0.0	0.0	Global	BP1	292;79
FL1	4.7	-0.5	-1.6	0.0	0.0	0.0	Global	BP1	292;80
FL1	4.7	1.0	-1.4	0.0	0.0	0.0	Global	BP1	292;102
FL1	3.6	-0.6	-0.4	0.0	0.0	0.0	Global	BP1	292;102
FL1	3.6	0.5	0.0	0.0	0.0	0.0	Global	BP1	292;125
FL1	0.7	1.4	-3.4	0.0	0.0	0.0	Global	BP1	258;11

Name	Fx [kN]	Fy [kN]	Fz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]	Direction	Master	Position [X;Z] [mm]
FL1	0.7	2.4	-2.4	0.0	0.0	0.0	Global	BP1	258;34
FL1	-0.8	0.2	-0.4	0.0	0.0	0.0	Global	BP1	258;34
FL1	-0.8	1.6	-0.1	0.0	0.0	0.0	Global	BP1	258;57
FL1	-1.1	-0.2	1.0	0.0	0.0	0.0	Global	BP1	258;57
FL1	-1.1	1.4	1.3	0.0	0.0	0.0	Global	BP1	258;79
FL1	-0.6	-0.5	1.3	0.0	0.0	0.0	Global	BP1	258;80
FL1	-0.6	1.0	1.6	0.0	0.0	0.0	Global	BP1	258;102
FL1	-0.5	-0.6	0.2	0.0	0.0	0.0	Global	BP1	258;102
FL1	-0.5	0.5	0.6	0.0	0.0	0.0	Global	BP1	258;125

Combination

Name	Type	Content
LE1	ULS	LE1

Results

Summary

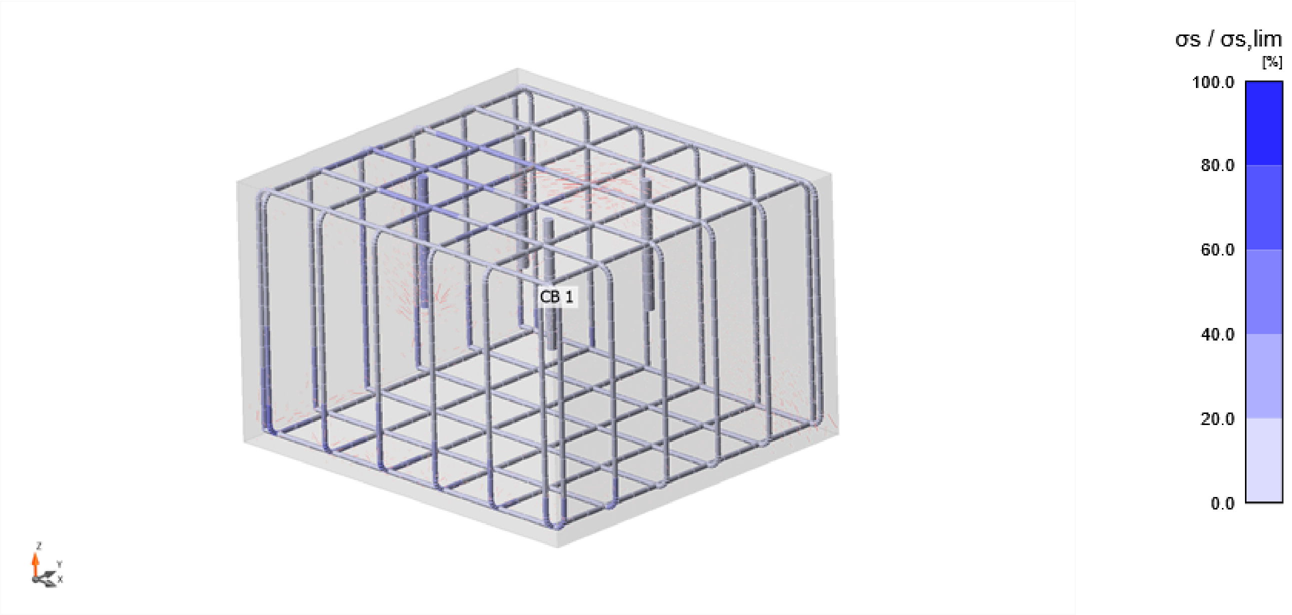
Overview table

Check item	Combination	Increment	Item	
ULS	LE1	G100.0%	Strength of concrete	✓

Check item	Item	Utilization	
Strength of concrete	CB 1	σc/σc,lim: 88.0%	✓
Strength of reinforcement		εs/εs,lim: 4.1%, σs/σs,lim: 47.3%	✓
Anchorage length		τb/fbd: 99.8%	✓

ULS - Summary

Stress flow



Above yield	Compression	Explanation
		Thickness proportional to force

Summary of reactions and applied loads: LE1, Load increment: G100.0%

Type	F_x [kN]	F_y [kN]	F_z [kN]	M_x [kNm]	M_y [kNm]	M_z [kNm]
Summary of reactions	-76.8	-100.0	-76.8	109.5	-122.6	-0.2
Summary of applied load	76.8	100.0	76.8	-108.7	122.9	0.0
Check of equilibrium	0.0	0.0	0.0	0.8	0.3	-0.1

ULS - Strength

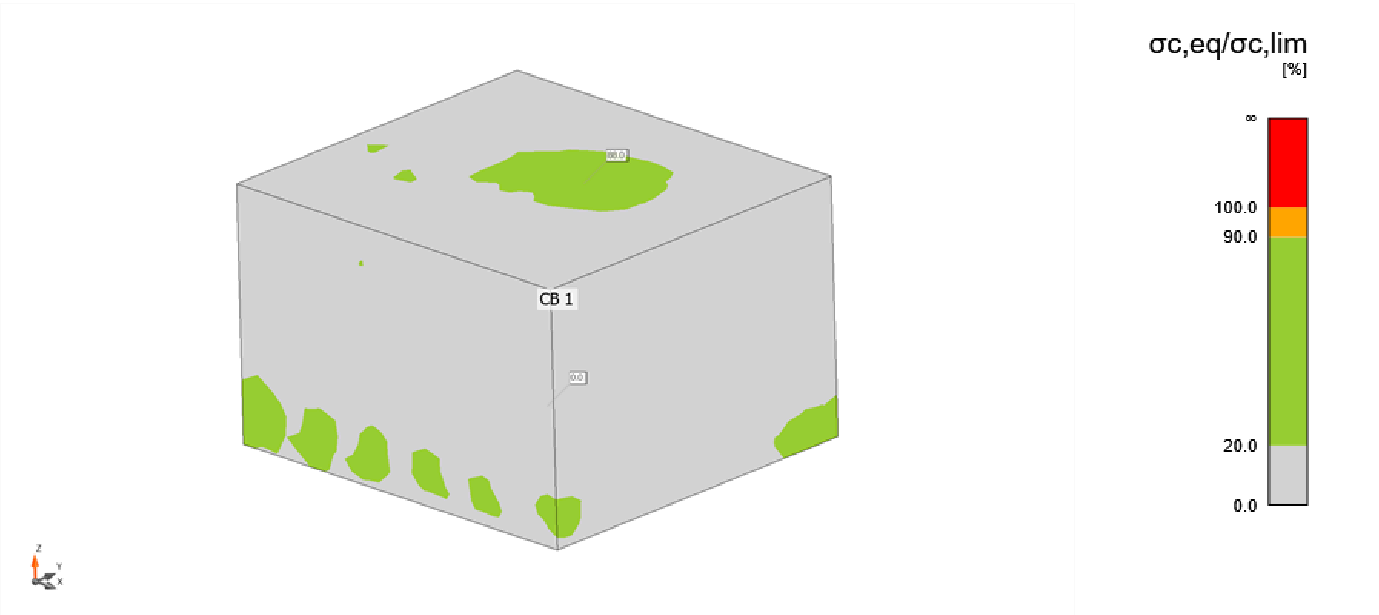
Detailed concrete strength results: LE1, Load increment: G100.0%

Member	X [m]	Y [m]	Z [m]	$\sigma_{c,eq}$ [MPa]	$\sigma_{c,3}/\sigma_{c,lim}$ [-]	ε_c [1e-4]	ε_{pl} [1e-4]	$\sigma_{c,eq}/\sigma_{c,lim}$ [%]	
CB 1	0.13	0.07	0.80	-14.7	100.0	-12.3	-3.6	88.0	OK
CB 1	0.13	0.07	0.80	-4.7	100.0	-2.3	0.0	28.0	OK
CB 1	0.13	0.07	0.80	-0.6	100.0	-0.3	0.0	3.6	OK

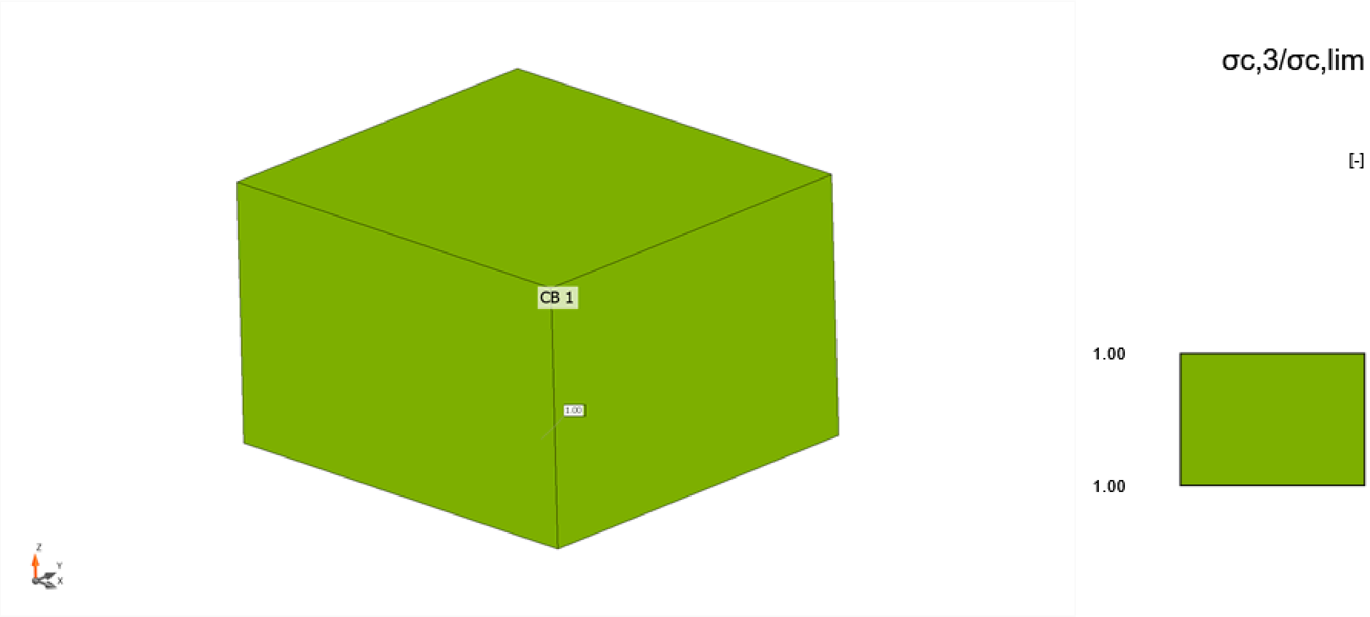
Detailed reinforcement strength results: LE1, Load increment: G100.0%

Member	X [m]	Y [m]	Z [m]	σ_s [MPa]	ε_s [1e-4]	$\sigma_s/\sigma_{s,lim}$ [%]	$\varepsilon_s/\varepsilon_{s,lim}$ [%]	
GB3D1	-0.55	-0.55	0.06	222.1	9.3	47.3	4.1	OK
GB3D2	-0.60	-0.52	0.09	151.8	6.4	32.3	2.1	OK
GB3D2	-0.60	-0.31	0.09	151.8	4.9	32.3	3.1	OK
AN2	-0.25	-0.20	0.74	220.2	1.8	31.7	1.5	OK
AN1	-0.25	0.20	0.74	107.3	0.5	15.4	0.4	OK
AN4	0.25	-0.20	0.74	67.9	0.3	9.8	0.3	OK
AN3	0.25	0.20	0.69	-3.2	-0.2	0.5	0.1	OK
AN3	0.25	0.20	0.40	-0.5	0.0	0.1	0.0	OK

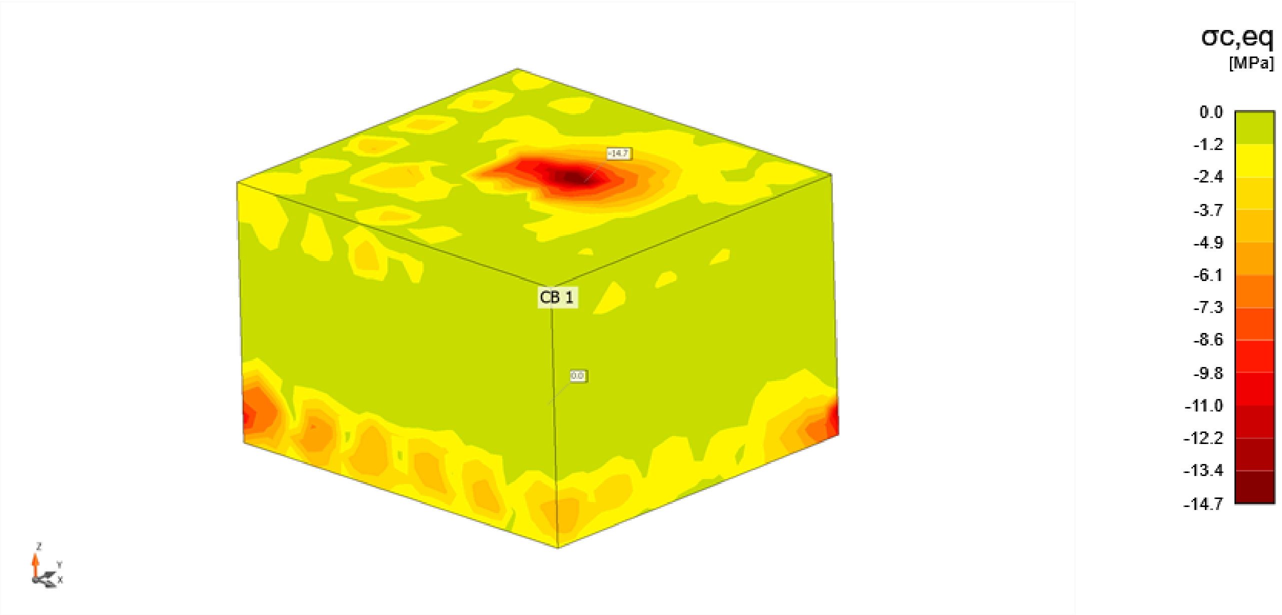
Concrete strain/limit strain ratio



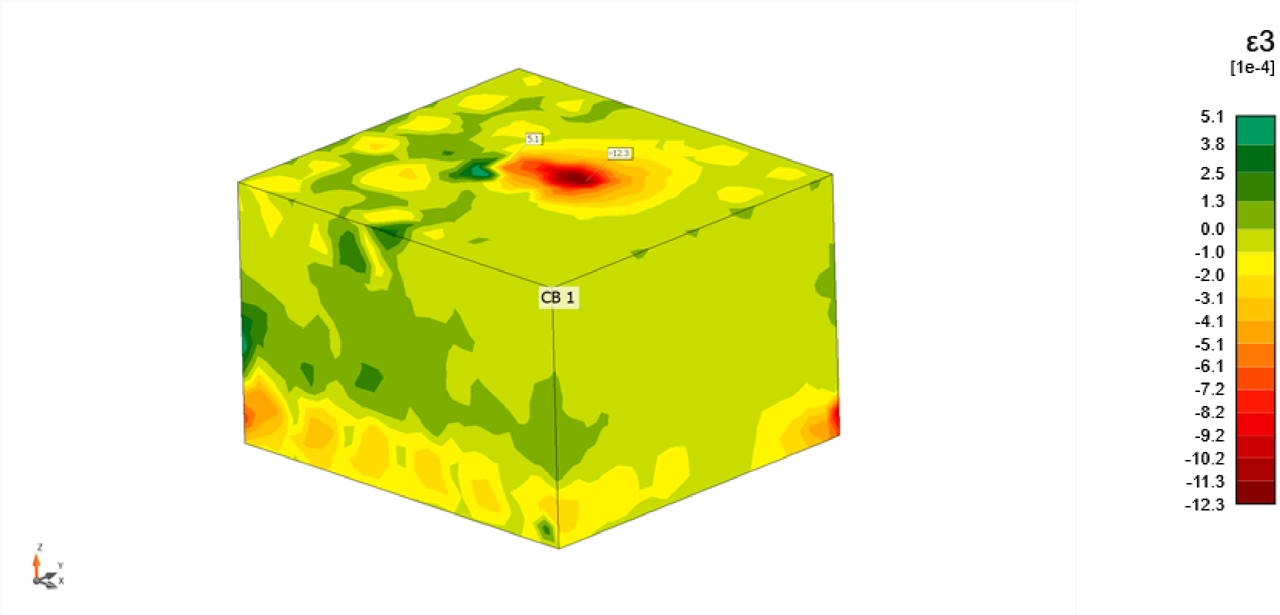
Concrete principal stress $\sigma_{c3}/\sigma_{c,lim}$



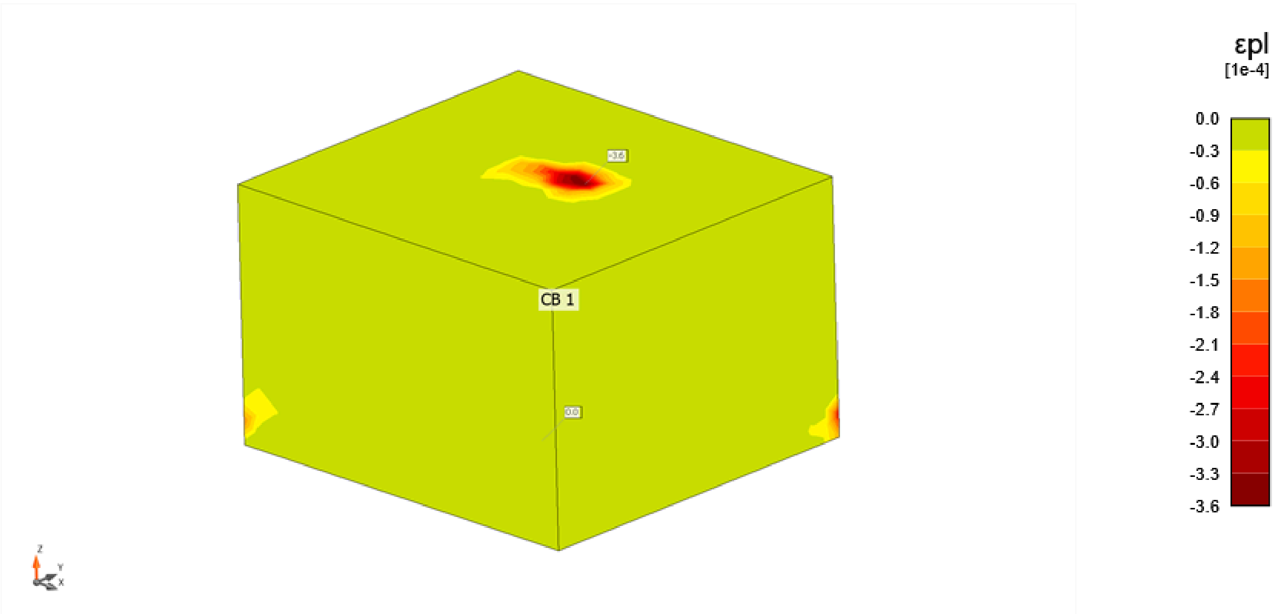
Concrete principal stress $\sigma_{c,eq}$



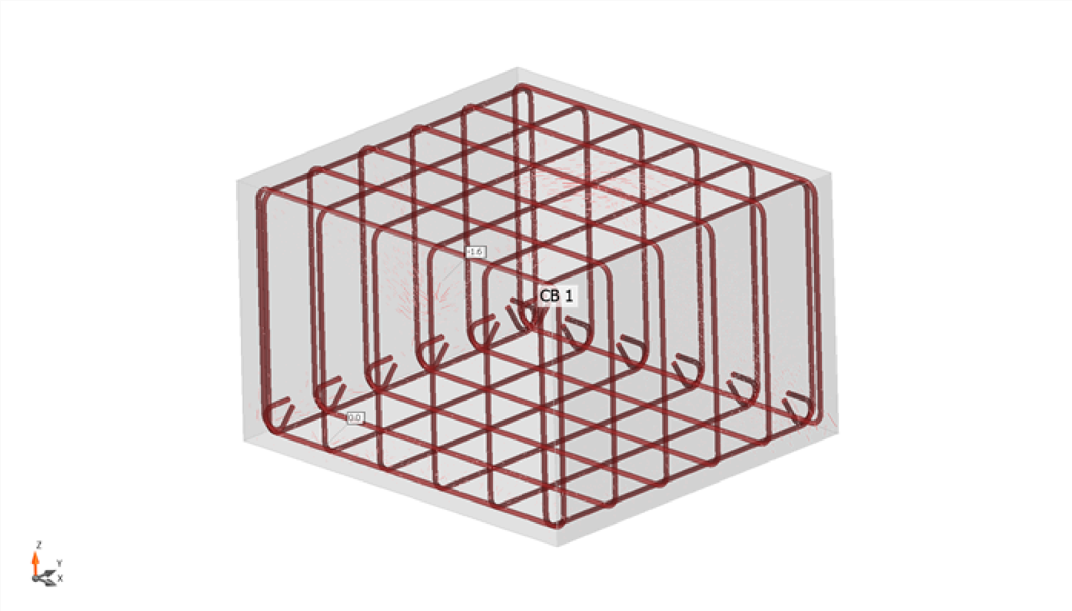
Concrete principal strain ε_c



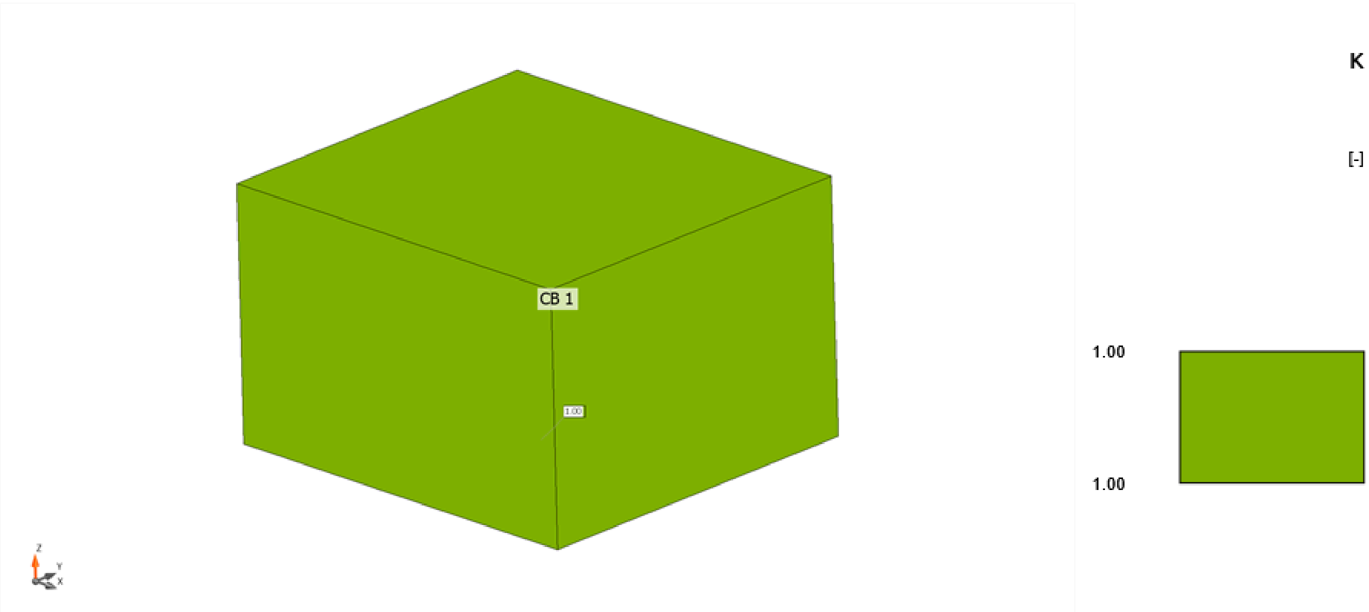
Concrete plastic strain ε_{pl}



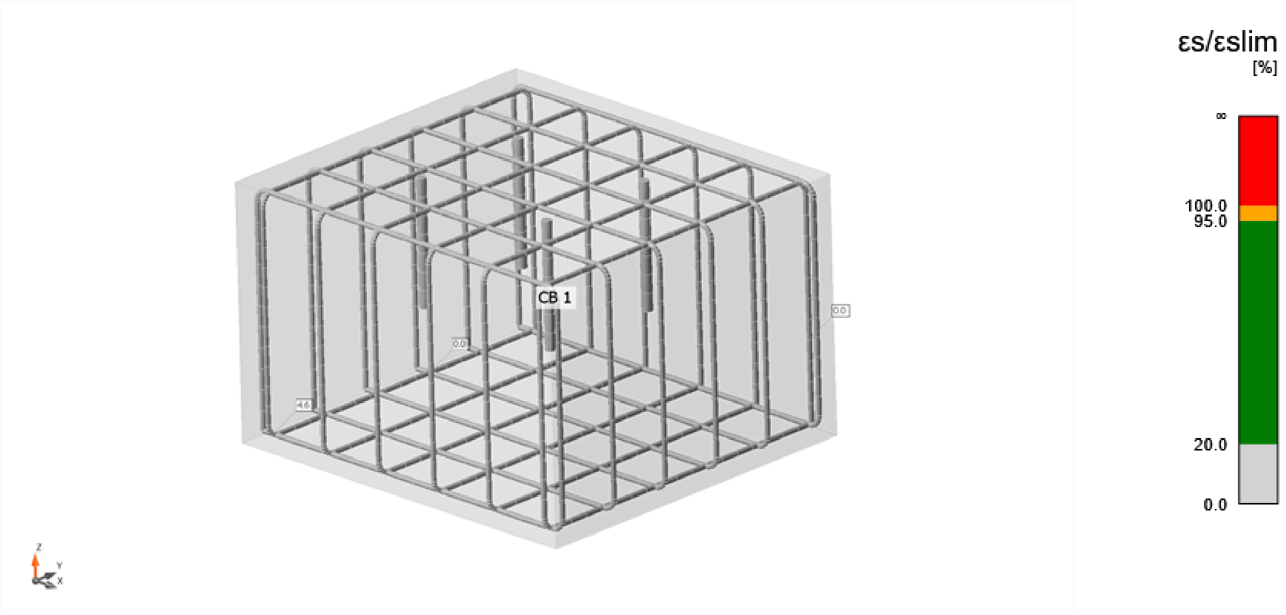
Directions of principal stresses



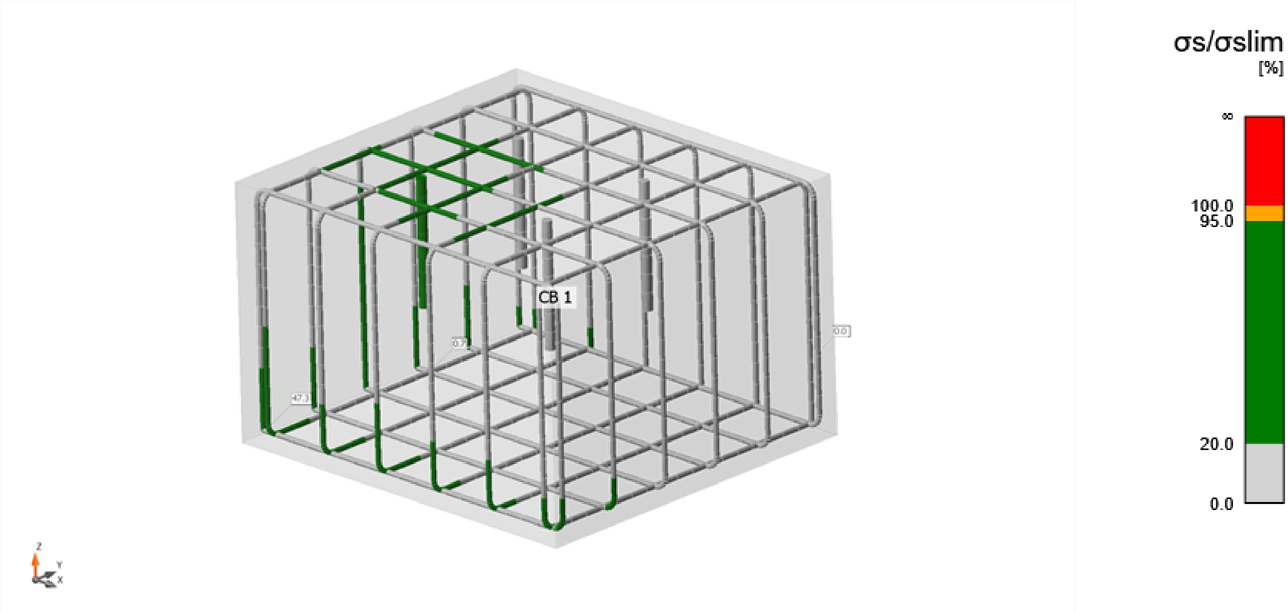
Compressive strength reduction factor κ



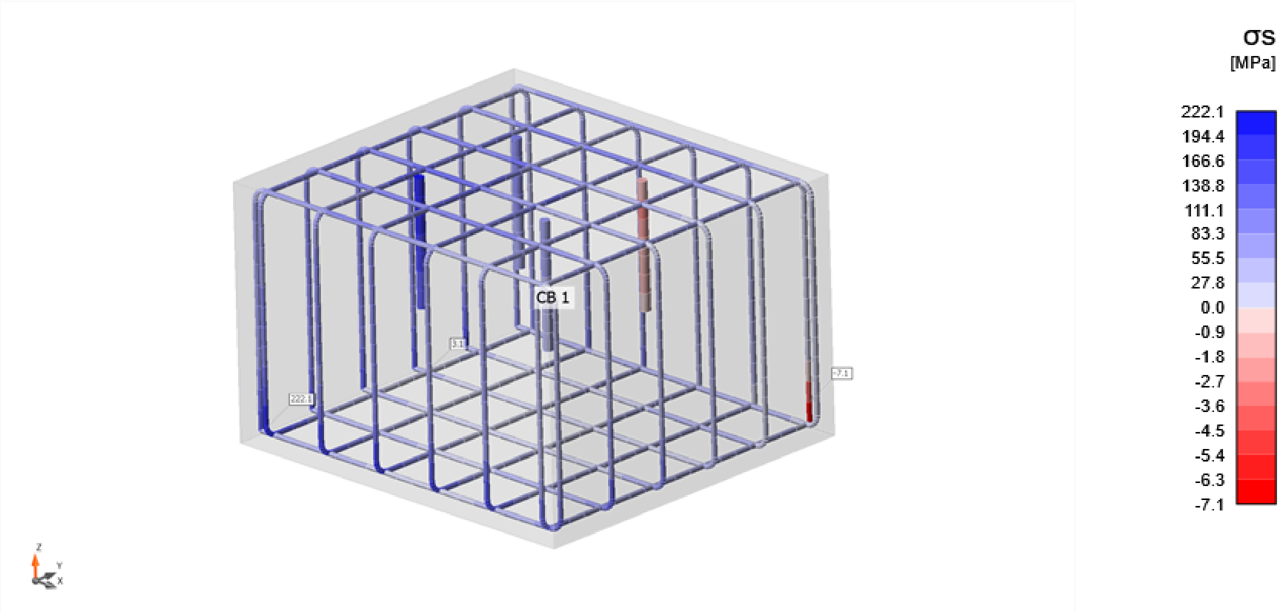
Reinforcement strain/limit strain ratio - $\varepsilon_s/\varepsilon_{s,lim}$ [%]



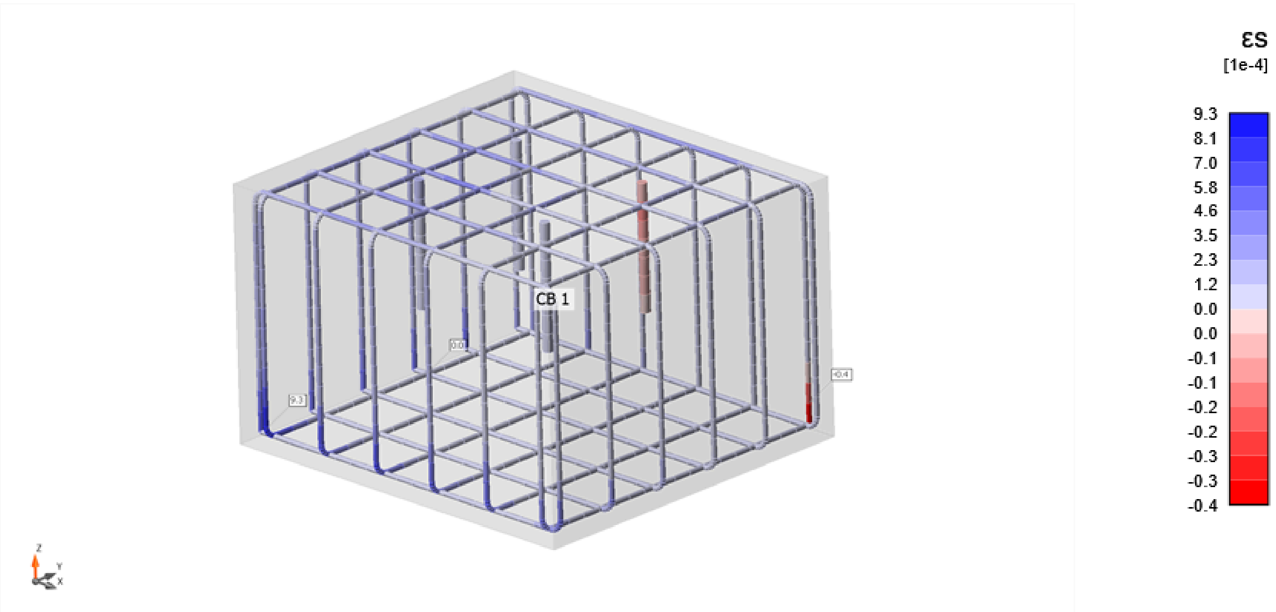
Reinforcement stress/strength ratio - $\sigma_s/\sigma_{s,lim}$ [%]



Reinforcement stress - σ_s [MPa]



Reinforcement strain - ε_s [1e-4]

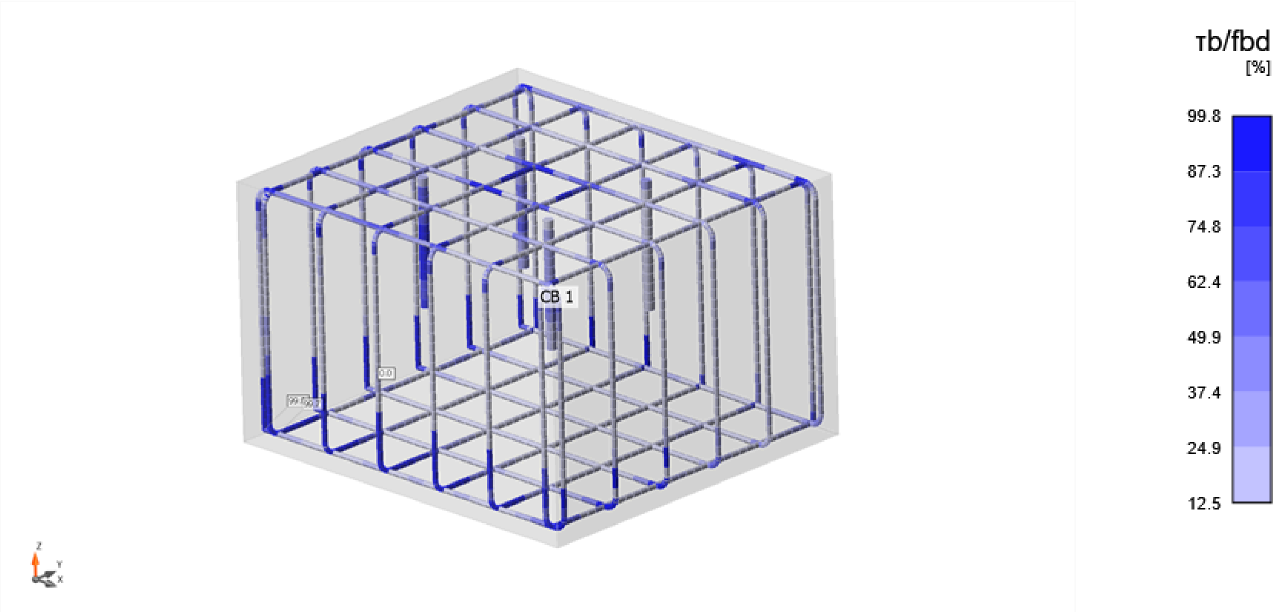


ULS - Anchorage

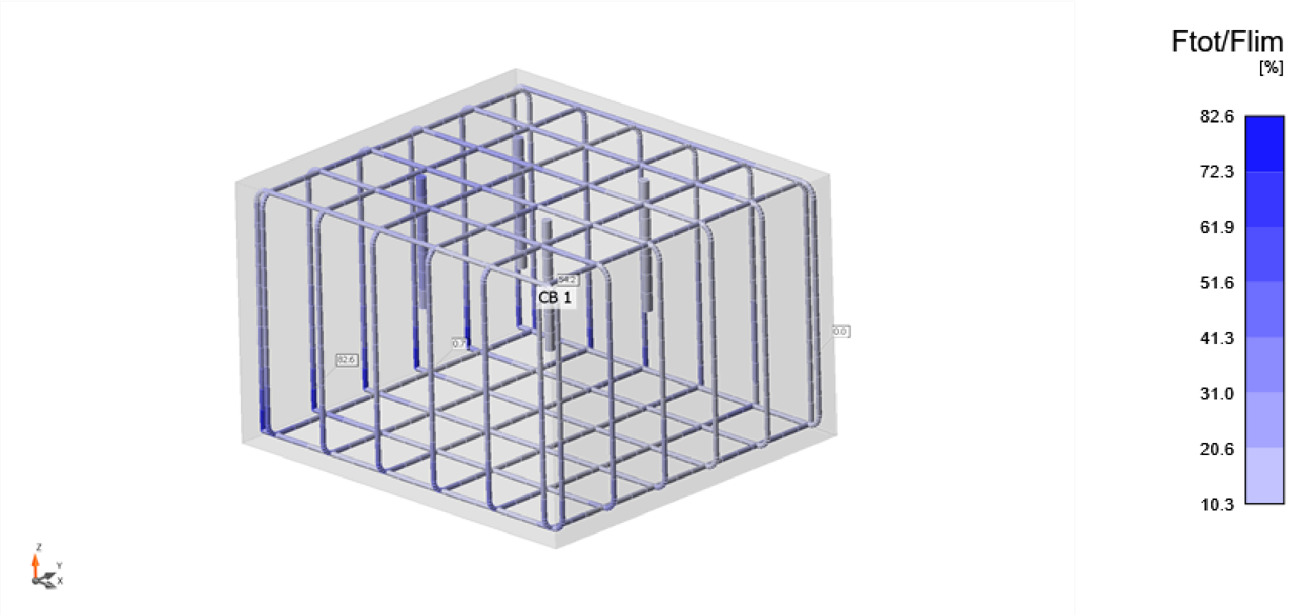
Detailed anchorage results - Reinforcement: LE1, Load increment: G100.0%

Member	X [m]	Y [m]	Z [m]	$τ_b$ [MPa]	F_a [kN]	F_{tot} [kN]	F_{tot}/F_{lim} [%]	F_{lim} [kN]	$τ_b/f_{bd}$ [%]	
GB3D2	-0.60	-0.52	0.03	2.7	26.2	30.5	82.6	37.0	99.8	OK
GB3D2	-0.60	-0.31	0.03	2.7	26.2	30.5	82.6	37.0	99.8	OK
GB3D2	-0.60	-0.31	0.09	2.7	26.2	30.5	82.6	37.0	99.7	OK
GB3D2	0.60	0.53	0.07	0.6	26.2	0.5	0.5	94.4	21.0	OK
GB3D2	0.37	-0.52	0.03	0.2	26.2	6.6	7.0	94.4	6.8	OK
GB3D1	-0.55	-0.51	0.03	2.7	20.0	32.7	34.6	94.4	99.7	OK
GB3D1	-0.55	-0.52	0.03	2.7	20.0	38.9	41.2	94.4	99.7	OK
GB3D1	-0.55	-0.55	0.06	2.7	20.0	44.7	47.3	94.4	99.7	OK
GB3D1	0.55	0.55	0.09	0.7	20.0	-1.4	1.5	-94.4	26.8	OK
GB3D1	-0.33	0.55	0.09	2.7	20.0	21.9	59.3	37.0	99.7	OK
GB3D1	-0.55	-0.45	0.03	2.7	20.0	32.7	34.6	94.4	99.7	OK
AN2	-0.25	-0.20	0.51	2.7	94.5	110.5	22.5	491.7	99.4	OK
AN2	-0.25	-0.20	0.74	1.3	94.5	155.7	31.7	491.7	70.4	OK
AN2	-0.25	-0.20	0.40	2.0	94.5	99.8	20.3	491.7	75.5	OK
AN2	-0.25	-0.20	0.51	2.7	94.5	110.5	22.5	491.7	99.4	OK
AN2	-0.25	-0.20	0.74	1.3	94.5	155.7	31.7	491.7	70.4	OK
AN2	-0.25	-0.20	0.40	2.0	94.5	99.8	20.3	491.7	75.5	OK
AN2	-0.25	-0.20	0.51	2.7	94.5	110.5	22.5	491.7	99.4	OK
AN2	-0.25	-0.20	0.74	1.3	94.5	155.7	31.7	491.7	70.4	OK
AN2	-0.25	-0.20	0.40	2.0	94.5	99.8	20.3	491.7	75.5	OK
AN2	-0.25	-0.20	0.51	2.7	94.5	110.5	22.5	491.7	99.4	OK
AN2	-0.25	-0.20	0.74	1.3	94.5	155.7	31.7	491.7	70.4	OK
AN2	-0.25	-0.20	0.40	2.0	94.5	99.8	20.3	491.7	75.5	OK

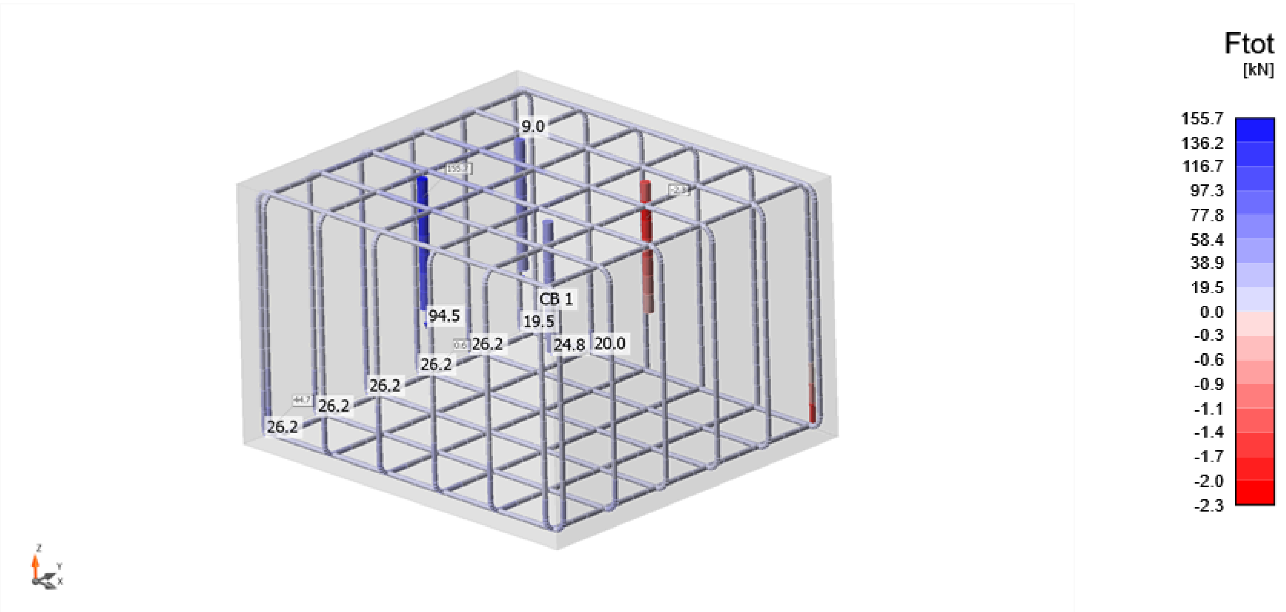
Bond stress check value - $τ_b/f_{bd}$ [%]



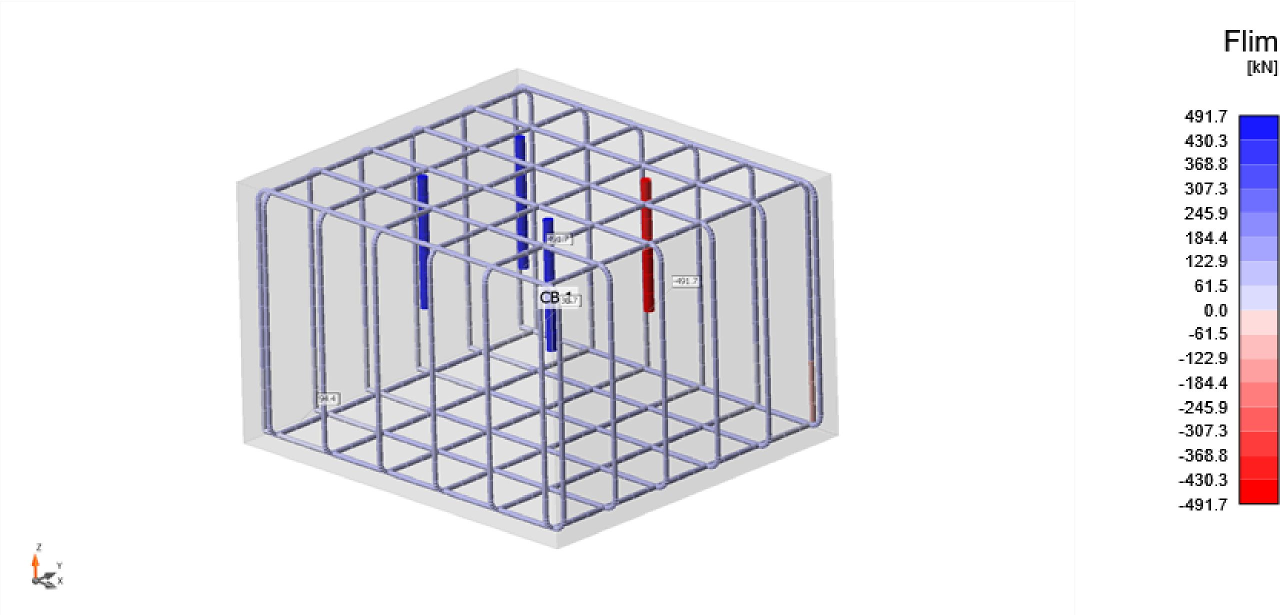
Force check value - F_{tot}/F_{lim} [%]



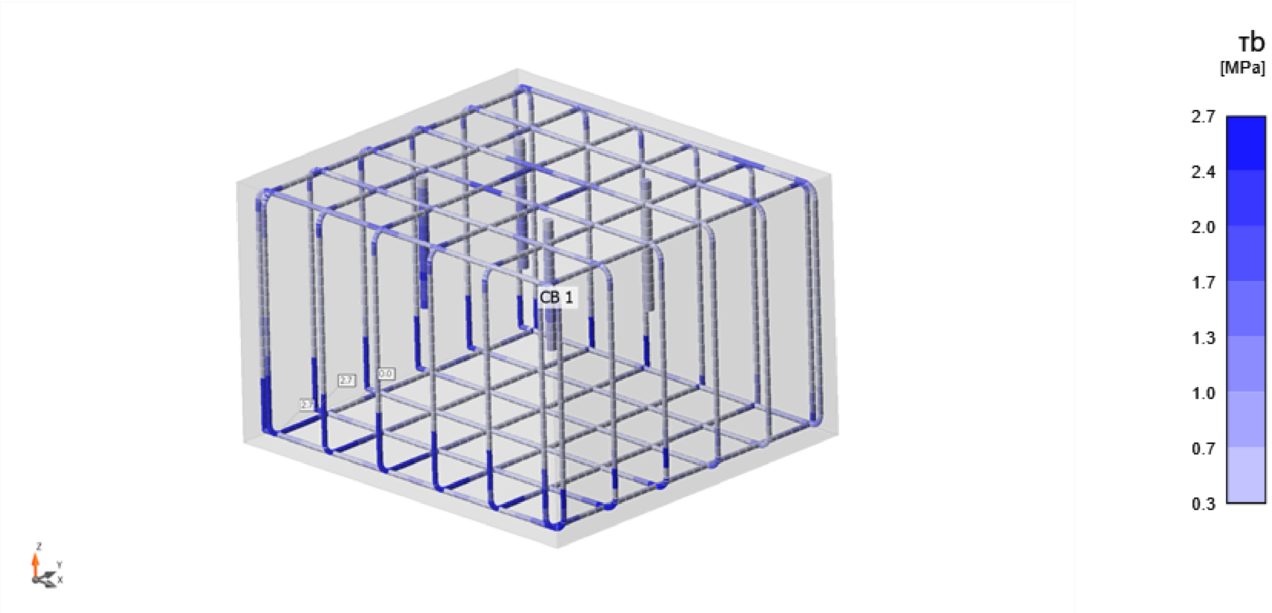
Total force in the bar - F_{tot} [kN]



Limit force in the bar - F_{lim} [kN]



Bond stress - τ_b [MPa]



Bill of material

Bill of material cannot be printed

Explanation

Symbol	Explanation
f_{ck}	Characteristic compressive cylinder strength of concrete at 28 days
$f_{ctk,0.05}$	Characteristic axial tensile strength of concrete 5% quantile
f_{ctm}	Mean value of axial tensile strength of concrete
E_{cm}	Secant modulus of elasticity of concrete
ν	Poisson ratio
ε_c	Compressive strain in the concrete at the peak stress fc

Symbol	Explanation
ε_{cu}	Ultimate compressive strain in the concrete
φ_{perm}	Final value of creep coefficient at time interval (t0 = 28 days, tinf = design working life) for permanent load
φ_{pres}	Final value of creep coefficient at time interval (t0 = 28 days, tinf = design working life) for prestressing load
f_{yk}	Characteristic yield strength of reinforcement
E_s	Modulus of elasticity of reinforcement steel
ε_{uk}	Characteristic strain of reinforcement or prestressing steel at maximum load
Properties	W - Width; H - Height; T - Thickness; D - Depth; L - Length; r - Radius; α - Inclination
Position	M - Master; MP - Master point; IP - Insert point
$\sigma_{c,eq}$	Equivalent principal stress Sigma c,eq, which expresses the equivalent uni-axial stress for a general tri-axial stress state.
ε_c	Minimum compressive strain of concrete
ε_{pl}	Minimum compressive plastic strain of concrete
$\sigma_{c,eq}/\sigma_{c,lim}$	The ratio of concrete stress and concrete strength. It presents the level of material utilization with respect to concrete strength.
σ_s	Maximum stress along the length of reinforcement bar.
ε_s	Maximum strain along the length of reinforcement bar.
$\sigma_s/\sigma_{s,lim}$	The ratio of stress and strength of the reinforcement. It presents the level of material utilization with respect to reinforcement strength.
$\varepsilon_s/\varepsilon_{s,lim}$	The ratio of strain and limit strain of the reinforcement. It presents the level of material utilization with respect to limit strain
τ_b	Bond stress on the surface of reinforcement bar.
F_a	The anchorage force. It is developed at the ends of the bars due to hooked anchorage.
F_{tot}	Total force developed along the length of the bar. It consists of the anchorage force due to hooked anchorage and bond force, which integrates bond stresses acting on the surface of the bar.
F_{tot}/F_{lim}	The ratio of total force in the bar and limit value of the force. It presents the level of utilization of the rebar. The limit value of the force is calculated as the minimum of two values: (a) the force calculated as the sum of ultimate anchorage force and the force developed from the end of the bar to the point of interest assuming ultimate bond strength, (b) the ultimate strength of the bar.
F_{lim}	The limit value of the force. The limit value of the force is calculated as the minimum of two values: (a) the force calculated as the sum of ultimate anchorage force and the force developed from the end of the bar to the point of interest assuming ultimate bond strength, (b) the ultimate strength of the bar.
τ_b/f_{bd}	The ratio of bond stress and ultimate bond strength for selected (group of) bars and applied portion of the load. It shows the level of utilization with respect to ultimate bond strength between the rebar and adjacent concrete.

Code settings

Clause	Name	Value	Description
2.4.2.4 (1)	γ_c	1.50	Strength reduction factor for concrete
2.4.2.4 (1)	γ_s	1.15	Strength reduction factor for reinforcement
3.1.6 (1)	α_{cc}	1.00	Coefficient taking into account the long term effect on the compressive strength and the unfavourable from the way the load is applied
3.2.7 (2)	$\varepsilon_{ud}/\varepsilon_{uk}$	0.90	Ratio of design and characteristic strain limit.
3.2.7 (2)	$\varepsilon_{ud}/\varepsilon_{uk}$	0.90	Ratio of design and characteristic strain limit.
5.10.2.1(1)	k1	0.80	Coefficient for calculation of maximal tensile stress in the tendon immediately before anchoring.
5.10.2.1(1)	k2	0.90	Coefficient for calculation of maximal tensile stress in the tendon immediately before anchoring.

Clause	Name	Value	Description
5.10.3(2)	k7	0.75	Coefficient for calculation of maximal tensile stress in the tendon immediately after tensioning or transfer
5.10.3(2)	k8	0.85	Coefficient for calculation of maximal tensile stress in the tendon immediately after tensioning or transfer
7.2(2)	k1	0.60	Coefficient for calculation of the maximum compressive stress in concrete under SLS characteristic combination
7.2(3)	k2	0.45	Coefficient for calculation of the stress in the concrete under the SLS quasi-permanent combination
7.2(5)	k3	0.80	Coefficient for calculation of maximal tensile stress in the reinforcement under SLS characteristic combination
7.2(5)	k5	0.75	Coefficient for calculation of maximal tensile stress in the tendon under SLS characteristic combination
8.3(2)	Φ m,min - Φs <= 16mm (4.00 Φs)	4.00	Minimum mandrel diameter of stirrups as multiple of stirrups diameter.
8.3(2)	Φ m,min - Φs > 16mm (7.00 Φs)	7.00	Minimum mandrel diameter of stirrups as multiple of stirrups diameter.

Calculation presumptions

- Minimum amount of reinforcement resisting at least the tensile stresses prior cracking has to be provided in cracked zones.
- It is assumed that a transverse rebar or adequate overlap is provided to enable full anchorage of the stirrups.
- The analysis and code checks are performed for support conditions as specified in the project. No change of supports in construction/service stages is considered.

Theoretical Background

3D CSFM for anchoring and complex details

In practice, engineers may encounter problems that are not amenable to solutions using established analytical procedures, linear FEM calculations, or cannot be simplified to axial or planar behavior. These include complicated spatially stressed discontinuity regions (so-called D-regions) like cases of anchorage in concrete where the load capacity of plain or weakly reinforced concrete is insufficient.

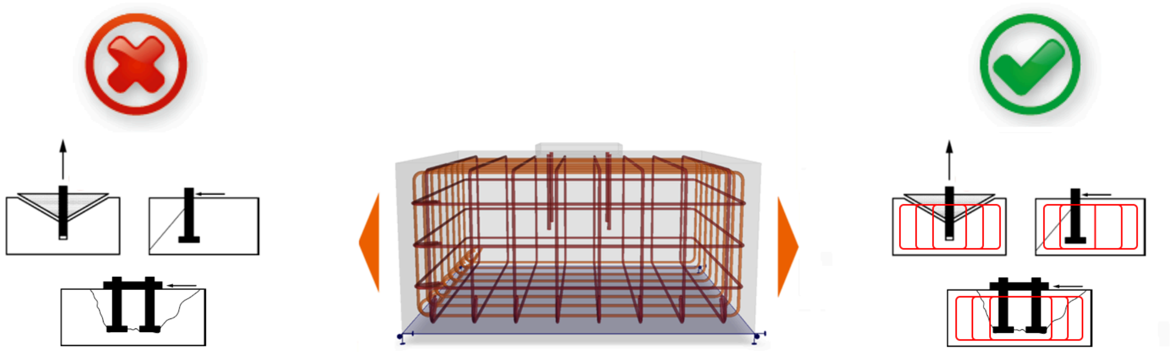


Fig. 1 3D CSFM for anchoring and complex details

The 3D Compatible Stress Field Method (3D CSFM) extends the established CSFM into a third dimension, offering a fast and code-compliant solution for the above-mentioned issues.

Main assumptions for 3D CSFM

3D CSFM defines the concrete behavior based on the **Modified Mohr-Coulomb** plasticity theory for monotonic loading. The method considers principal concrete stresses in compression and reinforcement stresses (σ_{sr}) at the cracks while **neglecting the concrete tensile strength** (tension cut-off), except for its stiffening effect on the reinforcement (Tension stiffening).

$\sigma_{c1r}, \sigma_{c2r}, \sigma_{c2r} \leq 0$ **MPa**

Constraints of the Bond model allow slip between the concrete and reinforcement. 3D CSFM **is not suitable for simulating plain concrete** due to the absence of tension, which may result in misleading deformation and model divergence. **3D CSFM assumes a zero angle of internal friction** φ (Fig. 1e), leading to a safe design due to the plasticity surface resembling the Tresca model, which is independent of the first stress invariant.

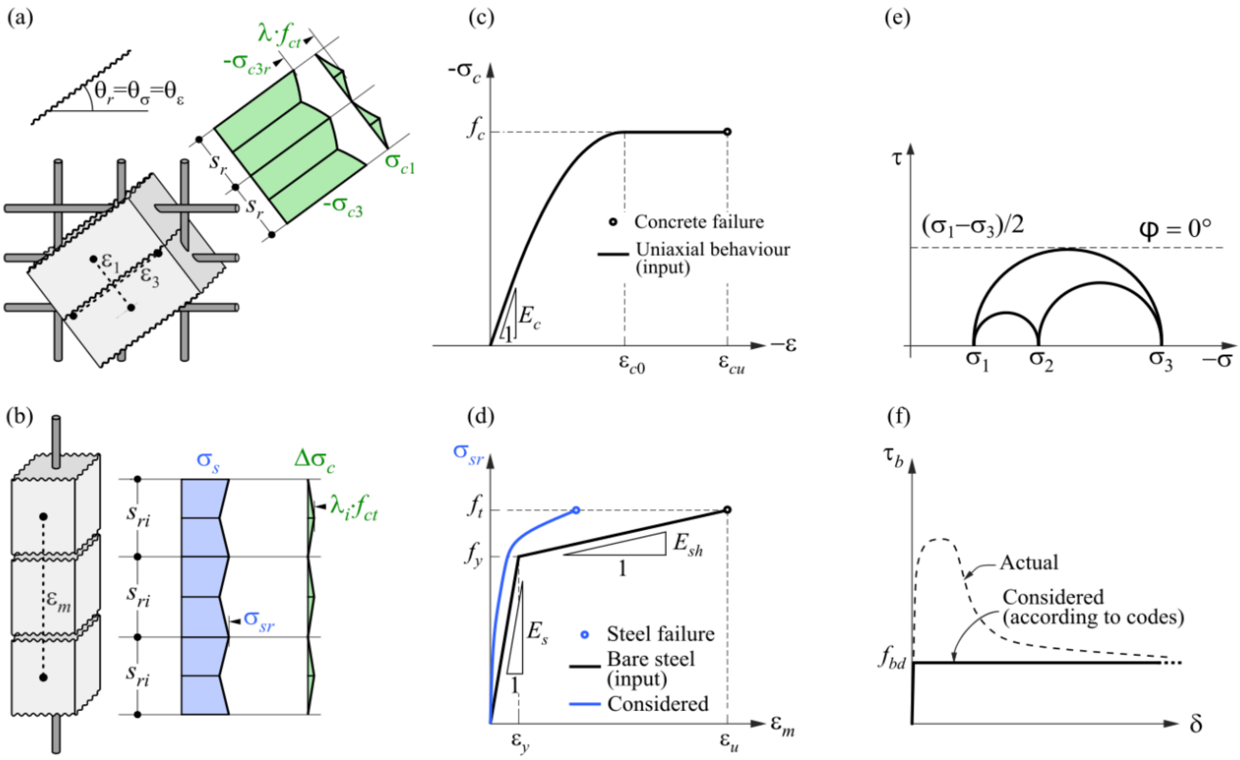


Fig. 2 Basic assumptions of the 3D CSFM: (a) principal stresses in concrete; (b) stresses in the reinforcement direction; (c) stress-strain diagram of concrete in terms of maximum axial stresses; (d) stress-strain diagram of reinforcement; (e) Mohr's circles for concrete model in 3D CSFM; (f) bond shear stress-slip in terms of stresses at cracks and average strains; (e) Mohr's circles for concrete model in 3D CSFM; (f) bond shear stress-slip relationship for anchorage length verifications

The concrete model is based on the uniaxial compression constitutive laws prescribed by design codes for the design of cross-sections, which only depends on compressive strength. The parabola-rectangle diagram is used by default (see Fig. 2c), or a simplified elastic ideal plastic relationship can be chosen.

$$f_{c,red} = \eta_{fc} \cdot f_c$$

$$\eta_{fc} = \left(\frac{30}{f_c}\right)^{\frac{1}{3}} \leq 1.0$$

Where f_c is the concrete cylinder characteristic strength (in MPa for the definition of η_{fc}); η_{fc} represents the increase in the brittleness of concrete as its strength rises – defined in *fib* Model Code 2010.

The $f_{c,red}$ is then compared with the Equivalent Principal Stress $\sigma_{c,eq}$ (defined further).

The idealized bilinear stress-strain diagram for reinforcement (Fig. 2d) is considered. A user-defined stress-strain relationship can also be defined. Tension stiffening is automatically considered for each reinforcement element by modifying the input stress-strain relationship.

Bond-slip between the reinforcement and concrete is introduced in the finite element (FE) model by the relationship presented in Fig. 2f, with f_{bd}being the design value (factored value) of the ultimate bond stress specified by the design code for the specific bond conditions.

Anchors are defined as 1D elements being able to transfer normal forces as well as shear forces also considering the bending stiffness. However, only normal stress in the anchors is evaluated. The Cast-in-place reinforcement anchor behavior is the same as ribbed reinforcement (Anchorage type, bond, etc.) For Adhesive anchors, the user must define the design (factored) value of Bond strength based on the properties of assumed mortar.

Mohr-Coulomb plasticity theory implementation in 3D CSFM

In 3D CSFM implemented in IDEA StatiCa Detail, the angle of internal friction is considered as $\varphi = 0°$, as shown in Fig. 3

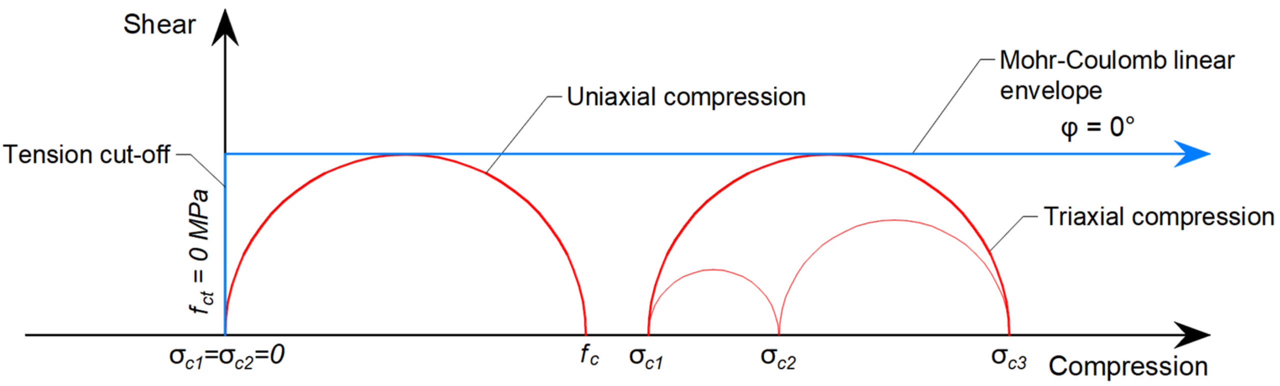


Fig. 3 Mohr's circles for concrete implemented in IDEA StatiCa Detail

Where f_c is concrete strength in compression, f_{ct} is concrete strength in tension, φ is the angle of internal friction, and σ_{c1}, σ_{c2}, σ_{c3} are the principal stresses of concrete under triaxial compression.

Equivalent Principal Stress expresses the equivalent uni-axial stress for a general tri-axial stress state.

$$\sigma_{c,eq} = \sigma_{c3} - \sigma_{c1}$$

The $\sigma_{c,eq}$ value is directly compared with uniaxial strength limits according to codes.

For a better understanding of the areas affected by tri-axial compression stress, the expression of the increase of the effective material strength due to tri-axial compression has been added to the IDEA StatiCa Detail application as a ratio $\sigma_{c3}/\sigma_{c,lim}$.

Finite element types for a 3D solution

Concrete and reinforcement elements are meshed independently and connected using multi-point constraints (MPC). Bond and anchorage end spring elements are inserted between the reinforcement and the MPC elements.

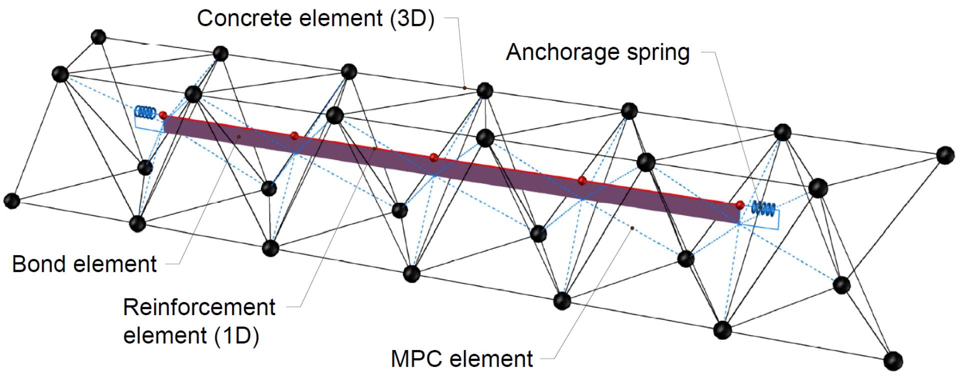


Fig. 4 Finite element model: reinforcement elements mapped to concrete mesh using MPC elements and bond elements.

$$G_b = k_g \cdot E_c/\emptyset$$

Concrete is modeled using mixed tetrahedral elements with nodal rotations. Implemented formulation guarantees accurate deformation results without spurious shear stress known as the shear lock effect even for the coarse mesh which would not be suitable for linear tetrahedral elements formulation. Elements are equipped with four integration points situated within the volume.

Reinforcement bars are modeled by 1D elements (only axial stiffness) which are connected to the bond elements modeling the slip behavior between rebars and concrete.

The bond element is a shell element with only a non-zero stiffness in shear between the two layers of nodes. The first layer (upper) nodes are connected to the reinforcement elements and the second layer (lower) nodes to the concrete mesh via MPC. The behavior of this element is described by the bond stress τ_b as a bilinear function of the slip between the upper and lower nodes, δ_u (see Fig. 5).

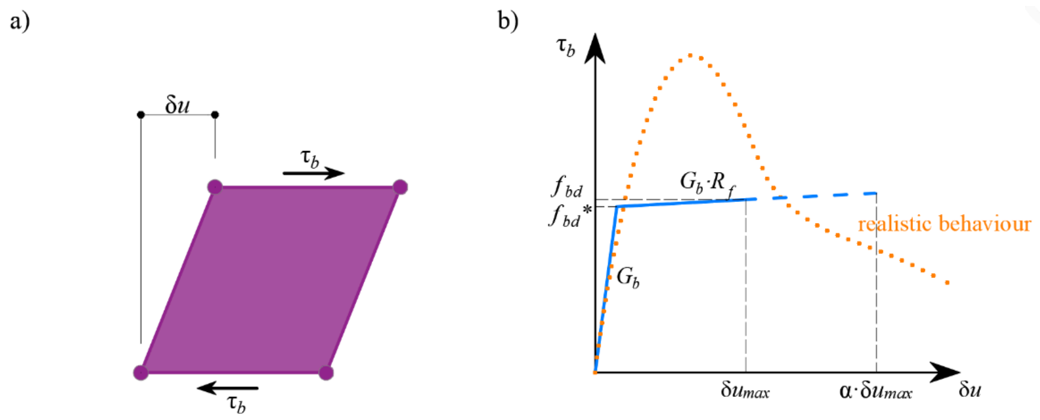


Fig. 5 (a) a conceptual illustration of the deformation of a bond element; (b) a stress-deformation function.

Where k_g is the coefficient depending on the reinforcing bar surface, E_c is the secant modulus of elasticity of concrete, Φ is the diameter of the rebar, and f_{bd} is the ultimate bond stress defined in the specified design code. The hardening of the plastic branch is calculated as $G_b/10^5$.

Anchorage spring behavior is determined from prescriptions of design codes, allowing the reduction of the basic anchorage length of the bars ($l_{b,net}$) due to bends, hooks, loop, etc., by a certain factor β. The intended reduction in $l_{b,net}$ is equivalent to the activation of the reinforcing bar at its end at a percentage of its maximum capacity given by the anchorage reduction coefficient β, as shown in Fig. 6a.

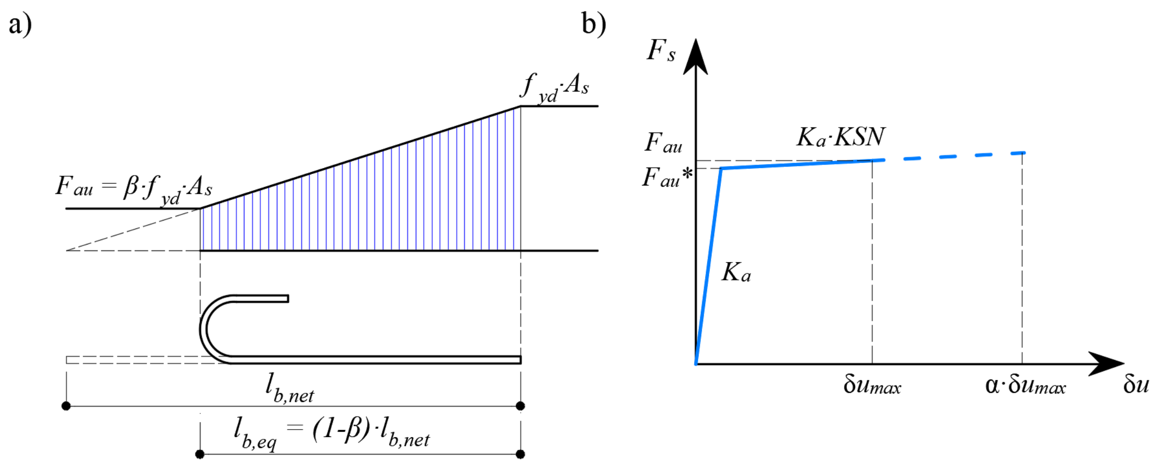


Fig. 6 A model for the reduction of the anchorage length: (a) anchorage force along the anchorage length of the reinforcing bar; (b) the slip-anchorage force constitutive relationship.

Where $l_{b,eq}$ is the design value (factored value) of the anchorage length, f_{yd} is the design value (factored value) of the yield strength of the reinforcement, A_s is the area of the cross-section of the reinforcing bar.

Load transfer devices

The base plate is modeled as a linear shell element defined by the modulus of elasticity *E*. The base plate can be loaded by the point load (Fx, Fy, Fz, Mx, My, Mz) and group of forces (Fx, Fy, Fz). Point loads and point moments directly load the corresponding node of the base plate. It means that there is no redistribution, only by the stiffness of the base plate.

Frictional compression-only contact is defined between the base plate and concrete, for the **shear transfer**, the user can choose from three options: **by anchors, by friction** (the design value of friction coefficient is to be input by the user), and **by shear lug**. The software does not allow the combination of these shear transfer mechanisms.

The shear lug is connected with the concrete mesh by constraints allowing only compression normal stress transfer.

Import from IDEA StatiCa Connection

The load is imported as a group of forces with values determined from the general stress state of the weld finite elements connecting the base plate and the adjacent element. To ensure identical forces in the anchors in both models, the anchors are disconnected in terms of axial forces after import. The anchors are then directly loaded with the force read from Connection and the plate is loaded in the same location with a directionally opposite force of the same value.

The solution method and load-control algorithm

A standard full Newton-Raphson (NR) algorithm is used. The load is applied sequentially in multiple increments. Results from the previous load increment are used to start the Newton solution of a subsequent one. If the NR iterations do not converge, the current load increment is reduced to half its value, and the NR iterations are retried. This load-control algorithm is also used to find the critical load, which corresponds to certain “stop criteria”.

·maximum strain in concrete 5% strain in compression (7% in tension)

·maximum strain in reinforcing bars – 5% strain in compression and tension by default

·maximum slip in bond elements – $\alpha \cdot \delta_{umax}$ (see Fig. 5)

·maximum displacement in anchorage elements – $\alpha \cdot \delta_{umax}$ (see Fig. 6)

·maximum shear deformation u_{xy} in frictional contact of a base plate and concrete

Where $\delta_{umax}$is the maximal slip used in code checks and α = 10.

Structural element checks according to Eurocode

The nonlinear solution of the 3D CSFM is in accordance with EN 1992-1-1 Cl. 5.7.

Material models:

The considered concrete model for ULS is defined in EN 1992-1-1 3.1.7 (1), (2).

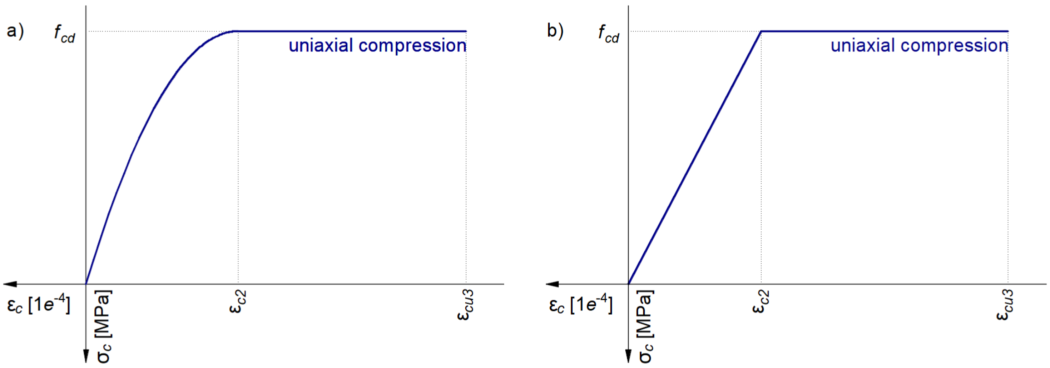


Fig. 7 The stress-strain diagrams of concrete for ULS: (a) a parabola-rectangle diagram; (b) a bilinear diagram.

An explicit failure criterion in terms of strains for concrete in compression is not considered (i.e., after the peak stress is reached it considers a plastic branch with ε_{cu2} (ε_{cu3}) in “stop criteria” of 5% while EN 1992-1-1 assumes ultimate strain less than 0.35%). This simplification does not allow the deformation capacity of structures failing in compression to be verified.

Assuming that f_c is considered as f_{ck} according to EN 1992-1-1 3.1.3, the design compressive and strength are calculated as follows.

$$f_{cd} = \alpha_{cc} \frac{f_{ck,red}}{\gamma_c} = \alpha_{cc} \frac{\eta_{fc} \cdot f_{ck}}{\gamma_c} \qquad \left(\eta_{fc} = \left(\frac{30}{f_{ck}} \right)^{\frac{1}{3}} \leq 1 \right)$$

The considered model for reinforcement is according to EN 1992-1-1, section 3.2.7.

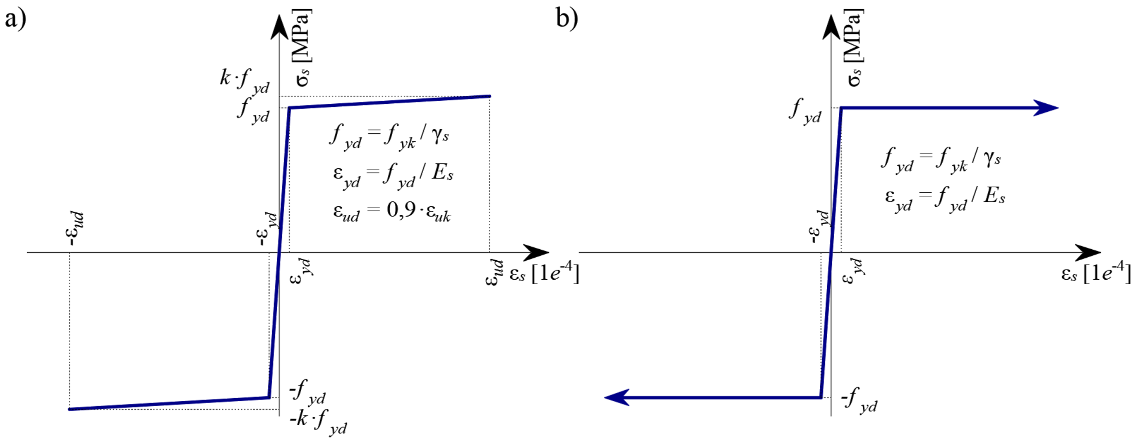


Fig. 8 A stress-strain diagram of the reinforcement: (a) a bilinear diagram with an inclined top branch; (b) a bilinear diagram with a horizontal top branch.

Tension stiffening is accounted for by modifying the stress-strain relationship of the bare reinforcing bar to capture the average stiffness of the bars embedded in the concrete (ε_i) (see Fig. 2d).

Ultimate limit state checks:

The concrete strength in compression is evaluated as the ratio between the maximum principal compressive stress $\sigma_{c,eq}$ obtained from FE analysis and the limit value $\sigma_{c,lim} = f_{cd}$

The strength of the reinforcement is evaluated in both tension and compression as the ratio between the stress in the reinforcement at the cracks $\sigma_s = \sigma_{sr}$ (see Fig. 2b) and the specified limit value $\sigma_{s,lim} = kf_{yd}$.

The bond shear stress is evaluated independently as the ratio between the bond stress τ_b calculated by the FE analysis and the ultimate bond strength f_{bd}, according to EN 1992-1-1, section 8.4.2.

The anchorage reduction coefficient β (see Fig. 9a) is determined according to EN 1992-1-1, section 8.4.4 Tab. 8.2, as follows.

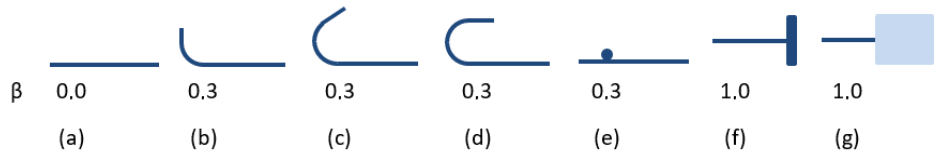


Fig. Available anchorage types and respective anchorage coefficients for longitudinal reinforcing bars in CSFM: (a) straight bar; (b) bend; (c) hook; (d) loop; (e) welded transverse bar; (f) perfect bond; (g) continuous

In order to comply with EN 1992-1-1, reinforcement must always be modeled with straight ends and the anchorage property must be used (anchorage spring must be applied). Modeling the anchorage hook by directly modifying the reinforcement geometry is not compliant with EN 1992-1-1.