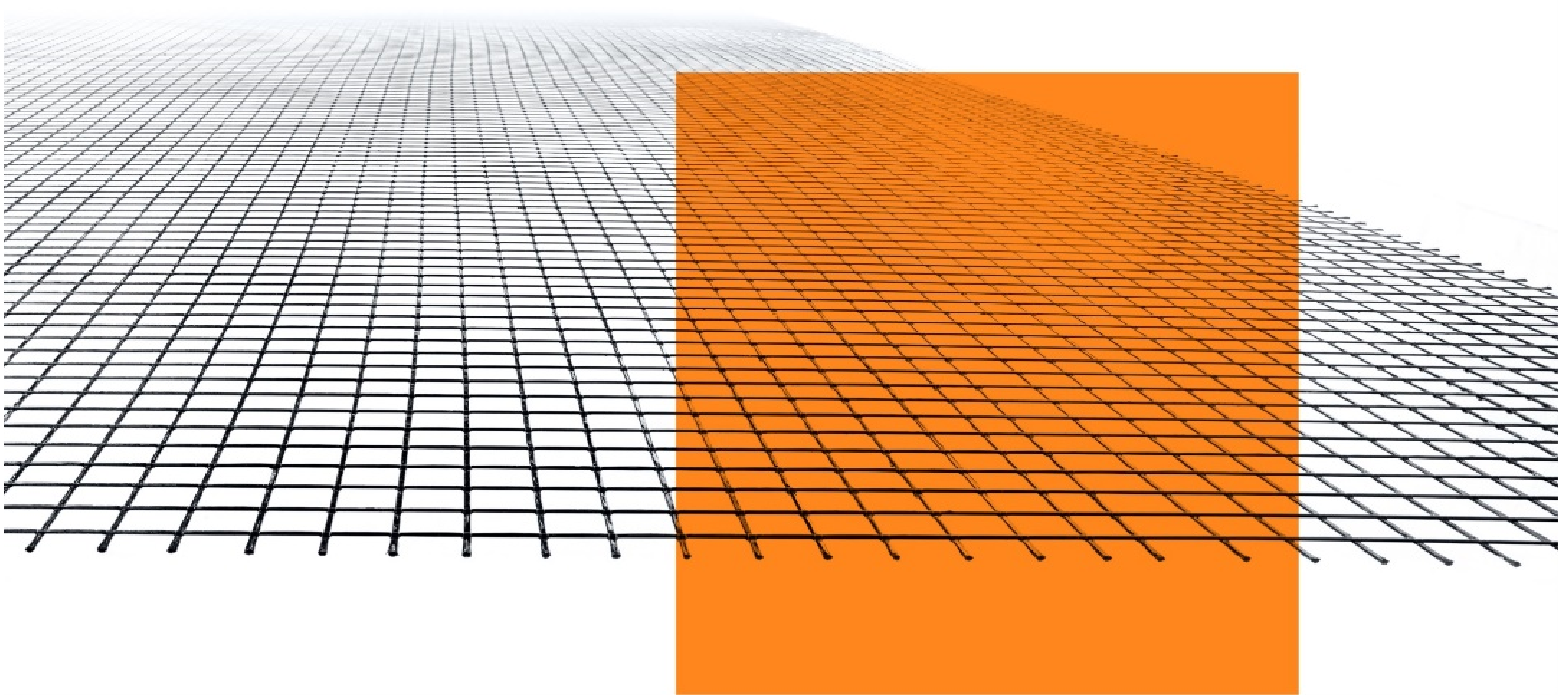
PRELIMINARY DESIGN CALCULATION

as a general recommendation for the design of plane carbon concrete components with solidian GRID

v1.3 | 07.2021



build solid.

Content

Changelog

Version	Date	Comment
1.0	26.01.2021	First release
1.1	16.03.2021	Correction in chapter 4.3.2 Shear load-bearing capacity
1.2	25.05.2021	Note in chapter 4.3.2 Shear load-bearing capacity
1.3	21.07.2021	Change of reinforcement in chapter 2.2 and following

1 Introduction

Building with non-metallic reinforcements is not entirely new: more than twenty years of basic research on textile or carbon concrete (for example: www.bauen-neu-denken.de) and pilot projects (www.solidian.com) show the enormous potential of this innovative and sustainable construction method. However, this promising building material has not yet been widely adopted in the daily planning practice, e.g. in engineering offices. This design example is intended to help to lower the hurdles in design and dimensioning.

1.1 Disclaimer

Carbon concrete and textile concrete components are currently not subject to any standards or guidelines. This design example should therefore be regarded as a preliminary design. It serves as an orientation and as a basis for the final structural design by a qualified structural engineer.

In the case of load-bearing components, in particular those whose load-bearing function poses a risk to life and limb, the responsible authoritiy of construction, structural engineers, experts, etc. may have to be consulted in order to assess the load-bearing capacity.

This design example and any further calculations, based on it, are only valid in conjunction with the materials listed here. This applies in particular to the reinforcements of solidian GmbH. Geometric and mechanical parameters can be found on our website www.solidian.com.

1.2 General information

The concrete slabs assessed in this preliminary design are balcony or pergola slabs, which are supported by steel structures (line bearings). A simply single-span beam is used as the structural system. The concrete elements are assumed without any superstructure.

Thus, only the dead weight of the concrete slab is used as dead load. Live loads are assumed according to DIN EN 1991-1-1/NA:2010-12.

Maximum (calculated) span of the slabs: 2,25 m

2 Material

2.1 Concrete

Design basis:

- Normal concrete according to DIN EN 206-1
- Concrete grade C50/60, d_g = 8 mm
- Mean concrete tensile strength f_{ctm} = 8,50 N/mm² (this value was determined/tested by the client for the concrete mixture according to DIN EN 12390-5)

2.2 Textile reinforcement

Chosen reinforcement:

- solidian GRID Q95-CCE-38-E5
- Assumed positional accuracy / installation tolerance = ± 3 mm

3 Assumed loads

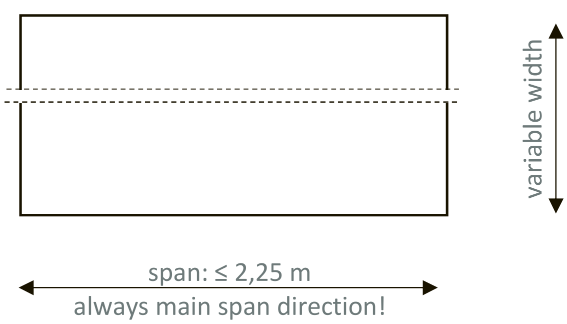
Dead loads slab: g_k = 24,0 kN/m³
Live loads: q_k = 4,0 kN/m² and Q_k = 2,0 kN (single load area: 50 mm x 50 mm square)

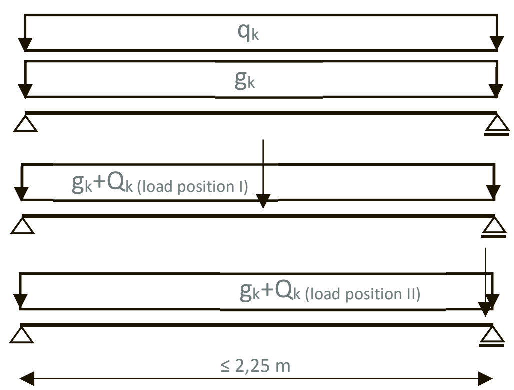
Transport and assembly conditions, bracing, supplementary live loads (e.g. wind or temperature), as well as extraordinary effects such as earthquakes are not subject of this structural design.

4 Structural design

4.1 Structural system

4.1.1 General information, geometry





4.1.2 Load arrangement

<u>Load case: dead load</u>

Slab: $g_k = 0{,}06 \times 24{,}0 = 1{,}44$ kN/m²

<u>Load case: live loads:</u>

Area live load: q_k = 4,0 kN/m²
Single load (alternative to q_k): Q_k = 2,0 kN (single load area: 50 mm x 50 mm square)

4.2 Analysis

Determination and presentation of internal forces - brief explanation:

- Bending moment m_x (required for the assessment of the ultimate limit state)
- Shear force q_y (required for the assessment of the ultimate limit state)

Subsequently, the decisive design internal forces are given as follows:

Ultimate limit state (basic combination):

$$E_d = E\left[\sum_{j\geq 1}\gamma_{G,j}\cdot G_{k,j}\oplus\gamma_P\cdot P_k\oplus\gamma_{Q,1}\cdot Q_{k,1}\oplus\sum_{i>1}\gamma_{Q,i}\cdot\psi_{0,i}\cdot Q_{k,i}\right]$$

4.3 Assessments

The following verifications are performed to ensure the load-bearing capacity in the ultimate limit state (ULS):

- Verification of the bending load-bearing capacity (ULS)
- Verification of the shear force bearing capacity (ULS)

4.3.1 Bending load-bearing capacity

Design internal forces:

Field moments for load combination $g_d + q_d$

max $m_{E,d}$ = (1,35 x 1,44 + 1,50 x 4,0) x 2,25²/8 = 5,02 kNm/m

Verification field moments:

$$\frac{M_d}{M_{Rd}} = \frac{5{,}02}{6{,}15} = 0{,}82 \quad \leq \quad 1{,}0 \quad ✓$$

Note:

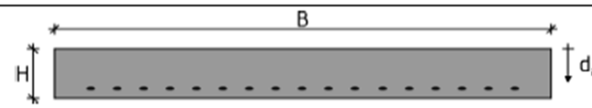
The investigation of the moment of resistance is determined by an iterative variation of the strain level, according to steel reinforced cross sections. The only difference is that the tension resistance is adjusted to the higher performance of the carbon reinforcement. To reduce the effort of this iterative calculation, an excel tool like shown on the following page is quite effective.

To support engineering offices in structural designs with solidian GRID, we like to provide this excel tool for free. Please don't hesitate to contact us to get the latest version.

Dimensioning reinforcement for field moments

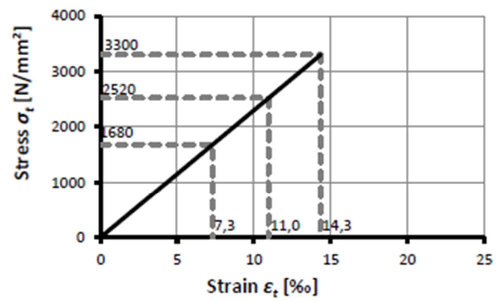
Cross section

Width	W =	1000	[mm]
Height	H =	60	[mm]
Effective height	d =	42	[mm]
Reinforcement layers	i =	1,0	



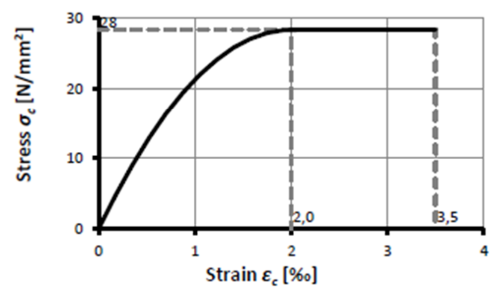
Reinforcement

solidian GRID	Q95-CCE-38-E5		(product in development)
Direction	logitudinal		
Bar cross section	A_r =	3,62	[mm²]
Reinforcement cross section	a_t =	95	[mm²/m]
Loss of strength	$\Delta_{f,t}$ =	0,10	[-]
Tensile strength	$f_{t,m}$ =	3.300	[N/mm²]
	$f_{t,k}$ =	2.800	[N/mm²]
	$f_{t,k,\Delta}$ =	2.520	[N/mm²]
	$f_{t,d}$ =	1.680	[N/mm²]
Modulus of elasticity	$E_{t,m}$ =	230.000	[N/mm²]
Failure strain	$\varepsilon_{t,m}$ =	14,3	[‰]
	$\varepsilon_{t,k}$ =	11,0	[‰]
	$\varepsilon_{t,d}$ =	7,3	[‰]



Concrete (acc. to DIN EN 1992-1-1:2011-01)

Concrete grade	C50/60		
Compression strength	$f_{c,m}$ =	58	[N/mm²]
	$f_{c,k}$ =	50	[N/mm²]
	$f_{c,d}$ =	28	[N/mm²]
Tensile strength	f_{ctm} =	4,1	[N/mm²]
Failure strain	ε_{c2} =	2,0	[‰]
	ε_{cu2} =	3,5	[‰]
Exponent	n =	2,00	[-]



Resisting bending moment

Concrete compression strain	$\varepsilon_{c,d}$ =	1,9	[‰]			
Max. reinforcement strain	$\varepsilon_{t,d}$ =	7,3	[‰]			
Height of compression area	x =	8,7	[mm]			
Concrete compression force	$F_{c,d}$ =	159,6	[kN]			
Reinforcement tensile force	$F_{t,d}$ =	159,6	[kN]			
Comcrete compression strain	$\varepsilon_{c,SP}$ =	1,19	[‰]			
Position compression force	a =	3,5	[mm]			
Sum horizontal forces	ΣH =	0	[kN]			
Partial safety factor	γ =	1,50	[-]			
Resisting bending moment	$M_{R,d}$ =	6,15	[kNm]	=	6,15	[kNm/m]

4.3.2 Shear load-bearing capacity

Design internal forces:

Shear load for load combination $g_d + q_d$

max $q_{y,d}$ = 7,94 kN/m

Shear load for load combination $g_d + Q_d$ (load position II)

max $q_{y,d}$ = 1,35 x 1,44 x 2,25/2 + 1,50 x 2,0 x 1/(0,05 + 2 x 0,03) = 29,46 kN/m

According to DIN EN 1992-1-1 (6.2.2) or DIN EN 1992-1-1/NA (6.2.2(1)), the shear load-bearing capacity $V_{Rd,c}$ without shear force reinforcement is as follows:

Concrete:	f_{ck} = 50,0 N/mm²
	f_{cd} = 28,3 N/mm²
Slab thickness:	h = 60 mm
Static effective height:	d = 42 mm

$$k = 1 + \sqrt{\frac{200}{d}} = 1 + \sqrt{\frac{200}{42}} = 3{,}18 \leq 2{,}0 \qquad \text{k = 2,0 [-]}$$

$$v_{min} = \frac{0{,}0525}{1{,}5} \cdot \sqrt{k^3 \cdot f_{ck}} = \frac{0{,}0525}{1{,}5} \cdot \sqrt{2^3 \cdot 50} = 0{,}70$$

$$V_{Rd,c} = 0{,}70 \cdot \frac{1.000 \cdot 42}{1.000} = 29{,}40\ kN/m$$

$$\frac{V_d}{V_{Rd,c}} = \frac{29{,}46}{29{,}40} = 1{,}00 \leq 1 \checkmark$$

Note:

The existing research-results (shear load resistance) of carbon-reinforcement are not totally comparable with an evaluation based EN 1992-1-1 for steel-reinforced elements.

To make sure that the evaluation above is correct, we suggest to do tests with the intended concrete and load bearing solution.

4.3.3 Absence of cracks

Decisive load combination in SLS:

Dead load + area live load (g_k + q_k)

Decisive internal forces (field moments):

$m_{1,k}$ = (1,0 x 1,44 + 1,0 x 4,0) x 2,25²/8 = 3,44 kNm/m

According to DIN EN 1992-1-1:2011-01, section 3.1.8, the bending tensile strength can be determined as follows:

$f_{ctm,fl}$ = (1,6 - h/1.000) x f_{ctm} ≥ f_{ctm}

$f_{ctm,fl}$ = (1,6 - 60/1.000) x 8,5 = 13,09 N/mm² > 8,5 N/mm²

f_{ctm} was determined and tested by the customer for the concrete mix he used according to DIN EN 12390-5. It's clearly higher than the standard value of 4,1 N/mm² according to DIN EN 1992-1-1.

To be on the safe side, the following evaluation and verification is carried out with the characteristic 5% quantile value (30% reduction). Basis for this reduction are existing test results of similar applications.

$$m_{Rk,crack} = \frac{13{,}09 \cdot 0{,}70 \cdot \frac{60^2}{6}}{1000} = 5{,}50\ kNm/m \qquad \text{for t = 60 mm}$$

$$\frac{m_{1,k}}{m_{Rk,crack}} = \frac{3{,}44}{5{,}50} = 0{,}63 < 1 \quad ✓$$

The slabs are uncracked by calculation in the serviceability state.

4.3.4 Deformation limits

Decisive load combination in SLS:

Dead load + area live load (g_k + q_k)

The maximum span is 2.250 mm.

In the following verification, it is assumed that the slab cross-sections in the SLS are uncracked. Thus, the full cross-section values can be applied for the deformation.

$$w_{max} = \frac{5 \cdot q l^4}{384 \cdot EI} = \frac{5 \cdot 5{,}44 \cdot 2{,}25^4}{384 \cdot 37.000.000 \cdot \frac{1 \cdot 0{,}06^3}{12}} = 0{,}0027\text{ m} = 2{,}73\text{ mm}$$

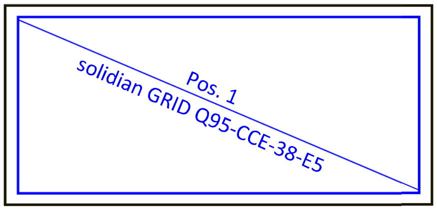
With assumed limits of L/300 in the field, the following limits and utilizations result:

$$\text{deformation limit}_{field} \frac{2.250}{300} = 7{,}50\ mm \qquad \eta_{field} = \frac{2{,}73}{7{,}50} = 0{,}36 < 1 \quad ✓$$

5 Reinforcement sketch and table of positions/pieces

Bottom layer

Span of the slab in the main direction: ≤ 2,25 m



Pos.	No. of pcs	Reinforcement-type	Length (mm)	Width (mm)
1	12	solidian GRID Q95-CCE-38-E5	6.000	2.210

Reinforcement type: solidian GRID Q95-CCE-38-E5 - 6,0 m x 2,21 m
Concrete cover (lower-side): 15 mm, max. position tolerance: ± 3 mm