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Deutschen Institut für Bautechnik • Allgemeine bauaufsichtliche Zulassung (abZ) vom
DIBt
Zulassung
Z-1.6-308
solidian GRID

Dimensioning example

as a general recommendation for the design of flat components made of carbon concrete with solidian GRID carbon mesh reinforcement approved by the building authority Germany

V1.0 | 2025

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Contents

1 Introduction

Building with non-metallic reinforcements is not new territory: over 20 years of research into innovative textile and carbon concrete as well as numerous pilot projects illustrate the enormous potential of this sustainable construction method. Despite the successes in research and practice, this innovative building material is still not widely used in planning practice, for example in engineering offices.

In 2024, the guideline "Components with non-metallic reinforcement" of the German Committee for Reinforced Concrete (DAfStb – Deutscher Ausschuß für Stahlbeton) was published in white print. This guideline facilitates the use of carbon, glass and basalt reinforcement in concrete construction and supplements DIN EN 1992-1-1 with the necessary information and specifications for design.

The guideline is formulated independently of the material and manufacturer. The specific material parameters can be found in the National technical approval of the respective manufacturers.

This dimensioning example is intended to help overcome hurdles in dimensioning and sizing.

1.1 Disclaimer

This document represents a preliminary structural design and serves as a guide and as a basis for the final structural design by a qualified structural engineer.

In the case of load-bearing components, especially those whose failure could pose a risk to life and limb, building authorities, structural engineers or experts must be consulted if necessary to check the load-bearing capacity.

The **DAfStb Guideline "Concrete components with non-metallic reinforcement"** in conjunction with the **National technical approval / General construction technique permit No. Z-1.6-308 for the "solidian GRID carbon reinforcement grid for the reinforcement of concrete components with non-metallic reinforcement"** is used for this preliminary design. The design example and the static calculations based on it apply exclusively in conjunction with the materials specified here. Geometric and mechanical characteristics of the carbon reinforcement grids are available on our homepage at www.solidian-kelteks.com or can be found in the approval document.

1.2 General information

The concrete slabs considered in this design example are used as balcony or pergola slabs with a component thickness of 8 cm and are supported on steel structures as linear bearings. The structural system is based on an articulated single-span beam. The maximum calculated span of the slabs is 2.25 m.

The component is classified in accordance with the exposure classes according to DIN EN 206-1 and DIN EN 1992-1-1/NA/A1 as an external component with direct sprinkling near the coast. This classification results in the following classes as component requirements: XC4 XS1 XF2 WA with an indicative minimum concrete strength class C30/37.

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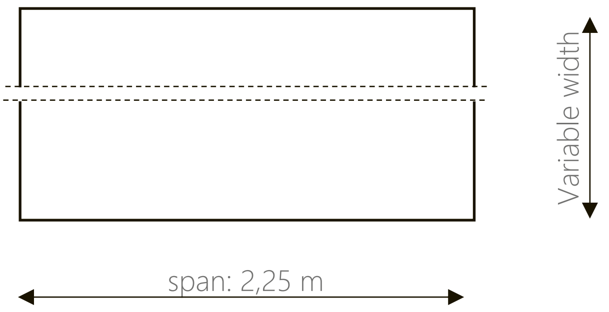
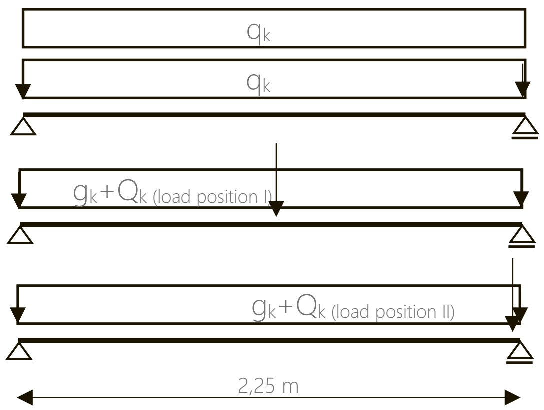
2 System and building materials

2.1 System





2.2 Concrete

Selected concrete strength class: **C40/50**

- Concrete strength class according to DIN EN 206-1 and DIN EN 1992-1-1
- Characteristic concrete compressive strength f_{ck} = 40,0 N/mm^2
- Mean value of the centric concrete tensile strength f_{ctm} = 4,1 N/mm^2
- Modulus of elasticity E_{cm} = 35.220 N/mm^2
- Limitation of the maximum grain size: d_g = 8 mm

2.3 Reinforcement

Selected reinforcement: **solidian GRID Q71-C-EP-s51-F207**

- Main load-bearing direction of the reinforcement: longitudinal direction
- Assumed positional accuracy / installation tolerance = ± 4 mm
- Laying the reinforcement grid with rovings in the direction of tension at the bottom
- Temperature range of the component: -20°C≤ T≤ 70°C

Material specifications and coefficients for the selected reinforcement mesh can be found in the approval document Z-1.6-308 or the technical product data sheets at www.solidian-kelteks.com. The selected grid reinforcement can be used for exposure classes X1-XC4, XD1-XD3 and XS1-XS3 in accordance with abZ/aBG Z-1.6-308.

2.4 Concrete cover and static effective height

Minimum concrete cover according to DAfStb Guideline, Part 1, Para. 4.4.1 or abZ/aBG No. Z-1.6-308, Para. 3.1:

$$c_{min} = \max(d_g + 5\text{ mm}; c_{min,b})$$

According to abZ/aBG No. Z-1.6-308, Para. 3.1: $c_{min,b}$ = 14 mm

$$c_{min} = \max(8\text{ mm} + 5\text{ mm}; 14\text{ mm}) = \max(13\text{ mm}; 14\text{ mm})\ 14\text{ mm}$$

Since static effective height d < 150 mm, the following applies according to DAfStb Guideline, Part 1, Section 4.4.1.3 (1): $\Delta c_{dev} = 5$ mm

Nominal dimension of the concrete cover: $c_{nom} = c_{min} + \Delta c_{dev}$

$c_{nom} = 14\ \text{mm} + 5\ \text{mm} = 19\ \text{mm}$

Through appropriate quality control during planning, design, manufacture and construction in accordance with DAfStb Guideline, Part 1, 4.4.1.3 (3) and Fig. R9-1, the retention dimension is reduced by 1 mm.
Laying dimension: $c_v \geq c_{nom} = c_{min} + \Delta c_{dev}$

$c_v = c_{nom} = 14\ \text{mm} + 4\ \text{mm} = 18\ \text{mm}$ selected: $c_v = 18$ mm

Despite laying the reinforcement grids with the lower rovings in the load-bearing direction, the static effective height d is simplified in accordance with DAfStb Guideline, Part 1, Section R6.1.1 (R3) and assumed to be on the safe side with:

$d = h - c_v - h_G/2 = 80\ \text{mm} - 18\ \text{mm} – 3{,}5\ \text{mm} / 2 = 60{,}25 \approx 60\ \text{mm}$

For thin components ($d \leq 70$ mm), the static effective height d according to DAfStb Guideline, Part 1, Para. 2.3.4.1 (R2) must be reduced to d_{eff} when verifying of bending load capacity.

$d_{eff} = (d - 4) / (66/70) = (60-4) / (66/70) = 59{,}4 \approx 59\ \text{mm}$

3 Impacts

3.1 Characteristic values

Carbon concrete weight: $\gamma = 24{,}0\ \text{kN/m}^3$
Dead weight: $g_k = 0{,}08 \times 24{,}0 = 1{,}92\ \text{kN/m}^2$
Payloads: $q_k = 4{,}0\ \text{kN/m}^2$
$Q_k = 2{,}0$ kN (individual load on an area of 50 x 50 mm)

Use without additional installation is assumed, so that only the dead weight of the concrete slab is taken into account as the dead load. The live loads are applied in accordance with DIN EN 1991-1-1/NA:2010-12. Transport and assembly conditions, bracing, additional live loads (e.g. wind, temperature) and extraordinary effects such as earthquakes are not included in this design example.

3.2 Design values in the ultimate limit states

Partial safety factors in accordance with the Annex to DIN EN 1990

Influence	Inexpensive	Unfavorable
permanent	$\gamma_{G,inf} = 1{,}0$	$\gamma_{G,sup} = 1{,}35$
variable	$\gamma_{Q,inf} = 0$	$\gamma_{Q,sup} = 1{,}5$

4 Determination of internal forces

4.1 Ultimate limit states

Determination and representation of internal forces - brief explanation:

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

The decisive design internal forces are then specified as follows:

Ultimate limit state (basic combination):

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

Relevant load cases:

Load case 1: $g_d + q_d$

max m_{Ed} = (1,35 x 1,92 + 1,50 x 4,0) x 2,25² / 8 = 5,44 kNm/m

max v_{Ed} = (1,35 x 1,92 + 1,50 x 4,00) x 2,25 / 2 = 9,67 kN/m

Load case 2: $g_d + Q_d$ (load position II)

For the shear force verification, the concentrated load is applied at a distance of 2 x d = 120 mm from the edge of the support. In this case, the load position of the concentrated load directly at the free edge of the slab is not possible due to the local edge conditions (caused by the balcony parapet and railing), which means that load propagation is possible in both directions. The distribution width of the shear force is set at:

$t_{y,M}$ = 50 mm + 2 x 40 mm = 130 mm

max v_{Ed} = 1,35 x 1,92 x 2,25/2 + 1,50 x 2,0 x 1/0,13 x (2,13/2,25) = 24,76 kN/m

4.2 Serviceability limit states

Relevant load case:

Load case 3: g_k + $_{q(k)}$

m_{Ek} = (1,0 x 1,92 + 1,0 x 4,0) x 2,25²/8 = 3,75 kNm/m

5 Design in the ultimate limit states

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)

5.1 Design values of the building materials

5.1.1 Partial safety factors

Concrete (permanent and temporary): γ_c = 1,5
Carbon grid (permanent and temporary): γ_{nm} = 1,3 (flexural tension)
γ_b = 1,5 (bond)

5.1.2 Concrete

Design compressive strength:

$$f_{cd} = \alpha_{cc} \cdot \frac{f_{ck}}{\gamma_c} = 0{,}85 \cdot \frac{40}{1{,}5} = 22{,}7\ \mathrm{N/mm^2}$$

5.1.3 Carbon grid

Rated tensile strength:

$$f_{nm,d} = \alpha_{nmt} \cdot \alpha_{Tt} \cdot \frac{f_{nm,k}}{\gamma_{nm}} = 0{,}83 \cdot 1{,}00 \cdot \frac{1200}{1{,}3} = 766\ \mathrm{N/mm^2}$$

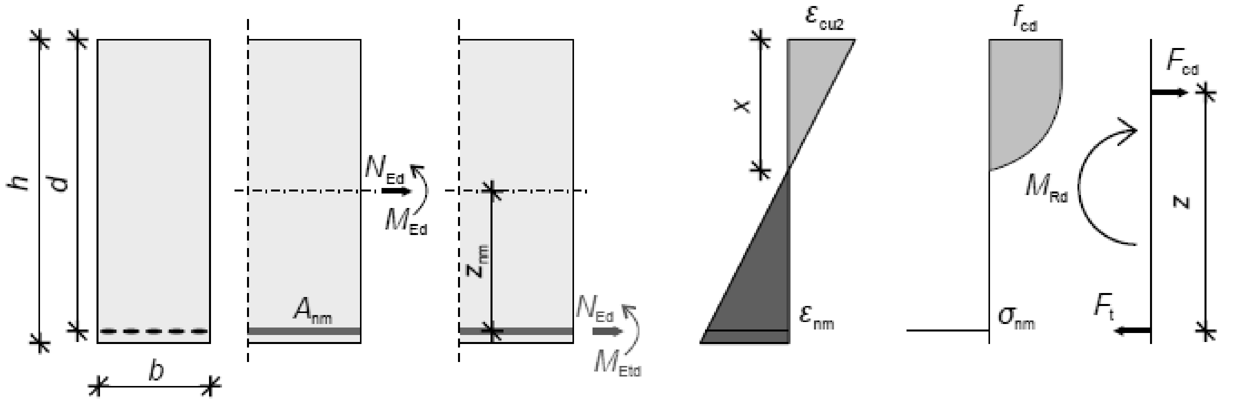
5.2 Verification of the bending load capacity

The absorbable bending moment is determined in the same way as for reinforced concrete by iterative variation of the expansion plane. The only difference is that the design strengths are adapted to the more powerful carbon reinforcements. To minimize the calculation effort, the iterative calculation is carried out using an Excel tool

We are happy to provide this Excel tool free of charge to support engineering offices in dimensioning with solidian GRID. Please contact us to receive the latest version.

Figure R6-3 of the DAfStb Guideline, Part 1, Section 6.1.2 shows the permissible limits of the strain distribution:

Concrete failure



Reinforcement failure

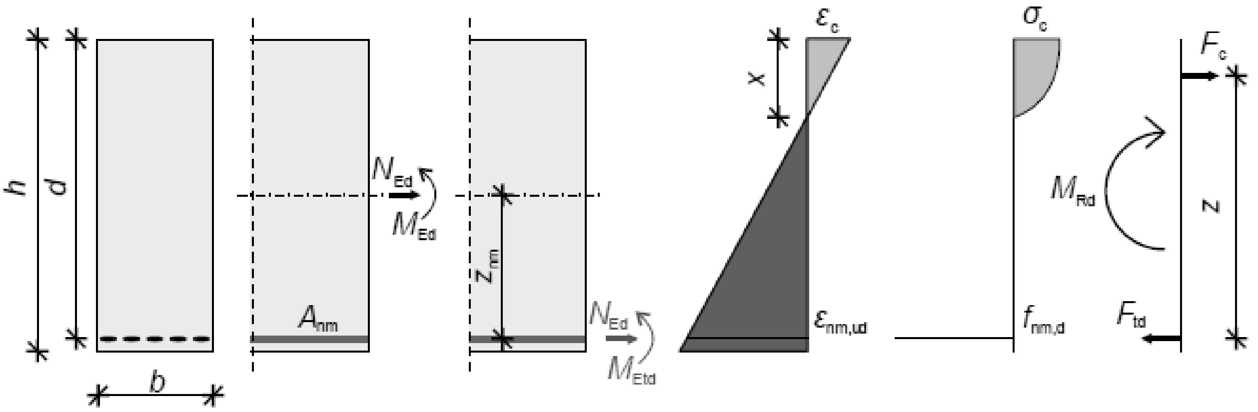


Figure R6-3: Limits of the strain distribution in the ULS of the DAfStb Guideline, Part 1

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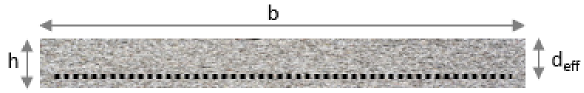
Dimensioning of reinforcement Field moments

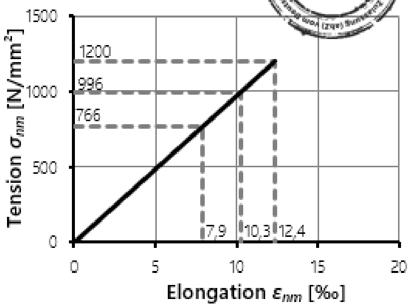
Cross section

Width	b =	1000	[mm]
Thickness	h =	80	[mm]
Static usable height	d =	60	[mm]
Static effective height	d_{eff} =	59,4	[mm]



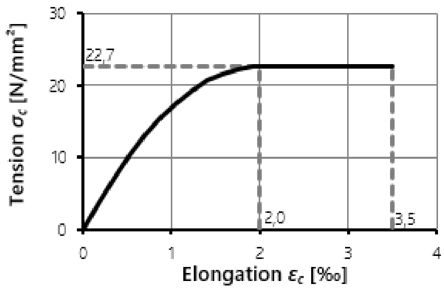
Reinforcement acc. to Germal technical approval abZ/aBG Z-1.6-308

solidian GRID	Q71-C-EP-s51-F207			(Reinforcement grid acc. to abZ/aBG Z-1.6-308)
Direction	Transverse direction			
Nominal cross section / strand	A_{nm} =	8,8	[mm²]	
Nominal cross section / m	a_{nm} =	173	[mm²/m]	
Char. short-term tensile strength	$f_{nm,k}$ =	1.200	[N/mm²]	
Coefficient of durability	α_{nmt} =	0,83	[-]	
Coefficient of temperature	α_{Tt} =	1,00	[-] für	$-20°C \leq T \leq 70°C$
Char. long-term tensile strength	$f_{nm,k\,100a}$ =	996	[N/mm²]	
Design value of the tensile stress	$f_{nm,d}$ =	766	[N/mm²]	
Modulus of elasticity	$E_{nm,m}$ =	97.000	[N/mm²]	
Char. elongation at break	$\varepsilon_{nm,uk}$ =	12,4	[‰]	
Char. elongation at break (long-t.)	$\varepsilon_{nm,uk\,100a}$ =	10,3	[‰]	
Design value elongation at break	$\varepsilon_{nm,ud}$ =	7,9	[‰]	



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

Designation	C40/50	(Concrete strength class usable acc. to abZ/aBG Z-1.6-308, Para. 1)	
Compressive strength	f_{cm} =	48	[N/mm²]
	f_{ck} =	40	[N/mm²]
	f_{cd} =	22,7	[N/mm²]
Tensile strength	f_{ctm} =	3,5	[N/mm²]
Elongation at break	ε_{c2} =	2,0	[‰]
	ε_{cu2} =	3,5	[‰]
Exponent	n =	2,00	[-]



Bending load capacity acc. to DAfStb Guideline "Concrete components with non-metallic reinforcement", Edition January 2024

Ultimate compressive strain	ε_c =	1,6	[‰]
Reinforcement elongation	ε_{nm} =	7,9	[‰]
Concrete compressive force	F_c =	132,5	[kN]
Reinforcement tensile force	F_{nm} =	132,5	[kN]
Total horizontal forces	ΣH =	0	[kN]
Pressure zone height	x =	10,0	[mm]
Position concrete compressive force	a =	3,6	[mm]
Lever arm of the internal forces	z =	55,8	[mm]
Absorbable bending moment	$M_{R,d}$ =	7,39	[kNm]
	$m_{R,d}$ =	7,39	[kNm/m]

Iteration Betonstauchung

Iteration Bewehrungsdehnung

Verification of the bending load-bearing capacity:

$$\frac{m_{Ed}}{m_{Rd}} = \frac{5{,}44}{7{,}39} = 0{,}74 \quad < \quad 1{,}0$$ ✓

5.3 Verification of the shear force bearing capacity

According to the DAfStb Guideline, Part 1, Section 6.2.2, the shear force load-bearing capacity $V_{Rd,c}$ of components without shear force reinforcement required by calculation (without normal force loading) is:

$$V_{Rd,c} = \left[C_{Rd,c} \cdot k \cdot k_\lambda \cdot \left(100 \cdot \rho_l \cdot \left(\frac{E_{nml}}{E_S}\right) \cdot f_{ck}\right)^{\frac{1}{3}}\right] \cdot b_w \cdot d$$

With:

- Pre-factor for calculating the shear force bearing capacity without shear force reinf.: $C_{Rd,c} = \frac{0,155}{1,5}$
- Coefficient for the influence of the static effective height $k = \frac{1}{\sqrt{1+\frac{d}{200}}} = \frac{1}{\sqrt{1+\frac{60}{200}}} = 0,877$
- Degree of longitudinal reinforcement: $\rho_l = \frac{A_{nm}}{b_w \cdot d} = \frac{173}{1000 \cdot 60} = 0,00288 \leq 0,02$
- Shear slenderness with decisive single load on single-span beam: $\lambda = \frac{(a-d)}{d} = \frac{215-60}{60} = 2,583$

  with distance between load axis and bearing axis: a = 25 + 120 + 70 = 215 mm
- Thrust slimming factor: $k_\lambda = 1 + 2,824 \cdot e^{\left(-\frac{\lambda}{4,538}\right)} = 1 + 2,824 \cdot e^{\left(-\frac{2,583}{4,538}\right)} = 2,598$
- E-module of reinforcing steel: E_S = 200.000 N/mm²

$$V_{Rd,c} = \left[\frac{0,155}{1,5} \cdot 0,877 \cdot 2,598 \cdot \left(100 \cdot 0,00288 \cdot \left(\frac{97.000}{200.000}\right) \cdot 40\right)^{\frac{1}{3}}\right] \cdot 1.000 \cdot 60 = 25.066\ N = 25,0\ kN$$

<u>Verification of shear force bearing capacity:</u>

$$\frac{v_{Ed}}{v_{Rd,c}} = \frac{24,78}{25,0} = 0,99 \leq 1 \checkmark$$

6 Design in the serviceability limit states

The following verifications are carried out to ensure serviceability in the serviceability limit state (SLS):

- Proof of freedom from cracks
- Verification of the deformation limits (SLS)

6.1 Freedom of cracks

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/1000) - f_{ctm} ≥ $_{f(ctm)}$

$f_{ctm,fl}$ = (1,6 - 80/1000) – 3,5 = 5,32 N/mm² > 3,5 N/mm²

$$m_{cr} = \frac{5{,}32 \cdot \frac{80^2}{6}}{1000} = 5{,}67\ \mathrm{kNm/m}$$ (for t = 80 mm)

To be on the safe side, the following evaluation and verification is carried out using the characteristic 5% quantile value (30% reduction). This reduction is based on existing test results from comparable applications.

$$m_{cr} = \frac{0{,}70 \cdot 5{,}32 \cdot \frac{80^2}{6}}{1000} = 3{,}97\ \mathrm{kNm/m}$$ (for h = 80 mm)

Proof of freedom from cracks

$$\frac{m_{Ek}}{m_{cr,0,05}} = \frac{3{,}75}{3{,}97} = 0{,}95 < 1$$ ✓ The panels are computational uncracked when in use.

6.2 Limiting the deformation

In the following verification, it is assumed that the slab cross-sections in the SLS are uncracked. This means that the full cross-section values can be used for the deformation. The component center deflection results in:

$$\mathrm{w_{max}} = \frac{5 \cdot \mathrm{ql}^4}{384 \cdot \mathrm{EI}} = \frac{5 \cdot 5{,}92 \cdot 2{,}25^4}{384 \cdot 35.000.000 \cdot \frac{1 \cdot 0{,}08^3}{12}} = 0{,}00132\ \mathrm{m} = 1{,}32\ \mathrm{mm}$$

Assuming limit values of L/300 in the field, the following limits and utilizations result:

$$\mathrm{Grenzwert}_{Feld} \frac{2.250}{300} = 7{,}50\ mm$$

Proof of utilization:

$$\eta_{Feld} = \frac{1{,}32}{7{,}50} = 0{,}18 < 1$$ ✓

7 Reinforcement rules

7.1 Anchoring at the end support

According to DAfStb Guideline, Part 1, Section 8.4.3, the required basic value of the anchorage length $l_{b,rqd}$ for anchoring the force A_{nm} - $f_{nm,d}$ of a grid assuming a constant bond stress f_{bd}:

$$l_{b,rqd} = \frac{Ø_{nm}}{4} \cdot \frac{f_{nm,d}}{f_{bd}}$$

With:

- Nominal diameter of the non-metallic reinforcement: ϕ_{nm} = 3,35 mm
- Applicable char. reinforcement stress in the anchorage check: $\sigma_{nm,max,lb}$ here $f_{nm,k}$= 1.020 N/mm²
- Characteristic short-term bond strength for anchoring: f_{bk} = 2,90 N/mm²

Design stress in the anchorage verification:

$$f_{nm,d} = \alpha_{nmt} \cdot \alpha_{Tt} \cdot \frac{f_{nm,k}}{\gamma_{nm}} = 0{,}83 \cdot 1{,}0 \cdot \frac{1020}{1{,}3} = 651 \text{ N/mm}^2$$

Compound voltage:

$$f_{bd} = \alpha_{nmb} \cdot \alpha_{Tb} \cdot \frac{f_{bk}}{\gamma_b} = 0{,}83 \cdot 1{,}0 \cdot \frac{2{,}90}{1{,}5} = 1{,}60 \text{ N/mm}^2$$

Required basic value of the anchorage length:

$$l_{b,rqd} = \frac{Ø_{nm}}{4} \cdot \frac{f_{nm,d}}{f_{bd}} = \frac{3{,}35}{4} \cdot \frac{651}{1{,}60} = 340 \text{ mm}$$

According to DAfStb Guideline, Part 1, Section 8.4.4, the design value of the anchorage length is l_{bd}:

$$l_{bd} = \frac{a_{nm,erf}}{a_{nm,vorh}} \cdot \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_4 \cdot \alpha_5 \cdot l_{b,rqd} \geq l_{b,min}$$

With:

- $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 1{,}0$
- Minimum anchoring length: $l_{b,min}$ = 76 mm

The existing edge tensile force F_{Ed} in the reinforcement is calculated using the shear force

V_{Ed}= 1,35 x 1,92 x 2,25/2 + 1,50 x 2,0 x 1/0,13= 25,99 kN/m

based on load position II for load case 2:

$$F_{Ed} = V_{Ed} \cdot \frac{a_l}{0{,}9 \cdot d} \geq \frac{V_{Ed}}{2} = 25{,}99 \cdot \frac{0{,}06}{0{,}9 \cdot 0{,}06} = 28{,}88 \text{ kN/m} \geq 13{,}0 \text{ kN/m}$$

This results in the reinforcement required to absorb the edge tensile force:

$$a_{nm,erf} = \frac{F_{Ed}}{f_{nm,d}} = \frac{28880}{651} = 44{,}4 \text{ mm}^2/m$$

Design value of the anchorage length:

$$l_{bd} = \frac{44{,}4\ mm^2/m}{173\ mm^2/m} \cdot 340\ mm = 87{,}3\ mm$$

The existing support length is 140 mm minus the concrete cover on the end face:

$l_{b,vorh} = t - c_v = 140\ mm - 18\ mm = 122\ mm > l_{bd} = 87{,}3\ mm > l_{b,min} = 76$ ✓

8 Constructive design

8.1 Minimum reinforcement

According to DAfStb Guideline, Part 1, 9.3.1.1, a minimum reinforcement $A_{nm,min}$ must generally be provided. This is calculated for the cracking moment M_{cr} with the mean value of the concrete tensile strength f_{ctm} and the design stress of the reinforcement $f_{nm,d}$.

Cracking moment (assuming $f_{ct,eff} = f_{ctm}$) in accordance with DAfStb Guideline, Part 1, Section 7.1 (2)):

$$M_{cr} = f_{ctm} \cdot W_u$$

$$M_{cr} = 3{,}5 \cdot \frac{100 \cdot 8^2}{6} \cdot 10^{-3} = 3{,}73\ kNm/m$$

In accordance with DAfStb booklet 660, B-17, the calculation for z^{II} is simplified to 0,8 - d (here 0,8 - d_{eff}).

$$a_{nm,min} = \frac{M_{cr}}{z^{II} \cdot f_{nm,d}}$$

$$a_{nm,min} = \frac{3{,}73 \cdot 10^6}{0{,}8 \cdot 59 \cdot 766} = 103\ mm^2/m \quad < 173\ mm^2/m$$

As the bending tensile strength $f_{ctm,fl} = 5.32\ N/mm^2$ (see Chapter 6.1) was used for the verifications in the SLS in accordance with DAfStb Guideline, Part 1, 7.1 (2), the minimum reinforcement for the corresponding cracking moment is also calculated.

$$M_{cr} = 5{,}32 \cdot \frac{100 \cdot 8^2}{6} \cdot 10^{-3} = 5{,}67\ kNm/m$$

$$a_{nm,min} = \frac{5{,}67 \cdot 10^6}{0{,}8 \cdot 59 \cdot 766} = 157\ mm^2/m \quad < 173\ mm^2/m$$ ✓

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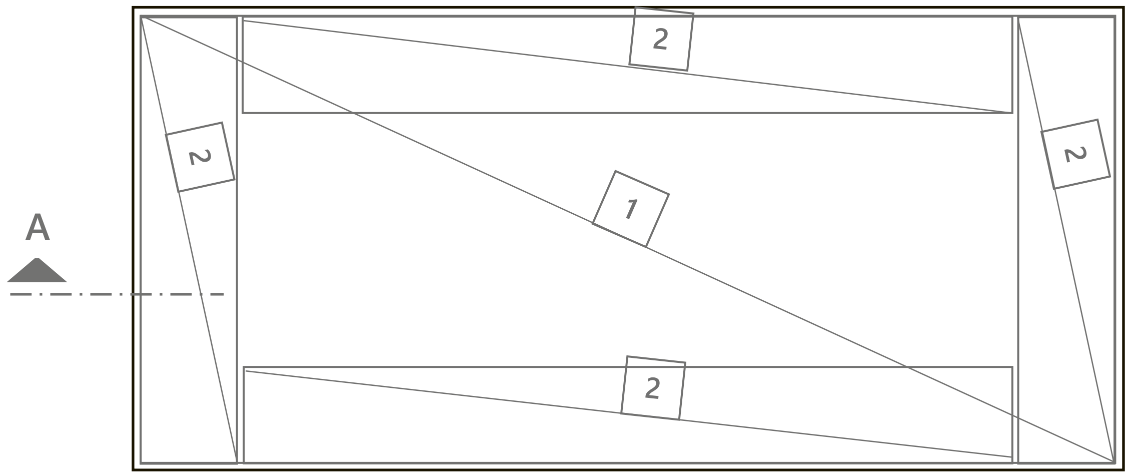
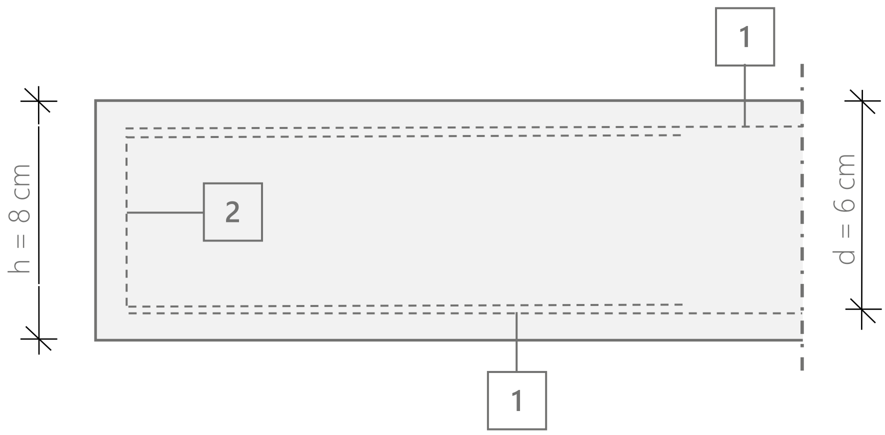
9 Reinforcement sketch

Top (and bottom) layer and edging (all-round)



Section A

Recommended structural edging (all-round)



Bending list

Pos.	pcs.	Bending form (not to scale)	Reinforcement type
1	2		solidian GRID Q71-C-EP-s51-F207
2	2		solidian GRID Form Q71-CCE-51-U

Change list

Version	Date	Comment
1.0	01/2025	First publication

build solid.

CERTIFIED
ISO 9001
ISO 14001

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