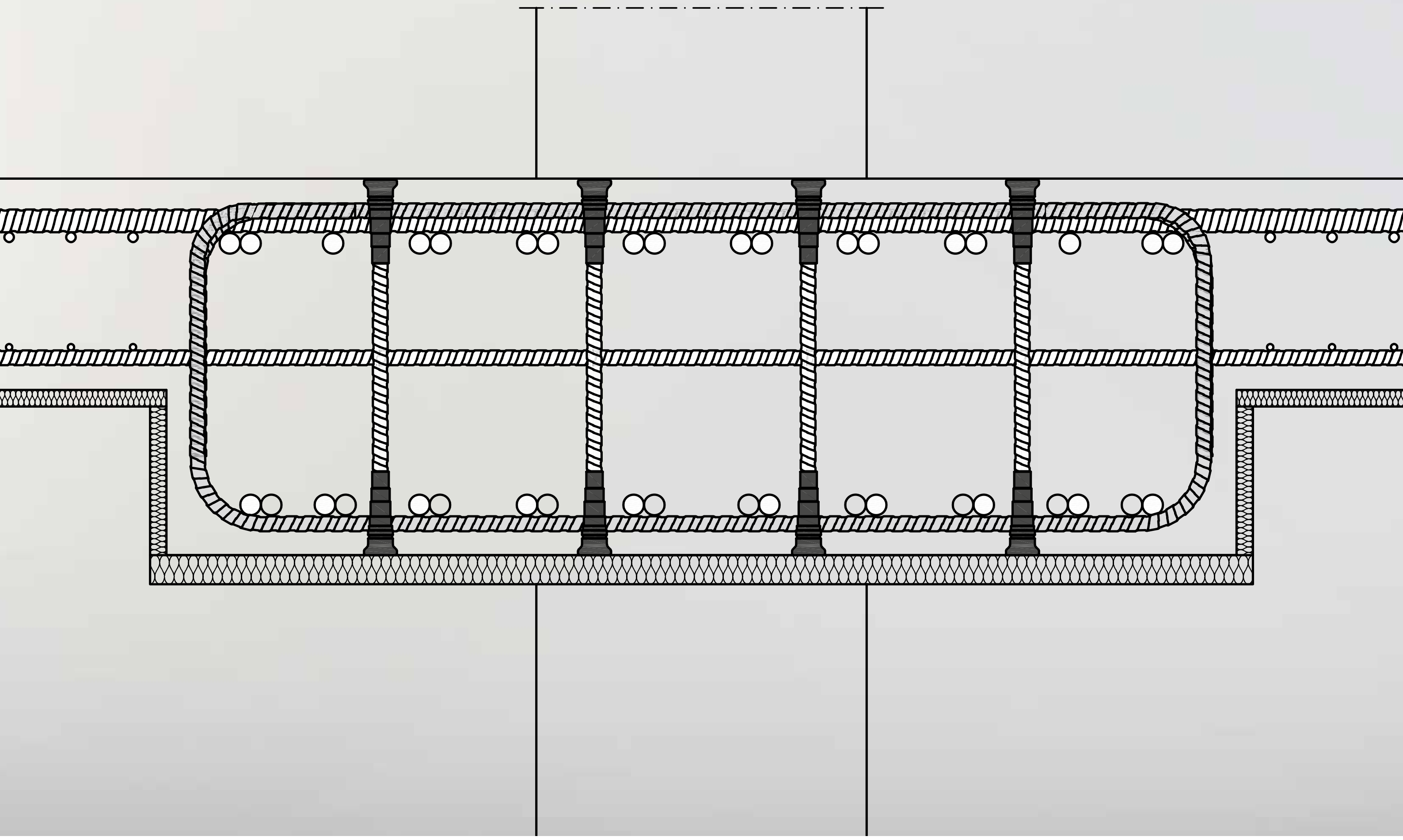


TECHNICAL INFORMATION – NOVEMBER 2025

Combar®
glass-fibre reinforcement

Planning and consulting service

The engineers of Schöck's technical design department would be very happy to advise you on static, structural and building-physics questions and will produce for you proposals for your solution with calculations and detailed drawings.
For this please send your planning documentation (general arrangements, sections, static specifications) with the address of the building project to:

Schöck Bauteile GmbH
Schöckstraße 1
D-76534 Baden-Baden

Contact
Tel.: +49 (0) 7223 967-144
E-Mail: export@schoeck.com

Product information
Information about our products is available online at
www.schoeck.com

Terms and conditions of sale and delivery
The currently applicable terms and conditions of sale and delivery are available online at
www.schoeck.com/conditions.

Notes | Symbols

Technical Information

- This Technical Information on the respective product application is valid only if complete and therefore may only be reproduced as a whole. With texts and graphics published solely as extracts there is a danger of communicating insufficient or even misleading information. Therefore dissemination is the sole responsibility of the user or the person carrying out the process!
- This Technical Information takes into account the european standards (Eurocode 2/EN) and product specific approvals.
- If the installation takes place in countries not applying these standards, then the valid Technical Information of the respective country is to be applied.
- The current Technical Information is to be applied. A current version is available at: www.schoeck.com/download-technical-information/en

Notes Symbols

Hazard note
The triangle with exclamation mark indicates a hazard warning. This means there is a danger to life and limb if compliance is not observed.

Info
The square with an “i” indicates important information which, for example, must be read in conjunction with the design.

Check list
The square with a tick indicates the check list. Here, the essential points of the design are briefly summarised.

Table of contents

Summary of types

Straight bars

As load-bearing reinforcement to absorb tensile forces

Diameters / standard lengths
⌀ 8 mm / 12 m and 6 m
⌀ 12 mm / 12 m and 6 m
⌀ 16 mm / 12 m and 6 m
⌀ 20 mm / 12 m and 6 m
⌀ 25 mm / 12 m and 6 m
⌀ 32 mm / 12 m and 6 m

Longer lengths are available on request

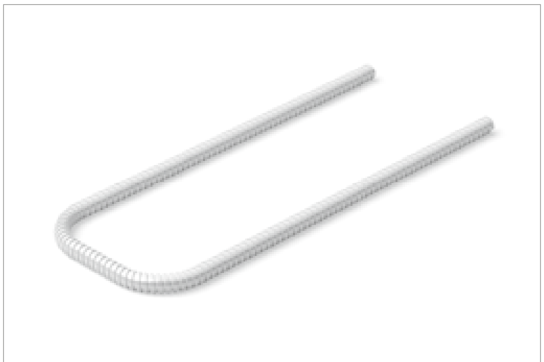
Bar with anchorage head

As shear reinforcement and to reduce the anchorage length of straight bars.

Diameters / standard lengths
⌀ 12 mm / up to 5 m
⌀ 16 mm / up to 5 m
⌀ 20 mm / up to 5 m
⌀ 25 mm / up to 5 m
⌀ 32 mm / up to 5 m

Longer lengths are available on request

U-bar

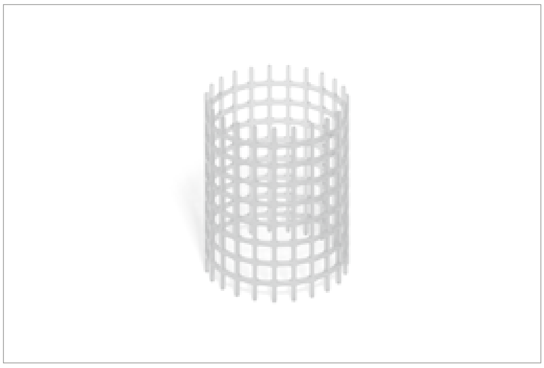


As shear reinforcement, outside dimensions up to 2.0 × 3.2 m, minimum bending roll diameter = 7 $\cdot d_s$

Diameter / maximum length
⌀ 12 mm / up to 12 m
⌀ 16 mm / up to 12 m
⌀ 20 mm / up to 12 m

Schöck Combar® Part C clips (⌀8 and ⌀12)

Schöck Combar® Part D spacer



In addition, cable ties and cable clamps are available for joining the bars.

Overview of applications

Floor slabs with risk of corrosion
Underground car parks, ramps, industrial halls, vehicle depots, fire stations
Minimum concrete cover required
No damage due to chloride attack and carbonation
No cost-intensive surface coating and maintenance necessary
Cost-effective in the long-term

Bridge construction
Bridge parapets, emergency walkways, bridge decks
Minimum concrete cover required
No damage due to chloride attack and carbonation
No maintenance necessary
Cost-effective in the long-term

Hydraulic engineering, marine construction and delicate prefabricated parts
Minimum concrete cover required
No damage due to chloride attack and carbonation
No maintenance necessary
Cost-effective in the long-term

Power plants and industrial facilities
No heating of the reinforcement due to induction
No stray currents/losses during operation

Railway and track construction, industrial floors
No interference with signalling and control systems
No induction currents in the area of points

Specialised civil engineering applications
Smooth passage through the shaft wall by tunnel boring machine
Reduction in construction time and cost savings

Medical and research facilities
No interference with electromagnetic instruments

Structural biology
No distortion of the Earth's magnetic field
No propagation of alternating electric fields

Material

Material | Approval

Combar® glass fibre composite
Combar® (composite rebar) is classified as a fibre composite. In these composites, fibres are combined with other materials to improve their properties and synergy effects. The properties of the resulting material can be customised using fibrous material, fibre strand orientation and suitable additives and bonding agents.
One of the best known materials in this class is glass fibre-reinforced plastic (GFRP). This is used in many areas, such as the electrical or shipbuilding industry to obtain products that are lightweight, strong, robust and durable.

Approval
Combar® is approved by the German Institute for Structural Engineering (DIBt) (Z-1.6-238). Regulations in the form of expert opinions are available for design situations outside the scope of the approval.

Environmental product declaration
An environmental product declaration (EPD) is available for Schöck Combar®.

Material properties

Material properties

As a fibre composite, Combar® can be used for a range of solid construction applications due to the following properties:

- Durable
- Corrosion resistant
- Non-magnetic
- Electrically non-conductive
- Easy to machine
- Considerably lighter than steel

Comparison of reinforcing steel and Schöck Combar®

In special applications, such as in corrosive and electromagnetic environments, the material properties of reinforcing steel do not meet the given requirements. In such cases, the Combar® glass fibre composite opens up completely new possibilities.

Material properties (straight bars)	Reinforcing steel EN ISO 15630 DIN 488	Schöck Combar® according to EC2
Characteristic yield strength f_{yk} (N/mm²)	500	≥ 1000
Design value for the yield strength f_{yd} (N/mm²)	435	≥ 445
Young's modulus for tension (N/mm²)	200,000	60,000
Design value of the bonding stress f_{bd} – C20/25 (N/mm²)	2.3	2.03
Design value of the bonding stress f_{bd} – C30/37 (N/mm²)	3.0	2.33
Concrete cover c_{nom} (mm)	according to EC2	d_s + 10 mm
Specific resistance µ (Ωcm)	$1–2 \cdot 10^{-5}$	$> 10^{12}$
Thermal conductivity λ (W/(mK)	60	0.7
Density ρ (kg/m³)	7,850	2,200
Load-bearing capacity at right-angles to the fibre according to ACI/CSA τ (N/mm²):	-	150

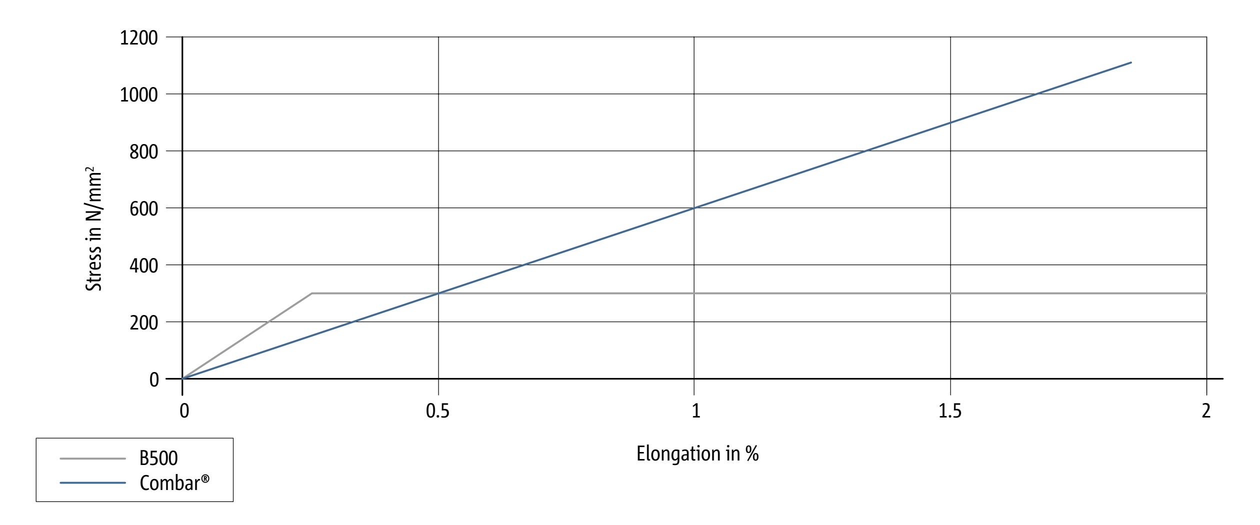


Fig. 1: Stress-strain diagram: Comparison of reinforcing steel and Combar®

By contrast with steel, Combar® exhibits a linear elastic behaviour until failure. The measured Young's modulus is over 60,000 N/mm² by contrast with reinforcing steel which is 200,000 N/mm². The characteristic short-term tensile strength of the glass fibre composite material is more than 1000 N/mm².

Manufacturing

Manufacturing process

The bar consists of a large number of endless E-CR glass fibres that are aligned in the direction of force and that embedded in a vinyl ester resin matrix. The bars are manufactured at the Halle (Saale) site in a closed pultrusion (extrusion) process. This guarantees the linear alignment of the fibres along the bar axis, complete impregnation of the glass fibres with the resin and an extremely high degree of curing of the resin.

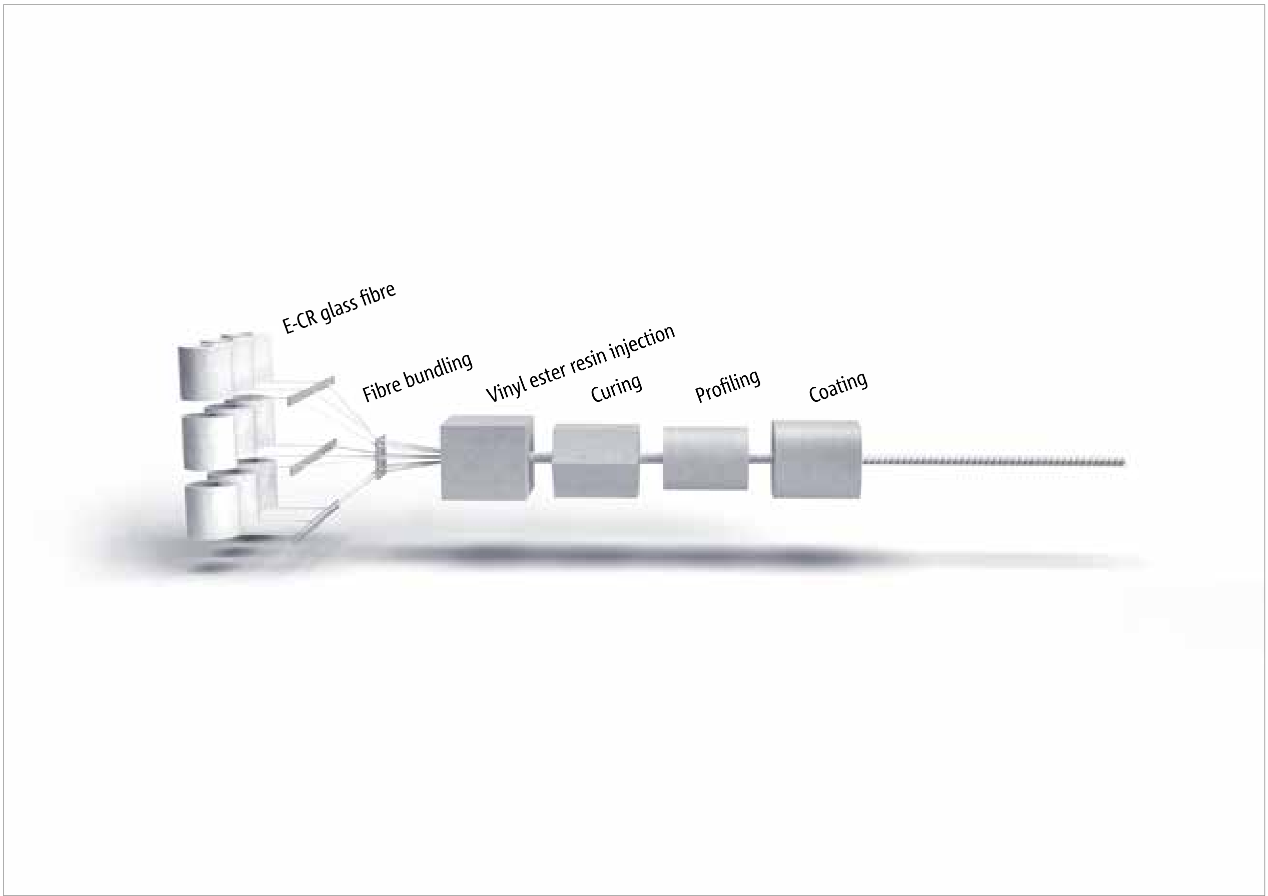


Fig. 2: Schöck Combar®: Schematic diagram of the pultrusion process

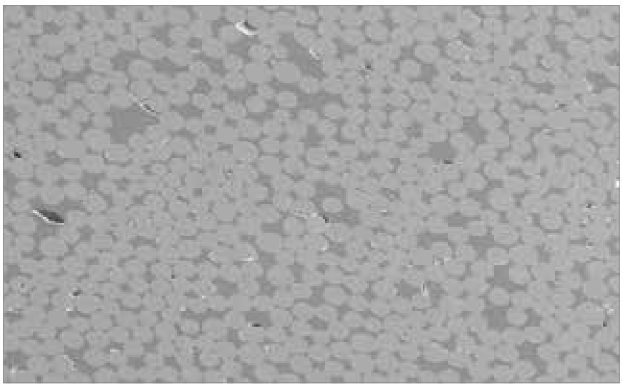


Fig. 3: Schöck Combar®: Cross section through the bar

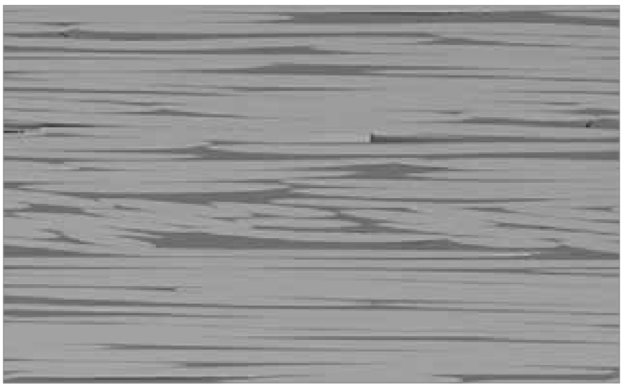


Fig. 4: Schöck Combar®: Longitudinal section through the bar

Manufacturing

The fibres give the material its strength and stiffness in the longitudinal direction. The resin matrix fixes the fibres in their position, transfers the load and protects the fibres from harmful influences.
The unique rib geometry and subsequent milling of the ribs into the cured bar guarantee a composite behaviour equivalent to that of reinforcing steel. This allows high forces to be transferred from the concrete to the Combar®.
This material structure with its unidirectional fibre orientation results in the following key material properties: high tensile strength in the fibre direction, low transverse compressive and tensile strength perpendicular to the fibre. In construction, the best way to explain the different properties in the various directions is by drawing a comparison with wood, a naturally occurring material.

Product dimensions

Straight bar

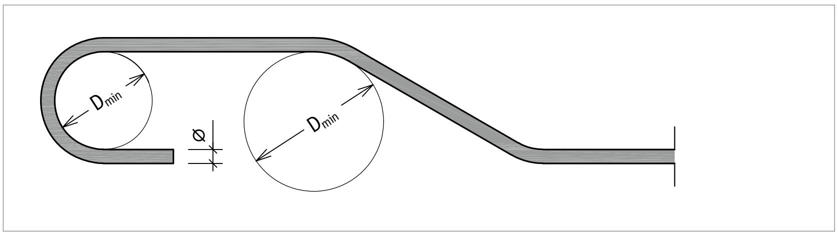
The straight bar can be used as load-bearing tensile reinforcement. It is available in the diameters ⌀ 8, 12, 16, 20, 25 and 32 mm and is regulated in the GTA. The Young's modulus must be taken into account in the design. It is determined by the proportion and type of glass fibres used and is 60,000 N/mm² with Combar®, which is about one third of the Young's modulus of reinforcing steel. Of all GFRP reinforcements, Combar® has the highest Young's modulus and can therefore belongs to the highest "quality class".

Dimensions and weight of straight Combar®			
Nominal diameter $⌀_f$ [mm]	External diameter [mm]	Design cross-section [cm²]	Weight [kg/m]
8	9	0.50	0.13
12	13	1.13	0.29
16	18	2.01	0.52
20	22	3.14	0.79
25	27	4.91	1.21
32	34	8.04	1.94

Stirrup

The U-bar/stirrup that cannot be subsequently shaped can be used as shear reinforcement for structural components exposed to shear forces. Schöck has developed a process which makes it possible to produce any bent shapes such as L-shapes, S-shapes or closed stirrups with or without end hooks from the ⌀ 12, 16 and 20 mm bars (similar to reinforcing steel). For production reasons, the maximum overall dimensions are 3.0 m by 2.0 m. From a structural point of view, the anchorage length of a stirrup should be ≥ ⌀ 12.
The Young's modulus for stirrups is 50,000 N/m².

Dimensions and weight of Combar® stirrup			
Nominal diameter core d_f [mm]	External diameter [mm]	Design cross-section [cm²]	Weight [kg/m]
12	15.5	1.06	0.30
16	19.8	1.91	0.48
20	23.8	2.87	0.69



Minimum bending roll diameter D_{min} for stirrups (e.g. hooks, angled hooks, loops)		
For all diameters, $D_{min} = 7 \cdot ⌀$	⌀ 12 mm	84 mm
	⌀ 16 mm	112 mm
	⌀ 20 mm	140 mm

Product dimensions

Bar with anchorage head

In order to be able to shorten the end anchorage length or as shear reinforcement, an anchorage head reinforcement with moulded heads is available for diameters of ⌀ 12, 16, 20, 25 and 32 mm. These bars can transfer significantly higher forces than straight bar ends due to the high-strength polymer concrete and the larger activatable surface.

Dimensions and weight of Combar® straight bar				
Nominal diameter core d_f [mm]	Head length [mm]	Head diameter [mm]	Minimum bar length double head bolts [mm]	Head weight [kg/head]
12	60	30	160	0.026
16	100	40	240	0.061
20	100	45	240	0.075
25	100	50	240	0.090
32	100	64	240	0.138

Basic design principles

Notes on the design

Design according to Eurocode

The design of Combar® is based on Eurocode 2 or EC2 (EN 1992-1-1:2011-01 and EN 1992-1-1/NA:2011-01) in the general technical approval (GTA Schöck Combar® Z-1.6-238 dated 8 July 2019). The design of the Schöck Combar® glass-fibre reinforcement for use in structural components with a service life of up to 5, 10 and 100 years on the basis of EC2 is explained below. The underlying design concepts and values represent the current level of knowledge based on extensive investigations conducted to date.

Design according to approval

All specifications given the General Technical Approval (GTA) Combar® (Z-1.6-238) are taken into account.
The following design concepts should be regarded as a design aid and recommendation for planners and users. They do not release the user from the duty of care and must not be regarded as a substitute for the applicable basic engineering rules.

References

The design concepts are based on the following references:
- General Technical Approval (GTA) Schöck Combar® Z-1.6- 238 (dated 8 July 2019)
- Design concept for GFRP shear reinforcement (Kurth/Hegger, RWTH Aachen) published in "Bauingenieur" Vol. 88, October 2013 under the title „Zur Querkrafttragfähigkeit von Betonbauteilen mit Faserverbundkunststoff-Bewehrung- Ableitung eines Bemessungsansatzes" (The shear force load-bearing capacity of concrete components with glass fibre composite reinforcement - derivation of a design approach)
- Expert opinion on Schöck Combar® reinforcing bars in specialised civil engineering (Soft Eye) (Kurth/Hegger, Aachen dated March 2022)
- Standards Committee for Construction (NABau): Design issues relating to DIN 1045-1 (dated 1 July 2012)

Design software

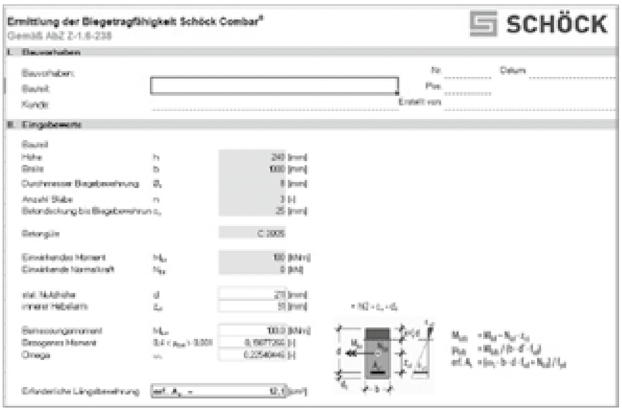
Integration of Schöck Combar® into structural analysis software
Combar® is integrated into the FRILO, RIB and Dostner & Christmann design software. Different concrete cross-sections can be selected and verifications can be provided in the ultimate limit state and in the serviceability limit state.

FRILO BY ALLPLAN RIB DC-SOFTWARE

Schöck Combar® design software
A design aid in Excel format is also available for quick and easy design of Schöck Combar®. The following verifications are implemented:

- ULS bending resistance
- ULS shear force load-bearing capacity
- SLS conversion of crack width reinforcement
- Anchorage length/overlapping length
- Minimum reinforcement
- Number of clips
- Number of spacers

Further information on the design software for Schöck Combar® can be found at:
www.schoeck.com/en-gb/software



Tensile strength

Essential differences compared to the design of reinforcing steel

The following special features/deviations must be taken into account when designing structural components reinforced with Combar® as opposed to reinforcing steel:

- The Young's modulus of straight Combar®bars is 60,000 N/mm².
- Combar® has a linear elastic behaviour until failure of well over 1000 N/mm² (short-term tensile strength).
- Cracked cross-sections reinforced with Combar® do not exhibit a load plateau.
- Structures reinforced with Combar® do not form plastic joints.
- There is practically no moment shift within structures reinforced with Combar® and this cannot be taken into account in the design.
- Due to the low Young's modulus, special attention must be paid to the verification of cross sections reinforced with Combar® in the serviceability limit state (SLS).

The durability of Schöck Combar® when used in concrete has been proven over 100 years as part of the general technical approvals. The results of the test series on which the approval is based, comprising more than 80 individual tests, are shown in the following chart.

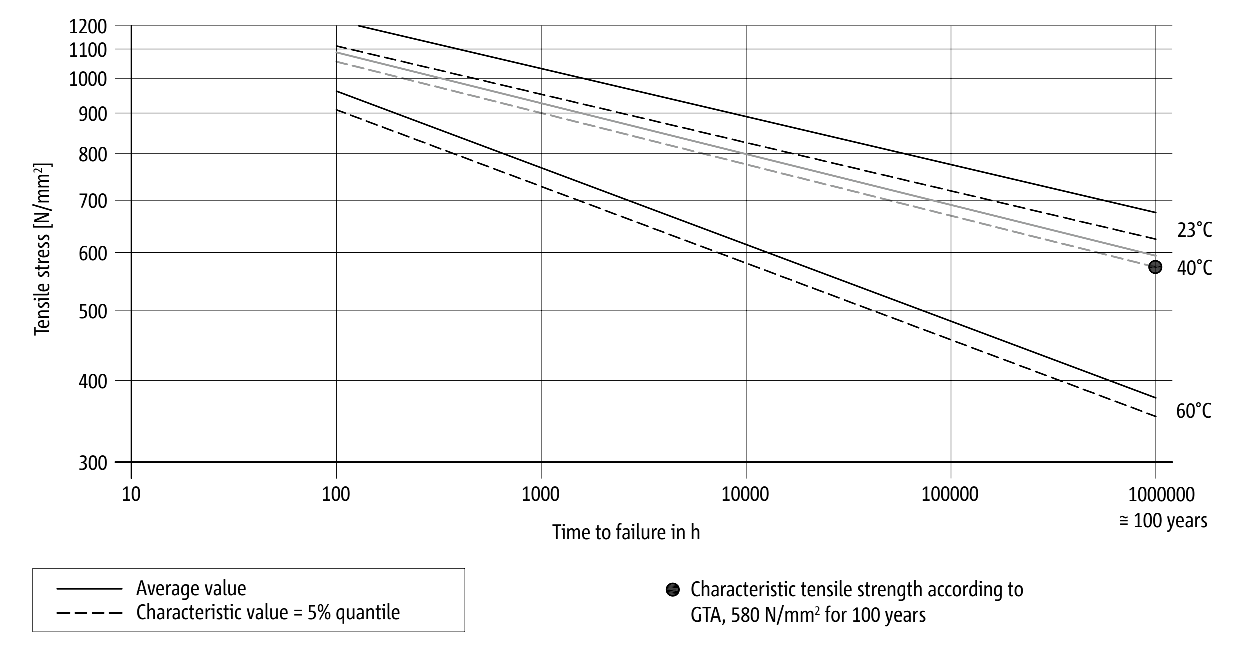


Fig. 5: Schöck Combar®: Fracture stress of Combar® in highly alkaline damp concrete

The characteristic value of the endurance tensile strength is extrapolated from this data for the intended service life of the structural component based on the 5% quantile. For external members in a normal Central European climate, the characteristic value of the endurance tensile strength for a service life of 100 years is defined as f_{fk} = 580 N/mm². Different (higher) values can be derived from the chart for other environmental conditions (average temperature) or a significantly shorter planned service life. In this case, safe assumptions must always be made regarding the service life and environmental conditions (cf. fib bulletin 40 'FRP reinforcement in RC structures').
The design value of the endurance tensile strength is determined in the same way as for reinforcing steel. The partial factor for Schöck Combar® is γ_f = 1.3. This results in a design value for the tensile strength of external members in a normal Central European climate in the ultimate limit state (ULS) of f_{fd} = 445 N/mm² for statically determinate systems. All Combar® design values mentioned below already include the verifications for endurance.
Although, due to the low Young's modulus of GFRP bars, they must not be used as arithmetically required compressive reinforcement in the design, Combar® may be located in the compression zone (bar anchorage, structural reinforcement, etc.).

Fatigue

Fatigue

Outside the approval, a maximum vibration amplitude $2\sigma_a$ of 50 N/mm² is possible, regardless of the maximum stress. With lower maximum stresses, higher dynamic loads and vibration amplitudes can be absorbed. For example, a maximum vibration amplitude $2\sigma_a$ of 180 N/mm² was achieved with a maximum stress in the straight Combar® of 250 N/mm² with 2 million load cycles.

Concrete cover | Fire protection

Concrete cover of Combar®

As Combar® does not corrode, only the concrete cover required for complete transfer of the loads from the concrete to the Combar® (bond) applies for all exposure classes, at variance with EC2.

$c_{nom} = c_{min} + \Delta c$ where Δc = 10 mm in-situ concrete (for prefabricated parts Δc = 5 mm)
where c_{min} = max ($\varnothing_f$, 10 mm)

Concrete cover						
Nominal diameter $\varnothing_f$ [mm]	8	12	16	20	25	32
Nominal dimension of the concrete cover c_{nom} for Combar® bars [mm]						
In-situ concrete	20	22	26	30	35	42
Precast part	15	17	21	25	30	37

Fire protection of Combar®

Combar® is flame retardant and contains only small amounts of combustible vinyl ester resin matrix. The fire behaviour of fibre composites is determined by the behaviour of the fibres and behaviour of the resin.

For fire protection classes > R30, Combar® reinforced concrete structural components require larger concrete covers than for steel reinforced concrete construction. If this is not the case, other fire protection measures must be taken (e.g. boarding). To be on the safe side, the following concrete covers can be assumed. These were determined for various limit temperatures at the core of the bar. A 16 cm thick slab reinforced with Combar® was subjected to the standard time-temperature curve (TTC) in accordance with EN 1992-1-2 on both sides and the concrete cover required to prevent the limit temperature in the bar being reached was determined. As can be seen in the following table, the concrete cover can be reduced for fire protection requirements if the bonding stress acting on the bar is reduced, for example by increasing the anchorage length. Furthermore, the concrete cover can be reduced by boarding the structural component.
In the case of 'cold' anchorage (boarding or support), the bonding is not decisive. The tensile strength is therefore decisive here, with limit temperatures of up to 450°C possible.

Minimum concrete cover for fire resistance class					
Minimum concrete cover with		R30	R60	R90	R120
Bonding stress decisive					
Bonding stress [N/mm²]	Limit temperature [°C]	c_{min} [mm]			
≤ 2.5	202	35	60	80	100
≤ 2.0	211	30	55	75	95
≤ 1.0	238	30	50	65	90
≤ 0.5	336	20	35	50	65
Bonding stress not decisive (cold anchorage)					
Tensile strength [N/mm²]	Limit temperature [°C]	c_{min} [mm]			
≤ 445	450	10	25	35	45

Choice of reinforcement

Straight bars

Cross-sections of flat reinforcements for straight bars A_f [cm²/m]							
Bar spacing [cm]	Nominal diameter $Ø_f$ [mm]						Bars per m
	8	12	16	20	25	32	
5.0	10.06	22.62	40.22	62.83	–	–	20.0
6.0	8.38	18.85	33.52	52.36	81.81	–	16.7
7.0	7.19	16.16	28.73	44.88	70.13	114.89	14.3
7.5	6.71	15.08	26.81	41.89	65.45	107.23	13.3
8.0	6.29	14.14	25.14	39.27	61.36	100.53	12.5
9.0	5.59	12.57	22.34	34.91	54.54	89.36	11.0
10.0	5.03	11.31	20.11	31.42	49.09	80.42	10.0
12.5	4.02	9.05	16.09	25.13	39.27	64.34	8.0
15.0	3.35	7.54	13.41	20.94	32.73	53.61	6.7
20.0	2.52	5.66	10.06	15.71	24.55	40.21	5.0
25.0	2.01	4.52	8.04	12.57	19.64	32.17	4.0

Cross-sections of beam reinforcements for straight bars A_f [cm²]										
Nominal diameter $Ø_f$ [mm]	Number of bars									
	1	2	3	4	5	6	7	8	9	10
8	0.50	1.01	1.51	2.01	2.52	3.02	3.52	4.02	4.53	5.03
12	1.13	2.26	3.39	4.52	5.66	6.79	7.92	9.05	10.18	11.31
16	2.01	4.02	6.03	8.04	10.06	12.07	14.08	16.09	18.10	20.11
20	3.14	6.28	9.42	12.56	15.70	18.84	21.98	25.12	28.26	31.40
25	4.91	9.82	14.73	19.64	24.55	29.45	34.36	39.27	44.18	49.09
32	8.04	16.08	24.13	32.17	40.21	48.25	56.29	64.34	72.38	80.42

Possible number of straight bars in one layer						
Beam width b [cm]	Nominal diameter $Ø_f$ [mm]					
	8	12	16	20	25	32
10	2	2	1	1	(1)	-
15	4	3	3	2	(2)	1
20	6	5	4	3	2	2
25	8	6	5	(5)	3	2
30	9	8	6	(6)	4	3
35	11	9	8	7	5	4
40	13	11	9	8	6	5
45	(15)	12	(11)	9	7	5
50	16	14	12	10	8	6
55	18	15	13	11	9	7
60	20	17	14	12	10	8

Note regarding reinforcement

- Bar spacing $a \geq Ø_f$ or ≥ 20 mm (in accordance with EC2). The values given in the table in () are slightly less than the required spacings.
- The outside diameter of Combar® rods is 1 to 2 mm larger than their core diameter (see table on page 14).
- Values without allowance for stirrup reinforcement that may be necessary

Choice of reinforcement

Stirrup

Cross-sections of flat reinforcements for stirrups A_f [cm²/m]				
Stirrup spacing [cm]	Nominal diameter $\varnothing_f$ [mm]			Bars per m
	12	16	20	
5.0	21.20	38.20	57.40	20.0
6.0	17.67	31.83	47.83	16.7
7.0	15.14	27.29	41.00	14.3
7.5	14.13	25.47	38.27	13.3
8.0	13.25	23.88	35.88	12.5
9.0	11.78	21.22	31.89	11.1
10.0	10.60	19.10	28.70	10.0
12.5	8.48	15.28	22.96	8.0
15.0	7.07	12.73	19.13	6.7
20.0	5.30	9.55	14.35	5.0
25.0	4.24	7.64	11.48	4.0

Cross-sections of beam reinforcements for stirrups A_f [cm²]										
Nominal diameter $\varnothing_f$ [mm]	Number of bars									
	1	2	3	4	5	6	7	8	9	10
12	1.06	2.12	3.18	4.24	5.3	6.36	7.42	8.48	9.54	10.6
16	1.91	3.82	5.73	7.64	9.55	11.46	13.37	15.28	17.19	19.1
20	2.87	5.74	8.61	11.48	14.35	17.22	20.09	22.96	25.83	28.7

Verification format | Safety factors

Verification format in the ultimate limit state	
Design situation	Load combination
Permanent and temporary ⊕ loading E_d	$E_{dA} = \sum_{j \geq 1} \gamma_{GA,j} \cdot E_{Gk,j} \oplus E_{Ad} \oplus \gamma_{QA,1} \cdot \psi_{1,1} \cdot E_{Qk,1} \oplus \sum_{i>1} \gamma_{QA,i} \cdot \psi_{2,i} \cdot E_{Qk,i}$
Accidental loading E_{dA}	$E_d = \sum_{j \geq 1} \gamma_{G,j} \cdot E_{Gk,j} \oplus \gamma_{Q,1} \cdot E_{Qk,1} \oplus \sum_{i>1} \gamma_{Q,i} \cdot \psi_{0,i} \cdot E_{Qk,1}$

- ⊕: in combination with
- Index 1: Relevant variable influence (lead action)
- $E_d \leq R_d$
- E_d: Design value of the load (applied internal forces)
- R_d: Design value of the load-bearing resistance (internal forces that can be absorbed)

Verification format in the serviceability limit state	
Design situation	Load combination
Rare combination of actions $E_{d,char}$	$E_{d,char} = \sum_{j \geq 1} E_{Gk,j} \oplus E_{Qk,1} \oplus \sum_{i>1} \psi_{0,i} \cdot E_{Qk,i}$
Frequent combination of actions $E_{d,frequ}$	$E_{d,frequ} = \sum_{j \geq 1} E_{Gk,j} \oplus \psi_{1,1} \cdot E_{Qk,1} \oplus \sum_{i>1} \psi_{2,i} \cdot E_{Qk,i}$
Quasi-permanent combination of actions $E_{d,perm}$	$E_{d,perm} = \sum_{j \geq 1} E_{Gk,j} \oplus \sum_{i \geq 1} \psi_{2,i} \cdot E_{Qk,i}$

- ⊕: in combination with
- Index 1: Relevant variable influence (lead action)
- $E_d \leq C_d$
- E_d: Design value of the load (applied internal forces)
- C_d: Design value of the serviceability criterion (e.g. permissible deflection)

Combination coefficients ψi for variable actions (building construction)			
Variable actions	ψ0	ψ1	ψ2
Imposed loads $Q_{k,N}$			
Category A: Living and recreation rooms	0.7	0.5	0.3
Category B: Offices	0.7	0.5	0.3
Category C: Meeting rooms	0.7	0.7	0.6
Category D: Salesrooms	0.7	0.7	0.6
Category E: Storerooms	1.0	0.9	0.8
Imposed loads $Q_{k,V}$			
Category F: Traffic areas, vehicle load ≤ 30 kN	0.7	0.7	0.6
Category G: Traffic areas, 30 kN < vehicle load ≤ 160 kN	0.7	0.5	0.3
Category H: Roofs	0	0	0
Snow and ice loads $Q_{k,S}$			
For locations up to SL + 1000 m	0.5	0.2	0
For locations above SL + 1000 m	0.7	0.5	0.2
Wind loads $Q_{k,W}$	0.6	0.2	0
Subsoil settlement $Q_{k,A}$	1.0	1.0	1.0
Other actions	0.8	0.7	0.5

Safety factors | Material characteristics

Partial factors γF for actions on load-bearing structures						
Partial factors	External actions				Indirect actions	
	Permanent action (G_k)		Variable action (Q_k)		Constraint action Internal or external constraint	
	Favourable effect	Unfavourable effect	Favourable effect	Unfavourable effect	Favourable effect	Unfavourable effect
Design situation	γ_G		γ_Q		γ_Q	
Permanent and temporary design situation	1.00	1.35	0	1.50	0	1.00
Accidental design situation	1.00	1.00	0	1.00	0	1.00

Partial factors γ_M for determination of the load-bearing resistance		
Design situation	γ_c concrete	γ_f Combar®
Permanent and temporary design situation	1.5	1.3
Accidental design situation	1.3	1.1

Material characteristics of concrete								
		C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
Characteristic cylinder compressive strength	f_{ck} [N/mm²]	20	25	30	35	40	45	50
Characteristic cube compressive strength	$f_{ck,cube}$ [N/mm²]	25	30	37	45	50	55	60
Design value of the concrete compressive strength (where γ_C = 1.5 and α_{cc} = 0.85)	f_{cd} [N/mm²]	11.3	14.2	17.0	19.8	22.7	25.5	28.3
Mean modulus of elasticity	E_{cm} [N/mm²]	30,000	31,000	33,000	34,000	35,000	36,000	37,000

Note

- $E_{cm} = 22{,}000 \cdot (f_{cm} / 10)^{0{,}3}$

Design of permanent structural components

Material characteristics

The design of the Combar® glass-fibre reinforcement for use in structural components with a service life of up to 100 years is explained below using EC2 as the basis.

Material characteristic values for Combar® straight bars for concretes ≥ C20/25 [DIBt GTA Z-1.6-238]			
		Statically determinate systems	Statically indeterminate systems
Characteristic endurance tensile strength	f_{fk} [N/mm²]	580	580
Design value of the endurance tensile strength (where γ_f = 1.3)	f_{fd} [N/mm²]	445	370
Modulus of elasticity	E_f [N/mm²]	60,000	60,000
Design elongation	ε_{fd} [‰]	7.4	6.1

Material characteristic values for Combar® stirrups for concretes ≥ C20/25 (outside GTA)			
		Bending tensile reinforcement Statically determinate systems	Bending tensile reinforcement Statically indeterminate systems and shear reinforcement
Characteristic endurance tensile strength	f_{fk} [N/mm²]	250	208
Design value of the endurance tensile strength (where γ_f = 1.3)	f_{fd} [N/mm²]	192	160
Modulus of elasticity	E_f [N/mm²]	50,000	50,000
Design elongation	ε_{fd} [‰]	3.8	3.2

Note
- The matching factor between statically determinate and statically indeterminate systems is defined with η_{red} ≈ 0.83.

Material characteristic values for Combar® bar with two heads for concretes ≥ C20/25 (outside GTA)				
Nominal diameter $⌀_f$ [mm]	Anchoring force Head $F_{head,k}$ [kN]	Design value for the tensile strength fully anchored f_{fd} [N/mm²]		Design value of the tensile strength partially anchored f_{fd} [N/mm²]
		Bending tensile reinforcement	Shear reinforcement	Bending tensile and shear reinforcement
12	31	210	200	143
16	68	240	200	178
20	85	208	200	140
25	106	166	166	114
32	136	130	130	89

Note
- For use as shear reinforcement, a combination in which the stirrup accounts for at least 50% of the load-bearing component is required for permanent structural components according to EC2.
- The Young's modulus is 60,000 N/mm².

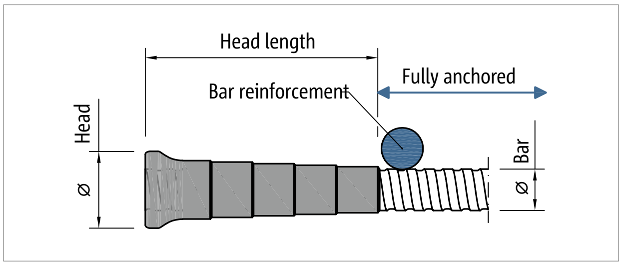


Fig. 6: Fully anchored head bolts

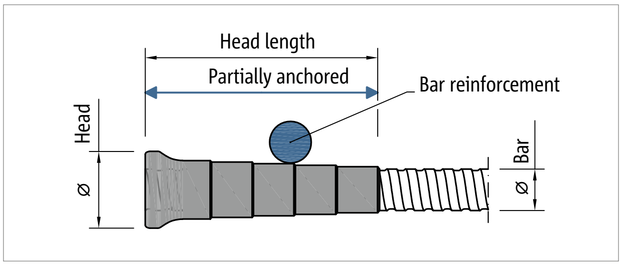


Fig. 7: Partially anchored head bolts

Verifications in the ultimate limit states

Verifications in the ultimate limit state
The internal forces are determined according to EN 1992-1-1, section 5.4 for uncracked cross-sections.

Bending with/without normal force
The design for bending with or without normal force is carried out by iteration of the strain plane. The material properties of Schöck Combar® must be taken into consideration. Although Combar® straight bars must not be used as arithmetically required compressive reinforcement, they may be located in the compression zone (bar anchorage, structural reinforcement, etc.).
The design tables were determined with a design value for the endurance tensile strength along the same lines as reinforcing steel B500 (f_{yd} = 435 N/mm² ≙ f_{fd} = 435 N/mm² for statically determined systems).
Although the Combar® straight bar has a design value of the endurance tensile strength of 445 N/mm², the design tables were determined with a design value of the endurance tensile strength along the same lines as reinforcing steel B500. This provides a basis for comparison.
A redistribution of the moments only occurs to a very limited extent and, deviating from EC2, cannot be taken into account in the design. The procedures stated in EC2 paragraph 5.6 according to the plasticity theory therefore do not apply to cross-sections reinforced with Combar®.

Values for concrete strength class ≥ C20/25

Combar® ω-table								
μ_{Edf}	ω_f	ξ	ζ	ε_c [‰]	Statically determinate systems		Statically indeterminate systems	
					ε_f [‰]	σ_{fd} [N/mm²]	$\eta_{rot} \cdot \varepsilon_f$ [‰]	$\eta_{rot} \cdot \sigma_{fd}$ [N/mm²]
0.001	0.0010	0.017	0.994	-0.123	7.250	435	6.000	360
0.006	0.0061	0.041	0.986	-0.311	7.250	435	6.000	360
0.011	0.0112	0.056	0.981	-0.431	7.250	435	6.000	360
0.016	0.0164	0.068	0.977	-0.529	7.250	435	6.000	360
0.025	0.0258	0.086	0.971	-0.679	7.250	435	6.000	360
0.050	0.0523	0.123	0.957	-1.021	7.250	435	6.000	360
0.075	0.0794	0.154	0.945	-1.321	7.250	435	6.000	360
0.100	0.1070	0.182	0.934	-1.610	7.250	435	6.000	360
0.125	0.1360	0.208	0.922	-1.908	7.250	435	6.000	360
0.150	0.1650	0.235	0.910	-2.229	7.250	435	6.000	360
0.200	0.2270	0.292	0.882	-2.989	7.250	435	6.000	360
0.240	0.2800	0.346	0.856	-3.500	6.605	396	5.466	328
0.250	0.2950	0.364	0.849	-3.500	6.118	367	5.063	304
0.300	0.3710	0.458	0.810	-3.500	4.146	249	3.431	206
0.350	0.4580	0.565	0.765	-3.500	2.692	162	2.228	134
0.360	0.4770	0.589	0.755	-3.500	2.442	147	2.021	121
0.370	0.4970	0.614	0.745	-3.500	2.203	132	1.823	109
0.380	0.5180	0.640	0.734	-3.500	1.973	118	1.633	98
0.390	0.5400	0.667	0.723	-3.500	1.751	105	1.449	87
0.400	0.5630	0.695	0.711	-3.500	1.535	92	1.270	76

Note
- $M_{Ed1} = M_{Ed} - N_{Ed} \cdot z_{s1}$ (N_{ed} is positive as a tensile force)
- $\mu_{Edf} = M_{Ed1} / (b \cdot d2 \cdot f_{cd})$
- Required: $A_f = (\omega_1 \cdot b \cdot d \cdot f_{cd} + N_{Ed}) / f_{fd}$

Verifications in the ultimate limit states

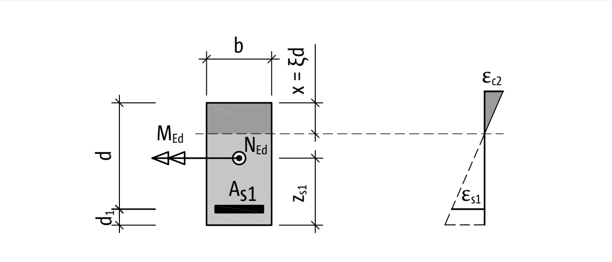


Fig. 8: Variables for bending design

Minimum reinforcement
A minimum reinforcement is required to ensure ductile component behaviour. The minimum reinforcement of Combar® is determined along the same lines as reinforcing steel. Failure of the structural component in the event of initial cracking without prior notice is to be avoided. Upon initial crack formation, the stress in the rebar is equal to the concrete tensile strength $\sigma_f = f_{ctm}$.

For pure bending:

$$f_{ctm} = \frac{M_{cr}}{W_c} \quad \text{bzw.} \quad M_{cr} = f_{ctm} \cdot \frac{b \cdot h^2}{6} \quad \text{(Rechteckquerschnitt)}$$

$$A_{f,min} = \frac{M_{cr}}{\sigma_f \cdot z} = \frac{f_{ctm} \cdot W_c}{\sigma_f \cdot z}$$

$\sigma_f = 0.83 \cdot f_{fk} = 445$ N/mm² (according to GTA, deviating from EC2)

Maximum reinforcement
The cross-sectional area of the Combar® reinforcement that can be calculated for the bending design of a concrete cross-section must not exceed the maximum value of 0.035 A_c:
$A_{f,max} = 0.035\ A_c$ (A_c = cross-sectional area in condition I)

Shear force

Relevant shear force

With a uniformly distributed load and direct support, the design value V_{Ed} at a distance d from the support edge can be determined for the design of the shear reinforcement. With an indirect support, the shear force in the support axis is decisive.

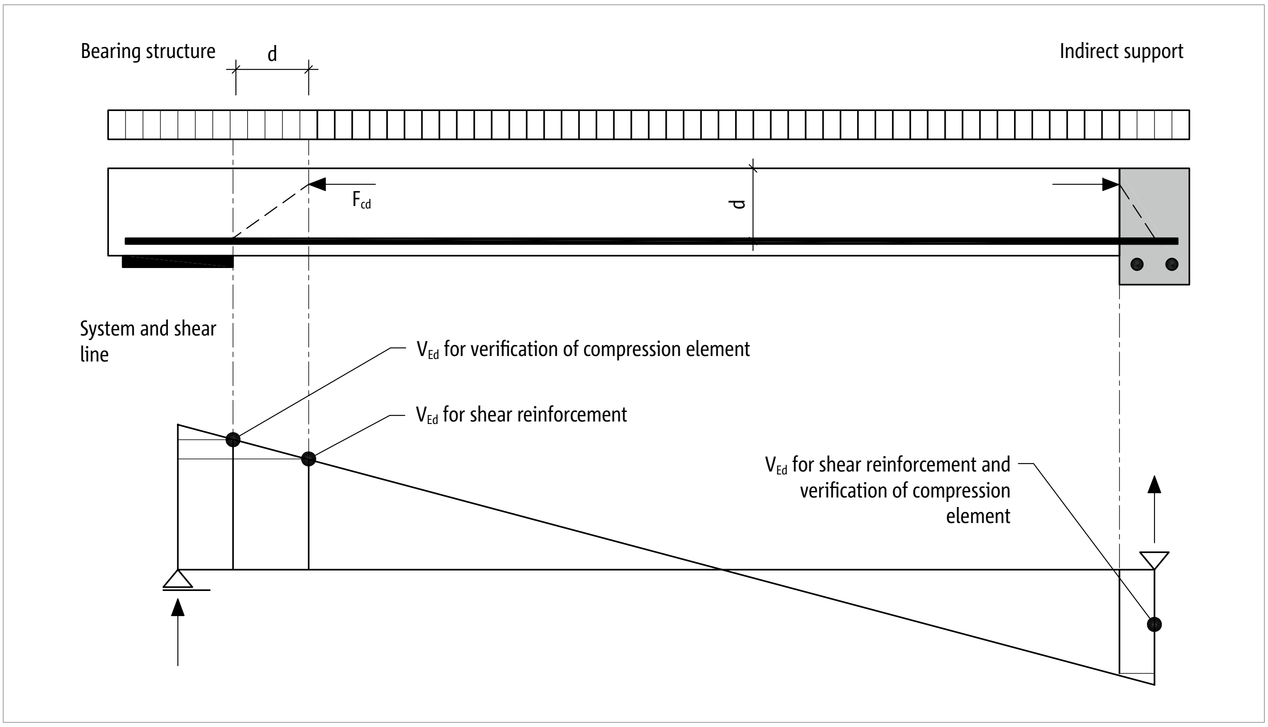


Fig. 9: Design sections for the shear force verifications

Shear force

With concentrated loads close to the support in the range $0.5d \leq a_v < 2d$ from the support edge, the shear force component from the concentrated load can be reduced by the coefficient β_E for the design of the shear reinforcement in the case of direct support.

$$ß_E = \frac{a_v}{2 \cdot d}$$

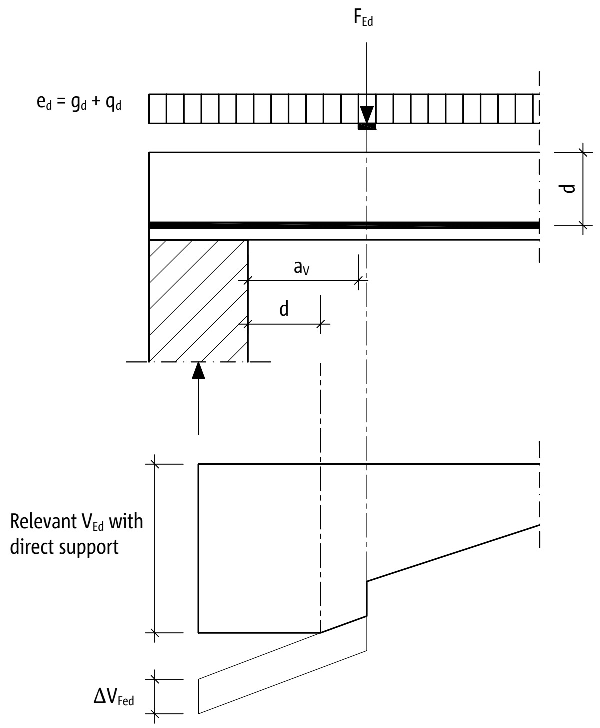


Fig. 10: Determination of the design shear force for concentrated loads close to the support

The shear force calculated without reduction β_E must satisfy the following condition as a rule:

$$V_{Ed} \leq 0{,}3375 \cdot b_w \cdot d \cdot f_{cd}$$

This reduction is not permitted when verifying $V_{Rd,max}$.

Verification for structural components without arithmetically required shear reinforcement

a) Verification according to the General Technical Approval (GTA): $\beta_E \cdot V_{Ed} \leq V_{Rdc}$

Equation 6.2a according to DIN EN 1992-1-1/NA is replaced for Schöck Combar® by:

$$V_{Rd,c} = \frac{0{,}138}{\gamma_c} \cdot \kappa \cdot (100 \cdot \rho_l \cdot \frac{E_f}{E_s} \cdot f_{ck})^{1/3} \cdot b_w \cdot d$$

γ_c = partial factor for concrete

κ = scale factor; d in mm

$$\kappa = 1 + \sqrt{\frac{200}{d}} < 2{,}0$$

ρ_l = degree of longitudinal reinforcement; $\rho_l = A_{fl} / (b_w \cdot d) \leq 0.02$

$E_f / E_s = E_{Combar®} / E_{reinforcing\ steel}$

f_{ck} = characteristic value of the concrete compressive strength

b_w = smallest cross-section width within the tension zone of the cross-section

d = static effective height

Shear force

b) Verification according to Hegger/Kurth (outside the GTA): $V_{Ed} \leq V_{Rdc}$

b) Verification according to Hegger/Kurth: $V_{Ed} \leq V_{Rdc}$

$$V_{Rd,c} = \beta_R \cdot \frac{1}{425 \cdot \gamma_c} \cdot \kappa \cdot (100 \cdot \rho_l \cdot E_{fl} \cdot f_{ck})^{1/3} \cdot b_w \cdot d$$

Increase factor for allow for the influences of the loads close to the support:

$$\beta_R = \frac{3}{a_v/d} \geq 1$$

When using the increase factor β_R on the component resistance side, the rerating factor $ß_E$ on the action side must not be taken into consideration.
κ = scale factor; d in mm

$$\kappa = 1 + \sqrt{\frac{200}{d}} < 2{,}0$$

ρ_l = degree of longitudinal reinforcement; $\rho_l = A_{fl} / (b_w \cdot d) \leq 0.02$
E_{fl} = Young's modulus of the longitudinal reinforcement
f_{ck} = characteristic value of the concrete compressive strength
b_w = smallest cross-section width within the tension zone of the cross-section
d = static effective height

c) Minimum steel shear reinforcement (along the same lines as EC2, within GTA)

$$\rho_{w,min} = 0{,}16 \cdot \frac{f_{ctm}}{f_{yk}}$$

f_{ctm} = mean value of the centric tensile strength of the concrete
f_{yk} = characteristic yield strength of the steel

d) Minimum Combar® shear reinforcement (outside GTA)

$$\rho_{w,min} = 0{,}16 \cdot \frac{f_{ctm}}{f_{fd,w}}$$

f_{ctm} = mean value of the centric tensile strength of the concrete
$f_{fd,w}$ = design value for the tensile strength of the Combar® shear reinforcement

Shear force

Verification for components with arithmetically required shear reinforcement
The use of Combar® bars as shear reinforcement is not covered by the Combar® GTA. In this case, Combar® longitudinal reinforcement can also be combined with stainless steel shear reinforcement. Safe-side recommendation (deviating from EC2):

a) Method according to Hegger/Kurth
In the technical report “Querkrafttragfähigkeit von Betonbauteilen mit Faserverbundkunststoff-Bewehrung - Ableitung eines Bemessungsansatzes” (shear force load-bearing capacity of concrete components with fibre composite reinforcement - deriving a design approach) [Bauingenieur Volume 88, October 2013] by M. Kurth and J. Hegger, a more accurate, less conservative method for determining the shear force load-bearing capacity is derived for concrete cross-sections with longitudinal reinforcement made of Combar® and with longitudinal and shear reinforcement made of Combar®.
The total load-bearing capacity of the cross-section consists of the load-bearing capacity of the concrete and the load-bearing capacity of the shear reinforcement.

$$V_{Rd} = V_{Rd,c} + V_{Rd,f}$$

The load-bearing capacity of the shear reinforcement is obtained from

$$V_{Rd,f} = a_{fw} \cdot f_{fwd} \cdot z \cdot \cot \theta$$

a_{fw} = cross-sectional area of the GFRP shear reinforcement
f_{fwd} = design value of the tensile strength of the GFRP shear reinforcement ($f_{fwd} \leq E_{fw} \cdot \varepsilon_{fwd}$)
z = Lever arm of the internal forces
θ = Compression element angle (= β_f)

$$\varepsilon_{fd,w} = 2{,}3 + \frac{2 \cdot EI^* \, [MN/m^2]}{30} \leq 7{,}0 \, [‰]$$

$$\theta = \arctan \left[\sqrt[3]{\frac{\frac{M}{V} \cdot a_{fw} \cdot E_{fw}}{A_{fl} \cdot E_{fl}}} \right] \begin{cases} \geq 20° \\ \leq 50° \end{cases}$$

The shear force load-bearing capacity must not exceed the maximum value $V_{Rd,max}$.

$$V_{Rd,max} = V_{Rd,c} + \frac{1{,}1 \cdot b_w \cdot z \cdot f_{cm}^{2/3}}{\gamma_c \cdot (\cot(\theta) + \tan(\theta))}$$

The difference between the Young’s modulus of straight Combar® bars (60,000 N/mm²) and Combar® stirrups (50,000 N/mm²) must be taken into consideration in the calculation.
The Kurth and Hegger calculation method can also be used when combining Combar® longitudinal reinforcement with steel shear reinforcement.

b) Minimum steel or Combar® shear reinforcement (outside the GTA)

$$\rho_{w,min} = 0{,}16 \cdot \frac{f_{ctm}}{f_{fd,w}}$$

f_{ctm} = mean value of the centric tensile strength of the concrete
$f_{fd,w}$ = design value of the shear reinforcement tensile strength

Verifications in the serviceability limit states

Limitation of the stresses
Where demands are made on the serviceability of the structural components, the stress in the Combar® bar should not exceed 300 N/mm².

Limitation of the crack widths
Combar® does not corrode. Limiting the crack widths to protect the reinforcement is not necessary. The Combar® GTA limits the crack width to $w_k \leq 0.4$ mm. Determination of the minimum reinforcement for limiting the crack width according to EN 1992-1-1, section 7.3.2 and limitation of the crack width without direct calculation according to EN 1992-1-1, section 7.3.3 is not permitted.

Approximate manual calculation
A crack reinforcement consisting purely of BSt 500 can be converted to a Combar® reinforcement. As with reinforcing steel, the total slip at the bar end in a bond test has a quadratic relationship with the applied stress σ. Furthermore, in the case of early-onset induced stresses, approximately the same bond behaviour as reinforcing steel can be assumed. Furthermore, the crack width w_k is proportional to the Young's modulus of the rebar and to the rebar diameter ⌀. The the following conversion equation (for equal crack widths) is therefore obtained.

$$\frac{w_{k,Combar}}{w_{k,B500}} = \left(\frac{E_{Combar}}{E_{B500}}\right) \cdot \left(\frac{\varnothing_{Combar}}{\varnothing_{B500}}\right) \cdot \left(\frac{\sigma_{Combar}}{\sigma_{B500}}\right)^2 = 1{,}0$$

$$\frac{w_{k,Combar}}{w_{k,B500}} = \left(\frac{200.000\ N/mm^2}{60.000\ N/mm^2}\right) \cdot \left(\frac{\varnothing_{Combar}}{\varnothing_{B500}}\right) \cdot \left(\frac{\sigma_{Combar}}{\sigma_{B500}}\right)^2 = 1{,}0$$

With the same crack width and the same bar diameter, it follows that:

$$\text{erf. } A_{Combar} = \sqrt{\frac{200}{60}}\ A_{B500} = 1{,}83\ A_{B500}$$

Exact method
According to the GTA, the crack width is determined in accordance with EN 1992-1-1, section 7.3.4 with the following changes:

- ε_{sm} is substituted by ε_{fm} as the average elongation of the Schöck Combar®,
- E_s is substituted by E_f according to section 3.2.1.1 and is the Young's modulus of the Schöck Combar®,
- σ_s is substituted by σ_f and is the tension of the Schöck Combar® in the crack,
- Equation (7.11) according to EN 1992-1-1 is substituted by:

For Schöck Combar® bars

$$S_{r,max} = \frac{d_f}{2{,}8 \cdot \rho_{f,eff}} \leq \frac{\sigma_f \cdot d_f}{2{,}8 \cdot f_{ct,eff}}$$

$$\rho_{f,eff} = \frac{A_f}{A_{c,eff}}$$

Verifications in the serviceability limit states

Limitation of the deflection

Due to the relatively low Young's modulus of Combar®, special attention must be paid to limiting deflection during the design. The Combar® GTA contains detailed information on calculating the deflection of structural components reinforced with Combar®. These were prepared in accordance with booklet 533 of the DAfStb [German Committee for Reinforced Concrete]. Information is available online at:
www.schoeck.com

Alternatively, the deflection of concrete structural components reinforced with Schöck Combar® can be accurately verified using non-linear methods.

i Design example

The following table shows the required reinforcement cross-section for the following boundary conditions, depending on length, slab thickness and verification type. For example, for a uniaxially stressed slab strip under uniform load with L = 4.5 m and h = 200 mm, a reinforcement cross-section of 13.0 cm² is required to comply with the maximum deflection of L/250 = 18 mm. In the ultimate limit state, this must only be 3.9 cm².

- b = 1.0 m
- Concrete strength class C25/30
- Concrete cover c_v = 17 mm
- Bar diameter $\varnothing_f$ = 12 mm
- q = 3.5 kN/m² and g + $q_{quasi\text{-}permanent}$ = g + 0.3 q for deflection (SLS) and 1.35 g + 1.5 q for bending (ULS)

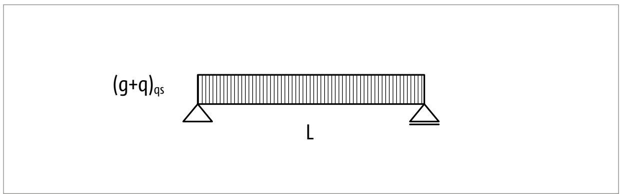


Fig. 11: Uniaxially stressed slab strip under uniform load

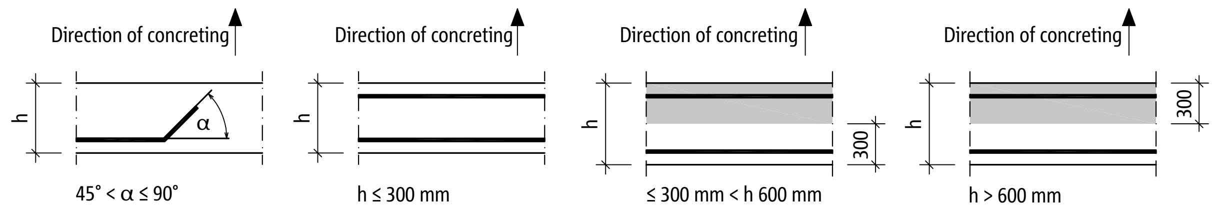
Required reinforcement cross-section in the serviceability limit state for max. deflection ≤ L/250						
Length of single-span beam	Reinforcement cross-section [cm²] for	Slab thickness h				
		160 mm	180 mm	200 mm	250 mm	300 mm
L = 3.5 m; L/250 = 14 mm	Deflection (SLS)	6.3	5.2	2.7	–	–
	Bending (ULS)	2.7	2.5	2.4	2.1	1.9
	Minimum reinforcement	1.9	2.1	2.3	2.8	3.3
L = 4.0 m; L/250 = 16 mm	Deflection (SLS)	13.6	9.7	6.6	3.1	–
	Bending (ULS)	3.5	3.3	3.1	2.8	2.6
	Minimum reinforcement	1.9	2.1	2.3	2.8	3.3
L = 4.5 m; L/250 = 18 mm	Deflection (SLS)	23.2	17.0	13.0	6.2	3.3
	Bending (ULS)	4.5	5.2	3.9	3.5	3.2
	Minimum reinforcement	1.9	2.1	2.3	2.8	3.3
L = 5.0 m; L/250 = 20 mm	Deflection (SLS)	ρ ≥ 2%	27.0	20.7	12.1	6.7
	Bending (ULS)	5.6	5.2	4.9	4.3	4.0
	Minimum reinforcement	1.9	2.1	2.3	2.8	3.3
L = 5.5 m; L/250 = 22 mm	Deflection (SLS)	ρ ≥ 2%	ρ ≥ 2%	31.4	18.5	12.2
	Bending (ULS)	6.9	6.3	5.9	5.3	4.8
	Minimum reinforcement	1.9	2.1	2.3	2.8	3.3
L = 6.0 m; L/250 = 24 mm	Deflection (SLS)	ρ ≥ 2%	ρ ≥ 2%	ρ ≥ 2%	26.7	18
	Bending (ULS)	8.3	7.6	7.1	6.3	5.8
	Minimum reinforcement	1.9	2.1	2.3	2.8	3.3

= degree of reinforcement req. reinforcement cross-section deflection ρ < minimum reinforcement according to Combar® GTA

= degree of reinforcement req. reinforcement quantity deflection ρ ≥ 2% (uneconomical)

Anchorages

Bonding conditions



Good bond conditions

Moderate bond conditions

Basic value of the anchorage length

$l_{b,rqd} = (\varnothing/4) \cdot (\sigma_f / f_{bd})$ where $\sigma_f = f_{fd} = 445\ \text{N/mm}^2$

Design values of the bond strength f_{bd} [N/mm²] for straight bars with ⌀8 to ⌀25									
Design values for	Concrete strength class								
	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
Good bond conditions	1.45	1.77	2.03	2.26	2.33	2.39	2.45	2.51	2.58
Moderate bond conditions	1.09	1.32	1.53	1.78	2.01	2.23	2.34	2.46	2.58

Design values of the bond strength f_{bd} [N/mm²] for straight bars with ⌀32									
Design values for	Concrete strength class								
	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
Good bond conditions	1.11	1.36	1.56	1.74	1.79	1.84	1.89	1.93	1.98
Moderate bond conditions	0.84	0.99	1.18	1.37	1.54	1.71	1.80	1.89	1.98

Design values of the bond strength f_{bd} [N/mm²] for stirrups (e.g. hooks, angled hooks, loops) (outside GTA)									
Design values for	Concrete strength class								
	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
Good bond conditions	1.45	1.77	2.03	2.30					
Moderate bond conditions	1.09	1.23	1.42	1.61					

Anchorages

Basic value of the anchorage length $l_{b,rqd}$ in cm for straight Combar® bars							
Concrete strength class	Bonding conditions	Nominal diameter $\varnothing_f$ [mm]					
		8	12	16	20	25	32
C20/25	Good	44	66	88	110	137	229
	Moderate	58	87	116	145	182	302
C25/30	Good	40	59	79	99	123	205
	Moderate	50	75	100	125	156	260
C30/37	Good	38	57	76	96	119	199
	Moderate	44	66	89	111	138	232
C35/45	Good	37	56	75	93	117	194
	Moderate	40	60	80	100	125	209
C40/50	Good	36	55	73	91	114	189
	Moderate	38	57	76	95	119	198
C45/55	Good	36	53	71	89	111	185
	Moderate	36	54	72	91	113	189
C50/60	Good	35	52	69	86	108	180
	Moderate	35	52	69	86	108	180

Anchorage lengths (tension bars only)

$l_{bd} = \alpha_1 \cdot \alpha_5 \cdot l_{b,rqd} \cdot (A_{f,erf} / A_{f,exist}) \geq l_{b,min}$

Coefficients α_1 and α_5 (tension bars only)	
Straight bar end	$\alpha_1 = 1.0$
Hooks, angled hooks, loops	$\alpha_1 = 0.7$
Loops with $D_{min} \geq 15\ \varnothing$	$\alpha_1 = 0.5$
Transverse pressure	$\alpha_5 = 1 - 0.04 \cdot \rho$

Notes

- $\alpha_5 = 2/3$ with direct support
- $\alpha_5 = 2/3$ providing there is min. 10 $\varnothing_f$ concrete cover secured by reinforcement on all sides. This does not apply to overlap joints with a centre-to-centre distance of $s \leq 10\ \varnothing_f$.
- $\alpha_5 = 1.5$ if there is transverse tension at right angles to the reinforcement plane that is expected to cause cracking parallel to the rebar axis in the anchorage area.
- Transverse pressure ρ perpendicular to the anchorage plane [N/mm²]
- cd[1] $\geq 3\ d_f$, otherwise $\alpha_1 = 1.0$

[1] c_d = min {a/2; c_1} for hooks (outside GTA)

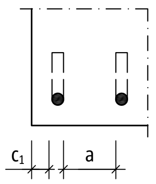


Fig. 12: Anchorage length for hooks

[1] c_d = c for loops (outside GTA)

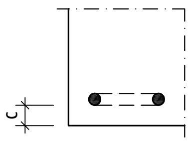
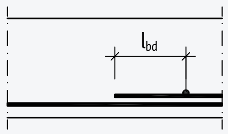
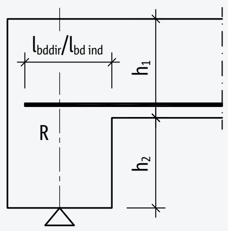
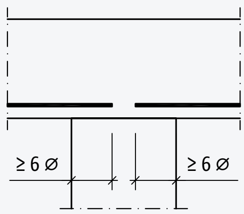


Fig. 13: Anchorage lengths for loops

Anchorages

Required anchorage lengths		
Application case	Anchorage length	Explanation
Feld 	l_{bd}	Anchorage of tension bars $l_{b,min} = 0.3 \cdot \alpha_1 \cdot l_{b,rqd} \geq 10 \cdot \varnothing_f \geq 160$ mm for nominal diameters ⌀8 to 25 mm
		$l_{b,min} = 0.3 \cdot \alpha_1 \cdot l_{b,rqd} \geq 13 \cdot \varnothing_f \geq 160$ mm for nominal diameter ⌀32 mm
		$l_{b,min} = 0.3 \cdot \alpha_1 \cdot l_{b,rqd} \geq 13 \cdot \varnothing_f \geq 224$ mm for nominal diameters ⌀8 to 25 mm
		$l_{b,min} = 0.3 \cdot \alpha_1 \cdot l_{b,rqd} \geq 18 \cdot \varnothing_f \geq 224$ mm for nominal diameter ⌀32 mm
End support direct* (h1 ≤ h2) End support indirect (h1 > h2) 	$l_{bd,dir} = l_{bd} \geq 6.7 \cdot \varnothing_f$	At least 25% of the span reinforcement for beams must be routed to the support and anchored.
	$l_{bd,ind} = l_{bd} \geq 10 \cdot \varnothing_f$	At least 50% of the span reinforcement for slabs must be routed to the support and anchored.
Zwischenauflager 	$l \geq 6 \cdot \varnothing_f$	The reinforcement must always be laid along the arithmetical support line.

Note

- * According to the GTA, structural components with $\varnothing_f$ = 32 mm may only be supported directly.

Offset

Offset

$$a_1 = \frac{z}{2} \cdot \cot\theta \geq 0$$

- θ = angle between concrete compression member and structural component axis
- z = inner lever arm; z = 0.9 • d can be generally assumed
- a_1 = 1.0 • d always applies for reinforced concrete slabs without shear reinforcement

Anchorages

Reduction of the anchorage length using anchorage heads (outside GTA)

The required anchorage length of straight Combar® bars can be reduced by using an anchorage head. The force that can be permanently absorbed by the head (design value) was determined by fatigue testing. This is to be subtracted from the total force that has to be anchored to obtain the force that still has to be anchored in the bar. Accordingly, and at variance with EC2, the total anchorage length l_{bd} is composed of the length of the head $l_{b,head}$ and the remaining anchorage length required at the bar $l_{bd\ bar}$.

Notes

- $F_d = F_{head,d} + F_{bar,d}$
- $l_{bd} = l_{b,head} + l_{bd,bar}$

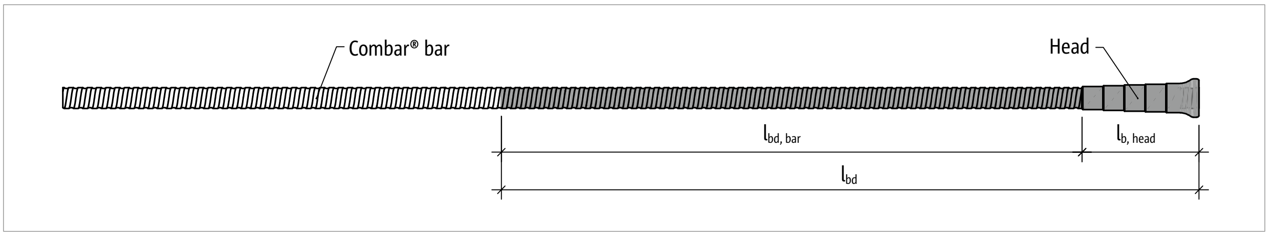


Fig. 14: Anchorage length for Combar® bar with head

Geometry and design value of the end anchorage force of Combar® heads			
Nominal diameter $⌀_f$ [mm]	$l_{b,\ head}$ [mm]	⌀ $head_{outer}$ [mm]	Anchor force (fully anchored) $F_{head,k}$ [kN]
12	60	30	31
16	100	40	68
20	100	45	85
25	100	50	106
32	100	64	136

Statically required reinforcement above the support

$F_{Ed} = |V_{Ed}| \cdot (a1 / z) + N_{Ed}$ where $z \approx 0.9 \cdot d$

$F_{Ed} \geq 0.5 \cdot V_{Ed}$

Required $A_f = F_{Ed} / (f_{fd} / 10)$

Structural component with shear reinforcement

$$a_1 = \frac{z}{2} \cdot \cot\Theta \geq 0$$

Structural component without shear reinforcement

$$a_1 = 1{,}0 \cdot d \geq 0$$

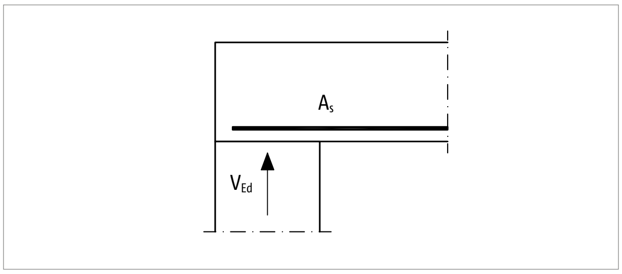
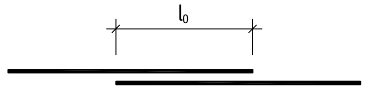


Fig. 15: Support

Overlapping joints of bars

Overlapping joints of bars (tensile joints only, outside GTA)



$$l_0 = \alpha_1 \cdot \alpha_5 \cdot \alpha_6 \cdot l_{b,rqd} \cdot \frac{A_{f,rqd}}{A_{f,exist}} \geq l_{0,min} \geq 20\ \text{cm}$$

$$l_{0,min} = 0.3 \cdot \alpha_1 \cdot \alpha_6 \cdot l_{b,rqd} \qquad \geq 15\ \varnothing_f$$

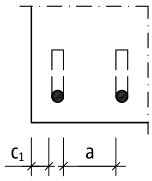


Fig. 16: Overlap joints (tensile joints only)

Coefficient α_6 to take into account the impact component for tensile joints			
Coefficients for		Proportion of bars butted without longitudinal offset	
		≤ 33 %	> 33 %
$\varnothing_f$ < 16 mm	a ≥ 8 $\varnothing_f$ and c_1 ≥ 4 $\varnothing_f$	α_6 = 1.0	α_6 = 1.0
	a < 8 $\varnothing_f$ and c_1 < 4 $\varnothing_f$	α_6 = 1.2	α_6 = 1.4
$\varnothing_f$ ≥ 16 mm	a ≥ 8 $\varnothing_f$ and c_1 ≥ 4 $\varnothing_f$	α_6 = 1.0	α_6 = 1.4
	a < 8 $\varnothing_f$ and c_1 < 4 $\varnothing_f$	α_6 = 1.4	α_6 = 2.0

Design of temporary structural components

Material characteristics

In addition to permanent structural components, Schöck Combar® glass-fibre reinforcement can be used in temporary structural components. One specialised civil engineering application of Combar® is as machinable reinforcement in the area of walls or bored piles through which a tunnel boring machine passes. These are generally construction pit walls (diaphragm walls and bored pile walls) or shaft walls of drainage systems. The ‘soft eye’ made of the machinable Combar® reinforcement therefore has only a relatively short service life. Higher design values can therefore be applied here.

An expert opinion on Schöck Combar® reinforcing bars which considerably simplifies the design of Combar® in specialised civil engineering is available: “Expert opinion on Schöck Combar® reinforcing bars in specialised civil engineering (Soft Eye)” (Kurth/ Hegger, Aachen dated March 2022)”. The expert opinion focuses on concrete components with round and rectangular cross-sections.

The design of the Combar® glass-fibre reinforcement for use in temporary structural components with a service life of 5 or 10 years is explained on the basis of EC2 below. In addition to EC2, the following guidelines are available: Recommendations of the “‘Baugruben” (construction pits) working group (EAB), DIN EN 1536, DIN SPEC 18140, DIN 4126, DIN 4127, DIN EN 1538, DIN 18313 VOB, EC1 and EC7.

Material characteristics of straight Combar® bars for concrete strength class ≥ C20/25			
		Statically determinate systems	Statically indeterminate systems
Characteristic endurance tensile strength (5 years)	f_{fk} [N/mm²]	680	680
Design value of the endurance tensile strength (where γ_f = 1.3) (5 years)	f_{fd} [N/mm²]	523	435
Characteristic endurance tensile strength (10 years)	f_{fk} [N/mm²]	640	531
Design value of the endurance tensile strength (where γ_f = 1.3) (10 years)	f_{fd} [N/mm²]	492	408
Modulus of elasticity	E_f [N/mm²]	60,000	60,000

- The matching factor between statically determinate and statically indeterminate systems is defined with η_{red} ≈ 0.83.

Material characteristic value of Combar® stirrups for concrete strength class ≥ C20/25				
			Statically determinate systems	Statically indeterminate systems
As bending tensile reinforcement	Characteristic endurance tensile strength (5 years)	$f_{fk,5a}$ [N/mm²]	330	273
	Design value of the endurance tensile strength (where γ_f = 1.3) (5 years)	$f_{fd,5a}$ [N/mm²]	253	210
	Characteristic endurance tensile strength (10 years)	$f_{fk,10a}$ [N/mm²]	315	261
	Design value of the endurance tensile strength (where γ^f = 1.3) (10 years)	$ff_{d,10a}$ [N/mm²]	242	201
As shear reinforcement	Characteristic endurance tensile strength (5 and 10 years)	$f_{fk,5a,10a}$ [N/mm²]	260	260
	Design value of the endurance tensile strength (where γ^f = 1.3) (5 and 10 years)	$f_{fd,5a,10a}$ [N/mm²]	200	200
Modulus of elasticity		E_f [N/mm²]	50,000	50,000

Note

- The matching factor between statically determinate and statically indeterminate systems when using the Combar® stirrup as bending tensile reinforcement is defined as η_{rot} ≈ 0.83.
- When using partially anchored Combar® double-headed bolts together with a Combar® stirrup, the elongation of the shear reinforcement should be limited to the corresponding smaller value.

Material characteristics

Material characteristic values for Combar® bar with two heads for concretes ≥ C20/25 (outside GTA)				
Nominal diameter $Ø_f$ [mm]	Anchoring force Head $F_{head,k}$ [kN]	Design value for the tensile strength fully anchored f_{fd} [N/mm²]		Design value of the tensile strength partially anchored f_{fd} [N/mm²]
		Bending tensile reinforcement	Shear reinforcement	Bending tensile and shear reinforcement
12	31	210	200	143
16	68	240	200	178
20	85	208	200	140
25	106	166	166	114
32	136	130	130	89

Note

- When using partially anchored Combar® double-headed bolts together with a Combar® stirrup, the elongation of the shear reinforcement should be limited to the corresponding smaller value.
- The Young's modulus is 60,000 N/mm².

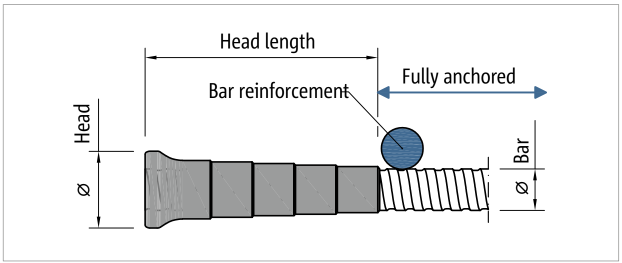


Fig. 17: Fully anchored head bolts

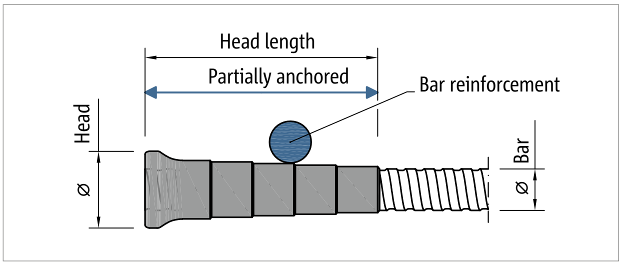


Fig. 18: Partially anchored head bolts

Verifications in the ultimate limit states

Verifications in the ultimate limit state

The internal forces are determined according to EN 1992-1-1, section 5.4 for uncracked cross-sections.

Bending with/without normal force

The design for bending with or without normal force is carried out by iteration of the strain plane. The material properties of Schöck Combar® must be taken into consideration. Although Combar® straight bars must not be used as arithmetically required compressive reinforcement, they may be located in the compression zone (bar anchorage, structural reinforcement, etc.).
The design tables were determined with a design value for the endurance tensile strength along the same lines as reinforcing steel B500 (f_{yd} = 435 N/mm² ≙ f_{fd} = 435 N/mm² for statically determined systems).
Although the Combar® straight bar has a design value of the endurance tensile strength of 445 N/mm², the design tables were determined with a design value of the endurance tensile strength along the same lines as reinforcing steel B500. This provides a basis for comparison.
Since the longitudinal reinforcement in specialised civil engineering for diaphragm walls is installed in several layers, the inner lever arm must be taken into account for each layer.
A redistribution of the moments only occurs to a very limited extent and, deviating from EC2, cannot be taken into account in the design. The procedures stated in EC2 paragraph 5.6 according to the plasticity theory therefore do not apply to cross-sections reinforced with Combar®.

Values for concrete strength class ≥ C20/25

Combar® ω-table								
μ_{Edf}	ω_f	ξ	ζ	ε_c [‰]	Statically determinate systems		Statically indeterminate systems	
					ε_f [‰]	σ_{fd} [N/mm²]	$\eta_{rot} \cdot \varepsilon_f$ [‰]	$\eta_{rot} \cdot \sigma_{fd}$ [N/mm²]
0.001	0.0010	0.017	0.994	-0.123	7.250	435	6.000	360
0.006	0.0061	0.041	0.986	-0.311	7.250	435	6.000	360
0.011	0.0112	0.056	0.981	-0.431	7.250	435	6.000	360
0.016	0.0164	0.068	0.977	-0.529	7.250	435	6.000	360
0.025	0.0258	0.086	0.971	-0.679	7.250	435	6.000	360
0.050	0.0523	0.123	0.957	-1.021	7.250	435	6.000	360
0.075	0.0794	0.154	0.945	-1.321	7.250	435	6.000	360
0.100	0.1070	0.182	0.934	-1.610	7.250	435	6.000	360
0.125	0.1360	0.208	0.922	-1.908	7.250	435	6.000	360
0.150	0.1650	0.235	0.910	-2.229	7.250	435	6.000	360
0.200	0.2270	0.292	0.882	-2.989	7.250	435	6.000	360
0.240	0.2800	0.346	0.856	-3.500	6.605	396	5.466	328
0.250	0.2950	0.364	0.849	-3.500	6.118	367	5.063	304
0.300	0.3710	0.458	0.810	-3.500	4.146	249	3.431	206
0.350	0.4580	0.565	0.765	-3.500	2.692	162	2.228	134
0.360	0.4770	0.589	0.755	-3.500	2.442	147	2.021	121
0.370	0.4970	0.614	0.745	-3.500	2.203	132	1.823	109
0.380	0.5180	0.640	0.734	-3.500	1.973	118	1.633	98
0.390	0.5400	0.667	0.723	-3.500	1.751	105	1.449	87
0.400	0.5630	0.695	0.711	-3.500	1.535	92	1.270	76

i Note

- $M_{Ed1} = M_{Ed} - N_{Ed} \cdot z_{s1}$ (N_{ed} is positive as a tensile force)
- $\mu_{Edf} = M_{Ed1} /(b \cdot d2 \cdot f_{cd})$
- Required: $A_f = (\omega_1 \cdot b \cdot d \cdot f_{cd} + N_{Ed})/f_{fd}$

Verifications in the ultimate limit states

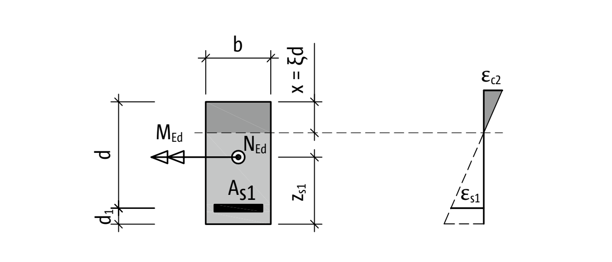


Fig. 19: Variables for bending design

Minimum reinforcement
A minimum reinforcement is required to ensure ductile component behaviour. The minimum reinforcement of Combar® is determined along the same lines as reinforcing steel. Failure of the structural component in the event of initial cracking without prior notice is to be avoided. Upon initial crack formation, the stress in the rebar is equal to the concrete tensile strength $\sigma_f = f_{ctm}$.

For pure bending:

$$f_{ctm} = \frac{M_{cr}}{W_c} \quad \text{bzw.} \quad M_{cr} = f_{ctm} \cdot \frac{b \cdot h^2}{6} \quad \text{(Rechteckquerschnitt)}$$

$$A_{f,min} = \frac{M_{cr}}{\sigma_f \cdot z} = \frac{f_{ctm} \cdot W_c}{\sigma_f \cdot z}$$

$\sigma_f = 0.83 \cdot f_{fk} = 445$ N/mm² (according to GTA, deviating from EC2)

Maximum reinforcement
The cross-sectional area of the Combar® reinforcement that can be calculated for the bending design of a concrete cross-section must not exceed the maximum value of 0.035 A_c:
$A_{f,max} = 0.035\ A_c$ (A_c = cross-sectional area in condition I)

Shear force

Relevant shear force

The decisive shear force lies in the area of the least favourable design sections for the shear force verifications. In specialised civil engineering with diaphragm walls and foundation pile walls, a variety of loads and load conditions occur that cause different internal forces. The least favourable internal force distribution is summarised in an ‘envelope’. The envelope of the shear forces is the basis for the shear force design in this case.

When determining the shear reinforcement, diaphragm wall elements whose thickness is greater than one-fifth of the width are to be considered as beams, provided that the individual elements are not dowelled together in a force-fitting manner. Diaphragm wall elements that comprise several reinforcement cages within one element length and are concreted in one operation without joints are considered to be dowelled with a force-fit connection.

Verification for structural components without arithmetically required shear reinforcement

a) Verification according to the General Technical Approval (GTA): $\beta_E \cdot V_{Ed} \leq V_{Rdc}$

Equation 6.2a according to DIN EN 1992-1-1/NA is replaced for Schöck Combar® by:

$$V_{Rd,c} = \frac{0{,}138}{\gamma_c} \cdot \kappa \cdot \left(100 \cdot \rho_l \cdot \frac{E_f}{E_s} \cdot f_{ck}\right)^{1/3} \cdot b_w \cdot d$$

γ_c = partial factor for concrete

κ = scale factor; d in mm

$$\kappa = 1 + \sqrt{\frac{200}{d}} < 2{,}0$$

ρ_l = degree of longitudinal reinforcement; $\rho_l = A_{fl} / (b_w \cdot d) \leq 0.02$

$E_f / E_s = E_{Combar®} / E_{reinforcing\ steel}$

f_{ck} = characteristic value of the concrete compressive strength

b_w = smallest cross-section width within the tension zone of the cross-section

d = static effective height

Shear force

b) Verification according to Hegger/Kurth (outside the GTA): $V_{Ed} \leq V_{Rdc}$

b) Verification according to Hegger/Kurth: $V_{Ed} \leq V_{Rdc}$

$$V_{Rd,c} = [C_{Rd,c} \cdot \kappa \cdot (100 \cdot \rho_l \cdot f_{ck})^{1/3} + \kappa_1 \cdot \sigma_{cp}\ ] \cdot b_w \cdot d$$

$$C_{Rd,c} = \frac{E_{fl}^{1/3}}{425 \cdot \gamma_c}$$

$$\rho_l = \frac{A_{fl}}{b_w \cdot d}$$

$A_{fl} = 1/3 \cdot A_{fl,tot}$ can be assumed without further verification when determining the degree of longitudinal reinforcement of circular cross-sections with circumferentially arranged bending tensile reinforcement $A_{fl,tot}$.
b_w = smallest cross-section width within the tension zone of the cross-section
With circular cross-sections, the smaller value of the widths can be used based on NABau at the height of the resulting tensile or compressive force (F_t, F_c, see following figure).

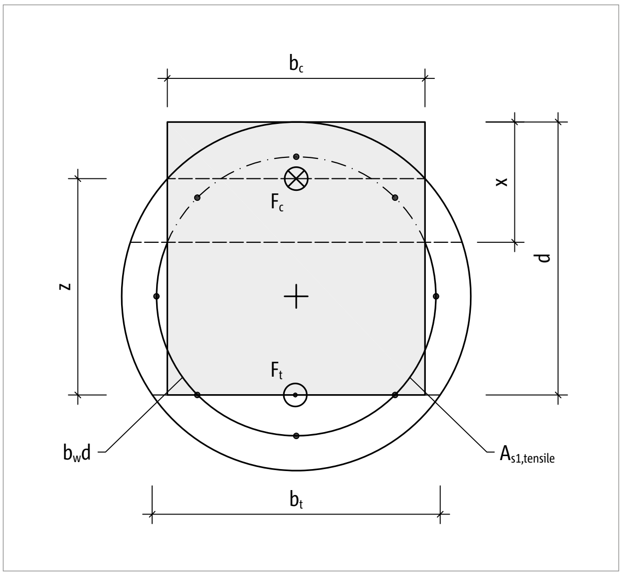


Fig. 20: Definition of the effective width b_w according to NABau

E_{fl} = Young's modulus of the longitudinal reinforcement
f_{ck} = characteristic value of the concrete compressive strength
d = static effective height
k_1 = 0.12

$$\sigma_{cp} = \frac{N_{ed}}{A_c} < 0{,}2\ f_{cd}$$

N_{ed} = normal compressive force in the cross-section due to load stress ($N_{ed} > 0$ for compression).
In the case of tensile stress, it is currently not possible to easily determine the shear force. The shear force load-bearing capacity of cross-sections subjected to corresponding stresses must therefore be considered in detail in each individual case.
A_c = concrete cross-sectional area

c) Minimum steel or Combar® shear reinforcement (along the same lines as EC2, within GTA)

$$\rho_{w,min} = 0{,}16 \cdot \frac{f_{ctm}}{f_{fd,w}}$$

f_{ctm} = mean value of the centric tensile strength of the concrete
$f_{fd,w}$ = design value of the shear reinforcement tensile strength

Shear force

Verification for components with arithmetically required shear reinforcement
The use of Combar® bars as shear reinforcement is not covered by the Combar® GTA. Safe-side recommendation (deviating from EC2):

a) Method according to Hegger/Kurth
In the technical report “Querkrafttragfähigkeit von Betonbauteilen mit Faserverbundkunststoff-Bewehrung - Ableitung eines Bemessungsansatzes” (shear force load-bearing capacity of concrete components with fibre composite reinforcement - deriving a design approach) [Bauingenieur Volume 88, October 2013] by M. Kurth and J. Hegger, a more accurate, less conservative method for determining the shear force load-bearing capacity is derived for concrete cross-sections with longitudinal reinforcement made of Combar® and with longitudinal and shear reinforcement made of Combar®.
The total load-bearing capacity of the cross-section consists of the load-bearing capacity of the concrete and the load-bearing capacity of the shear reinforcement.

$$V_{Rd} = V_{Rd,c} + V_{Rd,f}$$

The load-bearing capacity of the shear reinforcement is obtained from

$$V_{Rd,f} = a_{fw} \cdot f_{fwd} \cdot z \cdot \cot \theta$$

a_{fw} = cross-sectional area of the GFRP shear reinforcement
f_{fwd} = design value of the tensile strength of the GFRP shear reinforcement ($f_{fwd} \leq E_{fw} \cdot \varepsilon_{fwd}$)
z = Lever arm of the internal forces
θ = Compression element angle (= β_f)

$$\varepsilon_{fd,w} = 2{,}3 + \frac{2 \cdot EI^* \,[MN/m^2]}{30} \leq 7{,}0\ [‰]$$

$$EI^* = E_{fl} \cdot A_{fl} \cdot (0{,}8 \cdot d)^2$$

$$\theta = \arctan \left[\sqrt[3]{\frac{\frac{M}{V} \cdot a_{fw} \cdot E_{fw}}{A_{fl} \cdot E_{fl}}} \right] \begin{cases} \geq 20° \\ \leq 50° \end{cases}$$

The shear force load-bearing capacity must not exceed the maximum value $V_{Rd,max}$.

$$V_{Rd,max} = V_{Rd,c} + \frac{1{,}1 \cdot b_w \cdot z \cdot f_{cm}^{2/3}}{\gamma_c \cdot (\cot(\theta) + \tan(\theta))}$$

The difference between the Young’s modulus of straight Combar® bars (60,000 N/mm²) and Combar® stirrups (50,000 N/mm²) must be taken into consideration in the calculation.
The Kurth and Hegger calculation method can also be used when combining Combar® longitudinal reinforcement with steel shear reinforcement.

b) Minimum steel or Combar® shear reinforcement (outside the GTA)

$$\rho_{fw,min} = 0{,}16 \cdot \frac{f_{ctm}}{f_{fd,w}}$$

f_{ctm} = mean value of the centric tensile strength of the concrete
$f_{fd,w}$ = design value of the shear reinforcement tensile strength

Verifications in the serviceability limit states

Limitation of the stresses

Where demands are made on the serviceability of the structural components, the stress in the Combar® bar should not exceed 300 N/mm².
This verification is generally not required for temporary structural components reinforced with Combar®.

Limitation of the crack widths

Combar® does not corrode. Limiting the crack widths to protect the reinforcement is not necessary. The Combar® GTA limits the crack width to $w_k \leq 0.4$ mm. Determination of the minimum reinforcement for limiting the crack width according to EN 1992-1-1, section 7.3.2 and limitation of the crack width without direct calculation according to EN 1992-1-1, section 7.3.3 is not permitted.
This verification is generally not required for temporary structural components reinforced with Combar®.
However, if the crack width must comply with specific requirements, such as in a water-impermeable structural component, the maximum crack width can be determined as follows.

Approximate manual calculation

A crack reinforcement consisting purely of BSt 500 can be converted to a Combar® reinforcement. As with reinforcing steel, the total slip at the bar end in a bond test has a quadratic relationship with the applied stress σ. Furthermore, in the case of early-onset induced stresses, approximately the same bond behaviour as reinforcing steel can be assumed. Furthermore, the crack width w_k is proportional to the Young's modulus of the rebar and to the rebar diameter ⌀. The the following conversion equation (for equal crack widths) is therefore obtained.

$$\frac{w_{k,Combar}}{w_{k,B500}} = \left(\frac{E_{Combar}}{E_{B500}}\right) \cdot \left(\frac{\varnothing_{Combar}}{\varnothing_{B500}}\right) \cdot \left(\frac{\sigma_{Combar}}{\sigma_{B500}}\right)^2 = 1{,}0$$

$$\frac{w_{k,Combar}}{w_{k,B500}} = \left(\frac{200.000\ N/mm^2}{60.000\ N/mm^2}\right) \cdot \left(\frac{\varnothing_{Combar}}{\varnothing_{B500}}\right) \cdot \left(\frac{\sigma_{Combar}}{\sigma_{B500}}\right)^2 = 1{,}0$$

With the same crack width and the same bar diameter, it follows that:

$$\text{erf. } A_{Combar} = \sqrt{\frac{200}{60}}\ A_{B500} = 1{,}83\ A_{B500}$$

Exact method

According to the GTA, the crack width is determined in accordance with EN 1992-1-1, section 7.3.4 with the following changes:

- ε_{sm} is substituted by ε_{fm} as the average elongation of the Schöck Combar®,
- E_s is substituted by E_f according to section 3.2.1.1 and is the Young's modulus of the Schöck Combar®,
- σ_s is substituted by σ_f and is the tension of the Schöck Combar® in the crack,
- Equation (7.11) according to EN 1992-1-1 is substituted by:

For Schöck Combar® bars

$$S_{r,max} = \frac{d_f}{2{,}8 \cdot \rho_{f,eff}} \leq \frac{\sigma_f \cdot d_f}{2{,}8 \cdot f_{ct,eff}}$$

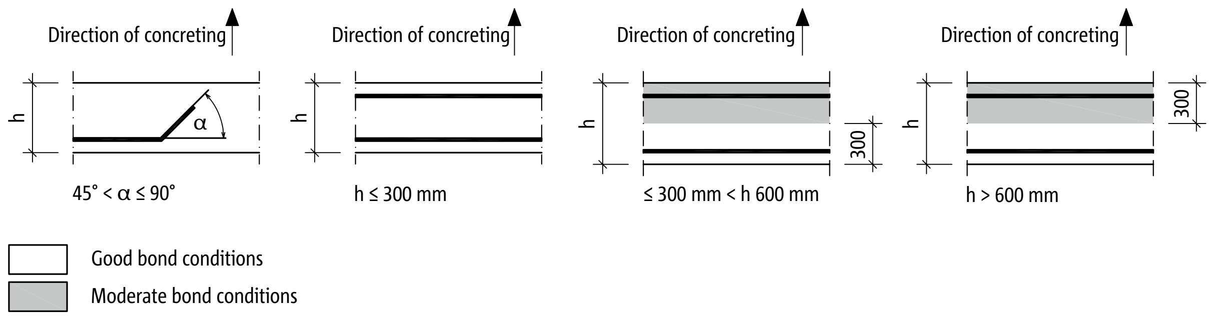
$$\rho_{f,eff} = \frac{A_f}{A_{c,eff}}$$

Limitation of the deflection

This verification is generally not required for temporary concrete structural components reinforced with Combar®. An exact verification of the deflection can only be carried out on the entire system, also taking a mixed reinforcement of Combar® and reinforcing steel into consideration.

Anchorages

Bonding conditions



Basic value of the anchorage length

$l_{b,rqd} = (\varnothing/4) \cdot (\sigma_f / f_{bd})$ where $\sigma_f = f_{fd} = 445$ N/mm²

Design values for the bond strength f_{bd} [N/mm²]

The expert opinion on Schöck Combar® reinforcing bars in specialised civil engineering (Soft Eye) by Kurth/Hegger provides the following equation for determining the design value of the bonding stress for temporary structures with a service life of 5 years. If the service life is increased to 10 years, the bond strength values for the 5-year service life should be reduced by approximately 10%. Furthermore, the bonding stresses must not be more than 1.2 times the bonding stresses specified in the GTA.

Design values of the bond strength f_{bd} [N/mm²] for stirrups (e.g. hooks, angled hooks, loops) (outside GTA)									
Design values for	Concrete strength class								
	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
Good bond conditions	1.45	1.77	2.03	2.30					
Moderate bond conditions	1.09	1.23	1.42	1.61					

For bored piles and diaphragm walls, the stirrups act as horizontal reinforcement in the moderate bond area.

$$f_{bd} = \eta \cdot 2{,}13 \cdot \frac{f_{ctk;0,05}}{\gamma_c} \leq \frac{4{,}8\ \text{N/mm}^2}{\gamma_c}$$

η = factor to allow for the bond conditions
Good bond conditions 1.0
Moderate bond conditions 0.7

$f_{ctk;0,05}$ = characteristic value of the 5% quantile for the centric concrete tensile strength

Anchorages

Characteristic values and design values of the bond strength for Schöck Combar® depending on the concrete strength for temporary applications (5 years) and favourable bond conditions				
Concrete strength class	Characteristic value of the bond strength $f_{bk,5a}$ [N/mm²]	Design value of the bond strength $f_{bd,5a}$ [N/mm²]	Approval value for permanent use ⌀ 32 mm $f_{bd,5a}$ [N/mm²]	Approval value for permanent use ⌀ 8–25 mm $f_{bd,5a}$ [N/mm²]
C25/30	3.83	2.56	1.74	2.26
C30/37	4.19	2.79	1.79	2.33
C35/45	4.30	2.86	1.84	2.39
C50/60	4.64	3.10	1.98	2.58

Characteristic values and design values of the bond strength for Schöck Combar® depending on the concrete strength for temporary applications (10 years) and favourable bond conditions		
Concrete strength class	Characteristic value of the bond strength $f_{bk,10a}$ [N/mm²]	Design value of the bond strength $f_{bd,10a}$ [N/mm²]
C25/30	3.45	2.30
C30/37	3.77	2.51
C35/45	3.87	2.57
C50/60	4.18	2.78

Anchorage lengths (tension bars only)

$l_{bd} = \alpha_1 \cdot \alpha_5 \cdot l_{b,rqd} \cdot (A_{f,erf} / A_{f,exist}) \geq l_{b,min}$

Coefficients α_1 and α_5 (tension bars only)	
Straight bar end	$\alpha_1 = 1.0$
Hooks, angled hooks, loops	$\alpha_1 = 0.7$
Loops with $D_{min} \geq 15$ ⌀	$\alpha_1 = 0.5$
Transverse pressure	$\alpha_5 = 1 - 0.04 \cdot \rho$

Notes

- $\alpha_5 = 2/3$ with direct support
- $\alpha_5 = 2/3$ providing there is min. 10 $⌀_f$ concrete cover secured by reinforcement on all sides. This does not apply to overlap joints with a centre-to-centre distance of s ≤ 10 $⌀_f$.
- $\alpha_5 = 1.5$ if there is transverse tension at right angles to the reinforcement plane that is expected to cause cracking parallel to the rebar axis in the anchorage area.
- Transverse pressure ρ perpendicular to the anchorage plane [N/mm²]
- cd[1)] ≥ 3 d_f, otherwise $\alpha_1 = 1.0$

1) c_d = min {a/2; c_1} for hooks (outside GTA)

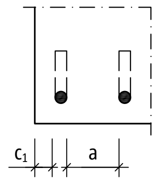


Fig. 21: Anchorage length for hooks

1) c_d = c for loops (outside GTA)

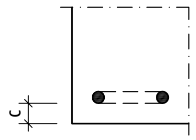
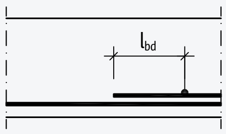
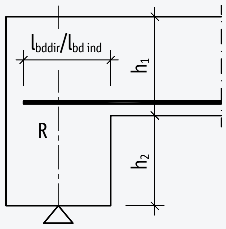
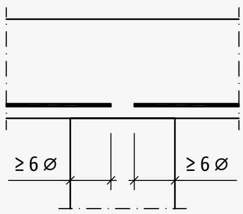


Fig. 22: Anchorage lengths for loops

Anchorages

Required anchorage lengths		
Application case	Anchorage length	Explanation
Feld 	l_{bd}	Anchorage of tension bars $l_{b,min} = 0.3 \cdot \alpha_1 \cdot l_{b,rqd} \geq 10 \cdot \varnothing_f \geq 160$ mm for nominal diameters ⌀8 to 25 mm
		$l_{b,min} = 0.3 \cdot \alpha_1 \cdot l_{b,rqd} \geq 13 \cdot \varnothing_f \geq 160$ mm for nominal diameter ⌀32 mm
		$l_{b,min} = 0.3 \cdot \alpha_1 \cdot l_{b,rqd} \geq 13 \cdot \varnothing_f \geq 224$ mm for nominal diameters ⌀8 to 25 mm
		$l_{b,min} = 0.3 \cdot \alpha_1 \cdot l_{b,rqd} \geq 18 \cdot \varnothing_f \geq 224$ mm for nominal diameter ⌀32 mm
End support direct* (h1 ≤ h2) End support indirect (h1 > h2) 	$l_{bd,dir} = l_{bd} \geq 6.7 \cdot \varnothing_f$	At least 25% of the span reinforcement for beams must be routed to the support and anchored.
	$l_{bd,ind} = l_{bd} \geq 10 \cdot \varnothing_f$	At least 50% of the span reinforcement for slabs must be routed to the support and anchored.
Zwischenauflager 	$l \geq 6 \cdot \varnothing_f$	The reinforcement must always be laid along the arithmetical support line.

Offset

Offset

$$a_1 = \frac{z}{2} \cdot \cot\theta \geq 0$$

- θ = angle between concrete compression member and structural component axis
- z = inner lever arm; z = 0.9 • d can be generally assumed
- $a_1 = 1.0 \cdot d$ always applies for reinforced concrete slabs without shear reinforcement

Anchorages

Reduction of the anchorage length using anchorage heads (outside GTA)

The required anchorage length of straight Combar® bars can be reduced by using an anchorage head. The force that can be permanently absorbed by the head (design value) was determined by fatigue testing. This is to be subtracted from the total force that has to be anchored to obtain the force that still has to be anchored in the bar. Accordingly, and at variance with EC2, the total anchorage length l_{bd} is composed of the length of the head $l_{b,head}$ and the remaining anchorage length required at the bar $l_{bd\ bar}$.

Notes

- $F_d = F_{head,\ d} + F_{bar,\ d}$
- $l_{bd} = l_{b,head} + l_{bd,bar}$

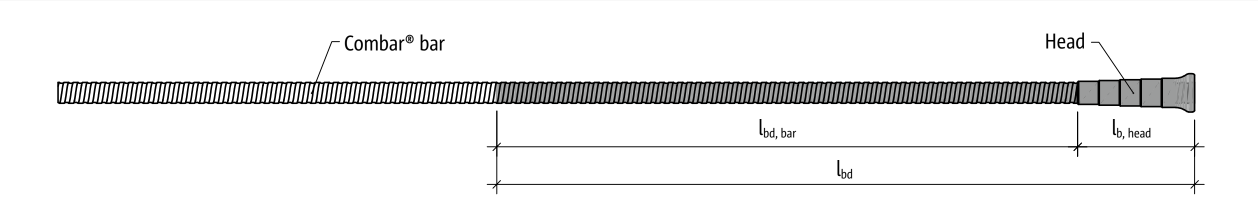


Fig. 23: Anchorage length for Combar® bar with head

Geometry and design value of the end anchorage force of Combar® heads			
Nominal diameter $⌀_f$ [mm]	$l_{b,\ head}$ [mm]	⌀ $head_{outer}$ [mm]	Anchor force (fully anchored) $F_{head,k}$ [kN]
12	60	30	31
16	100	40	68
20	100	45	85
25	100	50	106
32	100	64	136

Statically required reinforcement above the support

$F_{Ed} = |V_{Ed}| \cdot (a1 / z) + N_{Ed}$ where $z \approx 0.9 \cdot d$

$F_{Ed} \geq 0.5 \cdot V_{Ed}$

Required $A_f = F_{Ed} / (f_{fd} / 10)$

Structural component with shear reinforcement

$$a_1 = \frac{z}{2} \cdot \cot\theta \geq 0$$

Structural component without shear reinforcement

$$a_1 = 1{,}0 \cdot d \geq 0$$

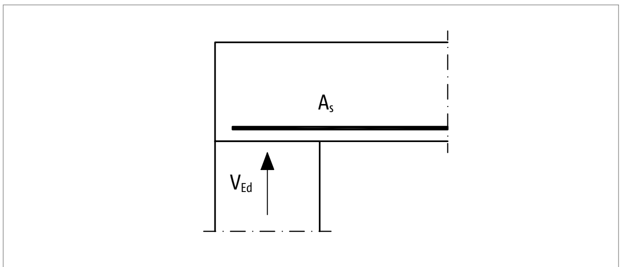
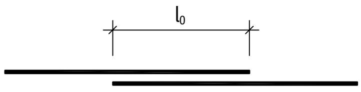


Fig. 24: Support

Overlapping joints of bars

Overlapping joints of bars (tensile joints only, outside GTA)



$$l_0 = \alpha_1 \cdot \alpha_5 \cdot \alpha_6 \cdot l_{b,rqd} \cdot \frac{A_{f,rqd}}{A_{f,exist}} \geq l_{0,min} \geq 20\ \text{cm}$$

$$l_{0,min} = 0.3 \cdot \alpha_1 \cdot \alpha_6 \cdot l_{b,rqd} \geq 15\ \varnothing_f$$

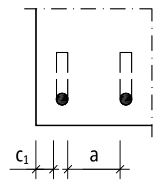


Fig. 25: Overlap joints (tensile joints only)

Coefficient α_6 to take into account the impact component for tensile joints			
Coefficients for		Proportion of bars butted without longitudinal offset	
		≤ 33 %	> 33 %
$\varnothing_f < 16$ mm	$a \geq 8\ \varnothing_f$ and $c_1 \geq 4\ \varnothing_f$	$\alpha_6 = 1.0$	$\alpha_6 = 1.0$
	$a < 8\ \varnothing_f$ and $c_1 < 4\ \varnothing_f$	$\alpha_6 = 1.2$	$\alpha_6 = 1.4$
$\varnothing_f \geq 16$ mm	$a \geq 8\ \varnothing_f$ and $c_1 \geq 4\ \varnothing_f$	$\alpha_6 = 1.0$	$\alpha_6 = 1.4$
	$a < 8\ \varnothing_f$ and $c_1 < 4\ \varnothing_f$	$\alpha_6 = 1.4$	$\alpha_6 = 2.0$

Design example
Floor slab

Design example | Element arrangement – with linear loading

Basic principles

Corrosion damage to floor slabs in underground car parks, ramps, industrial halls, vehicle depots or fire stations is an expensive and unpleasant ongoing issue for operators. When water and air penetrate reinforced concrete structural components through cracks in the concrete and reach the reinforcing steel, the steel begins to corrode. The chloride which enters almost every parking structure, for example from road salt in winter, intensifies and/or initiates the corrosion. A conventional method of protecting , such structures from corrosion damage is to apply maintenance-intensive surface coatings.
A cost-effective solution is to use corrosion-resistant Combar® reinforcement instead. This eliminates the need for surface coatings, thereby avoiding maintenance costs.
The following design example considers a strip of floor slab with waterproof concrete under a reinforced concrete column.

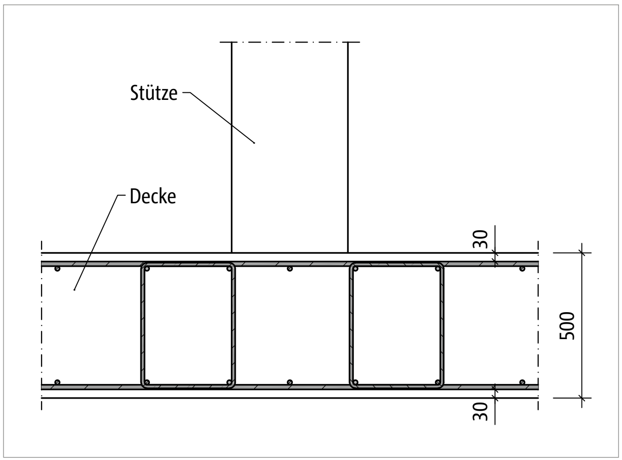


Fig. 26: Slab strip under reinforced concrete column

- Width b = 100 cm
- Height h = 50 cm
- Length L = 100 cm
- Concrete cover

$$c_v = c_{min} + \Delta_c$$

$$c_v = 16\text{ mm } (d_s) + 10\text{ mm (Ortbeton)} = 26\text{ mm} \rightarrow 30\text{ mm}$$

- Static effective height

$$d = h - c_v - d_{Bügel} - \frac{d_{Stab}}{2}$$

$$= 500 - 30 - 12 - \frac{16}{2} = 450\text{ mm}$$

- Statically determinate system
- Maximum crack width w_{per} = 0.2 mm
- Design shear force V_{Ed} = 200 kN/m
- Applied moment M_{Ed} = 200 kNm/m
- Concrete strength class C30/37
- Characteristic value for the concrete compressive strength f_{ck} = 30 N/mm²
- Average concrete compressive strength f_{cm} = 38 N/mm²
- Average concrete tensile strength f_{ctm} = 2.9 N/mm²
- Selected Combar® longitudinal reinforcement on each side 6 - d_f = 16 mm; A_s = 12.06 cm²
- Young's modulus of Combar® longitudinal reinforcement E_{fl} = 60,000 N/mm²
- Selected Combar® stirrup reinforcement d_f = 12 mm; 3 sections every 15 cm; a_{fw} = 22.6 cm²/m
- Young's modulus of Combar® stirrup reinforcement E_{fw} = 50,000 N/mm²
- Selected steel B 500 NR for stirrup reinforcement (1.4482) stainless steel d_s = 12 mm; 2 sections every 30 cm; a_{sw} = 7.54 cm²/m
- Young's modulus of steel B 500 NR for stirrup reinforcement (1.4482) E_s = 160,000 N/mm²

Verifications in the ultimate limit states

Ultimate limit state – verification of bending

Bending design using ω chart
Inner lever arm

$$z_{s1} = \frac{h}{2} - c_v - d_{Bügel} - \frac{d_{Stab}}{2}$$

$$= \frac{500}{2} - 30 - 12 - \frac{16}{2} = 200 \text{ mm}$$

Design moment $M_{Ed1} = M_{Ed} - N_{Ed} - z_{s1}$ = 200 kNm/m
Referenced moment

$$\mu_{Ed1} = \frac{M_{Ed1}}{(b \cdot d^2 \cdot f_{cd})}$$

$$= \frac{200 \cdot 10^6 \text{ [Nmm/mm]}}{(1000 \text{ [mm]} \cdot 452^2 \text{ [mm}^2\text{]} \cdot 17 \text{ [N/mm}^2\text{]})} \approx 0{,}06$$

From Omega table: ω_1 = 0.063
Required reinforcement

$$\text{erf. } A_s = \frac{(\omega \cdot b \cdot d \cdot f_{cd} + N_{Ed})}{f_{yd}}$$

$$= \frac{(0{,}063 \cdot 1000 \text{ [mm]} \cdot 450 \text{ [mm]} \cdot 17 \text{ [N/mm}^2\text{]} + 0)}{445 \text{ [N/mm}^2\text{]}} = 1083 \text{ mm}^2$$

Minimum reinforcement
Inner lever arm z ≈ 0.9 - d = 0.9 - 450 mm = 405 mm
Resistance moment

$$W_c = \frac{(h^2 \cdot b)}{6}$$

$$= \frac{(0{,}5^2 \text{ [m}^2\text{]} \cdot 1 \text{ [m]})}{6} = 0{,}04167 \text{ m}^3$$

Mean value of the centric concrete strength f_{ctm} = 2.9 N/mm² = 2,900 kN/m²
Crack moment $M_{cr} = f_{ctm} - W_c$ = 2,900 [kN/m²] - 0.04167 [m³] = 120.83 kNm
Bar tension $\sigma_f = 0.83 - f_{fk}$ = 445 N/mm²
Minimum reinforcement

$$A_{f,min} = \frac{M_{cr}}{\sigma_f \cdot z}$$

$$= \frac{120{,}83 \cdot 10^6 \text{ [Nmm]}}{445 \text{ [N/mm}^2\text{]} \cdot 405 \text{ [mm]}}$$

$$= 670 \text{ mm}^2 = 6{,}7 \text{ cm}^2 < \text{gewählte } A_f = 12{,}06 \text{ cm}^2 \checkmark$$

Maximum reinforcement
Concrete cross-sectional area A_c = 50 cm - 100 cm = 5,000 cm²
$A_{f,max} = 0.035 - A_c$ = 0.035 - 5000 cm² = 175 cm² < selected. A_f = 12.06 cm²

Shear force

Without shear reinforcement

Partial factor for the concrete $\gamma_c = 1.5$

Scale factor

$$\kappa = 1 + \sqrt{\frac{200}{d}}$$

$$= 1 + \sqrt{\frac{200}{446}} = 1{,}67$$

Degree of longitudinal reinforcement

$$\rho_l = \frac{A_{fl}}{b_w \cdot d}$$

$$= \frac{12{,}06 \text{ cm}^2}{100 \text{ cm} \cdot 45 \text{ cm}} = 0{,}268\ \%$$

Design value of shear force that can be resisted for structural components without shear reinforcement

$$V_{Rd,c} = \frac{0{,}138}{\gamma_c} \cdot \kappa \cdot (100 \cdot \rho_l \cdot \frac{E_f}{E_s} \cdot f_{ck})^{1/3} \cdot b_w \cdot d$$

$$= \frac{0{,}138}{1{,}5} \cdot 1{,}67 \cdot (100 \cdot 0{,}00268 \cdot \frac{60.000}{200.000} \cdot 30)^{1/3} \cdot 1.000 \cdot 450$$

$$= 92{,}7 \text{ kN} < V_{ed} = 200 \text{ kN}$$

Shear reinforcement is required

Shear force

With Combar® shear reinforcement
Design value for the shear force that can be resisted by the concrete

$$V_{Rd,c} = \beta_R \cdot \frac{1}{425 \cdot \gamma_c} \cdot \kappa \cdot (100 \cdot \rho_l \cdot E_{fl} \cdot f_{ck})^{1/3} \cdot b_w \cdot d$$

$$= 1 \cdot \frac{1}{425 \cdot 1,5} \cdot 1,67 \cdot (100 \cdot 0,00268 \cdot 60.000 \cdot 30)^{1/3} \cdot 1.000 \cdot 450 = 92,6 \text{ kN}$$

Simplified structural component bending stiffness

$$EI^* = E_{fl} - A_{fl} - (0.8 - d)^2 = 60,000 \text{ [N/mm}^2\text{]} - 1206 \text{ [mm}^2\text{]} - (0.8 - 450 \text{ [mm]})^2$$

$$= 9.83 - 1012 \text{ N/mm}^2 = 9.83 \text{ MN/m}^2$$

Design value of the maximum elongation of the shear reinforcement

$$\varepsilon_{fd,w} = 2,3 + \frac{2 \cdot EI^* \text{ [MN/m}^2\text{]}}{30} \leq 7,0 \text{ [‰]}$$

$$= 2,3 + \frac{2 \cdot 9,83}{30} = 2,93 \text{ ‰} \leq 7,0 \text{ ‰}$$

Design value of the tensile strength of the shear reinforcement

$$f_{fd,w} = 160 \text{ N/mm}^2 \leq \varepsilon_{fd,w} - E_{fw}$$

$$= 2.93 \text{ ‰} - 50,000 \text{ [N/mm}^2\text{]} = 146 \text{ N/mm}^2$$

$$V_{Rd,c} = \beta_R \cdot \frac{1}{425 \cdot \gamma_c} \cdot \kappa \cdot (100 \cdot \rho_l \cdot E_{fl} \cdot f_{ck})^{1/3} \cdot b_w \cdot d$$

$$= 1 \cdot \frac{1}{425 \cdot 1,5} \cdot 1,67 \cdot (100 \cdot 0,00268 \cdot 60.000 \cdot 30)^{1/3} \cdot 1.000 \cdot 450 = 92,6 \text{ kN}$$

Compression element angle

$$\theta = \arctan \left[\sqrt[3]{\frac{\frac{M}{V} \cdot a_{fw} \cdot E_{fw}}{A_{fl} \cdot E_{fl}}} \right] \begin{cases} \geq 20° \\ \leq 50° \end{cases}$$

$$= \arctan \left[\sqrt[3]{\frac{\frac{200}{200} \cdot 2.262 \text{ [mm}^2\text{/m]} \cdot 50.000 \text{ [N/mm}^2\text{]}}{1.205 \text{ [mm}^2\text{/m]} \cdot 60.000 \text{ [N/mm}^2\text{]}}} \right] = 49,2°$$

Shear force

Design value of the shear force that can be resisted by the shear reinforcement

$V_{Rd,f} = a_{fw} \cdot f_{fd,w} \cdot z \cdot \cot(\Theta)$

$= 2260\ [mm^2/mm] \cdot 0.146\ [kN/mm^2] \cdot 405\ [mm] \cdot \cot(49.2°) = 115.4\ kN$

Design value of the shear force that can be resisted by the complete structural component

$V_{Rd} = V_{Rd,c} + V_{Rd,f}$

$= 92.6\ [kN] + 115.4\ [kN] = 208\ kN \geq V_{Ed} = 200\ kN$ ✓

Design value of the shear force that can be resisted by the concrete compression member

$$V_{Rd,max} = V_{Rd,c} + \frac{1{,}1 \cdot b_w \cdot z \cdot f_{cm}^{2/3}}{\gamma_c \cdot (\cot(\Theta) + \tan(\Theta))}$$

$$= 92{,}6 + \frac{1{,}1 \cdot 1.000 \cdot 405 \cdot 38^{2/3}}{1{,}3 \cdot (\cot(49{,}2°) + \tan(49{,}2°))} = 1753\ kN \geq V_{ed}$$ ✓

Minimum shear reinforcement

$$a_{fw,min} = 0{,}16 \cdot \frac{f_{ctm}}{f_{fd,w}} \cdot s \cdot b_w$$

$$= 0{,}16 \cdot \frac{2{,}9\ [N/mm^2]}{160\ [N/mm^2]} \cdot 100\ cm \cdot 50\ cm$$

$$= 14{,}5\ cm^2/m \leq a_{fw,vorh} = 22{,}6\ cm^2/m$$ ✓

Shear force

With shear reinforcement using stainless reinforcing steel B 500 NR (material number: 1.4482)

This component with arithmetically required shear reinforcement is verified using a combination of Combar® as longitudinal reinforcement and steel as shear reinforcement in accordance with EC2, section 6.2.3 with NA, subject to the following boundary conditions:

- Limitation of the calculated compression element angle to cot (Θ) ≤ 2.0
- Determination of the offset with cot (Θ) ≤ 3.0
- Determination of compression element load-bearing capacity (max. shear force resistance) with v1 = 0.5 - v2

Inner lever arm

z ≈ 0.9 - d = 0.9 - 450 mm = 405 mm

Angle of the concrete compression element

$$V_{Rd,cc} = 0{,}5 \cdot 0{,}48 \cdot f_{ck}^{1/3} \cdot \left(1 - 1{,}2 \cdot \frac{\sigma_{cd}}{f_{cd}}\right) \cdot b_w \cdot z$$

$$= 0{,}5 \cdot 0{,}48 \cdot 30^{1/3}\,[\text{N/mm}^2] \cdot \left(1 - 1{,}2 \cdot \frac{0\,[\text{N/mm}^2]}{17\,[\text{N/mm}^2]}\right) \cdot 1.000\,[\text{mm}] \cdot 405\,[\text{mm}] = 302{,}0\,[\text{kN}]$$

Compression element angle

$$\cot(\Theta) = 1{,}0 \leq \frac{1{,}2 - 1{,}4 \cdot \frac{\sigma_{cp}}{f_{cd}}}{1 - \frac{V_{Rd,cc}}{V_{ed}}} \leq 2{,}0$$

$$= \frac{1{,}2 - 1{,}4 \cdot \frac{0\,[\text{N/mm}^2]}{17\,[\text{N/mm}^2]}}{1 - \frac{302\,[\text{kN}]}{200\,[\text{kN}]}} = -2{,}353$$

0.6 - $V_{Ed} \leq V_{Rd,cc}$

0.6 - 200 [kN] = 120 [kN] ≤ $V_{Rd,cc}$ = 302 [kN]

cot (Θ) = 3.0 ≤ 2.0 → cot (Θ) = 2.0

Verification of the concrete compression element

$$\nu_1 = 0{,}5 \cdot \left(1{,}1 - \frac{f_{ck}}{500}\right) \leq 0{,}5$$

$$= 0{,}5 \cdot \left(1{,}1 - \frac{30\,[\text{N/mm}^2]}{500}\right) = 0{,}52 \leq 0{,}5$$

$$V_{Rd,max} = \frac{\nu_1 \cdot f_{cd} \cdot b_w \cdot z \cdot \cot(\Theta)}{(1 + \cot^2(\Theta))}$$

$$= \frac{0{,}5 \cdot 17\,[\text{N/mm}^2] \cdot 1.000\,[\text{mm}] \cdot 405\,[\text{mm}] \cdot 2}{\frac{(1 + 0{,}2^2)}{1.000}} = 1.377{,}0\,[\text{kN}] \geq V_{ed} = 200\text{ kN} \checkmark$$

Shear force

Verification of the tensile element

Required shear reinforcement

$$a_{sw} = \frac{V_{Ed}}{f_{yd} \cdot \sin\alpha \cdot z \cdot (\cot \cdot \cot\alpha)}$$

$$= \frac{200\,[kN] \cdot 10^3}{435\,[N/mm^2] \cdot 1 \cdot 405\,[mm] \cdot 10^{-3} \cdot (2{,}0 \cdot 1)}$$

$$= 5{,}68\ cm^2/m \leq a_{sw,vorh} = 7{,}54\ cm^2/m\ \checkmark$$

Minimum shear reinforcement

$$a_{sw} = \frac{V_{Ed}}{f_{yd} \cdot \sin\alpha \cdot z \cdot (\cot \cdot \cot\alpha)}$$

$$= \frac{200\,[kN] \cdot 10^3}{435\,[N/mm^2] \cdot 1 \cdot 405\,[mm] \cdot 10^{-3} \cdot (2{,}0 \cdot 1)}$$

$$= 5{,}68\ cm^2/m \leq a_{sw,vorh} = 7{,}54\ cm^2/m\ \checkmark$$

Verifications in the serviceability limit states

The crack width of Combar® does not need to be limited for durability reasons. However, as the example involves a waterproof floor slab, the crack width is limited to 0.2 mm.
The required crack width reinforcement for early-onset constraint is calculated below. The centric tension from the dissipation of hydration heat is also factored into the calculation. As an alternative to the detailed verification below, the required crack width reinforcement can be calculated using reinforcing steel and converted to Combar® using the conversion factor '1.83' as shown on page 36.
The thicker the structural component, the longer it takes for the hydration heat to dissipate. With a cross-section thickness of 0.5 m, the dissipation of the hydration heat is estimated to take approximately 4 days. The effective concrete tensile strength at the time of crack formation is therefore assumed to be as follows.
$f_{ct,eff} = 0.7 \cdot f_{ctm} = 0.7 \cdot 2.9$ [N/mm²] = 2.03 N/mm²
A reduced forced stress can be assumed for the crack width reinforcement in a floor slab. The effective concrete tensile stress is thereby reduced in addition to EC2 and according to the recommendations of 'Lohmeyer Stahlbetonbau'.

The stress under the floor slab consists of the dead weight:
$\sigma_0 = \gamma_c \cdot h \cdot \gamma_{Combar\_concrete} = 1.35 \cdot 0.5 \cdot 25 = 16.88$ kN/m²
Assuming a smoothed sub-concrete and 2 layers of PE film, the resulting coefficient of friction is $\mu_0 = 0.8$. The design value of the friction is thus determined as follows, assuming a safety factor of $\gamma_R = 1.35$:
$\mu_d = \mu_0 \cdot \gamma_R = 0.8 \cdot 1.35 = 1.08$
The tensile stress under the floor slab σct,d may be assumed as the effective shear stress instead of the effective concrete tensile strength $f_{ct,eff}$.

$$\sigma_{ct,d} = \frac{\gamma_{ct} \cdot \mu_d \cdot \sigma_0 \cdot L}{2 \cdot A_{ct}}$$

$$= \frac{1 \cdot 1{,}08 \cdot 16{,}88\,[\text{kN/m}^2] \cdot 10\,[\text{m}]}{2 \cdot 0{,}5\,[\text{m}^2]} = 0{,}18\ \text{N/mm}^2$$

Effective height of the reinforcement

$$h_{c,ef} = 2{,}5 \cdot (h - d) \leq \frac{h}{2}$$

$$= 2{,}5 \cdot (500 - 450) \leq \frac{500}{2} = 125$$

Area of influence of reinforcement $A_{c,ef} = h_{c,ef} \cdot b = 0.125\ \text{m} \cdot 1\ \text{m} = 0.125\ \text{m}^2$
Coefficient $k_c = 1.0$ (centrical constraint)
Coefficient $k = 0.98 \cdot 6 \cdot 10^4 \cdot h\ [\text{mm}] \leq 0.8 \geq 0.5 = 0.98 \cdot 6 \cdot 10^4 \cdot 500\ \text{mm} = 0.68$
Area of concrete tension zone under centrical constraint $A_{ct} = h \cdot b = 0.5\ \text{m} * 1\ [\text{m}] = 0.5\ [\text{m}^2]$
h/d1 = 500/50 = 10 > 5 → Thick structural component
Area of influence of reinforcement $h_{c,ef} = 150$ mm (EC2-1-1 Figure NA.7.1d)
Area of influence of reinforcement $A_{c,eff} = h_{c,ef} \cdot b \cdot 2 = 0.15 \cdot 1 \cdot 2 = 0.3$ m
Crack force

$$F_{cr} = A_{c,ef} \cdot f_{ct,eff}$$

$$= \frac{0{,}3\ \text{m}^2 * 0{,}18\ [\text{N/mm}^2]}{1000^2} = 0{,}054\ \text{MN}$$

Steel tensile force $F_s = k_c \cdot k \cdot f_{ct,eff} \cdot A_{ct} = 1.0 \cdot 0.68 \cdot 0.18\ [\text{N/mm}^2] \cdot 0.5\ \text{m}^2 \cdot 1000^2 = 0.061$ MN
Initial crack force $F_s \geq F_{cr}$ → High structural component → Area of influence of the reinforcement decisive
Longitudinal reinforcement on both sides $A_{sl} = 12.06 \cdot 2 = 24.12$ cm²/m
Existing bar stress

$$\sigma_s = \frac{F_s}{A_{sl}}$$

Verifications in the serviceability limit states

$$= \frac{0{,}061\ [\text{MN}] \cdot 1.000}{24{,}12\ \text{cm}^2} = 25{,}37\ \text{N/mm}^2$$

$$\alpha_e = \frac{E_s}{E_{cm}}$$

$$= \frac{60.000}{28.300} = 2{,}12$$

Degree of reinforcement

$$\rho_{eff} = \frac{A_{sl}}{A_{c,eff}}$$

$$= \frac{24{,}12}{0{,}3 \cdot 1.000^2} = 0{,}80\ \%$$

Distance between cracks

$$S_{r,max} = \frac{d_f}{2{,}8 \cdot \rho_{f,eff}} \leq \frac{\sigma_f \cdot d_f}{2{,}8 \cdot f_{ct,eff}}$$

$$= \frac{16}{2{,}8 \cdot 0{,}80\ \%} \leq \frac{25{,}37 \cdot 16}{2{,}8 \cdot 0{,}18} = 714{,}3 \leq 805{,}4$$

Difference in expansion

$$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - \kappa_t \cdot \frac{f_{ct,eff}}{\rho_{p,eff}} \cdot (1 + \alpha_e \cdot \rho_{p,eff})}{E_s} \geq 0{,}6 \cdot \frac{\sigma_s}{E_s}$$

$$= \frac{25{,}37 - 0{,}4 \cdot \frac{0{,}18}{0{,}80\ \%} \cdot (1 + 2{,}12 \cdot 0{,}80\ \%)}{60.000} \geq 0{,}6 \cdot \frac{25{,}37}{60.000} = 0{,}000270 \geq 0{,}000254$$

Crack width

$$w_k = s_{r,max} \cdot (\varepsilon_{sm} - \varepsilon_{cm}) = 714.3 \cdot 0.000270$$
$$= 0.193\ \text{mm} \leq w_{per} = 0.2\ \text{mm}\ ✓$$

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Dependable by design

Schöck Bauteile GmbH
Schöckstraße 1
76534 Baden-Baden
Telephone: +49 7223 967-144
export@schoeck.com
www.schoeck.com

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