SIA 166:2024 Construction

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Replaces SIA 166:2004

Adhesively bonded reinforcement for strengthening existing structures
Adhesively bonded reinforcement for strengthening existing structures
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166

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FOREWORD

During the 50 to 100-year service life of a structure, stresses and/or uses change. Damage must also be repaired. An advantageous strategy for conserving valuable resources is to extend the service life of structures through targeted reinforcement, rather than demolition and new construction. One possible reinforcement measure is the use of bonded reinforcement.

Since the first edition of the SIA 166 (2004) pre-standard on *bonded reinforcement* was developed in the early 2000s, bonded reinforcement technology has evolved. There are now interesting new technologies for reinforcing load-bearing structures, such as groove laminates. In addition, practice has shown in various cases that bonded reinforcement is not being used in accordance with the system. The revision therefore aimed to clarify the technical basis in order to avoid errors in use as far as possible. The existing pre-standard has been extensively revised, adapted to the state of the art, and converted into a regular SIA standard.

The main and most significant changes in the current SIA 166 standard compared to the previous standard are as follows
– Structure of the content (new as in SIA standard 262),
– Sustainability and long-term performance,
– Building materials that comply with current international testing standards,
– Groove lamellas,
– Carbon fiber reinforced prestressed slats,
– Dimensioning for bending, confinement, and shear stress,
– Calculation of breaking energies based on characteristic values of the bond strength of surface concrete (instead of average values).

The purpose of using bonded reinforcement is not always to strengthen the structure. Equivalent objectives include, for example, improving ductility by confining compressed elements to activate multiaxial compressive stress states, or targeted reinforcement against brittle failure mechanisms in order to shift failure to locations where ductile failures occur. Pre-stressed bonded reinforcement also improves serviceability (reduction of deformations and crack opening).

The effect of bonded reinforcement is closely linked to the condition and behavior of existing load-bearing structures, whose characteristics are often insufficiently known and cannot be modified at will. As a general rule, it is already under stress, at least from its own weight, but the complete history of the stresses is almost never known. This is why bonded reinforcement only takes up part of the forces that occur after its application, unless a greater contribution is required by special measures (pre-unloading, prestressing). The use of construction materials without yield capacity (fiber-reinforced composites) and the consideration of supports with unfavorable tensile behavior after failure (concrete, masonry, wood) can lead to brittle failure. Fracture states therefore often originate in the existing load-bearing structure and can occur without significant deformation. Tests in accordance with this standard should make it possible to avoid such fracture states.

The bonding technique is not limited to concrete. The SIA 166 (2004) pre-standard already provided guidance on reinforcing steel, wood, and masonry with bonded reinforcement. In the current SIA 166 standard, specific chapters have been created for the reinforcement of steel, wood, and masonry, and these chapters have been considerably expanded.

The topic of reinforcing reinforced concrete with bonded reinforcement is covered in EN 1992-1-1:2023; *Eurocode 2: Design of concrete structures – Part 1-1: General rules – Rules for buildings, bridges and civil engineering works*, Annex J. The working group has adopted some of the design methods – which it considers appropriate – slightly adapted in this standard (confinement, shear reinforcement). However, it considers that the flexural design proposed therein is not suitable for practical use and has presented in this standard a design model that is easy to apply and suitable for practical use.

The Bonded Reinforcement Working Group of the SIA 262 Concrete Construction Commission has set itself the goal of drafting a user-friendly document that covers the latest reinforcement methods, highlights the possibilities and limitations of the technology, and proposes uniform design methods that do not hinder future development.

SIA 166 Working Group

0 SCOPE

0.1 Scope

0.1.1 Bonded reinforcement within the meaning of this standard is reinforcement that is bonded to existing parts of the structure at a later stage. It is generally used in the maintenance of existing load-bearing structures.

0.1.2 Bonded reinforcement is also used temporarily for construction site installations (scaffolding and barriers) or for transporting construction elements.

0.1.3 This standard applies to the design and execution of bonded reinforcement on concrete, steel, wood, and masonry substrates.

0.1.4 The following are not covered by this standard (non-exhaustive list):
- the use of fiber composite materials as internal reinforcement in concrete or as permanent formwork for concrete construction elements,
- the use as reinforcement for newly produced load-bearing wood elements, in the form of bonded reinforcements incorporated or applied,
- the use of steel profiles bonded to concrete slabs or other concrete construction elements,
- the use of bonding techniques for assembly purposes in metal, wood, lightweight, or solid construction.

0.2 Normative references

The text of this standard refers to the following publications, the provisions of which apply in full or in part as indicated in the reference. Undated references refer to the latest edition of the publication (for SN EN including amendments), dated references refer to the corresponding edition.

0.2.1 **SIA publications**

SIA Standard 179	Fixings in concrete and masonry
SIA Standard 260	Basis for the design of load-bearing structures SIA Standard
261	Actions on load-bearing structures
SIA Standard 262	Concrete construction
SIA Standard 263	Steel construction
SIA Standard 263/1	Steel construction – Additional specifications SIA Standard
265	Wood construction
SIA Standard 265/1	Wood construction – Additional specifications SIA 266
standard	Masonry construction
SIA Standard 266/2	Natural stone masonry
SIA Standard 269	Basis for the maintenance of load-bearing structures
SIA Standard 269/1	Maintenance of load-bearing structures – Actions
SIA Standard 269/2	Maintenance of load-bearing structures – Concrete structures
SIA Standard 269/3	Maintenance of load-bearing structures – Steel structures
SIA Standard 269/4	Maintenance of load-bearing structures – Composite steel-concrete
structures SIA Standard 269/5	Maintenance of load-bearing structures – Wood structures
SIA Standard 269/6-2	Maintenance of load-bearing structures – Masonry structures – Part 2: Bricks and concrete blocks
SIA Standard 269/8	Maintenance of load-bearing structures –

Earthquakes SIA Technical Report 2007 Quality in construction

0.2.2 European standards

SN EN ISO 527-1	Plastics – Determination of tensile properties – Part 1: General principles
SN EN 1504-3:2005	Products and systems for the protection and repair of concrete structures – Definitions, requirements, quality control and evaluation of conformity – Part 3: Structural and non-structural repair
SN EN 1504-4:2004	Products and systems for the protection and repair of concrete structures – Definitions, requirements, quality control and evaluation of conformity – Part 4: Structural bonding
SN EN 1542	Products and systems for the protection and repair of concrete structures – Test methods – Measurement of adhesion by direct traction
SN EN 1770	Products and systems for the protection and repair of concrete structures – Test methods – Determination of the coefficient of thermal expansion
SN EN 12614	Products and systems for the protection and repair of concrete structures – Test methods – Determination of the glass transition temperature of polymers
SN EN ISO 12944-2	Paints and varnishes – Anti-corrosion of steel structures by paint systems – Part 2: Classification of environments
SN EN ISO 12944-4	Paints and varnishes – Anti-corrosion of steel structures by paint systems – Part 4: Types of surface and surface preparation
SN EN 13791	On-site assessment of compressive strength of concrete structures and precast concrete elements

0.2.3 International standards

ISO	Adhesives — Determination of tensile lap-shear strength of rigid-to-rigid bonded assemblies
ISO 10406-2	Fiber-reinforced polymer (FRP) reinforcement of concrete — Test methods — Part 2: FRP sheets
ISO 10406-3	Fiber-reinforced polymer (FRP) reinforcement of concrete – Test methods – Part 3: CFRP strips

0.3 Exemptions

0.3.1 Exemptions from this standard are permitted provided that they are sufficiently based on theoretical data or tests, or are justified by new developments or new knowledge.

0.3.2 In the event of conditions not covered by this standard, the procedure must be agreed between the project author and the client, as well as any approval bodies. The chosen procedure must be documented step by step in the usage agreement and in the project database.

1 TERMINOLOGY

For the purposes of this standard, the terms defined below shall be used. These terms are listed in alphabetical order in two languages in Annex B.

1.1 Terms and definitions

1.1.1 **Active anchorage length**
The length over which a bonded reinforcement transmits its maximum anchorage resistance to the substrate.

1.1.2 **Cladding**
System (e.g., panels, plaster) for protecting load-bearing elements against the effects of fire.

1.1.3 **Coating**
Adherent protective layer applied in liquid form, in one or more coats.

1.1.4 **Failure behavior**
Load-bearing behavior after reaching the ultimate load.

1.1.5 **Groove strips**
Bonded reinforcements, which are bonded into grooves

1.1.6 **Fiber**
Elongated reinforcing particle, e.g., made of carbon, glass, aramid, or basalt.

1.1.7 **Composite**
Combination of materials consisting of fibers embedded in a plastic matrix.

1.1.8 **Nonwoven**
Textile composed of bundles of fibers superimposed in one or more directions, with or without fixation at the points of intersection. Nonwovens have a stretched fiber structure.

1.1.9 **Woven**
Textile woven from bundles of fibers arranged in different directions. Woven fabrics have a wavy fiber structure. In woven fabrics, the fibers can be oriented in one or more directions.

1.1.10 **Bonded reinforcement**
A set of load-bearing elements, usually linear, with high tensile strength and tensile resistance in the longitudinal direction, which are bonded to the load-bearing structure and reinforce it in a targeted manner.

1.1.11 **Adhesive**
A liquid or plastic substance applied between parts to be joined which, after hardening, allows the transmission of forces. It consists of two components, resin and hardener, can be filled with quartz sand, and is used for bonding laminates, nonwovens, and woven fabrics.

1.1.12 **Lamella**
Flat reinforcement made of steel or fiber-reinforced composite material with continuous fibers inserted in a unidirectional manner.

1.1.13 **Laminate joint**
Overlap for the transmission of forces from lamella to lamella.

1.1.14 **Matrix**
Plastic that coats the fibers of a composite material.

1.1.15 **Primer**
Primer that protects the surface and/or allows good adhesion to other coatings or glue.

1.1.16 **Interface**
Contact surface between the bonded reinforcement and the adhesive or between the adhesive and the substrate.

1.1.17 **Containment**
Method for reinforcing compressed elements using bonded reinforcement. It improves resistance to compressive forces by allowing a triaxial stress state.

1.1.18 **Unidirectional**
All fibers are inserted in one direction.

1.1.19 **Support**
The part of the load-bearing structure made of concrete, steel, masonry, or wood that needs to be repaired or modified.

1.1.20 **Support failure**
Failure of the support or internal reinforcement contained within the support.

1.1.21 **Anchorage resistance**
Ultimate strength that a bonded reinforcement can transmit to a substrate. The highest possible ultimate strength is obtained for anchor lengths greater than or equal to the active bond length.

1.1.22 **Anchorage zone**
Force introduction zone at the end of the reinforcement element, in which no contribution is made to the reinforcement of the structural element.

1.1.23 **Anchorage length**
Length over which a bonded reinforcement is bonded to the substrate using an adhesive.

1.1.24 **Adhesion failure**
Failure of adhesion between the substrate and the bonded reinforcement.

1.1.25 **Failure mode**
Description of the process leading to the exhaustion of ultimate strength.

1.1.26 **Surface protection**
Finishing layer applied by mechanical or chemical bonding without a reinforcing effect.

1.1.27 **Stiffening**
Increase in the rigidity (usually bending rigidity) of a section or structural element.

1.1.28 **Reinforcement**
Measures aimed at improving the ultimate strength and serviceability of a load-bearing structure or structural element.

1.1.29 **Reinforcement system**
System consisting of bonded reinforcement, adhesive and, where necessary, anchors and structural protection measures.

1.1.30 **Reinforcement failure**
Failure of the bonded reinforcement.

1.1.31 **Functional zone**
Area of the structural element between two anchorage zones in which the bonded reinforcement has a reinforcing effect.

1.2 Symbols, terms, and units

1.2.1 Capital Latin letters

A_f	section of the bonded reinforcement
A_s	cross-sectional area of the inner steel reinforcement
A_{sw}	cross-sectional area of internal stirrups
C_d	associated service limit
D	diameter
D_{ak}	characteristic value of the deformation energy of the adhesive
E_a	average value of the modulus of elasticity of the adhesive under compression
E_{cd}	design value of the modulus of elasticity of concrete E_{cm}
	average value of the modulus of elasticity of concrete E_d
	design value of an action effect
E_f	average value of the modulus of elasticity of bonded reinforcement E_{fd}
	design value of the modulus of elasticity of the bonded reinforcement E_{fk}
	characteristic value of the modulus of elasticity
E_s	average value of the modulus of elasticity of the internal steel reinforcement
$F_{b,R}$	anchorage resistance of the bonded reinforcement for bond lengths less than l_{b0}
$F_{b,Rd}$	design value of the anchorage resistance of the bonded reinforcement for anchorage lengths less than lb0
$F_{b,Rd,fat}$	design value of the anchorage resistance of the bonded reinforcement for anchorage lengths less than l_{b0} for fatigue stresses
$F_{b0,R}$	anchorage resistance of the bonded reinforcement for anchorage lengths greater than l_{b0}
$F_{b0,Rd}$	design value of the anchorage resistance of the bonded reinforcement for anchorage lengths greater than l_{b0}
F_f	tensile stress in the bonded reinforcement
F_{fcr}	tensile force of the bonded reinforcement at the location of the last crack in front of the anchorage zone
$F_{fcr,d}$	design value of the tensile force in the bonded reinforcement at the location of the last crack in front of the anchorage zone
F_{fw}	tensile force in the bonded reinforcement acting as a stirrup
F_{fwd}	design value of the tensile force in the bonded reinforcement acting as a stirrup
$F_{f,d}$	design value of the tensile force in the bonded reinforcement
$F_{f,Rd}$	design value of the tensile strength of the bonded reinforcement $F_{p\infty}$prestressing force in the

bonded reinforcement after deduction of all losses F_s tensile stress in the internal steel

reinforcement

F_{sd}	design value of the tensile force in the internal steel reinforcement
F_{td}	design value of the increase in tensile force due to shear force
F_y	tensile stress in the bonded reinforcement at the point where the internal steel reinforcement begins to flow
G_a	average value of the shear modulus of the adhesive, $G_a = E_a /2 (1+v)$, where v can be set at 0.3

G_{Fad}	design value of the specific breaking energy of the end anchorage of a reinforcement bonded to steel
G_{Fcd}	design value of the specific breaking energy of the end anchorage of a reinforcement bonded to concrete
G_{Fsd}	design value of the specific rupture energy of the end anchorage of a reinforcement bonded into grooves in concrete
L_p	determining perimeter of a lamella for grooves according to equation (21)
M_d	design value of the bending moment
T_g	average value of the glass transition temperature of an adhesive
T_{ser}	maximum operating temperature
R_d	ultimate strength design value
$R\{\ldots\}$	ultimate strength based on the design values indicated in parentheses
S_d	design value of internal force
V_d	design value of the shear force
V_{Rd}	design value of the shear resistance
$V_{Rd,f}$	design value of the shear resistance of bonded reinforcement acting as stirrups
$V_{Rd,s}$	design value of shear resistance of internal steel stirrups
X_d	design value of a property of the building material
X_k	characteristic value of a property of the building material

1.2.2 Lowercase Latin letters

a_d	design value of a geometric quantity
a_f	center distance between slats for grooves
a_{en}	distance to the edge
b_{eff}	effective width
b_f	width of the glued reinforcement
c	factor
d	static height
f_{ak}	characteristic value of the tensile strength of the adhesive
f_{am}	average tensile strength value of the adhesive
f_{ask}	characteristic value of the adhesive's tensile shear strength
f_b	compressive strength of masonry stone
f_{ccd}	design value of the compressive strength of concrete increased by confinement
f_{cd}	design value of the compressive strength of concrete on cylinders
f_{ck}	characteristic value of the compressive strength of concrete on cylinders
f_{ctd}	design value of concrete tensile strength $f_{ctk0.05}$
	5% fractile value of concrete tensile strength f_{ctm}
	mean value of the tensile strength of concrete
f_{fud}	design value of the tensile strength of the bonded reinforcement

f_{fuk}	characteristic value of the tensile strength of the bonded reinforcement
f_{smoke}	average tensile strength of the bonded reinforcement
f_h	adhesion strength of concrete close to the surface
f_{hd}	design value of the bond strength of concrete near the surface
f_{hk}	characteristic value of the bond strength of concrete near the surface
f_{hm}	average value of the bond strength of concrete near the surface
f_{sd}	design value of the yield strength of the internal steel reinforcement
f_{sk}	characteristic value of the yield strength of the internal steel reinforcement
f_{yd}	design value of the flow limit of the bonded reinforcement
k_n	fractile factor for determining the bond strength of the concrete near the surface resulting from pull-off tests
l_b	anchorage length of the bonded reinforcement
l_{bd}	design value for the anchorage length of the bonded reinforcement
l_{b0d}	design value of the effective bond length of bonded reinforcement (minimum length required to transmit $F_{b0,Rd}$)
l_{cr}	distance between the location of the last crack in front of the anchorage zone and the axis of the support
l_y	distance between the starting point of the internal steel reinforcement flow and the axis of the support
q	coefficient of behavior
n	number
r_c	angle radius
s	standard deviation of the bond strength of concrete near the surface resulting from pull-off tests
s_f	spacing of bonded stirrups
$s_{f,el}$	slip of the bonded reinforcement at the point of maximum shear bond stress
$s_{f,max}$	maximum slip of the bonded reinforcement
s_s	distance between inner brackets
t_a	nominal thickness of the adhesive
t_f	thickness of the bonded reinforcement
t_s	groove width
w_f	width of the groove strip
w_s	groove depth
x	height of the compressed deflected area
z_f	lever arm of the resultant tensile and compressive forces of the bonded reinforcement
z_s	raise arm of the resultant tensile and compressive forces of the internal reinforcement

1.2.3 Lowercase Greek letters

α_a	average value of the expansion coefficient of the adhesive
α_f	average value of the expansion coefficient of the bonded reinforcement
γ_f	resistance coefficients for determining the design values of the properties of building materials in the event of reinforcement failure
γ_h	resistance coefficients for determining the design values of the properties of building materials in the event of bond failure

e_f	elongation of bonded reinforcement
e_{fcr}	elongation of the bonded reinforcement at the location of the last crack in front of the anchorage zone
e_{fd}	design value of elongation in the bonded reinforcement
$e_{fd,lim}$	design value of the limit elongation of the bonded reinforcement
e_{fud}	design value of the elongation at break of the bonded reinforcement
e_{fuk}	characteristic value of the rupture elongation of the bonded reinforcement (5% fractile value) $e_{p\infty}$ elongation in the bonded reinforcement due to prestressing after deduction of all losses e_{ud} design value of the rupture elongation of the internal steel reinforcement
η	reduction factor for bonded reinforcement
η_e	reduction factor for different exposure classes
η_l	reduction factor for permanent or cyclic loading
η_{qu}	reduction factor for determining the ultimate strength of shear reinforcement
η_u	reduction factor for bond failures
η_{um}	reduction factor for determining the ultimate strength of confinement
v	Poisson's ratio
ρ	reinforcement ratio
$s_{al,ll}$	principal tensile stresses in the adhesive
s_c	stress in the concrete
s_{cd}	design value of the stress at the edge of the concrete
s_s	stress in the internal steel reinforcement
s_{1d}	design value of the average confinement stress
t_a	average value of the shear stress of the adhesive
$t_{a,max,d}$	design value of the maximum shear stress that can be absorbed by the adhesive
$t_{c,max,d}$	design value of the maximum shear stress that can be absorbed by the concrete near the surface
t_f	adhesion shear stress
$t_{f,gl}$	total shear stress
$t_{s,max,d}$	design value of the maximum bond shear stress in concrete grooves

1.2.4 **Special notations**

$_f$	diameter of composite material bar
$_s$	diameter of the inner steel reinforcing bar

1.3 Construction methods

For the basic construction methods and their combinations (mixed constructions) covered by this standard, different terms are used for the classes of construction materials, which can be found in the corresponding SIA standards.

2 PRINCIPLES

2.1 General

2.1.1 The basis comprises the initial and updated usage agreement and the project basis, as well as the results of the examination of the existing supporting structure.

2.1.2 The review based on the updating of actions and properties of building materials is carried out in accordance with SIA 269. The update must take into account all available information. The influences of degradation mechanisms in particular must be taken into account. As a general rule, the checks are carried out using the deterministic method, but probabilistic checks are also possible.

2.1.3 The examination of existing load-bearing structures is carried out in accordance with SIA 269/2 for concrete load-bearing structures, SIA 269/3 for steel load-bearing structures, SIA 269/5 for timber load-bearing structures, and SIA 269/6-2 for masonry load-bearing structures.

2.1.4 The examination of the existing load-bearing structure provides information about the entire structure and therefore also about the structural element or load-bearing structure to be reinforced with bonded reinforcement.

2.1.5 For the entire structure, the results of the following examination are required as a minimum:

- condition survey with condition assessment (including assessment of the building file),
- safety assessment (structural safety and service safety),
- assessment of serviceability,
- forecast of condition development,
- any emergency measures ordered,
- recommendations for follow-up action,
- information on user requirements, conservation value, and legal obligations.

2.1.6 For the structural element or load-bearing structure to be reinforced with bonded reinforcement, the following verification results are required as a minimum:

- nature and extent of any existing defects and damage,
- main dimensions and construction details,
- updated values for the strength of construction materials,
- deformation status of the existing structural element or load-bearing structure,
- load-bearing system, ultimate strength and reserves of the system,
- foreseeable failure of a construction element or load-bearing structure,
- assessment of structural safety and serviceability,
- characteristics of the substrate intended for bonding,
- physical and climatic conditions of the building,
- fire resistance requirements,
- exposure of the structural element to be reinforced.

2.1.7 If the examination shows that reinforcement is necessary, the design must be carried out in accordance with standards SIA 260 to SIA 266.

2.2 Building materials

The choice of construction materials for the reinforcement measure must be adapted to the requirements of the project as well as to technical feasibility and compatibility with the substrate to be reinforced. Preliminary tests must be carried out to determine the suitability of bonded reinforcement. The required properties must be recorded in the project documentation.

2.3 Structural analysis and dimensioning

2.3.1 General

2.3.1.1 The structural analysis must capture the behavior of the load-bearing structure to be reinforced in relation to the design situations to be considered, taking into account the decisive influencing factors. Before designing the bonded reinforcement, the overall reinforcement concept should be developed based on the updated usage requirements.

2.3.1.2 The design of the bonded reinforcement

- determines the chosen arrangement of the load-bearing construction elements and how they interact,
- describes the main dimensions, the properties of the construction materials, and the construction details,
- takes into account structural fire protection and prevention measures depending on the risk situations,
- and specifies the planned construction method.

2.3.1.3 Another consideration is that the strength of structural elements left in their original condition may no longer be sufficient to meet updated usage requirements.

2.3.2 Ultimate limit states

2.3.2.1 Structural safety is considered to be proven when the following design criterion is met:

$$E_d \leq R_d \qquad (1)$$

2.3.2.2 The design value of the ultimate strength R_d must be determined as follows, taking into account the available knowledge of the existing load-bearing structure, in accordance with the rules of the relevant load-bearing structure standard:

$$R_d = R\left\{\frac{\eta \cdot X_k}{\gamma_f}, \frac{\eta \cdot X_k}{\gamma_h}, a_d\right\} \quad \text{respectively} \quad R_d = R\{e_{fd,lim}, a_d\} \qquad (2, 3)$$

2.3.2.3 In general, the ultimate strength of an element reinforced with bonded reinforcement cannot be assessed on the basis of individual sections alone, but must be assessed over larger areas of the structural element.

2.3.2.4 The stress and strain conditions in a section are determined in accordance with the provisions of the structural standards for the corresponding support.

2.3.2.5 The stress and strain conditions at the time of application of the bonded reinforcement must be taken into account. In the case of presumed and uncalculable impediments, extreme state assumptions shall be used.

2.3.2.6 Bonded reinforcement is generally used as tie rods acting in their direction.

2.3.2.7 In areas where the internal flow of forces is significantly disturbed in the element to be reinforced (e.g., at the points where forces are applied, at the end anchors, where shear stresses exceed the design value of the tensile strength of the concrete), appropriate models or experimental studies should be used.

2.3.2.8 For the risk situation "failure of bonded reinforcement," the ultimate strength of the unreinforced section must be used (see also 4.1.1).

2.3.3 Serviceability limit states

2.3.3.1 Limit states, such as maximum deformations or crack control requirements, must be defined in the design basis or in the usage agreement.

2.3.3.2 The stress and strain state under service actions must be determined using the average values of the deformation modules.

2.4 Durability

2.4.1 General

2.4.1.1 The exposure and load conditions of bonded reinforcement must be identified during the design phase in order to assess their influence on durability. Measures to ensure durability must be recorded in the project documentation and maintenance plan.

2.4.1.2 The durability and long-term behavior of bonded reinforcement are determined by

- the type of bonded reinforcement and adhesive,
- the quality of the application,
- the condition and type of substrate,
- surface preparation,
- actions and exposure.

2.4.1.3 To take durability into account, conservative approaches should be adopted when choosing the exposure. The design value for the properties of building materials depends not only on the type of reinforcement failure according to Table 5, but also on the exposure conditions, as described in sections 2.4.1.4 to 2.4.1.6.

2.4.1.4 The reduction factor η_e according to Table 1, to account for damage to the bonded reinforcement, depends on the type of reinforcement used and the exposure. If a fiber type not listed in the table is used, the manufacturer must specify the reduction factor. The reduction factor η_e may be modified if tests on protective products have demonstrated a reduction in the effects of environmental exposure.

2.4.1.5 Degradation of the substrate due to exposure is taken into account using the reduction factor η_u according to Table 2.

2.4.1.6 If steel strips are used, η_e= 1 applies for determining the design values according to 4.2 and 4.3, but protective measures corresponding to the corrosivity categories according to SN EN ISO 12944-2 are absolutely necessary, see also 2.4.5.1.

2.4.1.7 The durability of concrete structural elements is not affected by reinforcement bonded into grooves, even if the grooves encroach on the concrete cover.

Table 1 Reduction factors η_e for damage to bonded reinforcement depending on exposure

Type of reinforcement	Protected from the elements and sunlight η_e	Exposed to the elements and/or sunlight sunlight η_e	Severe exposure [1] η_e
Carbon fiber reinforced polymer	1.0	0.90	0.9
Glass fiber reinforced polymer	0.75	0.65	0.5
Aramid fiber reinforced polymer	0.85	0.75	0.7
Steel strip	1.0	1.0 (with corrosion protection)	1.0 (with corrosion protection)

1) Examples: Environments with high humidity and/or aggressive atmospheres, e.g., indoor swimming pools, parking garages, chemical plants/wastewater treatment plants, tunnels, production plants, etc.

Table 2 Reduction factors η_u for adhesion degradation depending on exposure

Type of reinforcement	Protected from weather and sunlight η_u	Exposed to weather and/or sunlight η_u	Severe exposure [1] η_u
Lamellas glued to the concrete surface	1.0	0.8	0.7
Woven or non-woven fibers bonded to the concrete surface	1.0	0.5	0.4
Lamellas for grooves in concrete surface	1.0	0.9	0.8
Lamellas, woven or non-woven, bonded to the steel surface	1.0	0.8	Not permitted

1) Examples: Environments with high humidity and/or aggressive atmospheres, e.g., indoor swimming pools, parking garages, chemical plants/wastewater treatment plants, tunnels, production plants, etc.

2.4.2 Temperature

2.4.2.1 The mechanical properties of plastics (adhesive and matrix of the bonded reinforcement) are influenced by temperature. At high temperatures, when the glass transition temperature $T_g$is exceeded, plastics lose their strength and rigidity. As long as the temperature is above T_g, no force should be applied to the reinforcement.

2.4.2.2 The thermomechanical properties of the adhesive are important. Normally, adhesives for bonded reinforcements cure cold and therefore have relatively low glass transition temperatures T_g(in the range of approximately 40°C to 60°C). In contrast, hot-cured products (e.g., for prefabricated laminates) or adhesives that are heated during curing have significantly higher glass transition temperatures and are therefore less affected by high ambient temperatures.

2.4.2.3 The service temperature of the bonded reinforcement surface T_{ser} may reach a maximum of T_g – 10 °C, where T_g is the glass transition temperature of the adhesive. If the bonded reinforcement is prestressed or if the shear stress in the adhesive is higher due to permanent loading or fatigue stress, the surface temperature T_{ser} may only reach T_g – 20 °C. If this restriction cannot be met, a special adhesive must be used. To reduce the temperature, it is also possible to use a suitable coating or adequate insulation.

2.4.2.4 The curing temperature and curing time influence the glass transition temperature T_g. After application, post-curing at a higher temperature can improve the $T_g$value. On the other hand, low temperatures during curing delay the curing process and reduce $T_g$as well as the strength and stiffness of the adhesive.

2.4.2.5 The thermal expansion coefficients of unidirectional fiber-reinforced composite materials differ in the longitudinal and transverse directions, depending on the fiber types, matrix type, and fiber volume fraction.

2.4.2.6 Since composite materials have a different thermal expansion coefficient than the substrate, additional stresses may arise. These must be taken into account if end anchorage failure is expected.

2.4.2.7 The risk situation "failure of the bonded reinforcement" according to 4.1.1 in the event of fire must be taken into account if the bonded reinforcement is not protected by fire protection measures according to 5.4.3. Further information on the event of fire can be found in section 5.4.

2.4.3 Moisture (water and saline solution)

2.4.3.1 Since composite materials can absorb water, moisture (water or saline solutions) affects the durability of bonded reinforcements. The main effects of moisture absorption are a reduction in the modulus of elasticity and the glass transition temperature. This results in a decrease in strength and stiffness. Moisture penetration and direct contact between the reinforcement and water must therefore be prevented by protective measures.

2.4.3.2 Moisture absorption depends on the type of plastic, the composition and quality of the reinforcement system, the thickness of the bonded reinforcement, the curing conditions, and the installation conditions. Depending on the matrix and adhesive used, the exposure time, and the service temperatures, the effects caused by moisture may be partially or completely reversible.

2.4.3.3 The condition of the existing load-bearing structure prior to reinforcement is decisive for the quality of adhesion. Existing defects associated with water and chemical infiltration, which can further damage the substrate, must be corrected beforehand.

2.4.3.4 Bonded reinforcements seal the substrate and form a barrier against moisture. This effect must be taken into account.

2.4.3.5 A damp substrate during adhesive curing can lead to a reduction in glass transition temperature T_g, strength, and rigidity, as well as longer curing times. For this reason, the maximum moisture content of the substrate according to 6.3.1.6 and the dew point deviation according to 6.4.3.2 must be observed.

2.4.4 Freeze-thaw cycles

2.4.4.1 Freeze-thaw cycles can reduce the performance of the matrix, the adhesive, and the contact surfaces between the bonded reinforcement and the adhesive, as well as between the adhesive and the substrate, which can lead to delamination.

2.4.4.2 The effects of freeze-thaw cycles can be exacerbated by moisture, which weakens the adhesive, by fatigue stresses, and by constant high stress in the adhesive.

2.4.5 Chemical resistance

2.4.5.1 Bonded steel reinforcement must be protected against corrosion in accordance with SN EN ISO 12944-2, depending on the area of application and duration of use. On the bonding surface, the primer and adhesive provide protection.

2.4.5.2 The durability of bonded composite reinforcement in alkaline and acidic environments depends on the nature of the matrix and fibers. In general, carbon fibers are resistant to alkaline and acidic environments, while glass fibers can degrade in such environments. Structural elements located in environments with high alkalinity, high humidity, or high relative humidity should be reinforced with carbon fibers.

2.4.6 Galvanic corrosion

2.4.6.1 To prevent galvanic corrosion, carbon fiber reinforced composite materials should not come into direct contact with steel. On the steel bonding surface, primer and adhesive prevent galvanic corrosion.

2.4.6.2 Composite materials with glass fibers can be used as a separating layer to prevent galvanic corrosion.

2.4.7 UV protection

Plastics that decompose under the influence of UV rays must be protected. Possible protective measures are listed in section 5.3.

2.5 Long-term exposure

2.5.1 Fatigue

2.5.1.1 The behavior of bonded composite reinforcement subjected to fatigue loading is mainly influenced by the fatigue strength of the fibers used.

2.5.1.2 Bonded steel reinforcements must be dimensioned for fatigue in accordance with SIA 263.

2.5.1.3 Due to fatigue stresses, defects may appear at the interface, which can lead to lower bond strength compared to short-term static strength.

2.5.1.4 In the case of fatigue loading, the reduction factors according to Table 3 must be used. For the reinforcement of concrete structures, section 4.3.8 must also be taken into account, and for the reinforcement of steel structures, section 4.4.5.

2.5.2 Creep

2.5.2.1 Creep deformation and stress corrosion cracking may occur in bonded reinforcement, hence the need to limit stresses in the case of a combination with a quasi-permanent load. In general, the serviceability requirements according to 4.7 are sufficient for this purpose.

2.5.2.2 In the case of high temperatures and high permanent loads (e.g., prestressed bonded reinforcement), creep in the adhesive must be limited by using a suitable adhesive.

2.5.2.3 Carbon fiber reinforced polymer bonded reinforcement is highly resistant to stress corrosion cracking, high permanent loads, and fatigue failure under cyclic loading. Glass fiber and aramid fiber reinforced polymer bonded reinforcement should not be used for these load situations. Therefore, only carbon fiber reinforced bonded reinforcement should be used as prestressed reinforcement.

Table 3 Reduction factors η_l for different bonded reinforcements depending on the type of load (for steel strips η_l = 1.0)

Load	η_l		
	Fiber-reinforced polymer glass	Aramid fiber reinforced polymer	Carbon fiber reinforced polymer with carbon
Variable load (rare and frequent load cases)	0.5	0.7	1.0
Permanent load (quasi-permanent load cases)	0.3	0.5	0.8
Permanent load plus fatigue load	–	–	0.8

2.5.3 Long-term stress combinations with environmental conditions

The coupling effects of environmental conditions and load situations must be assessed with caution. The reduction factors η_e, $\eta_{(u)}$, and η_l allow environmental conditions and long-term behavior to be taken into account in order to account for fatigue loads and creep.

3 CONSTRUCTION MATERIALS

3.1 Support

The characteristic values X_k of the properties of the building materials of the support must be determined in accordance with SIA 269/2 for concrete load-bearing structures, in accordance with SIA 269/3 for steel load-bearing structures, in accordance with SIA 269/5 for timber load-bearing structures, and in accordance with SIA 269/6-2 for masonry load-bearing structures.

3.2 Reinforcement system

3.2.1 Requirements

3.2.1.1 The construction materials to be used must meet the requirements of 3.3 to 3.8, both as a product in itself and as part of the overall system.

3.2.1.2 The various construction materials must be suitable for the substrate and for each other, and must be compatible with each other. The most important parameters to be evaluated in the context of short- and long-term stresses, as well as, where applicable, in the case of construction elements subject to vibrations, are as follows:

- mechanical, chemical, and electrochemical properties,
- thermal expansion,
- behavior in the event of increased temperature and/or humidity.

3.2.2 Tests

3.2.2.1 The following types of tests are distinguished:

- Initial tests are used to characterize the properties of a construction material or the entire reinforcement system, as well as to provide evidence of fundamental suitability for the intended applications (e.g., through laboratory tests).
- Suitability tests are used to prove the suitability of a building material or the entire reinforcement system under specific conditions of use and in the context of the planned work (e.g., on the structure).
- Quality controls serve to prove the required quality during and after execution.

3.2.2.2 In principle, only construction materials for which initial test certificates or suitability test results are available should be used.

3.2.2.3 In order to verify the suitability of a building material for a specific application, it may be necessary to carry out suitability tests on construction elements that are close to reality.

3.2.2.4 The quality controls to be carried out must be defined in advance in the control plan. The scope of the controls depends on the importance of the reinforcement measure and the reinforcement system chosen.

3.2.2.5 Separate test specimens shall be prepared for proficiency testing and quality control, where applicable, so that the tests can be carried out using the same methods as for the initial test.

3.3 Adhesives

3.3.1 Types and designations

The adhesives used are epoxy resin-based adhesives with or without quartz filler. They are manufactured on site by mixing the two components, resin and hardener, and cure at room temperature.

3.3.2 Requirements, tests, and inspections

3.3.2.1 For bonded reinforcement intended for concrete load-bearing structures, the requirements for adhesives are those of standard SN EN 1504-4. The test standards to be used are also taken from standard SN EN 1504-4.

3.3.2.2 For bonded reinforcement of steel load-bearing structures, the requirements are the same as for concrete load-bearing structures according to 3.3.2.1. The specific deformation energy of the adhesive $D_{ak}$is calculated from the average value of the area under the stress-strain curve during the tensile test according to SN EN ISO 527-1. The characteristic value of the tensile shear strength $f_{ask}$is determined according to ISO 4587.

3.3.2.3 For bonded reinforcement of load-bearing timber structures, the general requirements for adhesives according to SIA 265 apply.

3.3.2.4 According to SN EN 1504-4, the following requirements apply to adhesives (non-exhaustive list):

- modulus of elasticity 2 GPa ≤ E_a≤ 15 GPa,
- glass transition temperature T_g≥ 40 °C,
- Coefficient of expansion α_a≤ 10–4in $^{K–1}$.

3.3.2.5 The following must be declared:

- product name,
- minimum and maximum application temperature (substrate and environment),
- mixing ratio, including the required accuracy (by weight),
- pot life, open time (for the maximum permitted working temperature),
- prerequisites for the surface of the parts to be bonded,
- maximum service temperature T_{ser} and glass transition temperature T_g (the glass transition temperature T_g corresponds to the extrapolated initial temperature T_f according to SN EN 12614)
- storage method, maximum storage time,
- safety requirements,
- density,
- average value of the coefficient of expansion α_a ,
- average value of the compressive modulus of elasticity E_a ,
- characteristic value of tensile strength f_{ak} ,
- characteristic value of tensile shear strength f_{ask} ,
- characteristic value of deformation energy D_{ak} .

3.4 Steel strips

3.4.1 Types and designations

3.4.1.1 The characteristic values must be used in accordance with SIA standard 263.

3.4.1.2 Classification, designation, testing, and inspection are defined in standards SIA 263 and SIA 263/1.

3.4.1.3 For bonded reinforcement, standard structural steel should be used.

3.4.2 **Requirements**

3.4.2.1 The requirements are defined in standards SIA 263 and SIA 263/1.

3.4.2.2 Welding work on bonded steel parts is not permitted.

3.4.2.3 The surface of the steel strips to be bonded must be cleaned to a surface preparation grade of Sa $2^1/_2$ in accordance with SN EN ISO 12944-4. Immediately afterwards, the surface must be protected with a primer that is suitable for the adhesive and the steel surface in terms of adhesion and thermal behavior. The adhesive strength of the primer used on the surface of the steel strips and of the adhesive on the primer must be sufficiently high to ensure that failure occurs in the substrate (in the case of concrete, wood, or masonry) or in the adhesive in the case of steel structural reinforcements.

3.5 Composite lamellas

3.5.1 **Types and designations**

3.5.1.1 Composite lamellas or bars have continuous fibers inserted unidirectionally into a synthetic matrix. They are prefabricated in the factory and bonded on site with adhesives according to 3.3 to the structural element to be reinforced or bonded into inserted grooves.

3.5.1.2 The laminates exhibit linear-elastic behavior up to tensile failure.

3.5.2 **Requirements, tests, and inspections**

3.5.2.1 The tensile strength, modulus of elasticity, and elongation at break of the lamellas shall be determined in accordance with ISO 10406-3. The nominal widths of the lamellas b_f and the nominal thicknesses of the lamellas t_f used for determining the tensile strength and modulus of elasticity shall be specified.

3.5.2.2 The thermal expansion coefficient of the lamellas shall be determined in accordance with SN EN 1770.

3.5.2.3 The following must be declared
- product designation,
- storage method, maximum storage period,
- maximum service temperature T_{ser} and glass transition temperature T_g of the matrix,
- safety requirements,
- type of fibers and fiber volume content,
- adhesive to be used,
- minimum bending radii for storage, transport, and gluing,
- average value of the expansion coefficient α_f ,
- characteristic value of tensile strength f_{fuk} ,
- characteristic value of the elongation at break e_{fuk} ,
- characteristic value of the modulus of elasticity E_{fk} .

3.5.2.4 The suitability of the lamellas in combination with the adhesive to be used must be proven as described in section 3.2.1.2.

3.6 Woven and non-woven composite materials

3.6.1 **Types and designations**

3.6.1.1 Woven and non-woven fabrics can be applied to the substrate by wet or dry bonding.

3.6.1.2 Woven and non-woven fabrics exhibit linear elastic behavior up to tensile failure.

3.6.2 Requirements, tests, and inspections

3.6.2.1 The tensile strength, modulus of elasticity, and elongation at break of woven and nonwoven fabrics, respectively, shall be determined in accordance with ISO 10406-2 for each main direction. The section used for woven and nonwoven fabrics, respectively (width $b_f$and thickness t_f), shall be indicated.

3.6.2.2 The coefficient of thermal expansion of woven fabrics and nonwovens, respectively, shall be determined in accordance with standard SN EN 1770.

3.6.2.3 The following must be declared:
- product designation,
- storage method, maximum storage period,
- maximum service temperature T_{ser} and glass transition temperature T_g of the adhesive,
- safety requirements,
- type of fibers and prescribed adhesive,
- average value of the expansion coefficient α_f ,
- characteristic value of tensile strength f_{fuk} ,
- characteristic value of elongation at break e_{fuk} ,
- characteristic value of the modulus of elasticity E_{fk} .

3.6.2.4 The suitability of fabrics and nonwovens in combination with the adhesive to be used must be proven as described in section 3.2.1.2.

3.7 Prestressing systems for bonded reinforcement

3.7.1 The suitability of prestressing systems for bonded reinforcement must be proven.

3.7.2 The following must be declared:
- safety requirements,
- dimensions of the bonded reinforcement,
- description of the components of the temporary and permanent fixings; the operation of the prestressing system, including the structural element to be reinforced, the bonded reinforcement, the connection, the end anchorage, the tensioning,
- prestressing forces,
- adhesive and strips to be used,
- requirements for adhesives according to 3.3,
- requirements for strips according to 3.5,
- minimum strength of the substrate to ensure that the prestressing forces are transmitted permanently,
- prestressing losses (short-term during application, long-term during the service life of the reinforcement system),
- minimum spacing between bonded prestressed reinforcement,
- maximum ultimate strength of the anchor used.

3.8 Auxiliary means

3.8.1 Repair mortar

Repair mortars are used to re-profile spalling. The specifications in Table NA.2 of standard SN EN 1504-3:2005 for the area of application "Mortars and concretes used for structural repairs and reinforcements" must be observed.

3.8.2 Cleaning products

Cleaning products must be suitable for the building materials used.

3.8.3 Steel anchors

Classification, requirements, and testing are defined in standards SIA 263 and SIA 263/1.

3.8.4 Coatings, surface protection, and cladding

The long-term compatibility of building materials used for structural, architectural, or fire protection reasons must be guaranteed.

4 STRUCTURAL ANALYSIS AND DIMENSIONING

4.1 Structural analysis

4.1.1 General

4.1.1.1 Risk situations for the existing load-bearing structure must be verified and supplemented, taking into account the project under consideration. The principles of standards SIA 260, SIA 261, SIA 262, SIA 263, SIA 263/1, SIA 264, SIA 265, SIA 265/1, and SIA 266 apply.

4.1.1.2 Risk situations for load-bearing structures with bonded reinforcement correspond to limit states of type 2 according to SIA 260. A distinction is made between the following two types of risk situations:
- risk situations arising from the intended use,
- failure of the bonded reinforcement as an exceptional design situation.

4.1.1.3 Failure of the bonded reinforcement due to
- high temperatures (e.g., due to fire, unexpected exposure to sunlight, etc.),
- impact,
- chemical attack,
- damage due to negligence or malicious intent

corresponds to an accidental design situation for the remaining structural element.

4.1.1.4 For serviceability limit states of type 4 according to SIA 260 (fatigue), the structural safety with regard to the failure of the construction materials used is considered to be proven if the procedure in 4.3.8 is followed for concrete supports and the procedure in 4.4.5 is followed for steel supports. The fatigue action must be determined in accordance with SIA 261.

4.1.1.5 For reinforcements related to dynamic actions, the principles of SIA 260 must be taken into account by analogy.

4.1.2 Imposed and restrained deformations

If restraints predominate, it must be ensured that the reinforced areas can also absorb the imposed deformations.

4.1.3 Structure model

For structural elements reinforced with bonded reinforcement, compatibility must be proven up to failure.

4.1.4 Calculation method

4.1.4.1 Bending reinforcement generally reduces the plastic deformation capacity of the supporting structure. The calculation method for determining internal forces must therefore be selected according to the supporting structure and reinforcement variants shown in Table 4. As a general rule, the internal forces in reinforced areas are determined using linear elasticity theory methods. For reinforced steel load-bearing structures, the EE and EER methods according to SIA 263 are used.

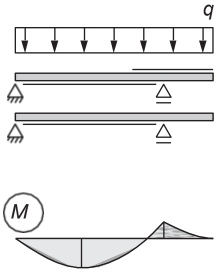
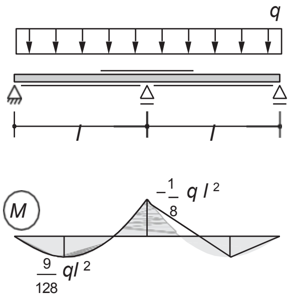
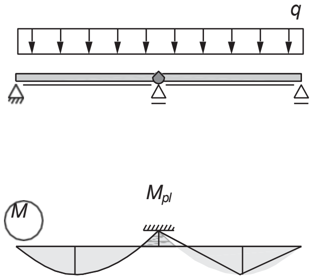
4.1.4.2 The dimensioning of bonded reinforcement for flexural reinforcement requires the determination of internal forces in all parts of the structure that are affected by the reinforcement.

4.1.4.3 Bonded reinforcement for flexural reinforcement must not be used to reinforce compressed areas. If cracked tension areas are reinforced with bonded reinforcement, care must be taken to ensure that these areas are not compressed under unfavorable load combinations, in order to prevent the bonded reinforcement from detaching or buckling.

4.1.4.4 The design value of the effect of actions E_d must be determined taking into account the load and deformation of the element prevailing at the time of application of the bonded reinforcement.

4.1.4.5 Pre-stressed bonded reinforcement bars generate internal forces that must also be taken into account.

Table 4 Calculation methods for determining internal forces

Static system	Isostatic	Hyperstatic	
Bending reinforcement Example	Total or partial reinforcement 	Complete reinforcement 	Partial reinforcement 
Calculation of internal forces	According to equilibrium	In general, elastic calculation internal stresses of the structure existing structure. In this is the case, the stiffening effect state is reached in the reinforced areas.	Redistributions are permitted—possible if plastic hinges exist in the structures, the effect unreinforced areas, and, when of the reinforcement when this is the case, they form before the ultimate limit ultimate limit state is reached in the reinforced areas.

4.1.5 Bonded prestressed reinforcement for strengthening concrete structures

4.1.5.1 In the case of prestressed composite strips, the anchoring forces must be considered as effects on the reinforced structure. Since the strips applied subsequently are generally straight, there are no deflection and friction forces.

4.1.5.2 For proof of the structural safety of the anchorage zones of the bonded prestressed reinforcement, the decisive prestressing force must be considered as a dominant action, by analogy with SIA 262 standard. The prestressing force of each strand must be increased by γ_p = 1.5, the prestressing force of several strands by γ_p = 1.2, with the highest value being decisive.

4.1.5.3 Prestressing creates a state of self-stress in the supporting structure and causes deformations of the supporting structure. For hyperstatic systems, the stresses generally result from impeded deformation. The models must be chosen so that they correspond as closely as possible to the behavior of the actual structure.

4.1.5.4 Proof of the fastenings of temporary prestressing devices and permanent anchors with studs must be provided in accordance with SIA standard 179.

4.1.5.5 Any loss of prestressing force must be noted in the manufacturer's declarations, see also 3.7. Losses of prestressing force due to long-term deformation of the substrate must be determined in accordance with the relevant standards.

4.1.5.6 The manufacturers' specifications regarding prestressing forces in composite laminates must be taken into account.

4.1.5.7 Compressive stresses in the concrete during and immediately after tensioning must not exceed the following value outside the anchorage zones, by analogy with SIA 262:

$$s_c \leq 0.6 \cdot f_{ck} \qquad (4)$$

4.1.6 **Anchoring aids**

4.1.6.1 Additional devices can be used to achieve higher anchoring strengths or shorter anchoring lengths than those specified in sections 4.3.2, 4.3.3, and 4.4.2. For example, anchor bolts can be used for steel strips or clamping plates for strips and woven or non-woven composite materials.

4.1.6.2 The behavior of such anchoring systems, in particular their anchoring resistance, must be determined on the basis of the manufacturer's declarations.

4.1.6.3 The resistances of different anchoring systems, such as mechanical fasteners combined with bonding, must not be superimposed.

4.2 sign values

4.2.1 For the design value X_d of the building material property, the following applies:

$$X_d = \frac{\eta \cdot X_k}{\gamma_f} \quad \text{resp.} \quad X_d = \frac{\eta \cdot X_k}{\gamma_h} \qquad (5)$$

where γ_f , γ_h and η are determined according to Table 5.

4.2.2 For specific failure modes of bonded reinforcement, the coefficients according to Table 5 shall be used for resistances.

Table 5 Coefficients for determining the design values of construction material properties

Reinforcement breakage		
Steel strip	γ_f = 1.05	$\eta = \eta_e \cdot \eta_l$ with η_e according to Table 1 and η_l according to Table 3
Composite material strip	γ_f = 1.10	
Woven/non-woven composite material	γ_f = 1.30	
Adhesion failure		
Adhesion failure in concrete substrate	γ_h = 1.50, other values η according to SIA 262	$\eta = \eta_u \cdot \eta_l$ with η_u according to Table 2 and η_l according to Table 3
Adhesion failure in the steel substrate or in the adhesive	γ_h = 1.50, other values η according to SIA 263	
Adhesion failure in the wood substrate	γ_M and other η values according to SIA 265 and SIA 265/1	
Adhesion failure in masonry substrate	γ_M according to SIA 266	
Failure of auxiliary anchoring devices When using anchoring devices in accordance with section 4.1.6, the coefficients must be determined by a scientific method, taking into account the intended use.		

4.2.3 For the design values of the tensile strength and elongation at break of bonded reinforcement, the following applies:

$$f_{fud} = \eta_e \cdot \eta_l \cdot \frac{f_{fuk}}{\gamma_f} \qquad (6)$$

$$e_{fud} = \eta_e \cdot \eta_l \cdot \frac{e_{fuk}}{\gamma_f} \qquad (7)$$

4.2.4 For the design values of the elasticity modules of bonded reinforcement, the following applies:

$$E_{fd} = \frac{E_{fk}}{\gamma_f} \quad (8)$$

In general, we can assume that $\gamma_f = 1.0$ in equation (8).

4.3 Verification of the structural safety of reinforcements to existing concrete load-bearing structures

4.3.1 General

4.3.1.1 For modeling purposes, a distinction is made between the functional zone and the anchorage zone of a bonded reinforcement (for concrete structures according to Figure 3). In the functional zone, the bonded reinforcement can absorb tensile forces and thus specifically reinforce the section of the structural element located in this zone. The tensile forces thus generated at the ends of the functional zone must be anchored in the anchorage zones. The prerequisite for verification according to 4.3.2.3 is that the anchorage is located in the theoretically uncracked zone of a structural element.

4.3.1.2 The theoretically uncracked zone is determined using the updated design value of the tensile strength of the concrete f_{ctd}. In this zone, the following applies

$$s_{cd} \; (S_d) \leq f_{ctd} \quad (9)$$

4.3.1.3 The internal forces at the end of the functional zone are determined according to the methods indicated in Table 4. The resulting tensile force in the bonded reinforcement $F_{fcr,d}$ is the anchorage force to be taken into account in the anchorage zone.

4.3.1.4 The structural safety of the anchorage is considered to be proven when the following condition is met:

$$F_{fcr,d} \leq F_{b,Rd} \quad (10)$$

4.3.1.5 For section calculations, such as in 4.3.1.2, the tensile strength of the concrete in the section f_{ct} must be used. For bond calculations, such as in 4.3.1.4, the bond strength of the concrete near the surface f_h must be used.

4.3.2 Surface bonded anchor

4.3.2.1 For the calculation of the anchor strength on the concrete, it is assumed that failure occurs when the tensile strength of the concrete is reached.

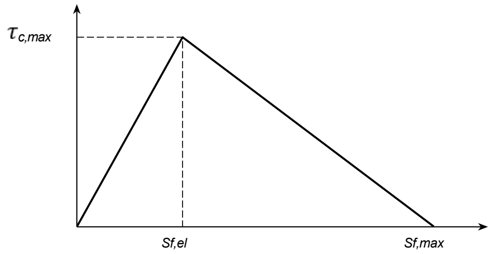
4.3.2.2 The anchorage zone corresponds to the bond length of the bonded reinforcement on the uncracked surface of the structural element. The following characteristic lengths and anchorage resistances that can be absorbed can be distinguished:

l_{bd} Design value of the length of the bonded reinforcement section located in the completely uncracked anchorage zone. The anchorage resistance $F_{b,Rd}$ that can be absorbed for this anchorage length can be determined according to equation (12).

l_{b0d} Design value of the active anchorage length, exceeding which does not increase the anchorage resistance. The maximum anchorage resistance that can be absorbed $F_{b0,Rd}$ can be determined according to equation (11).

4.3.2.3 Applying the adhesion law according to Figure 1 leads to the equations for the anchorage resistance of the reinforcement bonded to the concrete.

Figure 1 Adhesion law for determining the ultimate strength of bonded anchors



$$F_{b,Rd} = F_{b0,Rd} = b_f \cdot \sqrt{2 \cdot G_{Fcd} \cdot E_{fd} \cdot t_f} \qquad \text{if } l_{bd} \geq l_{b0d} \tag{11}$$

$$F_{b,Rd} = F_{b0,Rd} \cdot \frac{l_{bd}}{l_{b0d}} \cdot \left(2 - \frac{l_{bd}}{l_{b0d}}\right) \qquad \text{if } l_{bd} < l_{b0d} \tag{12}$$

4.3.2.4 The design value of the effective anchorage length l_{b0d} of reinforcement bonded to concrete can be determined by the following relationship:

$$l_{b0d} = 2.5 \cdot \sqrt{\frac{G_{Fcd} \cdot E_{fd} \cdot t_f}{t^2_{c,max,d}}} \tag{13}$$

4.3.2.5 The design value of the specific breaking energy G_{Fcd} of concrete close to the surface is, for concrete classes C20/25 to C50/60, approximately proportional to the bond strength of the surface concrete:

$$G_{Fcd} = \frac{1}{8} \cdot \eta_u \cdot \eta_l \cdot f_{hd} \qquad G_{Fcd} \text{ in N/mm} \qquad f_{hd} = \frac{f_{hk}}{\gamma_h} \text{ in MPa} \tag{14}$$

4.3.2.6 For preliminary design, the design value of the bond strength of the concrete near the surface may be simplified by taking $f_{hd} = f_{ctd}$. During execution, the bond strength of the concrete near the surface shall be determined in accordance with 6.2.4. The reduction factors η_u and η_l are given in Table 2 and Table 3.

4.3.2.7 The design value of the maximum shear stress $t_{c,max,d}$ of reinforcement bonded to concrete, which can be absorbed by the concrete near the surface, can be assumed to be approximately proportional to the bond strength of the surface concrete for concrete in strength classes C20/25 to C50/60:

$$t_{c,max,d} = \frac{4}{3} \cdot \eta_u \cdot \eta_l \cdot f_{hd} \qquad f_{hd} = \frac{f_{hk}}{\gamma_h} \tag{15}$$

4.3.2.8 The characteristic values of the absorbable shear stress and the specific rupture energy of concrete close to the surface can also be determined using pull-out tests on reinforcement bonded to the concrete (e.g., as described in ISO 10406-2 for woven fabrics).

4.3.2.9 Concrete structures with strength classes greater than or equal to C12/15 may only be reinforced with bonded reinforcement if the characteristic bond strength of the concrete near the surface f_{hk} is greater than or equal to 1.5 MPa. Otherwise, for these strength classes, groove strips must be used (see 4.3.3.15).

4.3.2.10 Carbonated concrete does not exhibit reduced bond strength.

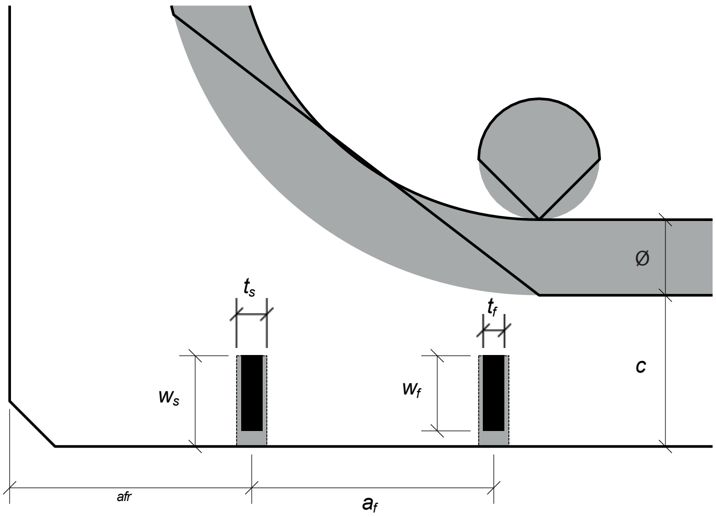
4.3.3 Bonded anchors in grooves

4.3.3.1 Rectangular composite strips are preferable to round or square composite bars for use as strips for grooves.

4.3.3.2 w_f and t_f correspond to the width and thickness of the strips. In cross-section, the strips are placed perpendicular to the surface; thus, the width of the groove strip w_f can also be referred to as the depth. The corresponding parameters are shown in Figure 2. w_s and t_s correspond to the depth and width of the groove. If the section of the lamella is square, $w_s = t_s$.

4.3.3.3 ${}_f$corresponds to the diameter of a bar for reinforcement bonded in grooves. Diameters must not exceed ${}_f$= 10 mm. Square bars for reinforcement bonded in grooves may be used up to maximum dimensions $w_f = t_f = 6$ mm.

Figure 2 Geometric parameters for the dimensioning of grooved lamellas



4.3.3.4 If several composite strips are glued into a groove, the maximum total thickness of 3 mm must be observed in accordance with Table 6, and a layer of adhesive must be applied between the strips.

4.3.3.5 The groove width $t_s$for the lamellae is

$$t_f + 1 \text{ mm} \leq t_s \leq t_f + 3 \text{ mm} \quad (16)$$

4.3.3.6 The groove width t_s for bars is

$${}_f + 2 \text{ mm} \leq t_s \leq \quad {}_f + 4 \text{ mm} \quad (17)$$

4.3.3.7 The depth of the groove is limited by the position of the internal steel reinforcement. The minimum depth of the groove is $w_s = w_f + 2$ mm or ${}_f$+ 2 mm. The bonded reinforcement must be placed as low as possible to prevent the concrete cover from detaching.

4.3.3.8 The distance a_{en} from the free edge of the structural element according to equation (18) or (19) must be observed:

$$a_{fr} \geq \max (2 \cdot w_s, 32 \text{ mm}) \quad (18)$$

4.3.3.9 The following rule applies to the minimum center distances a_f of the slats for grooves:

$$a_f \geq \max (1.5 \cdot w_s, 32 \text{ mm}) \quad (19)$$

4.3.3.10 Strips for grooves parallel to the outermost layer of the internal steel reinforcement should, as far as possible, be placed in the middle between the reinforcement bars.

4.3.3.11 Similar to anchors bonded to the concrete surface, anchors bonded in grooves must also be anchored in the uncracked anchorage zone according to Figure 3. The characteristic lengths and anchorage resistances that can be absorbed must be determined accordingly.

4.3.3.12 The design value of the ultimate strength $F_{b0,Rd}$of a reinforcement bonded in grooves can be determined using equations (20) and (21). The design specifications according to 4.3.3.1 to 4.3.3.11 must be observed.

$$F_{Fb,Rd} = F_{Fb0,Rd} = \sqrt{2 \cdot G_{Fsd} \cdot L_p \cdot E_{fd} \cdot A_f} \le f_{fud} \cdot A_f \qquad \text{if } l_{bd} \ge l_{b0d} \tag{20}$$

with $L_p = 2 \cdot (w_s + 1) + t_s + 2$ mm (21)

for $l_{bd} \le l_{b0d}$ equation (12) applies.

4.3.3.13 The design value of the effective anchorage length l_{b0d} of rebars bonded in grooves can be determined by the following relationship:

$$l_{b0d} = 2.5 \cdot \sqrt{\frac{G_{Fsd} \cdot E_{fd} \cdot t_f \cdot w_f}{t^2_{s,max,d} \cdot L_p}} \tag{22}$$

4.3.3.14 If the geometric parameters according to 4.3.3 are met, the design value of the specific rupture energy G_{Fsd} of bonded reinforcement in grooves can be determined using equation (23). The characteristic bond strength of the concrete near the surface f_{hk} can be determined from In a similar manner to 4.3.2. The reduction factors η_u and η_l are shown in Table 2 and Table 3.

$$G_{Fsd} = 2.0 \cdot \eta_u \cdot \eta_l \cdot \sqrt{\frac{w_s}{t_s}} \cdot f_{hd} \quad G_{Fsd} \text{ in N/mm} \qquad f_{hd} = \frac{f_{hk}}{\gamma_h} \text{ in MPa} \tag{23}$$

4.3.3.15 The design value of the maximum shear stress that can be absorbed by the concrete near the surface $t_{s,max,d}$ of bonded reinforcement in grooves can be determined approximately as follows for concrete of strength classes C12/15 to C50/60 (see also 4.3.2.10):

$$t_{s,max,d} = G_{Fsd} \qquad G_{Fsd} \text{ in N/mm} \tag{24}$$

4.3.4 Simple bending and bending with normal stress

4.3.4.1 Reinforced deflected beams generally fail according to one of the following failure mechanisms:

- breakage of the support in the reinforced or unreinforced area,
- failure of the reinforcement,
- adhesion failure.

Safety verification with regard to these failure mechanisms is considered to be established if the conditions defined in section 4.3.4.5 are met.

4.3.4.2 The ultimate strengths of the reinforced structural element must be determined taking into account the known properties of the supporting structure. In particular, pre-existing elongations due to the load history, the load at the time of reinforcement, and any prestressing must be taken into account.

4.3.4.3 To perform a detailed analysis of the sections, the following assumptions should be made:

- The sections remain flat and perpendicular to the bar axis.
- In accordance with section 2.3.2.6, the bonded reinforcement only transmits tensile forces in its direction.
- The tensile strength of the concrete is neglected.
- The stress-strain behavior of the building materials involved is taken into account in accordance with Chapter 3 and, where applicable, Section 4.3.4.4.

4.3.4.4 For flexural concrete structural elements, the simplified assumption of a rectangular distribution of compressive stresses is only permissible if the corresponding failure condition (concrete failure) can be proven by calculation. Otherwise, the parabolic stress-strain diagram specific to SIA 262 must be used.

4.3.4.5 In the case of bending, the structural safety of reinforced construction elements is considered to be proven if the following conditions are met:

$F_{fcr,d} \le F_{fb,Rd}$ (verification of the anchorage at the end of the functional zone) (25)

$F_{f,d} \le F_{f,Rd}$ (verification of tensile force in the functional zone) (26)

4.3.4.6 If the bending reinforcement is to be designed for loads that are not predominantly static, the fatigue verification must also be carried out in accordance with section 4.3.8.

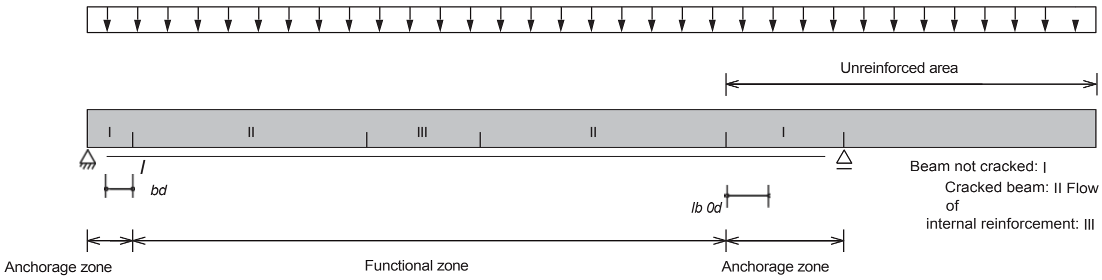
4.3.4.7 For structural elements mainly subjected to bending, in order to ensure minimal deformability, i.e., to prevent the type of failure known as "compression deformation of concrete before steel yielding," the height of the compressed zone at failure must be limited as follows:

$$\frac{x}{d} \le 0.5 \cdot \frac{435}{f_{sd}} \tag{27}$$

4.3.4.8 With regard to the failure mechanisms listed in section 4.3.4.1, the following comments apply:

- Adhesion failure is the usual failure mode for passive bonded reinforcement with high stiffness (detachment of the bonded reinforcement) due to the limited tensile strength of concrete. The origin of this failure mechanism is usually in the anchorage zone or in a force introduction zone where the internal steel reinforcement has already exceeded its yield strength.
- Shear failures in the adhesive, in the bonded reinforcement, or at one of the interfaces must be avoided by carefully selecting the components involved and complying with the execution and quality assurance requirements in Chapters 5 and 6.
- The structural safety verification procedure is carried out in accordance with Figure 3.

Figure 3 Checks on a partially reinforced deflected beam



4.3.4.9 The internal forces M_d and V_d are determined in accordance with section 4.1.4. They must be assigned to the components of the sections according to the following principles:

A. Reinforced bent beams: structural elements without shear reinforcement

The moment of flexion causes tensile forces in the reinforcement and compressive forces in the concrete (Figure 4a). The shear force is absorbed by the shear strength of the concrete (Figure 4b). To verify the internal forces in the functional zone, the following equations should be used:

$$F_{sd}(M_d) \leq A_s \cdot E_s \cdot e_{sd} \leq A_s \cdot f_{sd} \quad (28)$$

$$F_{fd}(M_d) \leq A_f \cdot E_{fd} \cdot e_{fd} \leq A_f \cdot E_{fd} \cdot e_{fd,lim} \quad (29)$$

B. Reinforced bent beams: structural elements with shear reinforcement

If the flexural reinforcement is supplemented by stirrup-shaped shear reinforcement, the deformation capacity at failure is increased. In this way, the internal forces acting in the lattice can be transmitted so that both the bending moment and the shear force generate tensile forces in the longitudinal direction of the bent beam (Figure 4c). The tensile force resulting from the shear force can be distributed between the internal steel reinforcement and the bonded reinforcement as follows:

- In areas where the internal steel reinforcement has not yet reached the yield limit due to the tensile force caused by bending, the share of the tensile force caused by the shear force is attributed to it.
- In areas where the internal steel reinforcement flows under the effect of bending tension, it must be ensured that the concrete can transmit the increase in tensile force due to shear stress to the bonded reinforcement, which is oriented in the longitudinal direction of the bending beam. Otherwise, stirrup-shaped bonded reinforcement should be placed to encompass the bonded reinforcement oriented in the longitudinal direction of the flexural beam. In addition, care must be taken to ensure that the longitudinal bonded reinforcement is sufficiently anchored.
- In the anchoring zone of the bonded reinforcement in the longitudinal direction of the flexural beam, the internal steel reinforcement must bear the entire tensile force due to bending and shear stress.

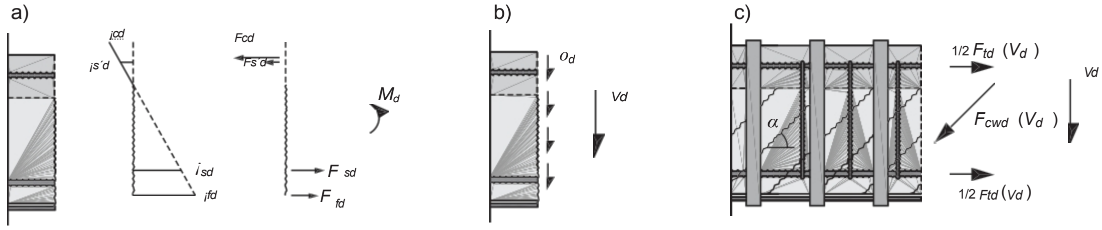
The following equations must be used to verify the internal forces in the functional zone of the bonded reinforcement:

$$F_{td}(V_d) \leq V_d \cdot cot\alpha \quad (30)$$

$$F_{sd}(M_d, V_d) \leq A_s \cdot E_s \cdot e_{ssd} + \frac{1}{2} \cdot F_{td}(V_d) \leq A_s \cdot f_{sd} \quad (31)$$

$$F_{fd}(M_d, V_d) \leq A_f \cdot E_f \cdot e_{fd} + \frac{1}{2} \cdot F_{td}(V_d) \leq A_f \cdot E_{fd} \cdot e_{fd,lim} \quad (32)$$

Figure 4 Internal forces for beams with flexural reinforcement: a) due to bending; b) due to shear stress without flexural reinforcement; c) due to shear stress with shear reinforcement

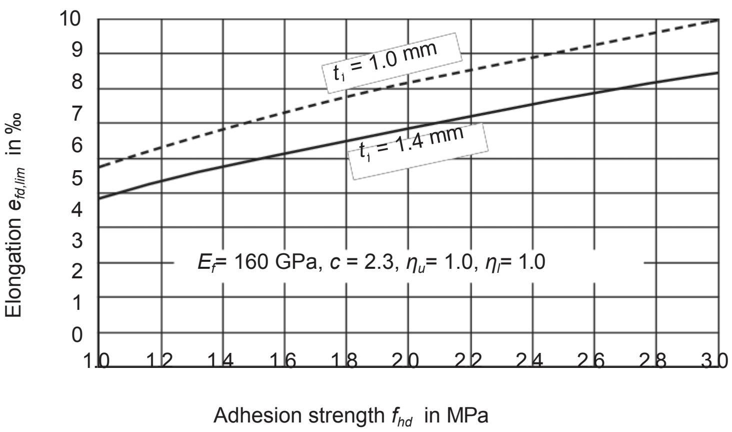


4.3.4.10 The maximum elongation $e_{fd,lim}$ of bonded reinforcement in concrete is limited in the functional zone by bond failure (or tensile failure of the bonded reinforcement) and can be determined for symmetrically distributed loads for concrete up to class C50/60 by the following relationship:

$$e_{fd,lim} = c \cdot \eta_u \cdot \eta_l \sqrt{\frac{f_{hd}}{E_{fd}\, t_f}} + e_{p\infty} \leq e_{fud} \qquad f_{hd} \text{ in MPa, } E_{fd} \text{ in MPa, } t_f \text{ in mm} \qquad (33)$$

with c = 2.3 for composite and steel laminates,
c = 1.6 for woven and non-woven composite materials,
$e_{p\infty} = F_{p\infty} / A_f$,
η_u and η_l according to Table 2 and Table 3.
Examples of maximum elongations are given in Figure 5.

Figure 5 Examples of design values for the maximum elongation $e_{fd,lim}$ of the strips according to equation (33) as a function of the design value of the bond strength f_{hd} of the concrete near the surface



The maximum elongation $e_{fd,lim}$ of the strips for grooves is limited in the functional zone and can be determined by the following relationship for symmetrical load transfer:

$$e_{fd,lim} = 0.8 \cdot e_{fud} \qquad (34)$$

4.3.5 **Shear force**

4.3.5.1 The shear resistance V_{Rd} of structural elements without shear reinforcement and without shear reinforcement is determined in accordance with SIA 262.

4.3.5.2 The shear resistance of steel and prestressed concrete beams can be increased by installing bonded stirrup-shaped reinforcement. The shear design of reinforced steel and prestressed concrete beams must be based on a state of equilibrium with constant inclination compression fields.

4.3.5.3 The shear strengths of the unreinforced structural element and the bonded stirrup-shaped reinforcement can be superimposed if the following conditions and rules are met:

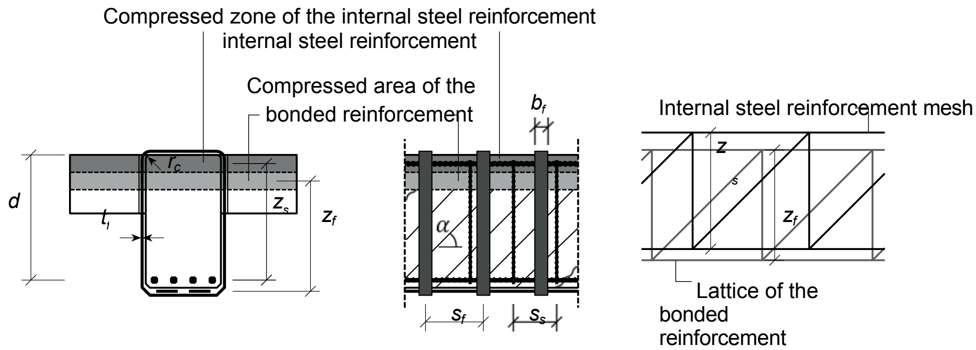
– In the unreinforced service condition, there are no shear cracks.
– The internal stirrups yield before the bonded stirrups reach their tensile strength F_{fw}.
– For both components of shear resistance, a 45° diagonal inclination should be applied.
– The proof of reduced compressive strength of the concrete in the beam core is satisfied ("concrete compression strut" in SIA 262).
– The proof of longitudinal tension due to shear force is satisfied according to 4.3.4.9. By

complying with these points, the resistance of the entire stirrup reinforcement V_{Rd} is:

$$V_{Rd} = V_{Rd,s} + V_{Rd,f} = \frac{A_{sw}}{s_s} \cdot z \cdot f_{sd} + \frac{2 \cdot F_{fwd}}{s_f} \cdot z_f \qquad (35)$$

$V_{Rd,s}$ design value of the shear resistance of the internal steel stirrups
$V_{Rd,f}$ design value of the shear resistance of bonded stirrups
A_{sw} cross-sectional area of internal steel stirrups (two or more sections)
s_s spacing between internal stirrups
z_s lever arm of the resultant tensile and compressive forces of the internal steel reinforcement
f_{sd} design value of the yield strength of the internal steel stirrups
F_{fwd} design value of the tensile force acting in the bonded reinforcement
s_f spacing of bonded stirrups
z_f lever arm of the resultant tensile and compressive forces of the bonded reinforcement

Figure 6 Model of the effect of shear reinforcement



4.3.5.4 If shear reinforcement surrounds the compressed zone and the tension zone as shown in Figure 6, the design value of the tensile force acting in the bonded reinforcement can be determined as follows, provided that the conditions in 4.3.5.3 are met:

$$F_{fwd} = b_f \cdot t_f \cdot \eta_{qu} \cdot f_{fud} \qquad (36)$$

where η_{qu} = 0.3 (for 25 mm ≤ r_c), r_c = angle radius

4.3.5.5 When the compressed area is surrounded as shown in Figure 6, the inner lever arms z_s and z_f can be assumed to be approximately equal to 0.9 · d according to SIA 262 or according to Figure 7.

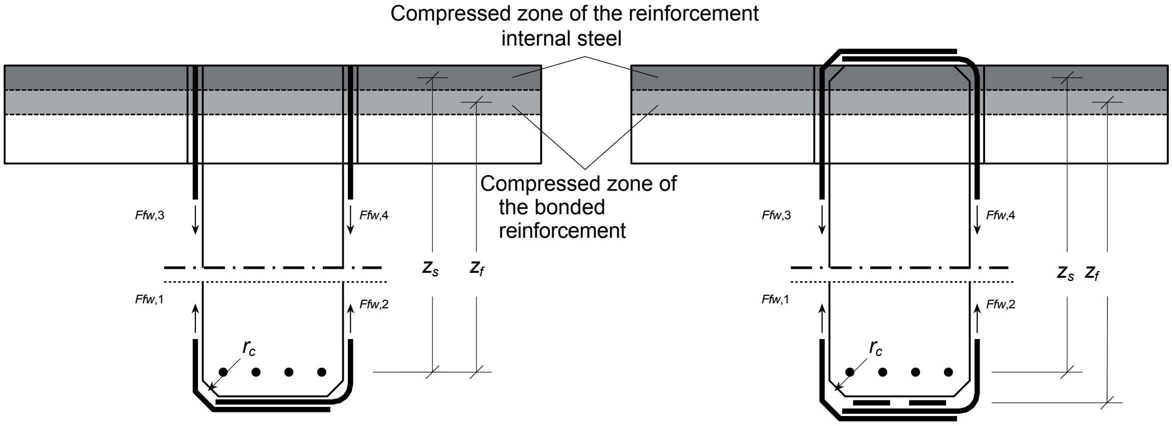
4.3.5.6 If the compressed area cannot be surrounded as shown in Figure 6, the anchorage of the tensile force F_{fw} in the bonded reinforcement (in the wing) shall be determined experimentally as shown in Figure 7. The design value of the tensile force F_{fwd} can be established from the tensile force F_{fw} , determined experimentally, according to equation (5) depending on the type of failure, environmental conditions, and long-term conditions, and equation (37). Finally, the shear force must be verified using equation (35).

$$F_{fwd} = \min(F_{fwd1}, F_{fwd2}, F_{fwd3}, F_{fwd4}) \qquad (37)$$

4.3.5.7 The anchoring of the tensile force F_{fw} in the bonded reinforcement by means of mechanical anchors, such as anchors or angle brackets with studs, must be proven experimentally in the same manner as in Section 4.3.5.6 and Figure 7. It must be demonstrated that the truss mechanism is activated. In addition, z_f must be reduced accordingly.

4.3.5.8 If the overlap of the bonded reinforcement is on the underside of the web, the anchoring of the tensile force F_{fwd} in the bonded reinforcement must be verified experimentally according to Figure 7. See also 5.2.6 and 5.2.8.

Figure 7 Principle of experimental tests for determining the stirrup force F_{fw} anchored in the bonded reinforcement



44.3.5.9 If a flexural beam is to be reinforced for shear stress and already has shear cracks in its unreinforced state, stirrups that cover the entire height of the beam and can be prestressed must be used. The bonding effect is thus only structural in nature.

4.3.5.10 The longitudinal tension due to shear force is assigned to the internal steel reinforcement in accordance with 4.3.4.9.

4.3.6 **Punching**

Bonded reinforcement may only be used for punching shear reinforcement if compatibility with the verification concepts according to SIA 262 (including the requirement regarding slab rotation and total collapse) is ensured.

4.3.7 **Confinement of compressed elements**

4.3.7.1 For compressed reinforced concrete elements, confinement with bonded reinforcement can perform all or some of the following functions:

- increased longitudinal compressive strength by creating a favorable multiaxial stress state,
- absorption of splitting forces in load introduction zones and reinforcement joints,
- absorption of shear stress for columns,
- prevention of buckling of the longitudinal reinforcement.

4.3.7.2 Confinement of compressed elements not only increases their strength, but also their deformation under compression at failure and therefore their deformability.

4.3.7.3 If the normal strength of compressed elements is to be increased with confinement, the design value of the average confinement stress s_{1d} can be calculated, if section 5.2.12 is complied with, as follows for full-surface confinement with woven or non-woven fabrics (see also Figure 8 and Figure 9):

Circular sections with diameter $D \geq 150$ mm with $\eta_{\mu m} = 0.5$:

$$s_{1d} = \frac{2 \cdot t_f}{D} \cdot \eta_{\mu m} \cdot f_{fud} \tag{38}$$

Rectangular sections with the longest side length A and the shortest side length B (with $A \leq 2 \cdot B$ and $B \geq 200$ mm):

$$s_{1d} = \left(\frac{B}{A}\right)^2 \cdot \left(1 - \frac{(B - 2 \cdot r_c)^2 + (A - 2 \cdot r_c)^2}{3 \cdot A \cdot B}\right) \cdot \frac{2 \cdot t_f}{\left(\frac{2 \cdot A \cdot B}{A + B}\right)} \cdot \eta_{um} \cdot f_{fud} \tag{39}$$

with r_c = angular radius and

$$\eta_{um} = 0.5 \cdot \frac{r_c}{50} \cdot \left(2 - \frac{r_c}{50}\right) \quad \text{for } 25 \text{ mm} \le r_c \le 50 \text{ mm} \tag{40}$$

Figure 8 Example of explanation of dimensioning values for the average (normalized) confinement stress of the envelope s_{1d} according to equations (38) to (40) as a function of the lengths of sides *A* and *B*

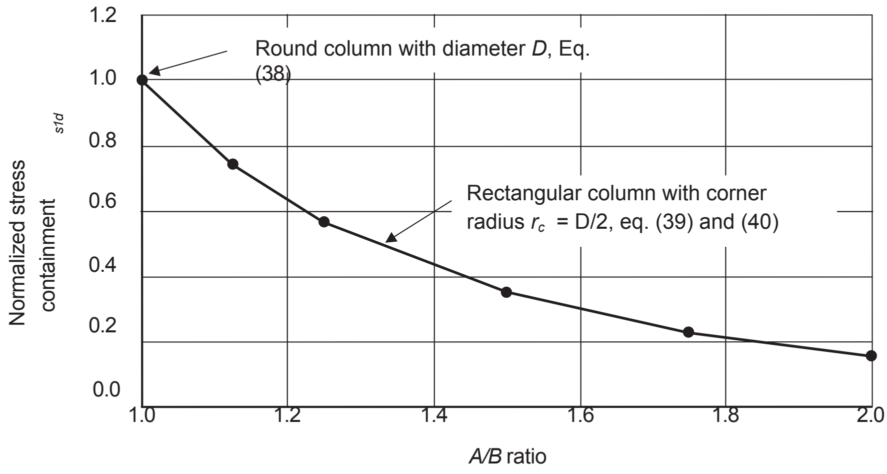
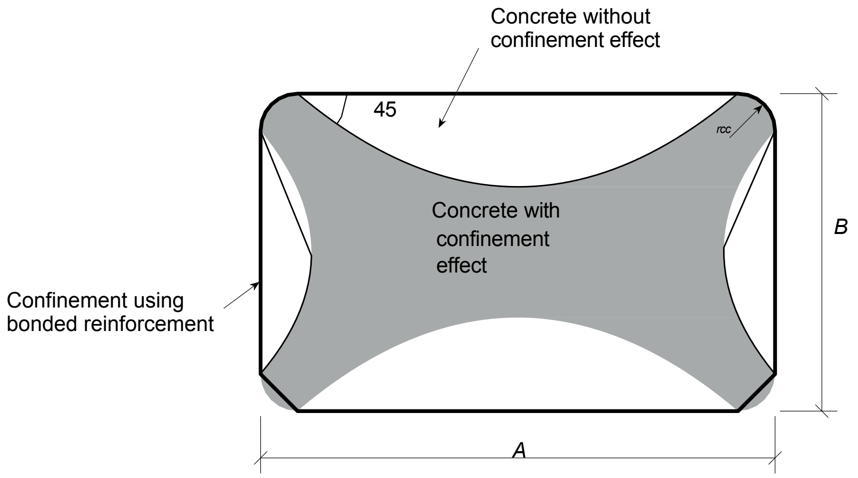


Figure 9 Containment with bonded reinforcement



4.3.7.4 The increase in concrete compressive strength due to confinement can be calculated as follows based on the average confinement stress s_{1d} (negative) according to SIA 262:

$$f_{ccd} = \left(1 - 4 \cdot \frac{s_{1d}}{f_{cd}}\right) \cdot f_{cd} \tag{41}$$

4.3.7.5 The calculation of the normal stress resistance of compressed elements in a partial containment is performed by analogy with that of containment stirrups according to SIA 262.

4.3.7.6 If the internal steel stirrups have a sufficiently high elongation at break (i.e., $e_{ud} > 0.5 \cdot f_{fud}/E_{fd}$), their confinement stress can be taken into account according to SIA 262 in addition to the external confinement. The two components can then be added together.

4.3.7.7 The effect of the vertical compression actions of the compressed elements on the rest of the load-bearing structure must be taken into account.

4.3.8 **Fatigue**

4.3.8.1 According to SIA 262, a fatigue check is necessary when more than 50,000 load cycles are expected.

4.3.8.2 Fatigue failure of reinforced concrete construction elements reinforced with bonded reinforcement can occur in the internal reinforcing steel, in the bonded reinforcement itself, or in the bond between the bonded reinforcement and the concrete surface.

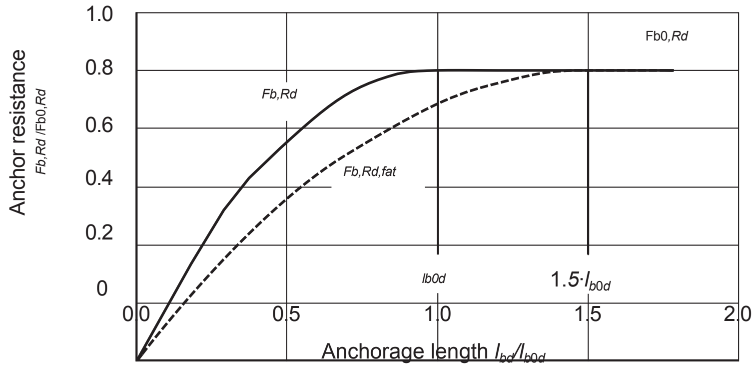
4.3.8.3 The fatigue check of the internal steel reinforcement according to SIA 262 is generally decisive in the case of fatigue loading of concrete structural elements reinforced with bonded reinforcement.

4.3.8.4 The design value of the maximum tensile stress and elongation at break in the bonded reinforcement under fatigue loads must be determined in accordance with section 4.2.3. For steel strips, the fatigue check must be carried out in accordance with SIA 263.

4.3.8.5 The design value of the anchor resistance that can be absorbed $F_{b,Rd,fat}$ for fatigue stress as a function of the anchor length l_{bd} is calculated as follows (see also Figure 10):

$$F_{b,Rd,fat} = F_{b0,Rd} \cdot \frac{l_{bd}}{1.5 \cdot l_{b0d}} \cdot \left(2 - \frac{l_{bd}}{1.5 \cdot l_{b0d}}\right) \quad \text{if } l_{bd} < 1.5 \cdot l_{b0d} \qquad (42)$$

Figure 10 Anchor resistance for static loading ($F_{b,Rd}$) and fatigue loading ($F_{b,Rd,fat}$) as a function of anchor length 1.2



4.3.8.6 Deflections and crack openings may increase under fatigue loading.

4.3.9 **Earthquake**

4.3.9.1 General

4.3.9.1.1 Bonded reinforcement may only be used to increase the deformability and/or strength of non-ductile load-bearing elements.

4.3.9.1.2 Reinforcing a load-bearing element with brittle behavior (4.3.9.2) allows the failure to be shifted to another location with ductile behavior.

4.3.9.1.3 For bonded reinforcement to be effective, sufficiently strong end anchors must be provided in non-cracked areas with appropriate construction details. End anchors must be dimensioned in accordance with 4.3.2 and 4.3.3 and overlaps in accordance with 5.2.7.

4.3.9.1.4 Bonded reinforcement cannot correct large irregularities in stiffness and strength in the plane. Where necessary, certain load-bearing elements (e.g., those previously considered non-stiffening) must be reinforced in order to reduce irregularities.

4.3.9.2 Reinforcements to increase deformability

4.3.9.2.1 Brittle failures, such as shear failures, bond failures in the case of overlapping internal steel reinforcement, buckling of internal steel reinforcement in columns, or failure of column-beam connections, can be prevented by confinement with bonded reinforcement. These measures do not increase the stiffness and strength of the overall system.

4.3.9.2.2 Confinements with bonded reinforcement can also improve the deformation capacity of plastic hinges.

4.3.9.3 Reinforcements to increase ultimate strength

4.3.9.3.1 When reinforcing columns and walls against bending with bonded reinforcement, care must be taken to ensure sufficient anchoring of tensile forces in adjacent elements. Anchoring must be carried out in uncracked areas, by analogy with the principle applied to static reinforcements in Figure 3 with a functional zone and an anchoring zone.

4.3.9.3.2 Bending reinforcement with bonded reinforcement can reduce deformation capacity.

4.3.9.3.3 The resistance of a load-bearing structure to horizontal forces can be increased by providing flexural and shear reinforcement with bonded reinforcement.

4.3.9.4 Behavior coefficient q

4.3.9.4.1 Structural analysis based on forces is performed in accordance with SIA 261. The effective flexural stiffness must be determined in accordance with SIA 269/8.

4.3.9.4.2 If bonded reinforcement is used to design load-bearing structures for non-ductile behavior, q = 1.5 should be used for the behavior coefficient.

4.3.9.4.3 If bonded reinforcement is used to design concrete load-bearing structures for ductile behavior, q = 3.0 should be used for the behavior coefficient. In areas where plastic hinges may form, bonded reinforcement may only be used in the form of confinement and stirrups.

4.3.9.5 Construction provisions

4.3.9.5.1 In concrete construction, the provisions of SIA 262 and SIA 269/8 relating to confinement can be applied by analogy.

4.3.9.5.2 The required anchorage lengths are determined in accordance with sections 4.3.2, 4.3.3, and 5.2.

4.3.9.5.3 In the case of flexural reinforcement, particular attention should be paid to the construction details for the transmission of tensile forces in the joints.

4.3.9.5.4 Bonded reinforcement used for flexural reinforcement of columns may be subjected to compression during an earthquake and must therefore be wrapped to prevent buckling and detachment.

4.3.10 **Fire**

Proceed as indicated in section 2.4.2.7.

4.4 Verification of the structural safety of reinforcements to existing steel structures

4.4.1 General

4.4.1.1 Bonded reinforcement can be used to

- increase structural safety,
- close existing fatigue cracks,
- stop crack propagation.

4.4.1.2 Structural safety must be determined using the principles set out in SIA 263, taking into account additional failure modes such as delamination and tensile failure of the bonded reinforcement.

4.4.1.3 If the bonded reinforcement is prestressed instead of being bonded passively, tensile stresses in steel structures can be reduced more effectively, particularly for brittle materials such as cast iron and in cases of fatigue loading.

4.4.2 Bonded anchorage on the surface

4.4.2.1 To calculate the resistance of the anchor on steel, it is assumed that failure occurs when the shear strength of the adhesive is reached. The maximum anchor resistance that can be absorbed $F_{b0,Rd}$ can be determined as follows:

$$F_{b,Rd} = F_{b0,Rd} = b_f \cdot \sqrt{2 \cdot G_{Fad} \cdot E_{fd} \cdot t_f} \quad \text{if} \quad l_{bd} \geq l_{b0d} \tag{43}$$

For $l_{bd} \leq l_{b0d}$, equation (12) applies.

4.4.2.2 The design value of the effective anchorage length l_{b0d} of the bonded reinforcement on the steel can be determined by the following relationship:

$$l_{b0d} = 2.5 \cdot \sqrt{\frac{G_{Fad} \cdot E_{fd} \cdot t_f}{t^2_{a,max,d}}} \tag{44}$$

4.4.2.3 The design value of the specific fracture energy G_{Fad} for static loads therefore depends on the mechanical and geometric properties of the adhesive:

$$G_{Fad} = \frac{243 \cdot \eta_u \cdot \eta_l \cdot t_a^{0.4} \cdot D_{ak}^{1.7}}{\gamma_h} \quad G_{Fad} \text{ in N/mm, } D_{ak} \text{ in MPa, } t_a \text{ in mm} \tag{45}$$

D_{ak} is the characteristic deformation energy, determined according to 3.3.2.2, η_u and η_l are determined according to Table 2 and Table 3. G_{Fad} is only valid for adhesives that follow the bilinear adhesion law according to Figure 1.

4.4.2.4 The design value of the maximum shear stress that can be absorbed by the adhesive is:

$$t_{a,max,d} = 0.9 \cdot \eta_u \cdot \eta_l \cdot f_{ad} \qquad f_{ad} = \frac{f_{ak}}{\gamma_h} \text{ in MPa} \tag{46}$$

4.4.2.5 The structural behavior of an anchor bonded to metal, for which trilinear adhesives are used to anchor greater forces, must be understood using a model that closely resembles reality. If there is no theory suitable for dealing with the anchoring case, the behavior of the anchor must be determined by testing.

4.4.3 Simple bending and bending with normal stress

4.4.3.1 Bonded reinforcement can increase the stiffness of steel beams, which can improve their stability.

4.4.3.2 As in Figure 3 for concrete load-bearing structures, it is also recommended to define anchorage zones and functional zones for steel load-bearing structures and to dimension them accordingly. In the absence of other studies, anchorage zones may be defined in the existing supporting structure where, due to design loads, tensile elongations are less than 0.1‰.

defined in the existing load-bearing structure where, due to the design loads, the tensile elongations are less than 0.1‰.

4.4.3.3 The ultimate strengths of the reinforced structural element must be determined taking into account the known properties of the supporting structure. In particular, pre-extensions due to the load history and the load at the time of reinforcement must be taken into account.

4.4.3.4 The principal tensile stresses $s_{al,II}$ in the adhesive due to static loads can be calculated using analytical or numerical methods and must be verified as follows:

$$s_{al,II} \leq \eta_u \cdot \eta_l \cdot f_{asd} \qquad f_{asd} = \frac{f_{ask}}{\gamma_h} \text{ in MPa} \qquad (47)$$

f_{ask} is the characteristic tensile shear strength of the adhesive, and η_u and η_l are determined according to Table 2 and Table 3.

4.4.4 Tensioned and compressed bars

4.4.4.1 When damaged tensioned or compressed bars are reinforced, the reinforcement must be designed in such a way that the tensile or compressive load capacity of the undamaged bar is restored.

4.4.4.2 The damaged bar must be able to bear at least half of the tensile or compressive stress, otherwise reinforcement must be abandoned and the bar replaced.

4.4.5 Fatigue

4.4.5.1 The conditions under which a fatigue check must be carried out are specified in SIA 263.

4.4.5.2 Fatigue failure of steel construction elements reinforced with bonded reinforcement can occur in the steel, in the bonded reinforcement itself, or in the bond between the bonded reinforcement and the steel surface.

4.4.5.3 The fatigue check of the steel construction element according to SIA 263 is generally decisive in the case of fatigue loading of steel construction elements reinforced with bonded reinforcement.

4.4.5.4 The design value of the maximum tensile stress and elongation at break in the bonded reinforcement under fatigue loads must be determined in accordance with section 4.2.3.

4.4.5.5 To prevent the bonded anchor from breaking under fatigue loads, the anchoring force resulting from the sum of the static loads and maximum fatigue loads must not exceed 50% of the maximum anchor resistance $F_{b0,Rd}$ that can be absorbed according to equation (43). For load combinations resulting in compressive stresses in the bonded reinforcement, refer to section 4.1.4.3.

4.4.6 Fire

Proceed as indicated in section 2.4.2.7.

4.5 Verification of the structural safety of reinforcements to existing load-bearing timber structures

4.5.1 General

4.5.1.1 In addition to the requirements in Chapter 3 relating to the building materials used, the general principles and requirements for bonding in timber construction as described in standards SIA 265 and SIA 265/1 must also be observed.

4.5.1.2 Bonded reinforcements may only be used for load-bearing timber elements belonging to moisture classes 1 and 2 according to SIA 265. The reduction factors η_e according to Table 1 must be used.

4.5.1.3 The influence of variations in wood moisture content and the resulting cracks must be taken into account.

4.5.1.4 It is possible to increase or restore the ultimate strength of load-bearing timber structural members using bonded reinforcement. However, reinforcement can lead to the premature onset of other types of failure.

4.5.1.5 The most common applications of bonded reinforcement to increase or restore the ultimate strength of load-bearing timber structural elements are the reinforcement of areas with local concentrations of unfavorable stresses, particularly in the case of tension perpendicular to the grain and shear stress. Examples include holes in beams, beams notched at their supports, loads suspended from the undersides of beams, double-curved beams, and curved beams.

4.5.1.6 The ultimate strength must be determined in accordance with SIA 265 and SIA 265/1. In addition, the types of failure to be taken into account are bond failure, tensile or compressive failure of the bonded reinforcement, and failure of the end anchorage of the bonded reinforcement.

4.5.1.7 Creep in load-bearing timber structures can cause changes in the stresses on the bonded reinforcement over time. This must be taken into account in the design.

4.5.1.8 Any reductions in the cross-section of the wood at the bonding and anchoring points must be taken into account during dimensioning.

4.5.1.9 Tests must be carried out beforehand, both to study creep (wood, glue, and their interaction) and to determine the dimensions of the end anchorage.

4.5.2 Anchor glued to the surface

4.5.2.1 To calculate the resistance of the anchor on wood, it is assumed that failure occurs when the shear and splitting resistance of the wood is reached.

4.5.2.2 The structural behavior of an anchor bonded to wood must be represented by a model that closely reflects reality. A bilinear adhesion law is recommended. If there is no theory suitable for dealing with the anchor case, the behavior of the anchor must be determined by testing.

4.5.2.3 Mechanical end anchors increase the strength of the anchor. If steel elements are used, section 2.4.6 must be taken into account. The weakening of wooden load-bearing elements in the anchorage area due to drilling and other factors must be taken into account in the design.

4.5.3 Anchors glued into grooves

4.5.3.1 To improve adhesion and/or fire resistance, it may be useful to place the bonded reinforcements in grooves similar to those used for concrete grooves (see Figure 2).

4.5.3.2 The dimensions and spacing of the grooves must be chosen so that the bonded anchors become decisive, i.e., tensile failure occurs in the bonded anchor and there is no detachment of the bonded anchors from the wood or detachment from the wood surface as in the case of surface-bonded anchors. If necessary, tests must be carried out.

4.5.3.3 The weakening of load-bearing timber elements due to the installation of grooves must be taken into account in the design.

4.5.4 **Simple bending and bending with normal stress**

4.5.4.1 As in Figure 3 for concrete load-bearing structures, it is also recommended to define anchorage zones and functional zones for timber load-bearing structures and to dimension them accordingly. In the absence of other studies, anchorage zones can be defined in the existing load-bearing structure where, due to the design loads, the tensile elongations are less than 0.1‰.

4.5.4.2 Deflected beams generally fail through one of the following failure mechanisms (see, however, 4.5.1.5):
- breakage of the support in the reinforced or unreinforced zone,
- shear failure in the wood,
- tensile or compressive failure of the bonded reinforcement,
- adhesion failure of the bonded reinforcement,
- failure of the end anchorage of the bonded reinforcement.

4.5.4.3 The ultimate strengths of the reinforced structural element must be determined taking into account the known properties of the load-bearing structure. In particular, pre-existing elongations due to historical loads and the load at the time of reinforcement must be taken into account.

4.5.4.4 To perform a detailed section analysis, the following assumptions should be made:
- The sections remain flat and perpendicular to the axis of the bar.
- In accordance with section 2.3.2.7, the bonded reinforcement only transmits tensile forces in its direction.
- The specific stress-strain behavior of the construction materials involved is taken into account in accordance with Chapter 3.

4.5.5 **Shear force**

4.5.5.1 Typical examples of shear reinforcement are described in Section 4.5.1.5.

4.5.5.2 Shear reinforcement with bonded reinforcement can be achieved using woven or non-woven composite materials bonded to the entire surface of the wood. Sufficient anchoring must be ensured. If the woven or non-woven materials are folded around corners, care must be taken to ensure that the radii of curvature are sufficiently large. The radius of curvature must not be less than 25 mm. If necessary, tests should be carried out.

4.5.5.3 Alternatively, shear reinforcement can consist of composite bars glued into pre-drilled holes. Care must be taken to ensure that the reinforcement is sufficiently anchored at the ends. The weakening of the wooden structural element caused by the drilled holes must be taken into account when dimensioning the construction element.

4.5.6 **Fire**

Proceed as described in section 2.4.2.7.

4.6 Verification of the structural safety of reinforcements to existing load-bearing masonry structures

4.6.1 **General**

4.6.1.1 Bonded reinforcements may only be used for load-bearing masonry structures that are not exposed to the weather and are located indoors. The reduction factors η_e according to Table 1 should be used.

4.6.1.2 If the masonry is subjected to tension (direct or indirect through bending or shearing), tensile forces may be attributed to the bonded reinforcement.

4.6.1.3 The calculation methods for masonry according to SIA 266 and SIA 266/2 must be applied. For reinforced masonry, the calculation methods for reinforced concrete according to SIA 262 must be applied by analogy, taking into account the characteristics of the building materials according to SIA 266 and SIA 266/2.

4.6.1.4 It is possible to achieve a state of equilibrium with stress fields.

4.6.1.5 Woven and non-woven fabrics applied over the entire surface of the masonry promote ductile fracture behavior under cyclic loading and distribute any cracks evenly.

4.6.1.6 Significant tensile and prestressing forces must be anchored in concrete or steel load-bearing elements using mechanical end anchors.

4.6.1.7 If large shear deformations of the cracks (parallel to the crack opening) are to be expected, the tensile strength of the bonded reinforcement must be reduced to take into account the low shear strength perpendicular to the fibers.

4.6.1.8 Repair mortars can be used to re-profile spalling areas, particularly in the case of natural stone. If the masonry is damaged or in poor condition, mortar or resin injections should be used to restore its monolithic behavior.

4.6.1.9 For the reinforcement of structures classified as historic monuments, removable reinforcements should be used where possible.

4.6.2 Surface-bonded anchors

4.6.2.1 Reinforcements bonded to masonry should, if possible, be anchored in adjacent concrete or steel load-bearing elements. If anchoring in masonry is unavoidable, sections 4.6.2.2 and 4.6.2.3 must be complied with.

4.6.2.2 The anchorage must be designed so that the anchoring force can be transmitted to the masonry mainly in the form of compression. Compressive stresses at the adhesive/masonry interface must be limited to the compressive strength of the stone in the direction of the corresponding force.

4.6.2.3 The compressive strength f_b(perpendicular to the bed joint) is specified in standards SIA 266 and SIA 269/6-2. Tests may be necessary to determine the compressive strength of the stone parallel to the bed joint.

4.6.2.4 Bed joints and vertical joints can transmit compressive stresses, but not tensile stresses. Bed joints can also transmit tangential stresses depending on the normal force; see the information in standard SIA 266 on this subject.

4.6.2.5 When calculating the resistance of the anchorage to masonry, it is assumed that failure occurs when the maximum shear stress at the masonry surface is reached. The application of the bilinear adhesion law according to Figure 1 is recommended. The characteristic values of the shear stress that can be absorbed and the specific rupture energy must be determined by tests on the masonry to be reinforced.

4.6.3 Simple bending and bending with normal stress

4.6.3.1 In the event of normal centered or eccentric stress on the masonry, bonded reinforcement can reduce brittle failure behavior. The structural safety check for normal stress must be carried out in accordance with the second-order theory according to SIA 266. To do this, the wall deformations must be determined on the basis of the relationship between the bending moment and the curvature, taking into account the influence of the bonded reinforcement on the formation of cracks in the masonry.

4.6.3.2 If the masonry is subjected to bending, tensile forces can be attributed to the bonded reinforcement.

4.6.4 **Transverse load**

The ultimate transverse strength in the plane of the wall is already improved by low reinforcement ratios. Similarly, the deformation capacity and energy dissipation are increased. Bending resistance can be determined from the equilibrium of internal and external forces and the compatibility of expansion in the section, assuming failure in the masonry. Detachment or failure of the bonded reinforcement should be avoided.

4.6.5 **Shear stress with centered and eccentric normal force**

4.6.5.1 Shear stresses with centered and eccentric normal forces can be checked by superimposed stress fields according to SIA 266 and SIA 266/2. For passive or prestressed reinforcements, simplified mesh models should be used. For the tensioned bar of the mesh, the resistance is limited at the anchorage point.

4.6.5.2 For masonry walls subjected to in-plane stresses, the primary purpose of bonded reinforcement is to ensure their integrity even under high and/or cyclic loads and large deformations. In addition, an increase in crack resistance and ultimate strength is expected.

4.6.6 **Earthquake**

4.6.6.1 The behavior coefficients of standard SIA 266 apply to masonry.

4.6.6.2 When seismically reinforcing masonry walls, care must be taken to increase the deformation capacity and energy dissipation of the masonry while preserving the integrity of the wall. Increasing strength is not a priority.

4.6.6.3 Seismic reinforcement of masonry walls can improve the deformation capacity both within and outside the wall plane. For masonry with increased deformation capacity (masonry according to SIA 266), it is important to prevent the bonded reinforcement from becoming detached or failing.

4.6.7 **Fire**

Proceed as indicated in section 2.4.2.7.

4.7 Verification of serviceability

4.7.1 **Concept**

Serviceability is considered to be proven when the following condition is met:

$$E_d \leq C_d \qquad (48)$$

E_d design value of the effect of the action (level of service)
C_d corresponding service limit

4.7.2 **Determination of internal forces and stresses**

4.7.2.1 The design value of the effect of an action E_d must be determined separately for actions occurring before and after the application of the bonded reinforcement.

4.7.2.2 The possible influences of the long-term behavior of the construction materials and systems used on the serviceability must be assessed.

4.7.3 **Concrete load-bearing structures**

4.7.3.1 The stresses $s_s$prevailing in the internal steel reinforcement of the reinforced concrete load-bearing structure under service loads must meet the cracking requirements (normal, increased, or high requirements) in accordance with SIA 269/2.

4.7.3.2 Due to the bonded reinforcement, the increase in section stiffness is less than the increase in ultimate strength. Deformations can therefore be decisive and must be checked accordingly.

4.7.3.3 The calculation of deformations in cracked concrete elements, mainly subjected to bending, can be carried out by analogy, as specified in SIA 262 for unreinforced concrete elements. To calculate the average reinforcement ratios, the weighted sum of the cross-sections of the various reinforcements should be used, as specified in equation (49). The static height *d* corresponds to the distance between the compressed edge and the weighted center of gravity of the different reinforcements. The weighting results from the ratio of the elastic moduli E_f/E_s.

$$\rho \leq \frac{A_s + A_f \cdot \frac{E_f}{E^s}}{_{beff} \cdot d} \qquad (49)$$

4.7.3.4 The calculation of crack opening in concrete structural elements reinforced with bonded reinforcement and mainly subjected to bending can be performed by analogy with the method described in standard SIA 262.

4.7.3.5 Pre-stressed bonded reinforcement can be used to reduce crack opening and deformation.

4.7.4 **Steel load-bearing structures**

4.7.4.1 Bonded reinforcement in steel load-bearing structures can reduce tensile forces under service conditions.

4.7.4.2 The serviceability of steel load-bearing structures reinforced with bonded reinforcement must be verified in accordance with SIA 263.

4.7.5 **Wooden load-bearing structures**

4.7.5.1 Bonded reinforcement can be used in timber load-bearing structures to improve their serviceability, i.e., to reduce deflections and improve vibration behavior.

4.7.5.2 The serviceability of load-bearing structures made of wood reinforced with bonded reinforcement must be verified in accordance with SIA 265 and SIA 265/1.

4.7.6 **Masonry load-bearing structures**

The serviceability of masonry load-bearing structures reinforced with bonded reinforcement must be verified in accordance with SIA 266.

5 CONSTRUCTION PROVISIONS

5.1 Principles

5.1.1 The structural design rules described in Chapter 5 apply primarily to the reinforcement of concrete load-bearing structures. They must be adapted by analogy to steel, timber, and masonry supports.

5.1.2 The structural model must be designed in such a way that the layout and anchoring of the bonded reinforcement correspond to the calculation model.

5.1.3 The structural design of the bonded reinforcement must take into account the installation conditions.

5.1.4 As a rule, tensile stresses perpendicular to the adhesive joint must be avoided. Appropriate measures must be taken for concave areas or gussets (e.g., doweling or reprofiling).

5.1.5 Care must be taken to ensure that forces are not unintentionally deflected by irregularities in the substrate.

5.2 Spatial arrangement of the bonded reinforcement

5.2.1 In order to ensure model-compliant behavior at the structural safety limit state and proper bonding, the dimensions in Table 6 are recommended for the lamellas.

Table 6 Recommended maximum and minimum dimensions for lamellas

	Steel strips	Composite strips
Minimum thickness	4 mm	1 mm
Maximum thickness	10 mm	3 mm
Maximum width	200 mm	150 mm

5.2.2 The minimum distance between adjacent strips must be chosen so that the adhesive can overflow laterally during installation.

5.2.3 Shear reinforcement must be designed to surround the tensile reinforcement. The transfer of the stirrup force in the flexural compression zone must be ensured.

5.2.4 Lamella joints in functional areas should be avoided, as their load-bearing capacity is significantly lower than when the lamellae are continuous. If joints cannot be avoided, the strips must be laid side by side and their length and load-bearing capacity must comply with the requirements for end anchoring in accordance with 4.3.2. and 4.3.3 (concrete) and 4.4 (steel).

5.2.5 Strip joints are not permitted for bonded reinforcement intended to strengthen walls against earthquakes.

5.2.6 The joints, i.e., overlaps, of woven and non-woven fabrics used to reinforce the shear strength of reinforced concrete structures must not be placed in the core area (where the main stress occurs), but must be placed on the bottom and/or top of the beam. The length and load-bearing capacity are determined in accordance with 4.3.5.

5.2.7 Woven and non-woven fabrics used for confinement of round compressed elements must have a joint, i.e., an overlap, of at least 150 mm in length. For rectangular compressed elements, the joints must be placed in the middle of the long side. The length and load-bearing capacity are determined by the overlap specifications in 5.2.8.

5.2.8 Tests must be carried out to determine the required length and load-bearing capacity of joints, i.e., overlaps, strips, woven and non-woven overlays.

5.2.9 If reinforced concrete slabs are reinforced with steel strips, these must be arranged mainly in the area of the main load-bearing effect.

5.2.10 In the event of overlapping slats, the following measures may be taken:

- Milling the substrate for the first layer of lamellae.
- Double the backing for the second layer of strips (reprofiling or application of an additional amount of adhesive). The maximum thickness of the adhesive for these applications must not exceed 5 mm.
- The combination of a first layer of composite lamellae and a second layer of steel lamellae.
- The use of woven and non-woven fabrics.

5.2.11 The use of multiple layers of strips for flexural reinforcement should be avoided, as their load-bearing capacity is not sufficiently known. If, in exceptional cases, two layers of strips are used for flexural reinforcement, the maximum total thickness according to 5.2.1 must be observed. For checks on flexural reinforcement in accordance with 4.3.4, the total thickness of the two superimposed layers must be used for t_f.

5.2.12 The maximum number of layers for woven and non-woven materials must be limited to eight.

5.2.13 In the case of grooved strips intended for reinforcing concrete load-bearing structures, the construction rules in accordance with 4.3.3 must be observed.

5.3 Constructive protective measures

5.3.1 Constructive measures serve, among other things, to protect bonded reinforcement from water and moisture, direct sunlight and temperature effects, as well as intentional, negligent, or ignorant damage.

5.3.2 Water can be kept away from bonded reinforcement on undersides by means of barriers against liquids, such as drip edges, milled grooves, and similar devices.

5.3.3 For steel slats on vertical surfaces, standing water can be prevented by chamfering the surface of the steel slat.

5.3.4 Surface protections protect against direct sunlight and intentional damage.

5.3.5 Cement-based coatings combined with a bonding layer can be used as protection against the effects of temperature, UV rays, and stress related to use.

5.3.6 Steel lamellas must be protected against corrosion by coatings in accordance with SN EN ISO 12944-2, depending on the area of application and duration of use. On the bonding side, the primer alone must fulfill this function. On the bonding side of steel lamellas, the application of a zinc dust primer is not recommended.

5.3.7 Light-colored paints can limit the heating of the bonded reinforcement when exposed to direct sunlight.

5.3.8 Markings can limit damage caused by negligence or ignorance, but encourage deliberate damage.

5.4 Fire protection measures

5.4.1 The fire resistance of construction elements reinforced with bonded reinforcement can be increased by fire protection measures such as the use of coatings. Suitable products are listed in the AEAI fire protection directory [1].

5.4.2 Fire-retardant paints should not be used, as their initial temperatures are not compatible with composite materials.

5.4.3 Insulating fire protection measures, such as fire protection boards or other similar fire protection measures, must be designed in accordance with the glass transition temperatures T_g of the adhesive and the matrix of the bonded reinforcement, in accordance with the principles set out in section 2.4.2.3, and the deformations that occur in the event of a fire.

5.4.4 Regardless of the design concept, steel slats must be secured to the structure in such a way that they cannot fall off after the adhesive fails due to heat (e.g., by fastening them with dowels at each end of the slat).

6 EXECUTION

6.1 General

6.1.1 The execution rules described in Chapter 6 apply primarily to the reinforcement of concrete load-bearing structures. They must be adapted by analogy to steel, wood, and masonry supports.

6.1.2 The bonded reinforcement, the surface to be bonded, and the load-bearing directions must be marked in such a way as to rule out any errors during execution.

6.1.3 Bonded reinforcement must be transported and stored in such a way as to prevent damage from weather, pollution, or mechanical influences.

6.2 Evaluation and inspection of the substrate

6.2.1 At the start of the work, it may be necessary to carry out an additional condition survey and an assessment of how the condition has changed.

6.2.2 The scope of the tests and checks on the substrate must be such that sufficient knowledge of its quality can be obtained. Critical areas, such as anchorage zones, must be examined with particular care.

6.2.3 The validity of the assumptions made in accordance with 4.3.2.6 must be verified by means of adhesion tests in accordance with SN EN 1542. The number of tests must be specified in the inspection plan.

6.2.4 Pull-off tests to determine the bond strength of concrete close to the surface shall be carried out in accordance with SN EN 1542. At least five tests shall be carried out. All individual values shall be greater than the minimum value of 1.5 MPa for strips and the minimum value of 1.0 MPa for woven and non-woven fabrics.

6.2.5 The characteristic bond strength of concrete close to the surface f_{hk} can be determined from the simplified relationship $f_{hk} = 0.7 \cdot f_{hm}$.

6.2.6 If at least eight individual pull-off test values are available, it is also possible to determine the characteristic bond strength f_{hk} of the near-surface concrete using the relationship

$$f_{hk} = f_{hm} - k_n \cdot s \qquad (50)$$

It should be noted that this assessment assumes a normal distribution of individual values. Outliers can be determined using the Grubbs test described in SN EN 13971.

f_{hm} and s denote the mean value and standard deviation of the bond strength of the near-surface concrete in the pull-off tests. The fractile factor k_n can be determined according to Table 7.

Table 7 k_n values to be used in equation (50) with n = number of pull-off tests

n	8	10	12	16	20	30	∞
k_n	2.00	1.92	1.87	1.81	1.76	1.73	1.64

6.3 Preparation of the substrate

6.3.1 Concrete substrate

6.3.1.1 The surface of the substrate must be such that the adhesive can bond to it and adhere perfectly.

6.3.1.2 Any grease, oil, or dirt residues on the surface of the substrate must be removed.

6.3.1.3 To remove the cement skin and non-load-bearing mineral layers, sanding, sandblasting, and shot blasting processes are available. The choice of process depends, among other things, on the shape and size of the object and the surrounding conditions.

6.3.1.4 The removal of the cement layer and non-load-bearing mineral layers must be carried out with care in order to avoid microstructural damage and cracks in the area close to the concrete surface. To check this work, adhesion tests should be carried out in accordance with standard SN EN 1542.

6.3.1.5 Dust, particles, and sludge residues must be removed from the pores and cavities of the substrate (e.g., with an industrial vacuum cleaner).

6.3.1.6 The maximum moisture content in the first 10 mm of the substrate must be less than 4 percent by mass, unless the adhesive used allows higher values.

6.3.1.7 Direct bonding to internal steel frames is not permitted.

6.3.1.8 In the case of rigid steel lamellas, irregularities in the substrate can lead to bonding defects. Due to their low inherent rigidity, lamellas, woven and non-woven composite materials often follow curved surfaces and exert deflection forces under tensile stress.

6.3.1.9 The following deviations from the flatness of the substrate must not be exceeded (measurements taken under a batten of corresponding length):

– 5 mm over a length of 2000 mm,
– 1 mm over a length of 300 mm.

6.3.1.10 If the required flatness of the substrate cannot be achieved by scraping, compatible leveling layers must be provided to ensure perfect force transmission.

6.3.1.11 Sharp edges that will be covered with adhesive must be prepared in such a way that the minimum radii of the bonded reinforcements, as specified by the manufacturers, are respected.

6.3.1.12 If composite woven and non-woven materials are bent around corners, these must be rounded and a minimum radius of 25 mm must be observed. The minimum permissible radii for lamellas are specified in the product specifications.

6.3.1.13 Repair mortars in accordance with 3.8.1 may be used for reprofiling areas of spalling, cavities, and small hollows. The adhesion of the repair mortar to the substrate may be verified by adhesion tests in accordance with SN EN 1542. The requirements set out in section 6.2 apply.

6.3.1.14 The surface roughness of the repair mortar must allow the adhesive to bond with the substrate surface.

6.3.1.15 The preparation of the substrate and the curing of the repair mortar must be planned and carried out in accordance with the system. Sludge residues and other dirt on the reprofiling surfaces must be removed. Bond bridges must be created in accordance with the system supplier's instructions. The system-related waiting times must be observed before carrying out the next work steps.

6.3.1.16 The residual moisture of the repair mortar must be less than 4 percent by mass, unless the adhesive used allows higher values.

6.3.1.17 The repair mortar and adhesive must be compatible with each other.

6.3.2 Steel substrate

6.3.2.1 The surface of the steel substrate to be bonded must be cleaned to a surface preparation grade of Sa $2^1/_2$ in accordance with SN EN ISO 12944-4.

6.3.2.2 Immediately after cleaning, the surface must be protected with a primer that is suitable for the adhesive and the steel surface in terms of adhesion and thermal behavior.

6.3.2.3 The adhesion resistance of the primer used on the steel substrate surface and the adhesive on the primer must be high enough to ensure that failure occurs in the adhesive.

6.3.3 Wooden substrate

6.3.3.1 The condition of the wood surface must be examined beforehand. It must be ensured that there are no mushrooms, wormholes, or cracks, for example. All infested parts must be removed beforehand.

6.3.3.2 Any grease, oil, or dirt residue on the surface of the substrate must be removed.

6.3.3.3 The treatment of the wood surface depends on the adhesive used. The adhesive manufacturer's instructions must be followed.

6.3.4 Masonry substrate

6.3.4.1 The condition of the masonry surface must be checked beforehand. Any loose or damaged masonry elements must be removed.

6.3.4.2 Grease, oil, and dirt residues on the surface of the substrate must be removed.

6.3.4.3 Sanding or sandblasting methods can be used to prepare the masonry surface before applying the bonded reinforcement. The choice of method depends, among other things, on the shape and size of the object and the surrounding conditions.

6.3.4.4 Repair mortars according to 3.8.1 can be used for reprofiling areas of spalling, cavities, and small hollows. The adhesion of the repair mortar to the substrate can be verified by adhesion tests in accordance with SN EN 1542. In addition, sections 6.3.1.14 to 6.3.1.17 should be observed.

6.4 Installation

6.4.1 Personnel

6.4.1.1 The contractor must have a qualified supervisor. This person must be present during all work that affects the final quality.

6.4.1.2 Specialist and auxiliary personnel must have sufficient training and experience in the installation of bonded reinforcement.

6.4.2 Protection of the workplace

6.4.2.1 The workplace must be protected from external influences that could affect quality, such as moisture, dust, heat, cold, drafts, vibrations, etc.

6.4.2.2 The reinforced area must not be loaded until the adhesive has reached its nominal strength, and certainly not before 48 hours.

6.4.3 Climatic conditions

6.4.3.1 Appropriate measures must be taken to ensure that the minimum and maximum application temperatures for the adhesive are maintained in the bonded reinforcement, the adhesive, and the adjacent substrate throughout the curing process.

6.4.3.2 The surface temperature of the bonded reinforcement and substrate must be at least 3°C above the dew point and must be checked at regular intervals throughout the day. It is recommended that the bonded reinforcement be stored at the installation site.

6.4.3.3 In case of unsuitable conditions during work and if it cannot be guaranteed that suitable conditions will prevail during the curing time, no bonding work should be carried out.

6.4.3.4 The following values must be measured and recorded at least twice a day before and during application and curing time:
- temperature and humidity of the substrate,
- air temperature in the work area,
- relative air humidity,
- dew point.

6.4.4 Preparation of the bonded reinforcement

The surface of the bonded reinforcement must be cleaned immediately before bonding. It must be free of grease, oil, and dirt.

6.4.5 Mixing the adhesive

If only parts of packaging drums are mixed, the following conditions must be observed:
- Weigh the actual components of the mixture using a calibrated scale, taking into account losses during transfer.
- Observe the mixing ratios with a tolerance according to the product data sheet.
- Record the weights measured.

6.4.6 Assembling the glued frame

6.4.6.1 To ensure that the bonding surface is completely covered, the adhesive must be applied in such a way that no air bubbles are trapped. You can check that the bonding surface is completely covered by observing the adhesive that overflows at the sides.

6.4.6.2 Pressure must be applied when positioning the bonded reinforcement. In the case of steel laminates, this pressure must be maintained until the adhesive has hardened. For composite laminates, a single pass with a hard rubber or Teflon roller is usually sufficient.

6.4.6.3 A uniform adhesive layer thickness is achieved by allowing the adhesive to overflow on both sides of the strip during the pressing operation (see 5.2.2). The adhesive layer must be at least 2 mm thick.

6.5 Quality control

6.5.1 The basis for quality management is provided by the SIA 2007 technical specifications. The following points must be specified in the quality management agreement:
- the scope, frequency, and location of the required tests,
- guidelines for recording them,
- requirements for the substrate,
- measures to be taken if the required properties are not achieved,
- the allocation of responsibilities.

6.5.2 The assumptions used in the design and the requirements defined in the quality management agreement must be consistent.

6.5.3 The project defines the qualifications that companies must have in order to be responsible for the planned work. Companies must maintain a quality assurance system that regulates, in particular, the acquisition and maintenance of specialized knowledge and the guarantee of the required tests.

6.5.4 The call for tenders and the award of contracts must be carried out within a timeframe that allows for the proper processing of bids and the possibility of defining the procedures to be applied in the context of technical negotiations prior to the award of contracts.

6.5.5 After the glue has hardened, check for cavities by tapping.

6.5.6 The quality of the adhesion of reinforcement bonded to concrete substrates can be determined in accordance with 4.3.2.7 and by analogy for steel, wood, and masonry substrates. As these tests are destructive, they must be planned in advance.

6.6 Protection against aggressive substances

6.6.1 When reinforcing load-bearing structures with bonded elements, adhesives and solvents are used that may have harmful effects on people and the environment before and during the work. All persons involved in the use of these substances must be familiar with and comply with the relevant safety data sheets. The product packaging contains instructions for the storage, transport, and use of the contents. These instructions, as well as the laws and regulations on which they are based, must be observed.

6.6.2 When handling adhesives and solvents, avoid skin contact with liquids, gases, vapors, and solids (dust). The requirements of SUVA information sheet 44013 "Chemicals for construction" [2] must be observed. When working overhead, headgear must be worn. Exposed parts of the body can be treated with a skin protection cream, which must be applied before starting work and after each wash.

6.6.3 When working with adhesives and solvents, avoid contact with the eyes. Always wear protective goggles, even when cleaning tools.

6.6.4 Inhalation of vapors and dust must be avoided. Extraction hoods must be installed as close as possible to sources of vapors or dust. If this is not possible, respiratory masks must be worn. Containers of resin, hardener, detergent, and solvent must be closed immediately after use.

6.6.5 Ingestion of plastic materials should be avoided. In areas where these products are used (work areas, filling areas), smoking, eating, and drinking should be avoided. Hands should be thoroughly washed before each meal.

6.7 Monitoring and maintenance

6.7.1 Bonded frames must be monitored during construction and throughout their entire service life.

6.7.2 Any regular maintenance work required to maintain the bonded reinforcement must be recorded in the maintenance plan. If necessary, inspection hatches must be provided.

6.7.3 The repair of bonded reinforcement may involve replacing or supplementing it.

Appendix A (informative)
Publications

This appendix lists various publications that deal with the same subject as this standard.

[1] AEAI Fire Protection Directory Link:
www.bsronline.ch

[2] SUVA Information sheet 44013 *Chemicals for construction*
Link: www.suva.ch

Appendix B (informative)
Index of terms

Table 8 Alphabetical index of terms defined in Chapter 1

French	German	Number
Bonded reinforcement	Klebebewehrung	1.1.10
Adhesive	Adhesive	1.1.11
Fracture behavior	Fracture behavior	1.1.4
Confinement	Wrapping	1.1.17
Coating	Coating	1.1.3
Fiber	Fiber	1.1.6
Interface	Layer boundary	1.1.16
Lamella joint	Lamella joint	1.1.13
Lamella	Lamella	1.1.12
Lamellae for grooves	Single-slot lamellae	1.1.5
Active anchorage length	Active anchoring length	1.1.1
Anchorage length	Anchoring length	1.1.23
Composite material	Fiber composite material	1.1.7
Matrix	Matrix	1.1.14
Failure mode	Failure mode	1.1.25
Nonwoven	Gelege	1.1.8
Primer	Primer	1.1.15
Surface protection	Cladding	1.1.26
Stiffening	Stiffening	1.1.27
Reinforcement	Verstärkung	1.1.28
Anchor resistance	Anchorage resistance	1.1.21
Cladding	Cladding	1.1.2
Adhesion failure	Verbundversagen	1.1.24
Reinforcement failure	Reinforcement failure	1.1.30
Support failure	Substrate failure	1.1.20
Support	Substrate	1.1.19
Reinforcement system	Reinforcement system	1.1.29
Woven	Fabric	1.1.9
Unidirectional	unidirectional	1.1.18
Anchorage zone	Anchorage zone	1.1.22
Functional zone	Impact zone	1.1.31

Organizations represented in the SIA 262 commission and the SIA 166 working group Empa Swiss

	Federal Laboratories for Materials Testing and Research
EPFL	Swiss Federal Institute of Technology in Lausanne
ETH Zurich	Swiss Federal Institute of Technology Zurich
FEDRO	Federal Roads Office
SSE	Swiss Contractors' Association

Adoption and validity

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