

Replaces the recommendation SIA 162/5, 1997 edition, and Appendix A of Technical Specification SIA 2018, 2004 edition

Erhaltung von Tragwerken – Betonbau

Maintenance des structures porteuses – Structures en béton

Conservazione delle strutture portanti – Costruzioni in calcestruzzo

Existing structures – Concrete structures

Reference number
SN 505269/2:2011 en

Valid from: 2011-01-01

Published by
Swiss Society of Engineers
and Architects
P.O. Box, CH-8027 Zurich

Number of pages: 44

Copyright © 2011 by SIA Zurich

Price category: 34

Any corrections to and comments on this publication can be found at www.sia.ch/korrigenda.

The SIA assumes no liability for any damages which might be caused through the application of this publication.

2016-09 1st Edition

CONTENTS

	Page		Page
Foreword	4	Appendix	
0 Scope	5	A Construction material properties	
0.1 Limitations	5	(normative)	37
0.2 References	5	B Structural measures (normative)	40
0.3 Deviations	6	C Determinations of the crack width index	
1 Terminology	7	(normative)	41
1.1 Technical terms	7		
1.2 Symbols	9		
2 Basic principles	12		
2.1 General	12		
2.2 Examination	12		
3 Construction materials	13		
3.1 General	13		
3.2 Concrete	13		
3.3 Reinforcing steel	14		
3.4 Prestressing steel	15		
4 Structural analysis and verifications	16		
4.1 General	16		
4.2 Examination value	17		
4.3 Verification of structural safety	17		
4.4 Verification of serviceability	18		
4.5 Special considerations	19		
5 Condition survey	23		
5.1 General	23		
5.2 Inspection methods	23		
6 Condition evaluation	25		
6.1 General	25		
6.2 Deterioration as a result of alkali-aggregate reaction	25		
6.3 Deterioration as a result of corrosion of the reinforcement	26		
6.4 Prediction of the development of the condition	26		
7 Interventions	27		
7.1 General	27		
7.2 Basic principles and methods	27		
7.3 Strengthening	30		
7.4 Methods	31		
7.5 Requirements applicable to the products and systems	35		
7.6 Quality assurance	35		

FOREWORD

Code SIA 269/2 describes the procedures to be followed in the preservation of concrete structures and is directed at specialists in the preservation of structures. It is also addressed to owners of structures as well as specialists involved in construction management and the execution of construction work.

Code SIA 269/2 forms part of the SIA's structural codes relating to existing structures and is supplemented by the following codes:

- Code SIA 269 Existing structures – Bases for examination and interventions
- Code SIA 269/1 Existing structures – Actions
- Code SIA 269/3 Existing structures – Steel structures
- Code SIA 269/4 Existing structures – Composite steel and concrete structures
- Code SIA 269/5 Existing structures – Timber structures
- Code SIA 269/6 Existing structures – Masonry structures
- Code SIA 269/7 Existing structures – Geotechnics.

Technical Specification SIA 2018 continues to apply to the examination of existing buildings with respect to earthquakes. However, it is planned to supplement the codes for existing structures with a Code SIA 269/8 *Existing structures – Seismic aspects*.

Code SIA 269/2 addresses various aspects concerning existing concrete structures that are not covered by Codes SIA 262 and 262/1.

Codes SIA 269 Project Management Team and Working Group SIA 269/2

0 SCOPE

0.1 Limitations

- 0.1.1 Code SIA 269/2 applies to the preservation of structures made of reinforced concrete, prestressed concrete and unreinforced concrete as a part of existing construction works.
- 0.1.2 The present code applies in conjunction with Codes SIA 269 and SIA 269/1 as well as with Code SIA 262. The principles of Code SIA 269/2 shall be applied analogously for applications outside of the scope of these codes.
- 0.1.3 The manufacture and processing as well as the testing of the construction materials used for the rehabilitation of concrete structures are treated insofar as this is necessary for the definition of quality requirements.
- 0.1.4 In the case of alterations to concrete structures, in general new structural components are to be treated according to Code SIA 262 and existing structural components according to Codes SIA 269 and 269/2. It is permissible to deviate from this rule with respect to the definition of the variable actions if different limitations are appropriate on the basis of specific considerations.
- 0.1.5 Code SIA 269/2 may not be used for the design and dimensioning of new concrete structures.

0.2 References

- 0.2.1 Reference is made to the standards named below. These are also applicable by way of reference:
- Pre-code SIA 166 *Externally bonded reinforcement*
 - Recommendation SIA 179 *Mountings in concrete and masonry*
 - Code SIA 233 *Clad external walls*
 - Code SIA 252 *Jointless industrial flooring*
 - Code SIA 269/3 *Existing structures – Steel structures*
 - Pre-code SIA 270 *Waterproofing and drainage – general principles and points of interaction*
 - CEN/TS 14038 *Electrochemical realkalisation and chloride extraction treatment for reinforced concrete, Parts 1 and 2*
 - SN EN 206-1 *Concrete – Part 1: Specification, properties, production and conformity*
 - SN EN 10080 *Steel for the reinforcement of concrete – weldable reinforcing steel*
 - SN EN 12504 *Testing concrete in structures, Parts 1 to 4*
 - SN EN 12696 *Cathodic corrosion protection of steel in concrete*
 - SN EN 13670 *Execution of concrete structures*
 - SN EN 13791 *Assessment of in-situ compressive strength in structures and pre-cast concrete components*
 - SN EN 14487 *Shotcrete – Parts 1 and 2*
 - SN EN 14629 *Products and systems for the protection and repair of concrete structures – test methods – determination of chloride content in hardened concrete*
 - SN EN 14630 *Products and systems for the protection and repair of concrete structures – test methods – determination of carbonation depth in hardened concrete by the phenolphthalein method – test*
 - SN EN 14889 *Fibres for concrete – Parts 1 and 2*
 - SN EN 1504 *Products and systems for the protection and repair of concrete structures – Definitions, requirements, quality control and evaluation of conformity, Parts 1 to 10*
 - SN EN ISO 15630 *Steel for the reinforcement and prestressing of concrete – test methods – Parts 1 to 3.*
- 0.2.2 Codes and guidelines that are no longer in use may not be incorporated in the service criteria agreement and in the basis of design as code-related requirements, but only by way of reference, and only in order to document former basic principles.

0.3 **Deviations**

- 0.3.1 Deviations from the present code are permissible provided they are sufficiently well-founded, theoretically or experimentally, or justified by new developments and new knowledge.
- 0.3.2 Deviations from the code shall be clearly documented in the construction documents together with the reasons for such deviation.

1 TERMINOLOGY

1.1 Technical terms

In addition to the technical terms used in the Codes SIA 260, SIA 262 and SIA 269 the technical terms defined below are used in the present code:

Acceptance test for suitability

Eignungsprüfung
essai de convenance
prova di qualificazione

Testing to verify the suitability of a construction material or system under object-specific conditions of use within the context of the chosen working procedures.

Carbonation

Karbonatisierung
carbonatation
carbonatazione

Chemical reaction between the calcium hydroxide of the hardened cement paste, the carbon dioxide from the air and water, which leads to a reduction in the alkalinity of the concrete.

Cathodic corrosion protection

Kathodischer Korrosionsschutz
protection cathodique contre la corrosion
protezione catodica contro la corrosione

Corrosion protection through compensation of the electrical current flowing during the corrosion process through an opposing protective current of equal or greater intensity.

Chloride contamination

Chloridanreicherung
contamination par chlorures
contaminazione da cloruri

Contamination due to ingress of chlorides into the hardened concrete from outside or the use of materials containing chloride.

Chloride extraction

Chloridentfernung
extraction de chlorures
estrazione dei cloruri

Removal of chlorides from existing concrete by electrochemical methods or removal of concrete.

Coating

Beschichtung
enduit
rivestimento

Construction materials applied to the concrete surface in order to create a continuous protective coating with a layer thickness of between 0.1 mm and 5 mm.

Concrete adding

Betonauftrag
ajout de béton
aggiunta di calcestruzzo

Layer of concrete applied to previously-treated concrete surface, altering the existing geometry.

Concrete removal

Betonabtrag
élimination de béton
rimozione del calcestruzzo

Removal of existing concrete by mechanical action (chipping, grinding, sandblasting, cutting, shotblasting and hydroblasting) and subsequent cleaning of the concrete surface (vacuum cleaning, blowing, spraying, steam and water jets).

Concrete replacement

Betonersatz
remplacement du béton
sostituzione del calcestruzzo

Removal of deteriorated concrete and its replacement with new concrete, retaining the existing geometry.

Corrosion inhibitors

Inhibitoren
inhibiteurs
inibitori

Organic or inorganic compounds which can prevent, delay or stop the corrosion of steel.

External prestressing tendon

Externes Spannglied
unité de précontrainte extérieure
cavo di precompressione esterno

Prestressing tendon placed outside of the concrete cross section.

Hydraulic mortar and hydraulic concrete <i>Hydraulisch gebundener Mörtel oder Beton</i> <i>mortier ou béton hydraulique</i> <i>malta o calcestruzzo idraulici</i>	Construction material that hardens through hydration and fulfils the requirements of the Codes SIA 262, SN EN 206-1 and SN EN 1504-3.
Hydrophobic impregnation <i>Hydrophobierung</i> <i>imprégnation hydrophobe</i> <i>idrofofizzazione</i>	Treatment of the concrete in order to produce a water-repellent surface. The pores and capillaries are only coated, but not filled. No film forms on the surface of the concrete. The external appearance is only altered slightly or not at all.
Identity test <i>Identitätsprüfung</i> <i>essai d'identification</i> <i>prova di identità</i>	Testing in order to verify a declared value of the composition or the property of a product or system in relation to the consistency of production.
Impregnation <i>Imprägnierung</i> <i>imprégnation</i> <i>impregnazione</i>	Treatment of concrete in order to reduce its surface porosity and strengthen the surface. The pores and capillaries are partially or completely filled.
Initial test <i>Erstprüfung</i> <i>essai initial</i> <i>prova iniziale</i>	Testing consisting of identity and performance tests that serve the purpose of characterising the properties of a construction material as well as verifying its fundamental suitability for the planned applications.
Injection <i>Injektion</i> <i>injection</i> <i>iniezione</i>	Injection of cement suspension, mortar or polymers under pressure in order to fill voids such as gravel pockets, cracks and ducts for prestressing tendons.
Interface <i>Schichtgrenze</i> <i>interface</i> <i>interfaccia</i>	Boundary between two construction material layers (substrate, concrete, mortar, surface protection layers).
Mortar adding <i>Mörtelauftrag</i> <i>profilage avec du mortier</i> <i>profilamento con malta</i>	Layer of mortar applied to a pre-treated concrete surface for the purpose of reprofiling, to provide corrosion and concrete protection.
Passivity <i>Passivität</i> <i>passivité</i> <i>passività</i>	Condition in which the steel in the concrete does not corrode due to a protective oxide film.
Polymer-modified hydraulic cement mortar or concrete <i>Kunststoffmodifizierter Mörtel oder Beton</i> <i>mortier ou béton modifiés par des matières synthétiques</i> <i>malta o calcestruzzo modificati con l'aggiunta di materie sintetiche</i>	Hydraulically bonded mortar and concrete with polymer admixtures in an adequate quantity to achieve special properties.
Polymer mortar or polymer concrete <i>Kunststoffmörtel oder Beton</i> <i>mortier ou béton de matières synthétiques</i> <i>malta o calcestruzzo di materie sintetiche</i>	Mixture of reactive polymer binding agents and graded aggregates, which hardens as a result of a reaction of organic substances.
Quality test <i>Qualitätsprüfung</i> <i>essai de qualité</i> <i>prova della qualità</i>	Verification of the required quality during and following execution.
Remaining chloride content <i>Restchloridgehalt</i> <i>teneur en chlorures restantes</i> <i>tenore di cloruri rimanenti</i>	Chloride content remaining in the concrete following rehabilitation.

Reprofilation <i>Reprofilierung</i> <i>reprofilage</i> <i>riprofilamento</i>	Restoration of the original geometrical form of a structural component through the application of concrete or mortar.
Roughening <i>Aufrauen</i> <i>repiquer</i> <i>irruvidire</i>	Removal of the existing concrete surface as preparation for the bonding of a rehabilitation or protection system.
Substrate <i>Untergrund</i> <i>support</i> <i>substrato</i>	Surface to which a protective or rehabilitation material is applied or which is intended for this purpose.
Surface protection measure <i>Oberflächenschutzmassnahme</i> <i>protection de surface</i> <i>protezione della superficie</i>	Application of an impregnation and/or coating, sealing or lining as well as compatible combinations of these.
Test surface <i>Musterfläche</i> <i>surface de test</i> <i>area di prova</i>	Surface created prior to execution that is used for testing the suitability of a rehabilitation and protection system applied to the structure.

1.2 Symbols

1.2.1 Latin upper case letters

A	ductility class
B	ductility class
C	ductility class, strength class
A_P	cross-sectional area of the prestressing steel
A_S	cross-sectional area of the reinforcing steel
$M_{Rd,act}^+$	maximum bending resistance (examination value)
$N_{d,act}$	examination value for the normal force
RI	crack width index
R_m	average roughness depth of the concrete substrate
$V_{d,act}^+$	increased shear force (examination value)

1.2.2 Latin lower case letters

c_{act}	updated cover of reinforcement
$c_{lat,act}$	updated cover of reinforcement in the case of reinforcing bars near edge (higher value)
d	effective depth, average effective depth when there are several layers of reinforcement
f_{bd}	dimensioning value for bond stress in accordance with Code SIA 262
$f_{bd,act}$	examination value for bond stress
$f_{cd,act}$	examination value for concrete compressive strength
$f_{ci,min}$	lowest test value for cylindrical compressive strength measured on cylinder

f_{ck}	characteristic value for cylinder compressive strength (5% fractiles)
f_{cm}	average value for cylinder compressive strength of concrete
$f_{cm,28}$	average value for cylinder compressive strength of concrete after 28 day
f_{pk}	characteristic value for tensile strength of prestressing steel
$f_{p0,1k}$	characteristic value for yield strength of prestressing steel in accordance with Code SIA 262
$f_{p0,1m}$	average tensile stress at 0,1% tensile strain of prestressing steel
$f_{p0,2k}$	characteristic value for yield strength of prestressing steel in accordance with earlier SIA codes
$f_{p0,2m}$	average tensile stress at 0,2% tensile strain of prestressing steel
$f_{R,act}$	updated relative ribbed surface
$f_{sd,act}$	examination value for yield strength of the reinforcing steel
$f_{sk,act}$	updated, characteristic value for yield strength of the reinforcing steel
f_{sm}	average value for measured yield strengths of the reinforcing steel for the purpose of updating
$f_{s0,2}$	characteristic value for the yield strength of reinforcing steel in accordance with Code SIA 262
f_t	tensile strength of reinforcing steel
f_{tm}	average value for the measured tensile strengths of the reinforcing steel for the purpose of updating
$k_{b,lat}$	factor for determination of the bond strength in the case of reinforcing bars near edge
k_c	factor for determination of the concrete strength
k_d	factor for determination of the shear resistance in accordance with Code SIA 262
k_v	factor for taking into account deformations
k_5	coefficient for determination of the 5% fractiles
k_{10}	coefficient for determination of the 10% fractiles
l_{bd}	anchorage length
$l_{bd,net}$	basic value for the anchorage length
$l_{bd,0}$	basic value for the anchorage length of prestressing steel in the pretensioning
l_s	length of the lapped joint
n	number, number of samples
s	standard deviation
s_{act}	updated bar spacing of parallel reinforcing bars
w_i	cumulative crack width
w_n	measured crack widths

1.2.3

Greek letters

α	compression field angle
γ_c	resistance factor for concrete
γ_{cE}	partial factor for the modulus of elasticity of concrete
γ_s	resistance factor for reinforcing steel and prestressing steel
$\Delta\varphi$	undesired unintentional deviations per unit of length
$\Delta\sigma_{pd,fat,act}$	examination value for the fatigue strength of prestressing steel
$\Delta\sigma_{sd,act}$	examination value for the increase in stress in the punching shear reinforcement
$\Delta\sigma_{sd,fat,act}$	examination value for the fatigue strength of reinforcing steel

ε_{ud}	dimensioning value for the ultimate strain of reinforcing steel or prestressing steel
$\varepsilon_{ud,act}$	examination value for the ultimate strain of reinforcing steel or prestressing steel
ε_{uk}	characteristic value for the ultimate strain of reinforcing steel or prestressing steel
$\varepsilon_{uk,act}$	updated characteristic value for the ultimate strain of reinforcing steel or prestressing steel
ε_{um}	average value for the ultimate strain of reinforcing steel or prestressing steel
$\varepsilon_{0,6d}$	axial strain (in the cross section) at a distance of $0,6d$ from the compressed edge of the cross section
$\varepsilon_{1d,act}$	examination value for the major principal strain
μ	friction coefficient
$\sigma_{s,adm}$	stress limit corresponding to crack formation in accordance with Code SIA 262
$\sigma_{s,adm,act}$	updated stress limit with respect to crack formation

1.2.4 Special symbols

$\varnothing$	diameter
$\varnothing_n$	equivalent diameter of a bar of equal cross-sectional area
$\varnothing_p$	equivalent diameter of a prestressing tendon
$\varnothing_w$	diameter of the punching shear reinforcement

1.2.5 Abbreviations

AAR	alkali-aggregate reaction in the concrete
CA	control of anodic areas
CC	hydraulically-bonded mortars and concretes
CP	cathodic protection
CR	concrete replacement
IP	protection against the ingress of substances
IR	increase in electrical resistance
KG	corrosion level of the reinforcement
MC	control of the water content of the concrete
PC	polymer mortars and concretes
PCC	polymer-modified mortars and concretes
PR	physical resistance
RC	resistance to chemicals
RP	preservation and restoration of passivity
SS	structural strengthening

2 BASIC PRINCIPLES

2.1 General

- 2.1.1 The examination of concrete structures and the planning of interventions require in-depth knowledge of concrete technology, structural behaviour, design and construction practice. Aesthetic aspects of the concrete structure also need to be considered.
- 2.1.2 Structural interventions in concrete structures depend on the defects present in the structures, the nature of the deterioration and the deterioration mechanisms affecting the construction materials concrete, reinforcing steel and prestressing steel.
- 2.1.3 When planning the interventions, a distinction is made between the rehabilitation of deterioration of concrete and the rehabilitation of deterioration as a result of corrosion to the reinforcement. The choice of the intervention measures is made on the basis the chosen protection and rehabilitation principles in accordance with SN EN 1504-9. These can involve different rehabilitation methods.
- 2.1.4 In general, acceptance tests for suitability are necessary to determine the suitability of a rehabilitation principle and method.

2.2 Examination

- 2.2.1 The structural analysis of existing concrete structures is carried out using examination values for the construction materials concrete, reinforcing steel and prestressing steel. The examination values are determined from the construction documents or by means of tests carried out on the existing structure. In the first case, the examination values must be examined critically and if necessary tests should be carried out on the existing structure.
- 2.2.2 If justified doubts exist as to the reliability of the test values for the construction materials, an increase in the partial safety factors is appropriate.
- 2.2.3 The influences of chemical, physical and biological actions and actions due to weathering on the properties of the construction materials concrete, reinforcing steel and prestressing steel shall be taken into consideration.
- 2.2.4 The effects of actions determined on the basis of the standards valid at the time of construction may serve as an indication of the expected examination values for the resistances.
- 2.2.5 The condition survey and evaluation focus on deterioration and deterioration mechanisms. In general, the measurement of dimensions, layer thicknesses of imposed loads, etc., are also necessary for the purpose of structural analysis.

3 CONSTRUCTION MATERIALS

3.1 General

- 3.1.1 The procedure for updating construction material properties is generally divided into three steps:
- updating on the basis of the construction documents
 - non-destructive tests as well as material exposure and probings for the product identification of concrete, reinforcing steel and prestressing steel
 - collection and testing of samples taken from the structure.
- 3.1.2 Class description and properties of concrete, reinforcing and prestressing steels from earlier codes can be found in Appendix A.
- 3.1.3 The necessary scope of the investigations to determine the construction material properties depends on the reserve ultimate strength, the failure mechanism or the failure type and the influence of the construction material properties on the ultimate strength.
- 3.1.4 For a rough analysis, the construction material properties may be determined from the construction works documents or cautiously estimated if:
- a ductile structural behaviour is to be expected
 - the requirements in terms of detailing in accordance with Code SIA 262 are fulfilled
 - or an adequate reserve ultimate strength is provided.
- 3.1.5 For a detailed analysis, the mechanical properties of construction materials in accordance with the designations used in earlier codes may be used as examination values if:
- they are confirmed and documented through a sufficient number of tests during execution or through condition surveys which have already been carried out
 - no indications of deterioration (e.g. deterioration of joints, AAR, frost, severe corrosion, etc.) are discerned.
- The specific conditions specified in Section 3.3.1 for reinforcing steel and in Section 3.4.1 for prestressing steel apply.
- 3.1.6 If the test results from the time of execution show higher values than assumed in the original design/dimensioning, this may be taken into account in the definition of the construction material properties for the examination, provided the conditions set forth in Section 3.1.5 are fulfilled.
- 3.1.7 If the conditions set forth in Sections 3.1.4 and 3.1.5 are not fulfilled, the construction material properties shall be determined on the structure itself.
- 3.1.8 The construction material properties of a structural member that has been exposed to fire shall be determined in situ on the structure.

3.2 Concrete

- 3.2.1 The examination values for the concrete compressive strength and the shear stress limit shall be determined in accordance with Code SIA 262 on the basis of the compressive strength class. If the test values for the concrete compressive strength lie between two compressive strength classes, the examination values may be interpolated.
- 3.2.2 The testing of drilled cores with a nominal diameter and a length of 100 mm represents the reference method for the determination of the concrete compressive strength from the structure. SN EN 12504-1 applies to the testing and SN EN 13791 applies to the determination of the compressive strength.
- 3.2.3 The concrete compressive strength may also be tested on the structure through indirect methods (e.g. rebound hammer, pull-out test, ultrasound). SN EN 12504, parts 2 to 4, applies to the testing, and SN EN 13791 applies to the determination of the compressive strength.

- 3.2.4 The compressive strength class shall be determined with the aid of Table 1 (approach B according to SN EN 13791). If more than 15 drilled cores are available, approach A according to SN EN 13791 shall be applied.
- The lower of the two values $f_{ci,min}$ or $f_{cm(n)}$ applies.

Table 1: Compressive strengths of drilled cores with a nominal diameter of 100 mm

Compressive strength class	Lowest test result $f_{ci,min}$ [N/mm ²]	Average value of n test results $f_{cm(n)}$ [N/mm ²]		
		$n = 3$ to 6	$n = 7$ to 9	$n = 10$ to 14
C8/10	5	16	15	14
C12/15	9	20	19	18
C16/20	13	24	23	22
C20/25	17	28	27	26
C25/30	22	33	32	31
C30/37	27	38	37	36
C35/45	34	45	44	43
C40/50	39	50	49	48
C45/55	43	54	53	52
C50/60	47	58	57	56
C55/67	53	64	63	62
C60/75	60	71	70	69
C70/85	68	79	78	77
.../...	> 68	> 79	> 78	> 77

- 3.2.5 If the determination of the compressive strength of concrete is carried out with small drilled cores with a diameter and a length of approximately 50 mm, the number of samples shall be increased in relation to the maximum grain diameter D_{max} :
- in the case of $D_{max} = 32$ mm, five samples are necessary for 1 test result
 - in the case of $D_{max} \leq 16$ mm, three samples are necessary for 1 test result.
- 3.2.6 The determination of the compressive strength of the concrete of the structure in a particular test area shall be based on at least three test results. The test areas shall be defined depending on the structural behaviour, loading, concreting stages, etc.
- 3.2.7 If the concrete does not contain additives for high early strength and the conditions set forth in Section 3.1.5 are fulfilled, the development of compressive strength in accordance with Code SIA 262 may be taken into account; for older concretes (construction before 1985/1990) without pozzolanic or latent hydraulic additives (type II in accordance with SN EN 206-1), the time-dependent increase in compressive strength may be estimated as follows:

$$f_{cm}(t) = f_{cm,28} \cdot 0,41 [(\log t) + 1] \quad t \text{ in days} \quad (1)$$

3.3 Reinforcing steel

- 3.3.1 The mechanical properties of reinforcing steel shown in Table 8 may be used if:
- the date of manufacture of the reinforcing steel is known
 - the steel type is clearly identified on the basis of the rib pattern following exposure
 - the reinforcing steel does not exhibit any deterioration.

- 3.3.2 The construction material properties of reinforcing steel samples should be tested in accordance with EN ISO 15630, Parts 1 and 2. Shorter samples may be taken and tested if:
- the test results give no grounds for justified doubts
 - no signs of deterioration are discerned
 - the influence on the ultimate resistance is not sensitive.
- 3.3.3 With the strength test, the yield point f_s is determined as the upper yield stress or as tensile stress at 0,2% strain ($f_{s0,2}$) as well as the tensile strength f_t . They are obtained through division of the corresponding tensile forces by the nominal cross-sectional area A_s of the bar. The characteristic yield point (5% fractiles) amounts to
- $$f_{sk,act} = f_{sm}(n) - k_5(n) \cdot s \quad (2)$$
- whereby $k_5(n)$ and A_s shall be determined in accordance with SN EN 10080. For a sample range of $3 \leq n \leq 30$, $k_5(n)$ may be determined approximately as follows:
- $$k_5(n) = 1,64 + 6 \cdot n^{-4/5} \quad (3)$$
- 3.3.4 The ductility properties of reinforcing steel shall satisfy the requirements of Code SIA 262. The hardening ratio $(f_t/f_s)_k$ and the strain at maximum load ε_{uk} are determined as 10% fractiles:
- $$\varepsilon_{uk,act} = \varepsilon_{um}(n) - k_{10}(n) \cdot s \quad (4)$$
- whereby $k_{10}(n)$ is to be determined in accordance with SN EN 10080. For a sample range of $3 \leq n \leq 30$, $k_{10}(n)$ may be determined approximately as follows:
- $$k_{10}(n) = 1,28 + 5 \cdot n^{-4/5} \quad (5)$$
- 3.3.5 The influence of the surface quality (corrosion, notches) on the fatigue strength shall be considered by taking into consideration the loading history.
- 3.3.6 The suitability for welding depends above all on the chemical composition. In general, naturally hardened steels with a date of manufacture after 1956 are suitable for welding. Welds on cold-worked reinforcing steels shall be planned carefully and the action effects of the heat input on the mechanical properties shall be taken into consideration.

3.4 Prestressing steel

- 3.4.1 The mechanical properties of prestressing steel as shown in Table 9 or the manufacturer's test certificate may be used if:
- the date of manufacture of the prestressing steel is known
 - the prestressing tendon type is clearly identified on the basis of exposures or construction documents
 - the prestressing steel shows no signs of deterioration.
- 3.4.2 The construction material properties of prestressing steel samples shall be tested in accordance with EN ISO 15630-3. Shorter samples may be taken and tested if:
- the test results give no grounds for justified doubts
 - no indications of deterioration are given
 - the influence on the ultimate resistance is not sensitive.
- 3.4.3 The 0,1% yield stress ($f_{p0,1}$) and the tensile strength (f_p) are determined with the tensile test. These are determined by dividing the corresponding tensile forces by the nominal cross-sectional area A_p of the prestressing steel.
- 3.4.4 The influence of the surface quality (corrosion, notches) on the fatigue strength is to be considered taking into consideration the loading history.

4 STRUCTURAL ANALYSIS AND VERIFICATIONS

4.1 General

4.1.1 Calculation method

- 4.1.1.1 The upper bound theorem applied in plasticity theory (kinematic method) may be used
- to identify insufficient structural safety
 - to define relevant load positions
 - to confirm the results of a calculation according to the lower bound theorem (static method).
- 4.1.1.2 The influence of insufficient or missing minimum reinforcement and the relevant structural detailing on the ductile behaviour of the structure shall be considered when verifying the structural safety.
- 4.1.1.3 The hardening characteristic of the reinforcement and the properties of the bond between reinforcement and concrete shall be considered when verifying the plastic deformation capacity.

4.1.2 Prestressed structures

4.1.2.1 General

- 4.1.2.1.1 The verification of the structural safety shall take into account that the residual stress resultants due to the sectional forces due to constraint effects of prestressing is only changed in the zones of plastic deformation.
- 4.1.2.1.2 Sectional forces due to constraint effects of prestressing influence the location and the sequence of the formation of zones with plastic hinges and thus the deformation required in order to reach the ultimate load.
- 4.1.2.1.3 In general, prestressing tendons display lower bond stiffnesses and bond strengths than reinforcing steels. The different bond behaviour shall be taken into consideration in the numerical verification of the plastic deformation capacity of structural members with mixed reinforcement.
- 4.1.2.2 Losses in prestressing force
- Values for μ and $\Delta\varphi$ should be defined on the basis of the manufacturer's data or comparable modern prestressing systems.
- 4.1.2.3 Prestressing force in the ultimate limit state
- 4.1.2.3.1 For grouted prestressing tendons with insufficient filling and insufficient grout strength, the consideration of extreme values is required in order to obtain the updated tensile force in the prestressing steel.
- 4.1.2.3.2 The determination of the variation along the tendon of the force in the prestressing steel shall take into account that an increase in prestressing force is only realistic in decompressed regions of the structure. In order to define the decompressed regions of the structure, it is practical to consider the prestressing as an action effect of the anchorage, deviation and frictional forces.

4.2 Examination values

4.2.1 Concrete

For the examination of shear walls and beam webs in the cracked condition, the reduced concrete compressive strength $k_c f_{cd,act}$ for concrete compressive strengths $f_{ck} > 30 \text{ N/mm}^2$ may be determined with the following factor k_c :

$$k_c = \frac{1}{1,25 + 60 \varepsilon_{1d,act}} \leq 1,0 \quad (6)$$

The value for the tensile strain perpendicular to the direction of the compression field shall be used for $\varepsilon_{1d,act}$.

4.2.2 Reinforcing and prestressing steel

When defining the examination values for the cross sections and yield strengths of reinforcing steel and prestressing steel, the notch effect and the embrittlement of deteriorated reinforcement (e.g. as a result of corrosion of the reinforcement) shall be taken into account.

4.3 Verification of structural safety

4.3.1 Shear force

4.3.1.1 Structural members without shear reinforcement

4.3.1.1.1 If the bending reinforcement remains in an elastic state, the factor k_v is defined as follows in order to take into consideration the deformations:

$$k_v = 2,5 \varepsilon_{0,6d} \quad \varepsilon_{0,6d} \text{ in } \text{‰} \quad (7)$$

The longitudinal strain in the direction of the principal shear force at a distance of $0,6 d$ from the compressed edge of the cross section shall be used for $\varepsilon_{0,6d}$.

4.3.1.1.2 If the reinforcement in one reinforcement direction consists of several layers over the depth of the cross section, the longitudinal strain $\varepsilon_{0,6d}$ in equation (8) may be determined with reference to the maximum effective depth. In contrast, the factor k_d for determination of the shear force resistance in accordance with Code SIA 262 is to be determined with the effective depth of all layers in the reinforcement direction under examination.

4.3.1.1.3 In the case of end supports of thick slabs subjected to uniformly distributed loading, the shear resistance shall, in general, be verified for the section at a distance of $2 d$ from the edge of the support, in addition to the verification sections in accordance with Code SIA 262.

4.3.1.2 Structural members with shear reinforcement

4.3.1.2.1 The choice of a compression field angle α lying outside of the limits specified in Code SIA 262 has to be justified. This should take into consideration the compatibility of the strains, the ductility properties of the reinforcement and the properties of the bond between reinforcement and concrete.

4.3.1.2.2 If plastic deformations of the chords cannot be ruled out in the investigated region of the member, and if shear reinforcement placed perpendicular to the member's axis is of ductility class A in accordance with Code SIA 262, in general a compression field angle $\alpha \geq 30^\circ$ shall be assumed.

4.3.1.2.3 If the relative rib area $f_{R,act}$ of the longitudinal reinforcement does not fulfil the requirements of Code SIA 262, the transfer of force between the compression field and tension chord has to be verified.

4.3.1.2.4 If doubts exist as to whether the tendon ducts have been properly grouted, the nominal value for the web width in accordance with Code SIA 262 for prestressing tendons without bond shall be used.

4.3.1.2.5 The shear resistance of flanges of profiled beams may be taken in account in justified cases.

4.3.1.3 Cross sectional consideration

4.3.1.3.1 The superposition of the resistances of vertical shear reinforcement and of bent-up longitudinal reinforcement used as shear reinforcement shall be determined using stress fields. A cross sectional consideration may not be applied.

4.3.1.3.2 If the strains are determined with a detailed cross sectional analysis in accordance with Code SIA 262, the longitudinal forces as a result of shear force and of prestressing shall be taken into account.

4.3.1.3.3 In order to define the factor k_c in accordance with equation (6), in the case of beam webs the strain $\varepsilon_{1d,act}$ at half the height of the lever arm of the inner forces has to be determined. If the relative rib surface $f_{R,act}$ of the longitudinal reinforcement does not fulfil the requirements of Code SIA 262, this generally leads to a reduction of the factor k_c .

4.3.1.4 Limitation of the shear forces due to ultimate flexural strength

4.3.1.4.1 When defining the relevant shear forces it may be taken into account that these are limited through the ultimate flexural strength of the structure or of a section of the structure.

4.3.1.4.2 In order to define shear forces $V_{d,act}^+$ corresponding to the ultimate flexural strength, the flexural resistances $M_{Rd,act}^+$ shall be determined analogously to Code SIA 262 taking into account the over-strengths, and a sufficient deformation capacity has to be verified.

4.3.2 Punching

4.3.2.1 Verification section

Construction joints between column and slab that lie above the lower edge of the slab are to be treated as a weakness in the slab in the punching verification, if the shear transmission to the shaft of the column cannot be verified.

4.3.2.2 Slabs without punching reinforcement

If the slab rotation is determined using non-linear calculation methods, the greatest value at a distance of $2d$ from the verification section is applicable.

4.3.2.3 Slabs with punching reinforcement

The stress in the punching reinforcement in accordance with the specifications of Code SIA 262 may be increased by the following amount:

$$\Delta\sigma_{sd,act} = 90 f_{R,act} \frac{d}{\varnothing_w} \leq 5 \frac{d}{\varnothing_w} \quad \Delta\sigma_{sd,act} \text{ in N/mm}^2 \quad (8)$$

4.4 Verification of serviceability

4.4.1 General

4.4.1.1 If the use has not been changed, the verification of serviceability concentrates on the determination of the cause of large crack widths, larger areas of spalling and excessive deformations.

4.4.1.2 For verification of the serviceability, the action effects of creep and shrinkage of the concrete during the remaining service life shall be estimated.

4.4.2 Cracks

The permissible stresses $\sigma_{s,adm}$ in accordance with Code SIA 262 for crack width limitation shall be updated as follows:

$$\sigma_{s,adm,act} = \sigma_{s,adm} \left(\frac{f_{bd,act}}{f_{bd}} \right)^{2/3} \quad (9)$$

4.5 Special considerations

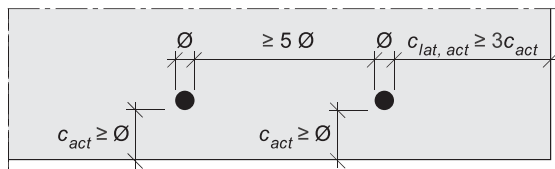
4.5.1 Bond stress

4.5.1.1 The dimensioning value for bond stress f_{bd} in accordance with Code SIA 262 may be used as the examination value $f_{bd,act}$ if the following conditions are fulfilled (Figure 1):

- The updated cover of reinforcement c_{act} corresponds to at least the bar diameter $\emptyset$.
- The updated bar spacing s_{act} amounts to at least $6\emptyset$.
- The increased cover of reinforcement $c_{lat,act}$ of reinforcing bars near edges amounts to at least three times the smaller cover of reinforcement c_{act} .
- The updated relative rib surface $f_{R,act}$ fulfils the requirements of Code SIA 262.
- The concrete and the reinforcement show no sign of deterioration influencing the bond.

If these requirements are not fulfilled, the bond failure generally takes place suddenly through spalling of the cover concrete.

Figure 1: Geometrical conditions for the use of the bond stress f_{bd} in accordance with Code SIA 262 as examination value



4.5.1.2 For $c_{act} = 0$, the transferable bond stress is halved in the case of reinforcing bars located away from the edge. Intermediate values may be obtained through linear interpolation.

4.5.1.3 For $s_{act} = \emptyset$, the transferable bond stress is reduced to zero in the case of reinforcing bars located away from the edge. Intermediate values may be obtained through linear interpolation.

4.5.1.4 In the case of reinforcing bars located near the edge, the transferable bond stress is reduced by the factor $k_{b,lat}$:

$$k_{b,lat} = \frac{1}{2} + \frac{\frac{c_{lat,act}}{c_{act}}}{4 + \frac{c_{act}}{2\emptyset}} \leq 1,0 \quad (10)$$

4.5.1.5 The total transferable bond stress is determined through multiplication of the reductions in accordance with Sections 4.5.1.2, 4.5.1.3 and 4.5.1.4.

4.5.1.6 The influence of the relative rib surface $f_{R,act}$ on the examination value for bond stress $f_{bd,act}$ is taken into account with equation (11):

$$f_{bd,act} = f_{bd} (0,55 + 8 f_{R,act}) \leq f_{bd} \quad (11)$$

4.5.2 Anchorage

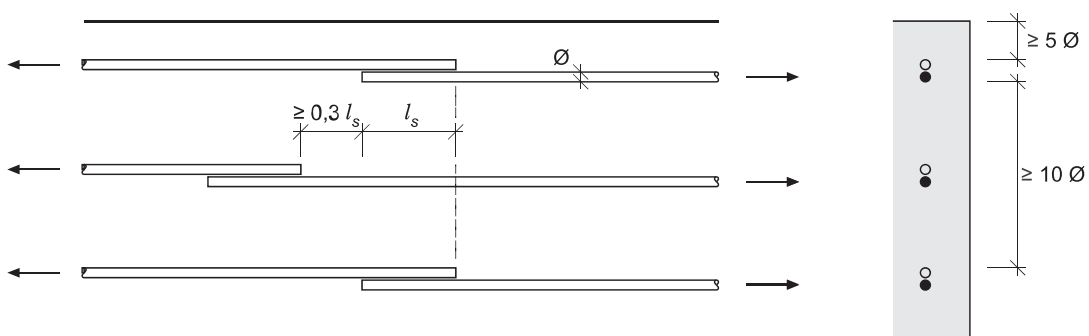
4.5.2.1 The basic value of the anchorage length $l_{bd,net}$ shall be determined in accordance with Code SIA 262 using the examination values for the bond stress $f_{bd,act}$ in accordance with Section 4.5.1, and shall be assumed as at least $10\emptyset$ and not less than 100 mm.

4.5.2.2 If, in the case of end and bent hooks, the length of straight bar adjacent to the curve has a length less than $5\emptyset$, the basic value for the anchorage length is to be increased by the dimension of the shortfall.

4.5.2.3 If, in the case of bundles of bars with different bar diameters, the ratio of the bar diameters exceeds 1,7 or if the reference diameter $\emptyset_n > 55$ mm, more detailed investigations are necessary for definition of the anchorage length.

- 4.5.2.4 If the cross-sectional area of the transverse reinforcement is less than 25% of the cross-sectional area of a single longitudinal reinforcing bar, the force in the anchored bar has to be reduced by an amount corresponding to the shortfall.
- 4.5.2.5 In order to determine the cross-sectional area of the transverse reinforcement in accordance with Section 4.5.2.4, in the case of anchorage of tension bars all transverse reinforcing bars within the anchorage length may be taken in account. In the case of anchorage of compression bars, transverse reinforcement over the last third of the anchorage length and at a distance of up to $4 \varnothing$ from the end of the bar may be taken into account.
- 4.5.3 **Splices**
- 4.5.3.1 A transfer of the yield force in splices of reinforcing bars requires a lap length which corresponds to the anchorage length in accordance with Section 4.5.2, but amounts to at least $15 \varnothing$ and not less than 200 mm.
- 4.5.3.2 If the clear distance between overlapping bars exceeds $4 \varnothing$, the lap length in accordance with Section 4.5.3.1 is increased by the excess length.
- 4.5.3.3 If the cross-sectional area of the transverse reinforcement within the two outer thirds of the lap length is less than the cross-sectional area of the lapped longitudinal reinforcing bar, the transferable bar force has to be reduced in proportion to the amount of shortfall. In the case of compression bars, transverse reinforcement at a distance of up to $4 \varnothing$ from the bar ends of the longitudinal reinforcement may be additionally taken in account.
- 4.5.3.4 If the proportion of splicing of several tension bars in accordance with Section 4.5.3.6 is a maximum of 30%, the lap length in accordance with Section 4.5.3.1 is increased by 40% if one of the following conditions is fulfilled (Figure 2):
- The concrete cover in the plane of the lapped joint amounts to less than $5 \varnothing$.
 - The clear distance between adjacent lapped joints amounts to less than $10 \varnothing$.
- 4.5.3.5 If the proportion of splicing of several tension bars in accordance with Section 4.5.3.6 is more than 30%, the lap length in accordance with Section 4.5.3.1 always has to be increased by 40%. If both conditions in accordance with Section 4.5.3.4 are fulfilled, the lap length is increased by 100%.
- 4.5.3.6 Splices are considered to be longitudinally offset and need not be taken in account in the determination of the proportion of joints if the distance between the spliced ends in accordance with Figure 2 corresponds to at least 30% of the lap length in accordance with Section 4.5.3.1.

Figure 2: Geometrical conditions for the lap length of joints



4.5.4 Prestressed structures

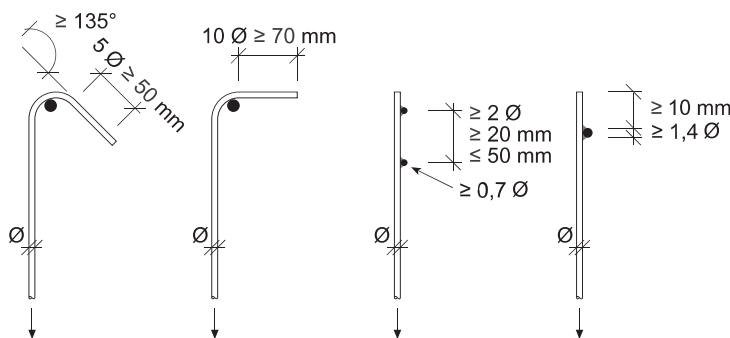
- 4.5.4.1 Without more precise investigations, the tensile strength of the concrete shall be neglected in the examination of the flow of forces. The presence of cracks in the regions of anchorages and couplings has to be considered in the modelling.

- 4.5.4.2 In the case of pretensioning with profiled wires ($0,010 \leq f_{R,act} \leq 0,015$) with a diameter $\varnothing_p$, the anchorage lengths may be determined in accordance with Code SIA 262 if the cover of reinforcement is $> \varnothing_p$ and the distance between the wires is $> 3 \varnothing_p$. Otherwise, the specifications in Section 4.5.1 may be applied analogously.
- 4.5.4.3 In the case of pretensioning with strands or ribbed wires ($0,020 \leq f_{R,act} \leq 0,025$) with a diameter $\varnothing_p$, the anchorage lengths may be determined in accordance with Code SIA 262 if the cover of reinforcement is $> 3 \varnothing_p$ and the distance between the wires is $> 2 \varnothing_p$. Otherwise, the specifications in Section 4.5.1 may be applied analogously.
- 4.5.4.4 The anchorage length $l_{bd,0}$ for the condition following the release of the prestressing anchorage may be estimated on the basis of Section 4.5.2.1; however, the examination value for the bond stress in accordance with equation (11) has to be reduced by 10%. Equation (11) is used without change in order to determine the anchorage length l_{bd} for the state under the examination values of the actions.
- 4.5.4.5 Permissible radii of curvature of prestressing tendons should be updated on the basis of the manufacturer's data or comparable modern prestressing systems.

4.5.5 Beams and T-beams

- 4.5.5.1 If the stirrup reinforcement does not enclose the longitudinal reinforcement, more detailed investigations into the transfer of force between stirrup reinforcement and longitudinal reinforcement are necessary.
- 4.5.5.2 The anchorage of stirrup reinforcement in the compression zone may be regarded as sufficient in order to absorb the tensile yield force if, depending on the structural detailing of the stirrup reinforcement, the dimensions shown in Figure 3 apply and the welds present in transverse bars resist the forces that have to be anchored.

Figure 3: Requirements for the anchorage of stirrup reinforcement in the compression zone in order to absorb the tensile yield force



- 4.5.5.3 If the conditions for the structural detailing of the stirrup reinforcement in compression zones in accordance with Section 4.5.5.2 are not fulfilled, the anchored force in the stirrup reinforcement may be determined analogously to the specifications set forth in Section 4.5.2 and Code SIA 262. The anchorage length needs to be located completely within the compression zone.
- 4.5.5.4 The contribution of bent-up longitudinal reinforcement to the shear strength may be examined with point-centred, fan-shaped stress fields. The superposition of ultimate strengths of vertical shear reinforcement and the effects on the concrete stresses in the compression fields shall be verified. The local transfer of the deviation forces of the reinforcement into the concrete shall be verified.
- 4.5.5.5 The verification of structural safety for the flow of forces in the vicinity of indirect supports shall be carried out using stress fields. The influence of a missing support reinforcement on the ultimate resistance and on the cross sectional ductility in terms of the longitudinal load-bearing behaviour (reduction of the lever arm of the internal forces) shall be taken into consideration.

4.5.6 Slabs

- 4.5.6.1 The detailing requirements of Code SIA 262 applicable to the punching reinforcement formed by bent-up reinforcing bars shall be related to the points at which they cross the central plane of the slab.
- 4.5.6.2 If the detailing requirements for the punching reinforcement in accordance with Code SIA 262 are not fulfilled, the structural safety shall be verified using stress fields, neglecting the tensile strength of the concrete. In general, a compression field angle α of 45° shall be assumed.

4.5.7 Compression members

- 4.5.7.1 If the cross section of the longitudinal reinforcement of compression members falls below the minimum requirements in accordance with Code SIA 262 or $0,15 N_{d,act} / f_{sd,act}$, the structural safety shall be verified assuming unreinforced structural members.
- 4.5.7.2 If the spacings between the stirrup reinforcement and hooks exceed the maximum distances in accordance with Code SIA 262, buckling of the longitudinal reinforcement shall be investigated.

4.5.8 Structures subjected to fatigue

- 4.5.8.1 The fatigue verification is restricted, in general, to the verification of the reinforcement. In the case of thin slabs without shear reinforcement, the fatigue strength for shear shall also be examined.
- 4.5.8.2 The examination values for the fatigue strength may be defined in accordance with Table 2. Missing specifications shall be taken unchanged from Code SIA 262.

Table 2: Examination values for fatigue strengths

Type of reinforcement	Examination value for fatigue strength $\Delta\sigma_{sd,fat,act}, \Delta\sigma_{pd,fat,act}$ [N/mm ²]
Reinforcing steel	
Straight bars $\varnothing < 30$ mm	150
Vertical stirrups $\varnothing < 20$ mm	150
– welded longitudinal lapped joints – welded bar intersections (e.g. wire meshes) – mechanical bar connections	70
Prestressing steel and prestressing tendons	
Prestressing tendons with wires or strands, with or without bond, in steel ducts	110

- 4.5.8.3 If the fatigue requirements cannot be verified, supplementary safety measures in accordance with Code SIA 269 shall be implemented. The supplementary safety measures take, among other things, into consideration the following points:
- The development of the relevant pattern of cracking on the concrete surface is recorded during interim inspections. Measurements of crack opening and the crack spacing allow estimating the fatigue stresses in the reinforcement.
 - The development of fatigue cracks and the interval between interim inspections may be estimated analogously to the procedure set forth in Code SIA 269/3.

5 CONDITION SURVEY

5.1 General

- 5.1.1 A distinction shall be made basically between deterioration affecting the concrete material and deterioration caused by the corrosion of non-prestressed and prestressed reinforcement.
- 5.1.2 Uncontrolled contact with water that may contain corrosive contaminants as well as significant differences in moisture contents have to be identified and documented.
- 5.1.3 The prevailing climatic and operating conditions during previous use have to be recorded for evaluation of the results of the condition survey.

5.2 Inspection methods

- 5.2.1 Sampling and probes for the examination and evaluation of deterioration and deterioration mechanisms are carried out on the basis of visual examination and the results of minor-destructive testing (see Tab. 3) as well as taking into consideration different exposure conditions and actions.
- 5.2.2 The determination of mechanical characteristics for the structural analysis may also require sampling and taking probes. In order to interfere as little as possible with the structure, the different objectives shall be coordinated.

Table 3: Visual inspection and minor-destructive testing methods

Visual inspection	Minor-destructive testing methods	
Recording and documentation of	Simple, random (low frequency) sampling methods	Complex methods used over extensive areas
– water ingress, major differences in moisture content – deteriorated surfaces, discolouration and sintering – water bearing and non-water bearing cracks – cracks and spalling caused by corrosion, exposed reinforcing bars – deformations, displacements, settlements – etc.	– tapping – use of the test hammer – determination of the cover of reinforcement – determination of crack widths – etc.	– potential measurements – measurement of permeability and moisture content – radar, ultrasound, impact echo – thermography – etc

- 5.2.3 In general, the taking and testing of drilled cores and/or the execution of probes are necessary for calibration and a reliable evaluation and interpretation of the measurements of minor-destructive testing methods. Among others, the following representative and specific properties are determined:
- chloride profile and/or carbonation depths
 - mechanical properties
 - degree of corrosion of the reinforcement and the cover of reinforcement.
- 5.2.4 Concrete properties, which are important in terms of durability or deterioration mechanisms that are taking place, can only be determined in the laboratory, for example:
- porosity, chloride resistance, capillary absorption capacity
 - resistance to frost, de-icing salt, AAR and sulphate
 - microscopic analysis of thin sections
 - contaminant profiles.

In addition, samples of the attacking medium need to be analysed.

5.2.5 Probes and sampling shall be carried out carefully and professionally. The structure is then rehabilitated in accordance with standard construction practice technology. In general, a record should be kept of the following:

- location and size of the probing/sampling point, recorded in an overview plan
- layer thickness of soil surcharge
- construction details (coating thicknesses, sealing, etc.)
- location and arrangement of the non-prestressed and prestressed reinforcement
- cover and diameter of the non-prestressed and the prestressed reinforcement
- rib pattern of the reinforcement
- degree of corrosion of the non-prestressed and the prestressed reinforcement
- possibly, condition and completeness of grouting of prestressing tendons.

5.2.6 The degree of corrosion is determined in accordance with Table 4. The presence of general or local corrosion (shallow craters, pitting) has to be recorded. If metal ducts of prestressing tendons are opened, the degree of corrosion is also to be determined on their inside surface. If necessary, a specialist should be consulted in order to evaluate the degree of corrosion of the tendons.

Table 4: Determination of the degree of corrosion

Degree of corrosion (KG)	Description in the case of corrosion as a result of carbonated concrete	Description in the case of corrosion as a result of ingress of chlorides	Description for metallic ducts of prestressing tendons
0	shiny	shiny	shiny
1	A few spots of rust on the surface	A few spots and patches of rust on the surface	A few spots and patches of rust on the surface
2	Patches of rust, slight local loss of material	Numerous patches of rust, slight local loss of material	Numerous patches of rust, local perforation cannot be ruled out
3	Completely rusty with slight loss of material (at worst, ribs lost due to corrosion)	First signs of pitting, reductions in cross-section $\leq 5\%$	Perforated
4	Completely rusty with clear signs of cratering, record amount of reduction in the cross section ¹⁾	Pitting with clear reductions in the cross section ¹⁾	Completely corroded through or corroded away
¹⁾ record loss of cross section in % of the original cross section..			

5.2.7 In general, records of cracks include the recording and documentation of:

- the position and direction of cracks
- crack lengths and crack widths
- type of crack (open crack, non-continuous crack, etc.)
- moisture, water flow conditions, sintering, efflorescence, discolorations
- movement of cracks.

Generally, the depth and cause of cracks can only be reliably determined through laboratory examinations of drilled cores. If need be, an initial evaluation may be carried out during the condition survey.

5.2.8 For the evaluation of cracks caused by AAR, the crack width index (*R_I*) is determined in areas with different degrees of deterioration as well as the previous crack width development, and the rate of expansion is estimated. The crack width index is determined in accordance with the specifications in Appendix C.

5.2.9 If no data from long-term measurements is available, the previous crack width development and the rate of expansion in accordance with Section 5.2.8 may be determined from the currently existing value for the crack width or for the crack width index and the age of the structure in question.

6 CONDITION EVALUATION

6.1 General

- 6.1.1 The condition evaluation includes statements concerning:
- the actual deterioration mechanisms
 - the extent of the deterioration (entire structure or structural member, affecting certain areas, sporadic or isolated, etc.)
 - the intensity and depth of the deterioration (only superficial, deterioration throughout the entire cross section, impairment of mechanical properties and/or other properties, etc.)
 - the stage of development of the deterioration (initial, final stage, etc.).
- 6.1.2 The importance of the deterioration found, of the extent of the existing deterioration, the previous and the anticipated future deterioration development for the structural member or the structure shall be judged on the basis of its relevance in terms of structural safety, serviceability and durability.
- 6.1.3 Open cracks may already be water-bearing from a width of around 0,1 mm and therefore represent an increased risk with respect to durability.
- 6.1.4 In the case of ductile structures, deformations and large crack widths in tension zones may provide early signs of defects or advanced deterioration of the reinforcement, in particular to the prestressed reinforcement. There is no such warning sign in the case of structures exhibiting brittle behaviour.
- 6.1.5 If fracture mechanisms with compressive failure in the concrete are dominant, this is an indication of brittle failure, which shall be given due consideration in the condition evaluation.

6.2 Deterioration as a result of alkali-aggregate reaction (AAR)

- 6.2.1 In the case of a grid pattern of surface cracks, the crack width index R_I [mm/m] in accordance with Section 5.2.8 and Appendix C shall be used in order to evaluate the extent of the deterioration:
- $R_I \leq 1$: slight deterioration
 - $1 < R_I < 3$: moderate deterioration
 - $R_I \geq 3$: major deterioration.
- 6.2.2 In the absence of a grid pattern of cracks the evaluation of the extent of the deterioration is based on the measurement of individual cracks.
- 6.2.3 It shall be established whether existing cracks have been caused solely by AAR and other deterioration mechanisms can be ruled out (e.g. frost, corrosion, etc.). As far as possible, only those cracks should be measured in which causes other than AAR can be ruled out.
- 6.2.4 The previous deterioration development is evaluated as follows:
- slow AAR:
Crack width development $< 0,05$ mm/year or expansion rate $< 0,10$ mm/m/year
 - rapid AAR:
Crack width development $\geq 0,10$ mm/year or expansion rate $\geq 0,20$ mm/m/year.
- In the case of prestressed structures, in general additional investigations are necessary for the evaluation of the deterioration development.
- 6.2.5 Where a detailed examination is carried out, the evaluation only takes place case-specifically. It includes, for example:
- an estimate of the still-existing deterioration potential
 - an estimate of the effect of the existing deterioration potential on the structural behaviour, restraints, etc.
 - an evaluation of the existing structural safety.
- 6.2.6 In general, no further significant AAR occurs in structural members in which the concrete moisture level, throughout the entire cross section, always corresponds to a relative atmospheric humidity of less than 80%.

6.3 Deterioration as a result of corrosion to the reinforcement

- 6.3.1 The critical chloride content before rehabilitation is the chloride content at the reinforcement level, which, under the previous exposure or moisture conditions, has not yet led to macroscopically detectable pitting (degree of corrosion KG 0 or KG 1).
- 6.3.2 The critical chloride content after rehabilitation is the chloride content at the reinforcement level, which, under the future exposure or moisture conditions – during the planned remaining service life – results neither in non-tolerable losses in the cross section nor non-tolerable cracks and spalling.
- 6.3.3 The corrosion risk is evaluated on the basis of the total chloride content at the reinforcement level. For normal reinforcing steel and a concrete moisture content in the area of the reinforcement corresponding to a maximum of around 80% relative atmospheric humidity, the following criteria apply:
- chloride content < 0,4 % by mass/cement content: hardly any corrosion risk present
 - chloride content 0,4 to 1,0 % by mass/cement content: corrosion possible
 - chloride content > 1,5 % by mass/cement content: high corrosion risk.
- 6.3.4 If the concrete moisture level is higher, or if the pH value of the concrete has fallen as a result of carbonation or if other corrosive contaminants, e.g. sulphates, etc., are present, the critical chloride content at the reinforcement level shall be set to a lower value. If drier conditions exist, it may be set to a higher value. Highly alloyed, stainless steels have a significantly higher critical chloride content with respect to corrosion.
- 6.3.5 The same values apply to prestressing steels with good corrosion protection, i.e. completely grouted prestressing tendons with compact grout, as apply to normal reinforcing steel. If grouting is incomplete or of defective quality, even the smallest quantities of chloride in combination with increased moisture can lead to significant deterioration. If necessary, a specialist should be consulted in order to evaluate corrosion deterioration of the prestressing steel.
- 6.3.6 When evaluating particular depths of carbonation and actual values of cover of reinforcement, the difference between the colour change determined with phenolphthalein and the pH value triggering corrosion shall be taken into account.
- 6.3.7 In the case of structural members with a concrete moisture content in the area of the reinforcement that always corresponds to a maximum relative atmospheric humidity of 80%, the yearly corrosion loss rates are, in general, low. When carrying out the evaluation, a distinction shall be made between local and general attacks.

6.4 Prediction of the development of the condition

- 6.4.1 The concrete moisture content has a decisive influence on the rate of progress of deterioration mechanisms. The prediction of the development of the condition shall therefore always be based on a qualitative estimate of the change in the moisture contents in the concrete, taking into consideration any cracks, wet/dry cycles, etc.
- 6.4.2 The change in the extent of the deterioration, the depth or intensity of the deterioration and possibly of the deterioration mechanisms shall be estimated on the basis of the stage reached in the development of the deterioration and any anticipated future actions, in particular of the moisture conditions.
- 6.4.3 In general, a quantitative prediction of the development of the condition is not possible. However, in qualitative terms a distinction can be made between slow or rapid, accelerating or decelerating developments.
- 6.4.4 Particular attention should be paid to the development of the conditions, which could, without any warning signs, or with only minor warning signs, lead to a failure of the structural member or the structure.

7 INTERVENTIONS

7.1 General

- 7.1.1 Interventions affecting structural safety are primarily addressed in Section 7.3.
- 7.1.2 When defining interventions to ensure durability the main focus should always be on eliminating the causes of deterioration. In general, the ingress of water has to be reduced. This delays the corrosion process of the steel in the concrete, the deterioration mechanisms destroying the concrete and the ingress of corrosive contaminants (e.g. chlorides).
- 7.1.3 The durability of structures made of reinforced and prestressed concrete with inadequately protected and corroding reinforcement is basically increased by:
- influencing of the anodic process
 - influencing of the cathodic process
 - reduction of the moisture content or of the electrolytic conductivity of the structural member.
- 7.1.4 Generally, deterioration as a result of AAR can only be retarded by reducing the moisture content in the concrete.
- 7.1.5 The effects of interventions carried out on adjoining elements on the moisture content of the structural member are to be taken into consideration (e.g. rehabilitation or renewal of drainage and sealing, expansion joints, hinges, etc.).
- 7.1.6 The exposure of structural members has to be taken into account when choosing suitable interventions. In addition to the exposure class in accordance with Code SIA 262, the microclimate should also be taken into consideration.

7.2 Principles and methods

- 7.2.1 The principles for rehabilitation and the associated rehabilitation methods in accordance with SN EN 1504-9 shall be chosen depending on the objectives (Tables 5 and 6).
- 7.2.2 The principles and methods can also be applied in combination. Only a few principles and methods should be used on individual structures or structural members. Mutual compatibility shall be verified.
- 7.2.3 Individual methods are used in the case of different principles. However, the performance requirements that need to be fulfilled by the products and systems used for the rehabilitation differ depending on the chosen principle and application.
- 7.2.4 Other methods are permissible if it is shown that they are consistent with the principles and their suitability has been adequately verified.

Table 5: Principles and associated methods for the protection and rehabilitation of concrete structures in the case of deterioration of the concrete (in accordance with SN EN 1504-9)

Principles in the case of deterioration of the concrete		Associated methods	Codes applicable to the design and product requirements
1 Protection against ingress [IP] Prevention of the ingress of substances that cause corrosion (e.g. water, other liquids, vapour, gas, chemicals) and biological life forms		1.1 Hydrophobic impregnation	SN EN 1504-2 and -10
		1.2 Impregnation	SN EN 1504-2 and -10
		1.3 Coating	SN EN 1504-2 and -10
		1.4 Local covering of cracks ¹⁾	SN EN 1504-10, Appendix
		1.5 Filling of cracks	SN EN 1504-5 and -10
		1.6 Conversion of cracks into joints ¹⁾	SIA 262, SN EN 1504-10
		1.7 Unbonded lining ^{1), 2)}	SIA 179 and SIA 233
		1.8 Use of membranes ¹⁾	SIA 270
2 Moisture control [MC] Adjustment and maintenance of the moisture content of the concrete within a defined range of values		2.1 Hydrophobic impregnation	SN EN 1504-2 and -10
		2.2 Impregnation	SN EN 1504-2 and -10
		2.3 Coating	SN EN 1504-2 and -10
		2.4 Unbonded lining ^{1), 2)}	SIA 179 and SIA 233
		2.5 Electrochemical treatment ¹⁾	–
3 Concrete restoration [CR] Restoration of a concrete structure in terms of its intended geometrical form and function. Restoration of the properties of the concrete structure through partial replacement of the concrete		3.1 Manual application of mortar	SN EN 1504-3 and -10
		3.2 Supplement cross section with concrete or mortar	SIA 262, SN EN 1504-3 and -10, SN EN 206, SN EN 13670
		3.3 Shotcrete or sprayed mortar	SN EN 14487-1 and -2, SN EN 1504-3 and -10
		3.4 Replacement of structural members	SIA 262, SN EN 206, SN EN 13670
4 Structural strengthening [SS] Increase or restoration of the resistance of a structural member of the concrete structure		4.1 Addition or replacement of embedded or external reinforcement	SIA 262, SN EN 1504-10, SN EN 13670
		4.2 Addition of reinforcement, anchored in grooves or boreholes	SIA 262, SN EN 1504-6 and -10
		4.3 Reinforcement with plates (steel or fibre laminate)	SIA 166, SN EN 1504-4 and -10
		4.4 Supplement cross section with concrete or mortar	SIA 262 and 179, SN EN 1504-3, -4 and -10
		4.5 Grouting of cracks, cavities or defects	SN EN 1504-5 and -10
		4.6 Filling of cracks, cavities or defects	SN EN 1504-5 and -10
		4.7 External prestressing ¹⁾	SIA 262
5 Increasing physical resistance [PR] Increasing the resistance to physical or mechanical attack		5.1 Coating	SN EN 1504-2 and -10
		5.2 Impregnation	SN EN 1504-2 and -10
		5.3 Bonded lining (overlays)	SN EN 1504-3 and -10, SN EN 14487-1 and -2, SIA 252

6	Resistance to chemicals [RC]	6.1 Coating	SN EN 1504-2 and -10
	Increasing the resistance of the concrete surface to deteriorations through chemical substances.	6.2 Impregnation	SN EN 1504-2 and -10
		6.3 Bonded lining (overlays)	SN EN 1504-3 and -10, SN EN 14487-1 and -2, SIA 252
1) With these methods, products and systems may be used, which are not part of the series of standards SN EN 1504.			
2) SN EN 1504-9: installation of cladding panels.			

Table 6: Principles and associated methods for the protection and the rehabilitation of concrete structures in the case of deterioration as a result of corrosion to the reinforcement (in accordance with SN EN 1504-9)

Principles in the case of deterioration due to corrosion of the reinf.		Associated methods	Codes applicable to the design and product requirements
7	Preserving or restoring passivity [RP] Creation of chemical conditions in which the surface of the reinforcement retains its passive condition or is restored to a passive condition.	7.1 Increase of the concrete cover with additional cement-bound mortar or concrete	SN EN 1504-3 and -10, SN EN 206-1, SN EN 14487-1 and -2, SIA 262 and 179
		7.2 Replacement of contaminated or carbonated concrete	SN EN 1504-3 and -10, SN EN 206-1, SN EN 14487-1 and -2
		7.3 Electrochemical realkalisation of carbonated concrete ¹⁾	CEN/TS 14038-1
		7.4 Realkalisation of carbonated concrete through diffusion	(SN EN 1504-10, the method is not recommended.)
		7.5 Electrochemical chloride removal ¹⁾	CEN/TS 14038-2
8	Increasing resistivity [IR] Increasing the electrical resistivity of the concrete.	8.1 Hydrophobic impregnation	SN EN 1504-2 and -10
		8.2 Impregnation	SN EN 1504-2 and -10
		8.3 Coating	SN EN 1504-2 and -10
9	Cathodic control [CC] Creation of conditions under which potential cathodic areas of the reinforcement cannot cause any anodic reaction.	9.1 Limitation of the oxygen content (on the cathode) through saturation or coating	(SN EN 1504-10, the method is not recommended.)
10	Cathodic protection [CP] (Cathodic protection [CP])	10.1 Application of an electric potential ¹⁾	SN EN 12696, SN EN 1504-10
11	Control of anodic areas [CA] Creation of conditions in which potential anodic areas of the reinforcement are prevented from taking part in the corrosion reaction.	11.1 Coating the reinforcement with actively pigmented coatings	SN EN 1504-7 and 10
		11.2 Coating the reinforcement with coatings based on the barrier principle	SN EN 1504-7 and 10
		11.3 Application of corrosion inhibitors within or to concrete ¹⁾	(SN EN 1504-10, Appendix)

¹⁾ With these methods, products and systems may be used which are not part of the series of standards SN EN 1504.

7.3 Strengthening

7.3.1 General

- 7.3.1.1 The purpose of strengthening is to improve the ultimate resistance or the serviceability of a cross section, structural member or structure.
- 7.3.1.2 In special cases (earthquake, imposed deformations), a reduction in the stiffness or ultimate resistance may also be suitable.
- 7.3.1.3 Starting from the updated service requirements, the overall concept for the strengthening measures needs to be ready prior to dimensioning.
- 7.3.1.4 The strengthening concept
- defines the chosen arrangement of the supporting structural members as well as the nature of their interaction
 - describes the most important dimensions, material properties and construction details
 - takes in account structural protection and fire protection measures according to the hazard scenarios
 - comments on the planned construction method.
- 7.3.1.5 If the functional principle of strengthening is largely based on adhesion, the hazard scenario “loss of the strengthening means” shall be examined as an accidental design situation.

7.3.2 Strengthening of the concrete cross section

- 7.3.2.1 The strengthening of a concrete cross section can be achieved by means of:
- an additional layer of concrete
 - additional reinforcement
 - reinforcement in an additional layer of concrete
 - the creation of a composite construction (e.g. steel-concrete or timber-concrete composite floor).
- In all cases, a composite cross section is created which shall be dimensioned and verified in accordance with the principles for composite construction.
- 7.3.2.2 It has to be ensured through detailing measures and corresponding dimensioning that the additional structural member or the additional reinforcement is permanently and positively connected with the existing cross section.
- 7.3.2.3 If a bond strength between new and existing concrete is taken into account, then the stresses resulting from differential expansion behaviour shall be taken into consideration and compared with the shear strength in accordance with Code SIA 262.
- The normal force necessary to activate the friction bond can be provided by a permanently acting external load, prestressing or the tensile strength of fastenings.
- 7.3.2.4 If the structural safety cannot be verified using the bond strength in accordance with Section 7.3.2.3, the applied shear forces that occur shall be transferred through a form-fit connection or a dowel effect.
- 7.3.2.5 The information given in Section 7.4.2 and 7.4.3. applies to the preparation of the existing concrete surface as well as the application of the new concrete or mortar.
- 7.3.2.6 SN EN 1504-4 specifies the requirements applicable to adhesives. SN EN 1504-6 specifies the requirements applicable to the anchorage of reinforcing bars.
- 7.3.2.7 The anchorage of dowels in the concrete of the existing structure shall be dimensioned in accordance with the recommendation SIA 179 or according to specifications of the manufacturer, confirmed through tests.

7.3.3 Externally-bonded reinforcement

- 7.3.3.1 In general, externally bonded reinforcement acts passively. In order to activate its structural participation in the cross section a deformation of the system as a whole and/or prestressing of the externally bonded reinforcement is necessary.

- 7.3.3.2 If externally-bonded reinforcement is prestressed, the specifications of Section 7.3.4 shall be applied analogously.
- 7.3.3.3 Externally-bonded reinforcement shall be designed and applied in accordance with the pre-code SIA 166. SN EN 1504-4 applies to the requirements applicable to adhesives.

7.3.4 External prestressing tendons

- 7.3.4.1 The use of external prestressing tendons is an active measure which has a favourable influence on the stress condition, the deformations and the closing of cracks.
- 7.3.4.2 The state of stress in the structure before and after application of the external prestressing shall be verified and evaluated. The transfer of forces into the structure shall be investigated in detail.
- 7.3.4.3 If the prestressing force is intended to act on a composite cross section consisting of new and existing concrete, it has to be ensured through a corresponding construction programme and prestressing sequence that part of the prestressing force is applied to the new concrete.
- 7.3.4.4 External prestressing tendons shall fulfil the requirements of Code SIA 262. Additional requirements may apply to the ducts and the protection of the anchor heads, the possibility of controlling the prestressing force as well as the monitoring and the possibility of replacing the prestressing tendons.

7.4 Methods

7.4.1 General

- 7.4.1.1 In general, the effectiveness and the scope of the rehabilitation methods depend on the extent of the deterioration of the existing concrete and/or the reinforcement, the exposure conditions and the future use.
- 7.4.1.2 The methods in accordance with SN EN 1504-9 can be combined in different structural measures. Specifications for the design of these structural measures are given in the following Sections, and possible structural measures are assigned to individual defects and types of deterioration in Appendix B.
- 7.4.1.3 The appropriate preparation of the substrate is an important prerequisite for the durable bonding of different construction materials. In particular, the following shall be ensured:
- the removal of foreign substances from the surface
 - the necessary roughness and moistness of the substrate, depending on the intervention
 - the removal of loose or easily detached parts
 - the removal of corrosion products from the reinforcement.
- 7.4.1.4 Requirements applicable to the nature and the scope of the preparation of the substrate, the application of products and systems as well as quality assurance are defined and specified in SN EN 1504-10 and in the corresponding national appendix.
- 7.4.1.5 In each case, product-specific requirements in terms of the preparation of the substrate, application, weather conditions before, during and following application and curing shall be defined and implemented.
- 7.4.1.6 The compatibility of existing and new construction materials shall be ensured by an appropriate choice of systems and products. Particular attention shall be paid to the different deformation behaviour (modulus of elasticity, thermal expansion, shrinkage, creep).
- 7.4.1.7 The durability of the composite systems consisting of new and existing concrete and mortar is primarily ensured by appropriate preparation and curing. In general, the curing measures go beyond the measures defined in Code SIA 262 in terms of type and duration.

7.4.2 Concrete removal and replacement

- 7.4.2.1 Concrete with superficial or local deterioration caused through mechanical, physical, chemical or biological actions as well as heavily chloride-laden concrete is removed and the structural member reprofiled.
- 7.4.2.2 The aim of the method is to achieve the following effects:
- manufacture of a cover concrete and a concrete surface that is of high quality, and in particular of low permeability
 - restoration of an environment conducive to passivity in the area of the reinforcement.
- 7.4.2.3 Concrete replacement is used
- in cases of locally advanced deterioration, manifested for example through spalling and cracking
 - in the case of high chloride contents extending to significant depths
 - if the depth of carbonation significantly exceeds the cover of the reinforcement and the conditions for ongoing corrosion apply.
- 7.4.2.4 In the case of corrosion of the reinforcement, the following aspects influence the definition of the extent and depth of the concrete removal as well as the choice of system for replacement:
- moisture conditions following the rehabilitation and their effect on the rate of corrosion
 - critical chloride content before and after rehabilitation
 - redistribution of chlorides from the remaining concrete into the new concrete (amount of the chloride deposit remaining in the concrete)
 - chloride content or carbonation outside of the rehabilitated areas (possible formation of new macroelements)
 - further chloride ingress or further carbonation during the remaining service life
 - location of interface between old/new concrete in relation to the location of the reinforcement.
- 7.4.2.5 In general, concrete removal represents a weakening of the structure. Redistributions of forces, shrinkage, creep and temperature differences usually lead to permanent additional loading on the existing structure. This has to be taken into consideration in the design of the interventions.
- 7.4.2.6 The roughness of the substrate and the maximum aggregate size of the new concrete are the decisive factors affecting the bond properties between the new and the existing concrete. Good bond properties are achieved if the substrate is brought to an average roughness depth R_m of $1/4$ of the maximum aggregate diameter (concrete) or of 1 maximum aggregate diameter (mortar) using high-pressure water jets.
- 7.4.2.7 SN EN 206-1 applies for the definition of the requirements applicable to concretes, SN EN 1504-3 for mortar, SN EN 14889-1 for steel fibres and SN EN 14889-2 for polymer fibres. If shotcrete is used, SN EN 14487-1 also applies and SN EN 14487-2 applies to its execution.
- 7.4.2.8 In the case of insufficient cover of reinforcement, coating the reinforcement may be suitable. The performance requirements applicable to the coating or corrosion protection of the reinforcement are defined in SN EN 1504-7.
- 7.4.2.9 In the case of frequent severe exposure or generally low cover of reinforcement, combination with a surface protection system may be suitable.

7.4.3 Application of concrete or mortar

- 7.4.3.1 Applications of mortar and concrete as well as protective concrete layers are additional cement-bonded layers in which the protection effect is more important than the strengthening and stiffening effect.
- 7.4.3.2 The aim of the method is to achieve the following effects:
- to increase the cover of reinforcement
 - manufacture of a cover concrete or mortar with a surface of sufficient durability
 - protection of the existing concrete against damaging environmental effects.
- 7.4.3.3 Where concrete and mortar is applied over extended areas, particular attention should be paid to the space available and the consequences of the increase in the permanent actions.

- 7.4.3.4 A perfect compaction and adhesion to the substrate has to be ensured. In addition to the indications in Section 7.4.2, attention should be paid to the following:
- When providing a protective concrete layer, a minimum layer thickness of 80 mm (with reinforcement) or 50 mm (without reinforcement) has to be maintained, and the maximum aggregate size shall not exceed $\frac{1}{3}$ of the minimum layer thickness.
 - Polymer mortar should, in general, only be used in the case of smaller rehabilitation jobs with a thin layer thickness. Its properties, which differ significantly from those of concrete (modulus of elasticity, thermal expansion, diffusion behaviour, alkalinity) shall be taken into consideration.
 - If special properties are required in the new concrete/mortar (e.g. leak tightness to water, resistance to frost and de-icing salt or chemical resistance), acceptance tests for suitability are necessary.
- 7.4.3.5 Section 7.4.2.7 applies to the definition of the requirements applicable to concretes, mortar and shotcrete.

7.4.4 Filling and grouting of cracks

- 7.4.4.1 The aim of filling and grouting cracks is either to prevent the ingress of water and contaminants into the concrete and thus improve durability or to restore the monolithic behaviour and thus improve the structural behaviour.
- 7.4.4.2 Before grouting or filling cracks, the following information needs to be obtained:
- the extent, location and cause of cracks, cavities and surface defects
 - the range of crack widths, minimum opening of the cracks to be grouted (as a criterion for feasibility of grouting)
 - anticipated changes in crack widths as a result of load, temperature, shrinkage and other imposed deformations
 - tensile strength of the concrete
 - moisture in the cracks.
- 7.4.4.3 In accordance with the main purpose, the filling of cracks, cavities and defects in concrete is categorised as follows (in accordance with SN EN 1504-5, Appendix A):
- rigid filling (category F)
 - flexible filling (category D)
 - expansive filling (category S).
- The requirements applicable to the crack filling materials follow from the main purpose.
- 7.4.4.4 SN EN 1504-5 applies to the definition of the requirements applicable to products and systems.

7.4.5 Surface protection measures

- 7.4.5.1 In the case of concrete surfaces that are frequently exposed to severe environmental conditions, the durability may be improved through the application of a surface protection system.
- 7.4.5.2 The following objectives can be aimed at:
- to prevent the ingress of water and contaminants into the concrete
 - to increase the mechanical, physical and chemical resistance of the surface
 - to reduce the concrete moisture content and thus increase the specific electrical resistance.
- 7.4.5.3 When applying a surface protection system, the influence of any further sources for the ingress of water and contaminants shall be taken into consideration. In the case of surface protection systems that are impermeable to water or water vapour, an increase in the concrete moisture content is possible, for example due to hydrostatic pressure from standing or rising water; the consequences of this shall be evaluated. The acceptability of a change in appearance shall be examined.
- 7.4.5.4 Surface protection systems are divided into:
- hydrophobic impregnation
 - impregnation
 - coatings
 - sealing
 - bonded linings, e.g. composite facings, overlays, etc.
 - unbonded linings, e.g. back-ventilated facades.

- 7.4.5.5 The bond and deformation behaviour of surface protection systems (e.g. crack bridging, modulus of elasticity) shall be adapted to the substrate, and different diffusion properties of the substrate and surface protection systems shall be examined carefully. The possibly conflicting requirements in terms of leak tightness and vapour diffusion have to be weighed against one another.
- 7.4.5.6 With a surface protection system, only in exceptional cases is the moisture in the concrete reduced to the point where ongoing corrosion processes in the reinforcement are stopped.
- 7.4.5.7 The following are considered to be sealing systems in terms of this code:
- non-cement-based rigid sealing systems, for example mastic asphalt (MA)
 - flexible sealing systems with sealing membranes, for example polymer bitumen sealing membranes, polymer sealing membranes and membranes with a clay sealing layer, as well as systems with liquid plastics.
- 7.4.5.8 Sealing systems shall be designed and applied in accordance with the pre-code SIA 270 and the codes referred to therein.
- 7.4.5.9 The symbols for the individual surface protection systems are defined in the national appendix to SN EN 1504-2. EN 1504-2 applies to the definition of the requirements applicable to (hydrophobic) impregnations and coatings.
- 7.4.5.10 Composite linings shall be designed and applied in accordance with the relevant construction-material-specific lining standard, cement overlays in accordance with Code SIA 252. SN EN 206-1 applies to the requirements applicable to concretes, SN EN 1504-3 for mortar and SN EN 1504-4 for adhesives.
- 7.4.5.11 Unbonded linings shall be designed and executed in accordance with Code SIA 233.
- 7.4.6 Corrosion inhibitors**
- 7.4.6.1 In general, corrosion inhibitors are applied to the mineral surface. However, depending on the product, they are also added to the rehabilitation concrete or mortar. Subsequently, the active substances should migrate through the concrete or mortar up to the steel surface through capillary suction and/or diffusion.
- 7.4.6.2 The effect of the corrosion inhibitors consists of influencing the anodic and/or the cathodic partial reaction. The formation of a protective layer on the reinforcing steel may be made possible or stimulated. If the inhibiting substances migrate through the concrete or mortar to the steel surface in the required concentration, the critical chloride content is increased and thus the start of corrosion is delayed and/or the rate of corrosion reduced.
- 7.4.6.3 Corrosion inhibitors are used where the deterioration is not much advanced, where the cover of reinforcement is generally thin and the concrete rather porous, or as a preventive measure.
- 7.4.6.4 In general, acceptance tests for suitability are necessary in order to determine the suitability of the method for the specific application. For quality assurance purposes, test methods and acceptance criteria based on the results of the acceptance tests for suitability shall be defined prior to execution.
- 7.4.6.5 In general, the verification that the active substances are present in the necessary concentration at the level of the reinforcement is carried out by analysing drilled cores or drilling dust obtained from the structure.
- 7.4.6.6 The actual effectiveness of corrosion inhibitors may only be measured with corrosion current measurement, preferably on insulated reinforcing bars or instrumented drilled cores, before and after application. Under precisely defined boundary conditions, indirect verification may be provided by potential measurement.
- 7.4.7 Electrochemical methods**
- 7.4.7.1 In the electrochemical method, a flow of current from the anode embedded in an electrolyte on the concrete surface (e.g. titanium mesh) to the cathode (reinforcement) is generated by applying a direct electrical current. With this method, in-depth knowledge is required during design and execution in order to prevent deterioration of the concrete and the reinforcement.

- 7.4.7.2 Depending on the objective, the duration of the measure and the current density, a distinction is made between:
- cathodic corrosion protection (CCP, permanent measure)
 - electrochemical chloride removal (ECR, temporary measure)
 - electrochemical realkalisation (ER, temporary measure).
- 7.4.7.3 The main effects are:
- The pH value at the cathode (reinforcement) is increased, which enables the repassivation of the reinforcement (realkalisation).
 - Electrically negatively charged ions (e.g. chlorides) migrate from the reinforcement (cathode) to the anode (chloride reduction) and the positive ions (e.g. potassium, sodium) migrate from the surface to the reinforcement.
 - The potential of the reinforcement (cathode) is shifted in the direction of negative potential (cathodic corrosion protection).
- 7.4.7.4 Electrochemical methods may be used where corrosion of the reinforcement is little advanced, or only moderately advanced, and as a preventive measure. The entire reinforcement has to be electrically connected, and the concrete has to possess a sufficient specific electrical conductivity.
- 7.4.7.5 In the case of prestressed structures, due to the danger of embrittlement of the prestressing steel, electrochemical realkalisation and chloride removal may only be used if the cathodic current density on the prestressing steel surface is maintained at a non-hazardous level and if it is ensured that no hydrogen is released on the prestressing steel.
- 7.4.7.6 In general, acceptance tests for suitability need to be carried out in order to determine the actual system performance parameters. The specified parameters shall be monitored continuously during execution.
- 7.4.7.7 Systems for cathodic corrosion protection shall be designed, installed and operated in accordance with SN EN 12696. CEN/TS 14038 provides information on the design and installation of realkalisation and chloride removal systems.

7.5 Requirements applicable to the products and systems

- 7.5.1 The minimum requirements applicable to the products and systems are defined in SN EN 1504, parts 2 to 7, depending on the intended application.
- 7.5.2 The performance characteristics that are to be verified on the construction works and the corresponding requirements shall be defined object-specifically.
- 7.5.3 Acceptance tests for suitability are often necessary when carrying out rehabilitation works. These allow the identification of the correct principles, methods, working procedures, systems and products as well as the definition of the precise specifications for the tendering procedure. Corresponding test surfaces may also serve as a reference for execution. Preliminary tests shall be systematically planned, prepared, carried out and evaluated.

7.6 Quality assurance

7.6.1 General

- 7.6.1.1 Quality assurance ensures that the products and systems used comply with this code and with the object-specific requirements.
- 7.6.1.2 The technical requirements applicable to the quality assurance for the implementation of rehabilitation measures are covered in SN EN 1504-10.

- 7.6.1.3 In order that the contractor may offer suitable systems, products and methods, the reasons and objectives of the interventions as well as the corresponding limiting conditions shall be described in the tender documents. These are, in particular:
- the deterioration mechanisms, which led to the current condition
 - the extent of the deterioration
 - the aims of the intervention, in particular durability
 - the nature of the planned interventions
 - the boundary conditions to be complied with during execution (use of the existing structure, possible temporary measures, disposal, etc.).
- 7.6.2 **Quality assurance and monitoring of performance**
- 7.6.2.1 A distinction is made between the following types of test:
- initial tests
 - acceptance tests for suitability
 - quality control tests.
- 7.6.2.2 The initial tests are defined in SN EN 1504, parts 2 to 7. If products are used, which are not included in SN EN 1504, parts 2 to 7, then all performance requirements and associated test methods shall be defined object-specifically. The preconditions for proper production shall be ensured by means of regular production checks. In exceptional cases, the initial test may be substituted by reliable and documented long-term experience.
- 7.6.2.3 A proof of conformity is necessary for rehabilitation products which are manufactured in accordance with SN EN 1504, parts 2 to 7.
- 7.6.2.4 Acceptance tests for suitability shall be prepared, performed, evaluated and documented systematically and under the specific conditions of application. The objectives are:
- to determine control parameters for the execution
 - to determine implementable requirements applicable to the rehabilitated structural member or structure (e.g. quality of new concrete surfaces, appearance, targeted strengths, penetration depths, etc.)
 - creation of model test surfaces as a reference for examination of the quality of execution.
- 7.6.2.5 The findings from acceptance tests for suitability shall be implemented in the design and in the construction inspection plan.
- 7.6.2.6 The quality control tests shall be defined in the construction inspection plan. Specifications concerning the nature and frequency of the most important tests are given in the SN EN 1504 series of standards. The construction inspection plan shall be reviewed periodically and adapted, if necessary, on the basis of the test results achieved and the condition of the construction works.
- 7.6.2.7 The effectiveness and durability of the intervention may be monitored during the remaining service life by means of tests, measurements and monitoring following the rehabilitation. These performance monitoring measures shall be specified in the monitoring plan. Possible checks of structural members or of the construction works include:
- functional serviceability of surface protection systems, drainage systems, etc.
 - changes in the moisture and temperature conditions, the chloride content as well as the depth of carbonation
 - corrosion currents and potentials
 - crack movements and new cracks
 - deformations, strains and vibrations.

APPENDIX A (normative)

CONSTRUCTION MATERIAL CHARACTERISTICS

Table 7: Concrete compressive strength and shear stress limit of concrete, depending on the code or guideline used

SIA code or guideline	Compressive strength class	Cement content [kg/m³]	Characteristic values (5% fractiles) f_{ck} [N/mm²]	Examination values	
				f_{cd} [N/mm²]	τ_{cd} [N/mm²]
262 ¹⁾ (2003)	... C30/37 ...		... 30,0 ...	... 20,0 ...	... 1,10 ...
162 (1989)	B20/10		9,6	6,4	0,63
	B25/15		13,6	9,1	0,74
	B30/20		17,6	11,7	0,84
	B35/25		21,6	14,4	0,93
	B40/30		25,6	17,1	1,01
	B45/35		29,6	19,7	1,09
	B50/40		33,6	21,6	1,16
	B55/45		37,6	23,3	1,23
162/34 (1976) and 162 (1968)	BN unreinforced	150	6,4	4,3	0,51
	BN unreinforced	200	9,6	6,4	0,62
	BN unreinforced	≥250	12,8	8,5	0,72
	BH unreinforced	≥250	19,2	12,8	0,88
	BN reinforced	300	12,8	8,5	0,72
	BH reinforced	≥300	19,2	12,8	0,88
	BS reinforced	≥300	24,0	16,0	0,98
162 (1956) and	normal concrete BN	150	3,4	2,2	0,37
		200	5,3	3,5	0,46
		250	7,7	5,1	0,55
		300	10,6	7,0	0,65
		350	13,4	9,0	0,73
115 (1935)	high-quality concrete BH	250 ²⁾	12,0	8,0	0,69
		300	16,3	10,9	0,81
		350	20,7	13,8	0,91

¹⁾ only given for comparison purposes

²⁾ only in Code SIA 115 (1935)

Table 8: Mechanical properties of reinforcing steel, depending on the code used

SIA code	Steel type <i>Produkt</i>	Ductility class	Mean values		Characteristic values (5% fractiles)			Examination values	
			f_{sm} [N/mm ²]	f_{tm} [N/mm ²]	f_{sk} [N/mm ²]	f_{tk} [N/mm ²]	ε_{uk} [N/mm ²]	f_{sd} [N/mm ²]	ε_{ud} [‰]
262 ¹⁾ (2003)	B500A	A	545	600	500	525	25	435	20
	B500B	B	550	710	500	540	50	435	45
	B450C	C			450–550	520–610 635–745	75	≥390	65
	<i>Topar-S 500C</i>	C	535	640	500	675	75	435	65
162 (1989)	S 235	B			235	360		205	
	S 500 a	B	550	710	500	600	50	435	45
	S 500 b	A	550		500	550		435	
	S 500 c	B	550	630	500	580	50	435	45
	S 500 d	A	545	600	500	550	25	435	20
	S 550	A	610	640	550	580		480	
162 (1968)	I	B	330		235	360		205	
	III a	B	550	580	450	550	50	390	
	<i>Box-Ultra</i>	C		730					
	<i>topar</i>	C		630					
	III b	A	550	580 - 630	450	470		390	
	IV	A			530	560		460	
162 (1956)	I	B			235	355		205	
	II a	B	440–530	530	345	410		300	
	<i>Caron steel</i>	C	440–530	680					
	II b	B	440	610	345	510		300	
112 (1935)	normal steel	B	300–330		240	360–450			
	high-quality steel	B	400–480	500	350	520–620			
	<i>steel 52</i>	B		590					
¹⁾ only given for comparison purposes									

Table 9: Mechanical properties of prestressing steel, depending on the code used

SIA code	Prestressing tendon type	Mean values			Characteristic values (5% fractiles)			Examination values	
		$f_{p0.1m}$ [N/mm ²]	$f_{p0.2m}$ [N/mm ²]	f_{pm} [N/mm ²]	$f_{p0.1k}$ [N/mm ²]	$f_{p0.2k}$ [N/mm ²]	f_{pk} [N/mm ²]	f_{pd} [N/mm ²]	ε_{ud} [%]
262 ¹⁾ (2003)	Y1860				1600		1860	1390	
	Y1770				1520		1770	1320	
	Y1670				1440		1670	1250	
	Y1570				1300		1570	1130	20
	Y1230				1080		1230	940	
	Y1100				900		1100	780	
	Y1030				830		1030	720	
162 (1989)					1670			1450	
					1640			1430	
					1590			1380	
					1500			1300	
					1410			1230	
					1000			870	
					830			720	
162 (1968)							1400		
							1300		
							1000		
162 (1956)									

¹⁾ only given for comparison purposes

APPENDIX B (normative)

STRUCTURAL MEASURES

Table 10: Relationship between the methods given in SN EN 1504-9 and the structural measures given in Section 7

Section of Code SIA 269/2	Structural measures		Methods in accordance with Tab. 5 and 6 or SN EN 1504-9
7.3.2	Strengthening	Restoration of cross section with concrete or mortar	4.4
7.3.3 and 7.3.4		Addition or replacement of embedded or external reinforcement, addition of reinforcement, anchored in grooves or drilled holes, externally bonded reinforcement (steel or fibre laminate), external prestressing	4.1, 4.2, 4.3, 4.7
7.4.2	Concrete removal and restoration	Manual application of mortar, increase of cross section with concrete or mortar, shotcrete or sprayed mortar	3.1, 3.2, 3.3, 7.2
		Coating of the reinforcement	11.1, 11.2
7.4.3	Concrete or mortar adding		5.3, 6.3, 7.1, (7.4)
7.4.4	Treatment of cracks	Covering of cracks and conversion of cracks into joints	1.4, 1.6
		Filling and grouting of cracks and cavities	1.5, 4.5, 4.6
7.4.5	Surface protection systems	Hydrophobic impregnation	1.1, 2.1, 8.1
		Impregnation	1.2, 2.2, 5.2, 6.2, 8.2
		Coating	1.3, 2.3, 5.1, 6.1, 8.3, (9.1)
		Sealing	1.8
		Bonded lining (overlays)	5.3, 6.3
		Bekleidung ohne Verbund	1.7, 2.4
7.4.6	Corrosion inhibitors		11.3
7.4.7	Electro-chemical methods	Electrochemical treatment of concrete	2.5
		Cathodic protection	10.1
		Electrochemical chloride extraction	7.5
		Elektrochemical realkalisation	7.3

APPENDIX C (normative)

DETERMINATION OF THE CRACK WIDTH INDEX

The crack width index RI is determined by means of the cumulative crack width w_i within a square metre on a cracked concrete surface, measured along the four reference lines O–A, O–B, O–C and A–B in accordance with Figure 4 and equation (12):

$$RI = \frac{1}{4} \sum_{n=1}^4 w_i \quad \text{with} \quad w_i = \frac{\sum w_n}{l_i} \quad (12)$$

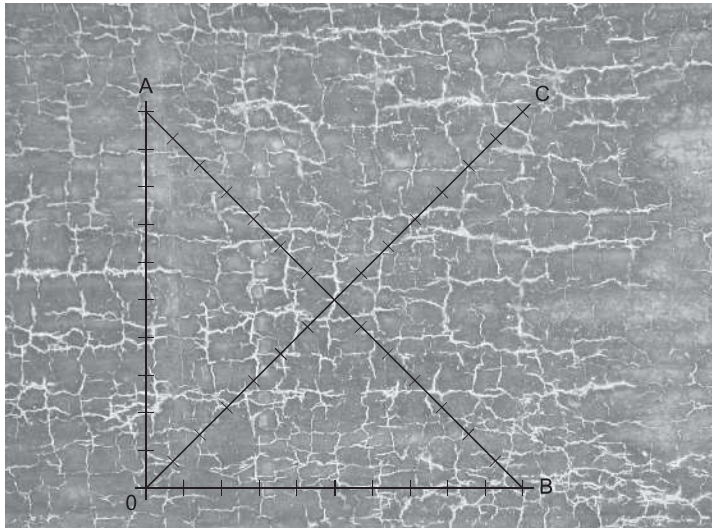
where

w_n measured crack width of all cracks intersected by any reference line, in mm

l_i length of the actual reference line in m

w_i cumulative crack width in mm/m

Figure 4: Arrangement of the four reference lines for the determination of the crack width index RI



Abbreviations of organisations represented in the commission SIA 262

Empa	Swiss Federal Laboratories for Materials Science and Technology
EPFL	Swiss Federal Institute of Technology, Lausanne
ETH Zürich	Swiss Federal Institute of Technology, Zurich
FEDRO	Federal Roads Office

Project Management – Codes for Existing Structures

Dr. Paul Lüchinger, dipl. Ing. ETH, Zurich (chairman)
Prof. Dr. Eugen Brühwiler, dipl. Ing. ETH, Lausanne
Thomas P. Lang, dipl. Ing. ETH, Berne
Prof. Thomas Vogel, dipl. Ing. ETH, Zurich

Working Group SIA 269/2

Existing structures – Concrete structures

Dr. Luc Trausch, dipl. Ing. ETH, Zurich (chairman)
Ruedi Gall, dipl. Ing. HTL, Chur
Prof. Dr. Albin Kenel, dipl. Ing. ETH,
Rapperswil-Jona
Dr. Heidi Ungricht, dipl. Ing. ETH, Chur
Prof. Dr. Daia Zwicky, dipl. Ing. ETH, Freiburg

Commission SIA 262 “Concrete structures”

President Prof. Thomas Vogel, dipl. Ing. ETH, Zurich

ETH Zürich

Members Dr. Manuel Alvarez, dipl. Ing. ETH, Berne
Daniel Buschor, dipl. Ing. ETH, Burgdorf
Aldo Chitvanni, dipl. Ing. ETH, Chur
Christoph Czaderski, dipl. Ing. ETH, Dübendorf
Nicola Guidotti, dipl. Ing. ETH, Bellinzona
Ernst Honegger, dipl. Ing. ETH, Wildegg
Dr. Bernard Houriet, dipl. Ing. ETH, Tramelan
Dr. Fritz Hunkeler, dipl. Ing. ETH, Wildegg
Prof. Dr. Albin Kenel, dipl. Ing. ETH, Rapperswil-Jona
Martin Knecht, Cornaux
Dr. Peter Lunk, dipl. Ing., Würenlingen
Dr. Konrad Moser, dipl. Ing. ETH, Zurich
Prof. Dr. Aurelio Muttoni, dipl. Ing. ETH, Lausanne
Erdjan Opan, dipl. Ing. ETH, Neuenburg
Dr. Luc Trausch, dipl. Ing. ETH, Zurich

FEDRO
Consulting Engineer
Consulting Engineer
Empa
Administration
Industry
Consulting Engineer
Material Testing
Univ. of Applied Sciences
Industry
Industry
Consulting Engineer
EPFL/Consulting Engineer
Consulting Engineer/Construction Management
Consulting Engineer

Approval and validity

The SIA's central committee for codes and regulations approved the present Code SIA 269/2 on 23rd November 2010.

It is valid as from 1st January 2011.

It replaces the recommendation SIA 162/5 *Maintenance of concrete structures*, 1997 edition, and Appendix A of the Technical Specification SIA 2018 *Examination of existing buildings with respect to earthquake*, 2004 edition.

Copyright © 2011 by SIA Zurich

All rights are reserved, including the right to print extracts, partial or full reproduction (photocopy, microcopy, CD-ROM, etc.), storage in data processing systems and translation.