SIA 269/2 – A NEW SWISS CODE FOR THE CONSERVATION OF CONCRETE STRUCTURES

Daia Zwicky, PhD, MSc ETH, Professor at the University of Applied Sciences of Western Switzerland, College of Engineering and Architecture of Fribourg
P.O. Box 32, CH-1705 Fribourg, Switzerland
e-mail: daia.zwicky@hefr.ch

ABSTRACT

Currently, the new series of codes SIA 269 for the conservation of existing structures is developed in Switzerland. It is a counterpart and complement to the Swiss codes SIA 260-267 for the design of new structures; it should come into force by mid 2010. The paper describes the general composition of the code series and its material-oriented sub-parts, illustrated by the features of the code SIA 269/2 for existing concrete structures:

- *Basic principles in the assessment of existing (concrete) structures,*
- *Updating basic material properties (e.g. concrete compressive strength),*
- *Particularities in structural analysis,*
- *Verification of structural safety with refined resistance models, and*
- *Particularities in the verification of frequent structural details.*

These features are complemented by extensive references underlying the proposals made in SIA 269/2 for the structural safety verification of existing concrete structures.

Keywords: Monitoring, Assessment, Maintenance, Standards, Specifications, Design Codes.

1. INTRODUCTION

1.1 WHAT IS "CONSERVATION" OF STRUCTURES?

Up to now, no generally accepted term could be found on an international level that describes all the measures and activities to be undertaken in monitoring, assessment, maintenance, modification, repair, and rehabilitation of construction works. Moreover, the term maintenance does evidently not cover it all; the Swiss Society of Engineers and Architects (SIA) has decided to use the term "Conservation". It is defined as (SIA 260[1])

> "All the activities and measures undertaken to ensure the continued existence of a construction works, including its material and non material values".

Fig. 1 shows the main activities and their relations of conservation of structures.

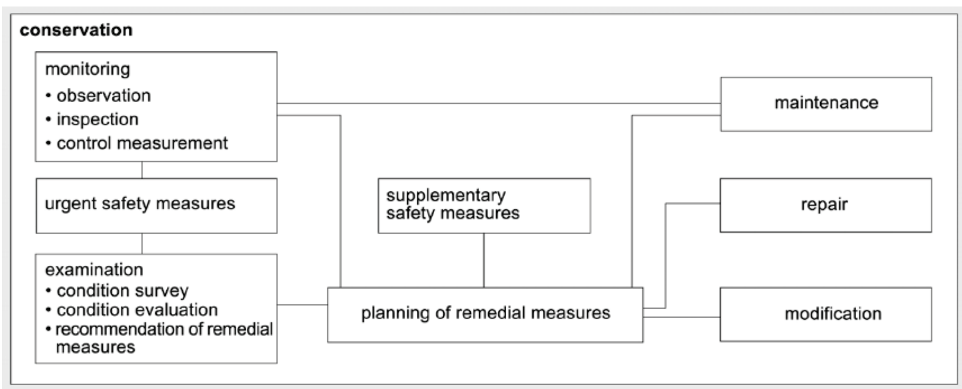

Fig. 1 Conservation of structures (figure taken from SIA 260[1]).

1.2 NEED FOR CODES FOR THE CONSERVATION OF STRUCTURES

As do most developed countries, Switzerland has an infrastructure stock of considerable value; it is estimated[2] that it would cost approx. CHF 2'400 billion (US$ 2'300 billion) to replace all of Switzerland's infrastructure, equaling almost 5 times the nominal gross domestic product (GDP; estimate of 2008[3], the highest so far).

The percentage of expenses spent on conservation (modification and maintenance) in comparaison to the overall expenses investments in the Swiss construction industry has been steadily on the increase in the last decades; having an allotment at the beginning of the 1980s of ca. 20%, it leveled off at approx. 40% of the total expenses in construction at the end of the millennium, see Fig. 2. Since "Switzerland is built", this percentage will nevertheless increase further in the future.

The need for codes on existing structures instead of the design of new structures thus becomes evident. In order to respond to this practical need, SIA runs since 2005 the project "SIA 269 – Conservation of Structures" with the aim to provide a comprehensive code series specifically for existing structures and to replace outdated documents[4,5].

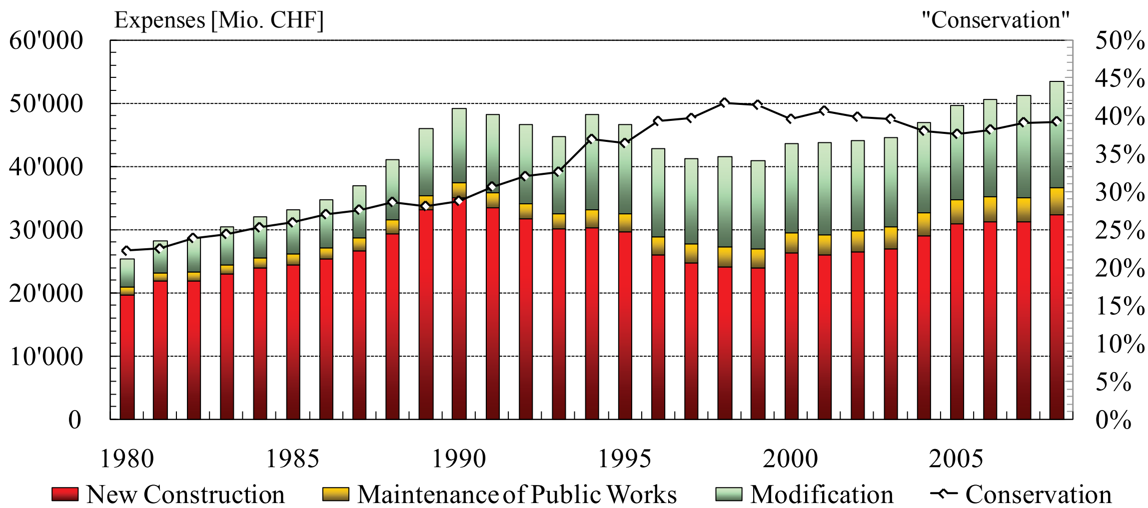

Fig. 2 Total investments in Swiss construction industry (1980-2007)[6], in current prizes.

2. COMPOSITION OF CODE SERIES SIA 269

Swiss codes are edited by the Swiss Society of Engineers and Architects (SIA). All codes are available at least in German and French; some codes are additionally available in Italian and English. In the latest series of design codes SIA 260-267 for new structures all basic volumes exist in the four languages. Swiss codes are traditionally material-oriented (see Table 1), including provisions for seismic resistance of the respective construction material. Seismic evaluation of existing structures shall be treated in a future code SIA 269/8; at present, the technical bulletin SIA 2018[7] for earthquake evaluation of buildings is still in force.

Swiss codes are normally developed in close collaboration of academia, research, consultants, and industry, in order to consider practical concerns from engineering applications, owners and suppliers, but also state-of-the-art concepts and models for principal design parameters, i.e. actions, structural models, materials and structural resistances, and latest findings from research.

Table 1: Swiss codes for design of new and conservation of existing structures

Code on	Code SIA Nr.… for	
	New structures	Conservation
Basic principles and concepts	260[1]	269[8]
Actions on Structures	261	269/1
Concrete Structures	262[9]	269/2[10]
Steel Structures	263	269/3
Composite Steel and Concrete Structures	264	269/4
Timber Structures	265	269/5
Masonry	266	269/6
Geotechnical Design	267	269/7

The basis of structural design is treated in SIA 260[1]; this code also standardizes technical terms and the general context for the conservation of structures, see Fig. 1. Basic principles for the conservation of construction works are regulated in SIA 469[11], focusing on technical terms, general goals and work flows in conservation of construction works.

3. MAIN PRINCIPLES IN CODE SERIES SIA 269

3.1 CONCEPT FOR DEVELOPMENT

A traditional requirement for Swiss codes is to limit code rules to a vital minimum (Pareto principle), leading to rather user-friendly, liberal codes.

The complete code series SIA 269 shall be a counter-part to the codes for the design of new structures, see Table 1. Consequently, the series SIA 269 for existing structures only contains rules that differ from those in the respective code series SIA 260-267 for new structures; e.g. SIA 269/2[10]only covers the possible and necessary deviations in the conservation of existing concrete structures from the rules for new concrete structures SIA 262[9].

3.2 STRUCTURAL SAFETY VERIFICATION FORMAT

The conservation codes follow the concept of load and resistance factor design (LRFD). The examination focuses on structural safety verification at ultimate limit state (ULS), since serviceability limits can usually be confirmed directly by measurement on the structure.

Contrary to SIA 260[1], ULS verification according to SIA 269[8] may also be explicitly based on probabilistic approaches, and the code also indicates target reliability indices; however, deterministic verification shall be carried out in the first place. Differently to the well-known equation $S_d \leq R_d$ for the design of new structures, structural safety is expressed by the so-called degree of compliance[8] n (shown here for the case of sectional verification):

$$n = \frac{R_{d,act}}{E_{d,act}} \tag{1}$$

where:

$R_{d,act}$ updated structural resistance, e.g. shear resistance $V_{Rd,act}$

$E_{d,act}$ updated action effect, e.g. shear force $V_{d,act}$

In general, the degree of compliance n has to be higher than one; if not, remedial measures should be applied.

More important, however, is the fact that structural resistances and actions, including load and resistance factors, shall be updated. To clearly distinguish updated material values from design values for new structures, the former are called examination values and denoted with a subscript “act” (for “actualized”).

3.3 PROPORTIONALITY OF REMEDIAL MEASURES

If structural interventions become very expensive, a criterion for assessing the proportionality of these measures may be applied, the efficiency of remedial measures EF_M:

$$EF_M = \Delta R_M / SC_M \tag{2}$$

where:

ΔR_M risk reduction for life and limb due to conservation measures
SC_M cost of measures for structural safety (and for structural safety only!)

Both coefficients have to be discounted, usually based on 2% annual interest rate. If $EF_M > 1$, the measures are considered proportional and shall be executed. If $EF_M < 1$, the planning of remedial measures shall be revised, or more refined assessments of the failure probability and its consequences (risk) shall be applied, or the actual situation must simply be accepted.

4. PARTICULARITIES OF SIA 269/2 FOR CONCRETE STRUCTURES

In general, SIA 269/2[10] determines possible and necessary deviations from the rules for the design of new concrete structures according to SIA 262[9]; it provides regulations for how to update material properties and structural models, how to determine structural resistances, and how to treat frequent particularities of existing structural elements. Moreover, it covers condition survey and evaluation of existing concrete structures, as well as possible remedial measures; these topics, however, will not be further treated here.

4.1 BASIC PRINCIPLES IN STRUCTURAL SAFETY EXAMINATION

Principally, SIA 269/2[10] follows the rules and models of SIA 262[9], but applies refined approaches where appropriate and necessary. This is due to the fact that modifying or strengthening an existing structure may be expensive and thus not necessarily proportional; remedial measures are not justified alone by underperformance with respect to design codes[2]. Furthermore, resistance models for new structures are often simplified to the safe side and do not automatically provide a sound reflection on the structural safety of an existing structure. The most important basic principles of SIA 269/2[10] are:

- Examination values for material properties are determined according to the format for design values; e.g., the examination value of yield stress $f_{sd} = f_{sk,act} / \gamma_{s,act}$ is determined with the actualized value of the characteristic yield stress $f_{sk,act}$ and the examination value of the partial resistance factor $\gamma_{s,act}$ for reinforcing steel.
- Structural analysis at ULS may be performed – as it is for SIA 262[9] – according to linear elastic theory, theory of plasticity and with non-linear methods, but on actualized structural models, hence also including defaults and deterioration of the structure.
- Verification of structural safety is generally based on plasticity theory (a.k.a. limit analysis, e.g.[12,13,14]) and usually checked deterministically according to Eq. (1).
- Structural resistances for transverse and punching shear in slabs and shear in beams are determined from more general models, having been initially simplified for SIA 262[9].

- Frequent particularities of structural elements, such as reduced concrete cover, insufficient anchorage and splice lengths of reinforcing bars, construction details of slabs, girders and T-beams etc. are treated by refining the rules of SIA 262[9].

4.2 ACTUALIZATION OF MATERIAL PROPERTIES

4.2.1 General Principles

Actualized material properties may be determined in three stages, based on:

1. Records of the structure (material testing results, drawings, condition surveys, etc.),
2. Non-destructive testing plus sounding for identification of reinforcement, and
3. Extraction and testing of samples, i.e. drilling cores and obtaining steel samples.

The investigation depth depends on the structural safety reserve (degree of compliance n), on the type and mechanism of failure, and on how a specific material property influences the respective structural resistance, with the goal of limiting the necessary effort in the investigation of material properties, e.g.:

- The structural safety reserve is high ($n >> 1$) and more refined methods would not significantly improve the result or only reveal an even higher structural capacity.
- The dominant failure is in bending by yielding of reinforcement, thus a ductile failure type; i.e., the exact value of concrete strength has a minor influence on the bending resistance (on the lever arm of inner forces only). On the contrary, if the dominant failure mechanism is web-crushing shear[14], the concrete strength has a very pronounced influence. Hence, a more refined analysis of material properties is justified.
- The material properties of reinforcing and prestressing steel are well documented over the last several decades, by code requirements and by supplier records. Significant increases of strength values may thus hardly be expected from destructive testing, and should only be executed if substantial doubts or no information at all exist.

Actualized material properties may be cautiously estimated (e.g. from the structure records, stage 1) if a sufficient structural safety reserve is verified ($n > 1$) or if the directives for deformation capacity and construction details of SIA 262[9], thus requirements for a new structure, are fulfilled. Otherwise, material properties must be determined on the structure (stages 2 and/or 3); the same applies for structural elements having been exposed to fire.

4.2.2 Concrete and Reinforcement Properties

If the concrete strength has to be determined destructively, at least three cored samples shall be tested in compression tests, executed and evaluated according to the respective codes[15,16]. Additionally, SIA 269/2[10] provides a table allowing the determination of the concrete strength class from the test results, based on SN EN 13791[16] (approach B for less than 14 samples).

Similar directives are provided for reinforcing and prestressing steel regarding testing and evaluation of sample results[17]. Annexes (from SIA 2018[7]) with mechanical properties of concrete and reinforcing and prestressing steel according to older Swiss codes are supplied.

4.3 STRUCTURAL ANALYSIS

The directives for structural analysis are essentially as liberal as for new structures; however, with ULS verification being the primary goal, the emphasis is on limit analysis and non-linear methods. Examples for the application of limit analysis tools in ULS evaluation can be found elsewhere, e.g.[18].

4.3.1 Importance of Deformation Capacity

Reaching the ultimate load according to limit analysis may require an important amount of redistribution of internal forces; a more pronounced focus in SIA 269/2[10] therefore is on deformation capacity (ductility) and demand.

Furthermore, the application of only the upper-bound method of limit analysis[13] in ULS verification is recommended but for simple cases; in general, ULS shall be evaluated by the lower-bound method, e.g. stress fields[19]. The upper-bound method can be applied for

- determining an insufficient ULS reserve (i.e. "negative" examination with $n < 1$),
- determining decisive load positions for the development of lower-bound solutions,
- confirming a result from the lower-bound method.

For prestressed concrete, ULS verification should additionally consider that restraint actions due to prestressing influence the position and order of plastic hinge zones and thus influence the plastic deformation demand for reaching the ultimate load; also, the self-equilibrating stresses leading to restraint actions are only altered in zones with plastic deformations[20]. If prestressed structures are analyzed in more detail, e.g. by stress fields[19], it should be considered that a force increase in the prestressing steel beyond the value after all losses is only realistic if the corresponding zone of the structure is decompressed at ULS[20].

4.4 EXAMINATION VALUES OF MATERIAL STRENGTH

Examination values of material strength are determined according to the format of SIA 262[9], see 4.1. The resistance factors for concrete (γ_c = 1.5), reinforcing and prestressing steel (γ_s = 1.15) remain unchanged for the analysis of existing concrete structures.

4.4.1 Examination Value of Concrete Strength

The main difference of SIA 269/2[10] to SIA 262[9] is a refinement of the effective strength $f_{ced} = k_c \cdot f_{cd}$ of inclined compression fields, i.e. for girder webs and panels in shear, thus a refinement of the coefficient k_c to be applied to the design value of concrete compressive strength f_{cd}. The proposal for k_c in SIA 269/2[10] is based on the so-called Cracked Membrane Model[21], additionally considering the difference between characteristic and average strength in order to be in accordance with the LRFD concept of SIA 260[1]:

$$k_c = \left(\left(0{,}45 + 35\varepsilon_1\right) \cdot \eta_{fc} \cdot f_{ck}^{1/3}\right)^{-1} \leq 1.0 \tag{3}$$

where:

ε_1 $= \varepsilon_x + (\varepsilon_x - \varepsilon_2)\cdot\cot^2\alpha$: major principal strain (perpendicular to the direction of the compression field); derived from Mohr's circle for strains, where ε_x = longitudinal strain, ε_2 = concrete compressive strain on reaching the compressive strength (usually taken as -2‰), and α = inclination of the compression field with respect to the girder axis (also see Fig. 3)

η_{fc} $= (30/f_{ck})^{1/3}$: conversion factor according to SIA 262[9], taking into account the more brittle failure behavior of higher strength concrete

f_{ck} characteristic value (5% fractile) of cylinder concrete compressive strength

In SIA 262[9], only two cases are differed for the effective concrete compressive strength f_{ced} in compression fields with reinforcement running obliquely to the direction of compression: the tension chord (hence the bending reinforcement) remains elastic (then $k_c = 0.6$) or it is plastified (then $k_c = 0.4$).

SIA 269/2[10] allows for a refinement, but remains with the same concept for determining the effective concrete strength. The coefficient k_c primarily depends on the longitudinal strain, the inclination of the compression fields, and the concrete quality.

4.4.2 Examination Values of Reinforcement

In defining examination values of mild and prestressing steel strength, notch effects and embrittlement due to deterioration (e.g. corrosion) shall be considered. Ideally plastic behavior of the reinforcement may be assumed in structural analysis if the deformation capacity in the decisive plastic hinge zones does not limit the ultimate load. If this cannot be proven, strain hardening and bond behavior of the reinforcement shall be adequately considered in the determination of deformation capacity. It should be noted that mild and prestressing steel normally exhibit different bond stiffness and strength[22].

4.5 RESISTANCE MODELS

4.5.1 Shear in Slabs

The resistance model for shear in structural members without shear reinforcement of SIA 262[9] is based on the so-called Critical Shear Crack Theory[23]. According to this model, the shear strength primarily depends on the crack width in the critical shear region (based on the deformation of the bending reinforcement), the roughness of the crack (aggregate interlock), and the concrete compressive strength. For the design of new structures with SIA 262[9], the model has been simplified by several assumptions[23]. SIA 269/2[10] considers the more general approach[24], essentially for the estimate of the critical crack width. More information and numerous comparisons with test results and code models can be found elsewhere[23,24].

4.5.2 Shear in Beams

According to SIA 262[9], the design for shear in members with stirrup reinforcement is based on stress fields[14,19], with a variable angle α of the compression fields in the web only and imposing the limits $25° \leq \alpha \leq 45°$ on this inclination, see Fig. 3.

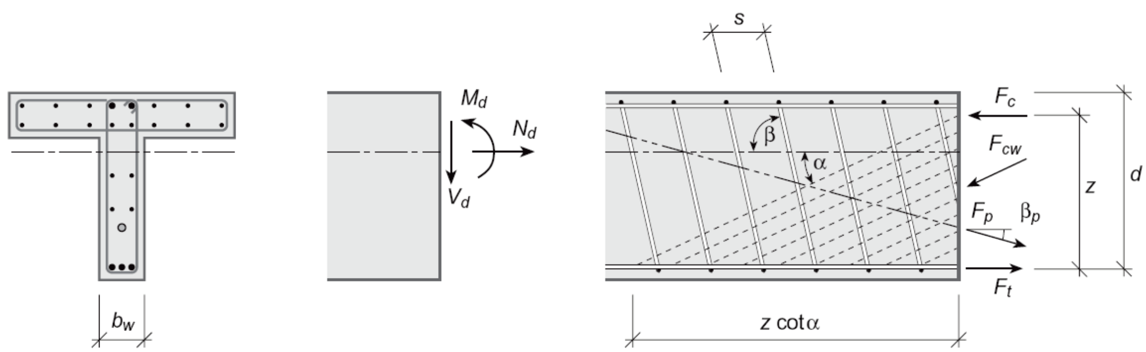

Fig. 3 Shear in structural members with stirrup reinforcement (figure taken from SIA 262[9])

In SIA 269/2[10], the compression field inclination α may be chosen beyond these limits, but the choice must be justified by considering the compatibility of deformations (strains) and the ductility properties of the shear reinforcement. Background information on the chosen approach can also be found elsewhere[25,26].

The goal of this regulation is that the strain in the shear reinforcement and the major principal strain ε_1 – for introduction in Eq. (3) – are explicitly calculated for the determination of the respective shear resistances; both these strains can be found from Mohr's circle for strains. Note that this approach does not prohibit considering the shear resistance of girder flanges and the application of non-linear calculations. Longitudinal strains may be calculated from section analysis, but must also consider the normal forces from shear and prestressing.

The lower limit of the compression field inclination α is delimited by the ductility properties of the stirrup reinforcement. Fig. 4 shows results for k_c from Eq. (3), for different concrete quality classes and levels of longitudinal strain ε_x, and depending on the chosen inclination α of the compression fields. Note that the lower ends of the curves are cut off if the transverse

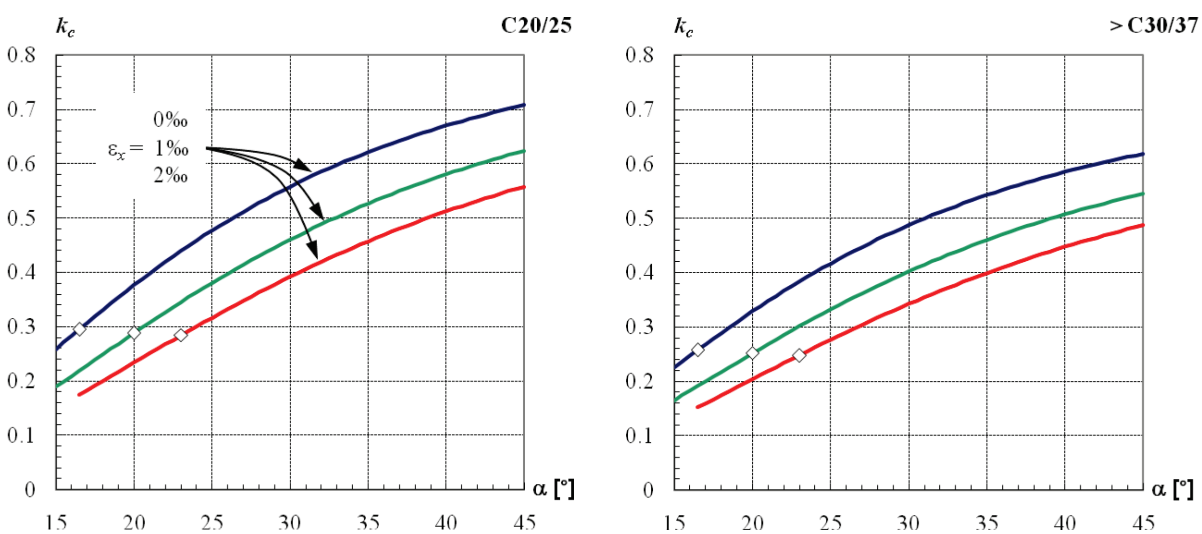

Fig. 4 Reduction coefficient k_c for effective concrete strength, as a function of compression field inclination, longitudinal strain and ductility properties of stirrup reinforcement.

strain ε_z (assumed in the vertical direction, thus vertical stirrups with $\beta = 90°$) exceeds 45‰, a regular value for ultimate reinforcement strain (ductility class B); the diamond symbol represents $\varepsilon_z = 20‰$, a low value for ultimate reinforcement strain (ductility class A).

4.5.3 Punching Shear

The punching shear resistance model for slabs with and without shear reinforcement underlying SIA 262[9] is also based on the Critical Shear Crack Theory, but founding on the slab rotation in the critical zone.

SIA 269/2[10] considers the more general approaches[27,28], where slab deformations shall be explicitly calculated, considering further effects such as prestressing, available bending resistances, bond properties of reinforcement etc.

4.6 PARTICULARITIES OF FREQUENT STRUCTURAL DETAILS

Among others, the regulations on frequent structural details treat the following:

- *Reinforcement Bond Strength and Anchorage and Splice Length*: The reinforcement bond strength and the derived anchorage and splice lengths are principally determined according to the Tension Chord Model[29], as it is also the case for SIA 262[9]. While quality and thickness for concrete cover, the lateral spacing and the relative rib area of reinforcing steel – the main parameters influencing the bond strength – can be appropriately chosen for new structures, this is usually not the case in existing structures. SIA 269/2[10] therefore provides directives for considering a reduced concrete cover[30], reduced relative rib area[31] and reduced lateral spacing, as well as provisions for assessing the influence of transverse reinforcement within the anchorage and splice length.
- *Prestressed Structures*: SIA 269/2[10] primarily provides directives on how to determine anchorage lengths of pre-tensioned structures. It further prescribes that the concrete tensile strength should generally be neglected in ULS verification.
- *Girders and T-Beams*: the regulations in SIA 269/2[10] generally deal with the effective depth of stirrup reinforcement, how to consider the combination of stirrup and bent-up longitudinal reinforcement as shear reinforcement, and the interaction of transverse and longitudinal structural behavior in indirectly supported beams.
- *Flat Slabs*: above all, the regulations in SIA 269/2[10] treat the case of how and which bent-up reinforcement may be considered as punching shear reinforcement as well as how to treat cases where certain geometrical conditions for this reinforcement are not fulfilled.
- *Fatigue*: the examination according to SIA 269/2[10] may focus on the verification of the fatigue resistance of the reinforcement. The provided values of fatigue resistance for several cases, e.g. straight bars, vertical stirrups and prestressing in steel ducts, slightly deviate from the values in SIA 262[9], where a partial safety factor of 1.15 has been introduced to reduce the number of cases where fatigue may be governing the design; for existing structures, more precise values and analysis should be provided, of course. It is also stated that supplementary safety measures – e.g. limitation of remaining service life or applied loads, or monitoring – should rather be applied than strengthening.

5. SUMMARY AND CONCLUSIONS

This paper summarizes the content of the new Swiss code SIA 269/2[10] for the conservation of concrete structures, focusing on issues of structural safety verification at ultimate limit state. Further topics of the code, i.e. condition survey and evaluation as well as possible intervention methods are not treated here in detail.

The paper aims at elaborating the differences in structural safety assessment of existing concrete structures compared to the design of new concrete structures. For further information, the paper also provides a comprehensive collection of the relevant references forming the basis of the new code rules.

The development of the new code SIA 269/2[10] based on the premise that the actual Swiss code for (the design of new) concrete structures SIA 262[9] defines state-of-the-art regarding structural resistance models of (Swiss) concrete structures; however, design models are often simplified to be on the safe side.

Underperformance of an existing structure with regard to actual design codes alone is not considered a sufficient reason for strengthening or replacement; probably no national economy in the world could support the rehabilitation of all existing structures to the structural safety level of actual design codes. SIA 269/2[10] therefore attempts to regulate conscious deviations from design rules for new structures and to provide a common basis for structural examination.

The introduction of the new Swiss code series SIA 269 will hopefully further improve awareness and education of (Swiss) structural engineers in conservation matters, as already required earlier[32]. Possibly, it may also provide a basis for the definition of technical terms, analysis, evaluation, rehabilitation, and repair of concrete structures to be applied elsewhere. In order to solve the pending problems of existing (concrete) structures, the structural engineering community should at least have a common language; structural resistance models will probably always differ in different countries.

ACKNOWLEDGEMENTS

The fruitful and pleasant collaboration with the members of the working group SIA 269/2: Dr. L. Trausch (chair), R. Gall, Prof. Dr. A. Kenel, Dr. H. Ungricht, and Prof. T. Vogel (supervision and chairman of concrete code commission SIA 262), is highly appreciated.

REFERENCES

N.B. SIA = Swiss Society of Engineers and Architects
CEN = European Committee for Standardization
IBK = Institute of Structural Engineering of Swiss Federal Institute of Technology (ETH)
IABSE = International Association of Bridge and Structural Engineering

1. SIA 260, “Basis of Structural Design”, *code,* Jan. 2003, 44 pp.
2. Vogel, T., Trausch, L., “New Swiss Codes for the Conservation of Concrete Structures”, *Concrete: 21st Century Superhero – Building a Sustainable Future*, proc. 11th Int’l fib Symp., London, June 2009, 8 pp. on CD.
3. International Monetary Fund, http://www.imf.org/external/datamapper/index.php
4. SIA 462, “Beurteilung der Tragsicherheit bestehender Bauwerke (Evaluation of Structural Safety of Existing Structures)”, *guideline,* June 1994, 16 p. (in German, French and Italian)
5. SIA 162/5, “Erhaltung von Betontragwerken (Conservation of Concrete Structures)”, *recommendation,* July 1997, 44 pp. (in German and French)
6. Swiss Federal Statistical Office (BFS), www.bfs.admin.ch
7. SIA 2018, “Überprüfung bestehender Gebäude bezüglich Erdbeben (Evaluation of Existing Buildings regarding Earthquakes)”, *technical bulletin,* Nov. 2004, 40 p. (in German and French)
8. SIA 269, “Grundlagen der Erhaltung von Tragwerken (Basis of Conservation of Structures)”, *code draft,* Dec. 2008, 31 p. (in German)
9. SIA 262, “Concrete Structures”, *code,* Jan. 2003, 90 p.
10. SIA 269/2, “Erhaltung von Tragwerken – Betonbau (Conservation of Structures – Concrete Structures)”, *code draft for consultation,* May 2009, 48 p. (in German and French)
11. SIA 469, “Erhaltung von Bauwerken (Conservation on Construction Works)”, *code,* Aug. 1997, 20 p. (in German, French and Italian)
12. IABSE Colloquium Copenhagen, “Plasticity in Reinforced Concrete”, *Introductory Report,* IABSE Vol. 28, 1978, 172 pp. and *Final Report*, IABSE Vol. 29, 1979, 360 pp.
13. Nielsen, M.P., *Limit Analysis and Concrete Plasticity*, Prentice-Hall, Englewood Cliffs, 1984, 420 pp.
14. Sigrist, V., Alvarez, M., Kaufmann, W., “Shear and Flexure in Structural Concrete Beams”, *CEB (Comité Européen du Béton) Bulletin,* Nr. 223, June 1995, pp. 7-49.
15. SN EN 12504-1 (CEN), “Testing concrete in structures – Part 1: Cored specimens – Taking, examining and testing in compression”, *code*, 2009, 10 p.
16. SN EN 13791 (CEN), “Assessment of in-situ compressive strength in structures and precast concrete components”, *code,* 2007, 31 p.
17. EN ISO 15630, “Steel for the reinforcement and prestressing of concrete – Test methods”, Parts 1-3, *code,* 2002.
18. Zwicky, D., “Plastic Assessment of Slab-and-Beam-Bridges”, *Metropolitan Habitats and Infrastructure,* proc. IABSE Symp. Shanghai, Sept. 2004, pp. 90/91 + 8 p. on CD.
19. Muttoni, A., Schwartz, J., Thürlimann, B., *Design of Concrete Structures with Stress Fields*. Birkhäuser Basel, 1997, 145 p.
20. Stoffel, P., “Zur Beurteilung der Tragsicherheit bestehender Stahlbetonbauten (On the Evaluation of Structural Safety of Existing Concrete Structures)”, *IBK Report,* No. 251, July 2000, 185 pp. (in German)

21. Kaufmann, W., Marti, P., "Structural Concrete: Cracked Membrane Model", *ASCE Journal of Structural Engineering*, V. 124, No. 12, Dec. 1998, pp. 1467-1475.
22. Alvarez, M., "Einfluss des Verbundverhaltens auf das Verformungsvermögen von Stahlbeton (Influence of Bond Behavior on the Deformation Capacity of Structural Concrete)", *IBK Report*, No. 236, July 1998, 182 p. (in German)
23. Muttoni A., Fernández Ruiz M., "Shear strength of members without transverse reinforcement as function of critical shear crack width", *ACI Structural Journal*, V. 105, No. 2, March-April 2008, p. 163-172.
24. Muttoni, A., "Schubfestigkeit und Durchstanzen von Platten ohne Querkraftbewehrung (Shear and Punching Strength of Slabs without Shear Reinforcement)", *Beton- und Stahlbetonbau*, V. 98, No. 2, Feb. 2003, p. 74-84. (in German)
25. Fernández Ruiz, M., Hars, E., Muttoni, A., "Résistance à l'effort tranchant des poutres précontraintes à âme mince (Shear strength of thin-webbed posttensioned girders)", Federal Departement of Transport, Communication and Energy, Federal Office of Routes, *Report*, No. 606, Dec. 2006, 68 p. (in French)
26. Fernández Ruiz M., Muttoni A., "Shear Strength of Thin-Webbed Post-Tensioned Beams", *ACI Structural Journal*, V. 105, No. 3, May-June 2008, p. 308-317.
27. Muttoni A., "Punching Shear Strength of Reinforced Concrete Slabs without Transverse Reinforcement", *ACI Structural Journal*, V.105, No. 4, July-Aug. 2008, p. 440-450.
28. Fernández Ruiz M., Muttoni A., "Applications of Critical Shear Crack Theory to Punching of Reinforced Concrete Slabs with Transverse Reinforcement", *ACI Structural Journal*, V. 106, No. 4, July-Aug. 2009, p. 485-494.
29. Marti, P., Alvarez M., Kaufmann W., Sigrist V., "Tension Chord Model for Structural Concrete", *Structural Engineering International,* V. 8, No. 4, Nov. 1998, p. 287-298.
30. Schenkel, M., "Zum Verbundverhalten von Bewehrung bei kleiner Betondeckung (On the Bond Behavior of Reinforcement with Little Concrete Cover)", *IBK Report,* No. 237, Sept. 1998, 162 p. (in German)
31. Zwicky, D., "Zur Tragfähigkeit stark vorgespannter Betonbalken (On the Load Bearing Capacity of Highly Prestressed Concrete Beams)", *IBK Report*, No. 275, Nov. 2002, 229 p. (in German)
32. Zwicky, D., "Structural Safety Assessment and Classification of Structures", *Structures and Extreme Events,* proc. IABSE Symp. Lisbon, Sept. 2005, pp. 351/352 + 8 p. on CD.