Compilation of a South African National Standard for the design of Liquid Retaining Structures

Volume II: Background to SANS 10100-3

Report to the
WATER RESEARCH COMMISSION

by

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This report forms part of a series of two reports. The other report is *Compilation of a South African National Standard for the design of Liquid Retaining Structures. Volume I: Compilation of SANS 10100-3* (WRC Report No. 2154/1/15)

EXECUTIVE SUMMARY

The technical background to the standard for the design of liquid retaining structures, for convenience referred to as SANS 10100-3 (WG Draft) *Design of concrete liquid retaining structures*, as compiled by the SABS Working Group and submitted to SABS TC98-02, is provided in this report. The technical background is compiled to assist future Working Groups in assessing SANS 10100-3 as input to future revisions of the Standard.

The technical background serves to report and record the technical basis for the decisions of the WG and records the critical input, motivations and decisions on which the published standard will be based. It serves the dual purpose of providing the information required for understanding the intentions of the standard and to allow for future development of subsequent editions of the standard.

A specific characteristic of SANS 10100-3 (WG Draft) is that for various reasons it is compiled as a single standard out of a number of reference standards. The point of departure was to base it on the relevant Eurocode Standards; although there is not a single self-contained Eurocode standard for liquid retaining structures. At the same time the standard should also be consistent with other local standards, particularly the general standard for structural concrete and the loading code. The Background Report therefore serves as a road map to referenced and related standards for structural design.

The Background Report concisely compiles information on which SANS 10100-3 (WG Draft) is based, consisting of the primary Eurocode Standard which provides for concrete liquid retaining structures (EN 1992-3:2006), the standard which serves as the *de facto* South African standard for liquid retaining structures (BS 8007), the related general structural concrete standards (EN 1992-1-1:2004; SANS 51992-1-1 (WG Draft); nominally also BS 8110); the Eurocode Standard which provides for actions on liquid retaining structures (EN 1991-4:2006), and lastly the South African Loading Code (SANS 10160:2011) with specific reference to the basis of structural design (SANS 10160-1:2011). A general source of background information from which information is abstracted is WRC Project K5-1764 Final Report (2010). The report WRC Project K5-2154-1 Guidelines for the Working Group (2012) which was compiled to motivate the New Work Item Proposal for a standard on the design of concrete liquid retaining structures and launching of a Working Group, also provides some general background information.

An overview is firstly provided of the relevant scope of the various reference documents and the way in which information from these references have been incorporated in SANS 10100-3 (WG Draft). Secondly, reference is made at a more detailed level of the basis of the various sections and where justified, the specific clauses of SANS 10100-3 (WG Draft) and the corresponding standard or source of information which is invoked in formulating the respective requirements or procedures.

The main stages of development of SANS 10100-3 consist of the following:

- Pre-normative draft, as compiled during WRC Project K5-1764 – Completed
- Working Group Draft (WG Draft) as modified and refined by the WG and submitted to SANS TC98-2 *Concrete Structures* – Completed
- Voted as Committee Draft (CD) by SC-2, for submission to SABS – Completed
- Converted into Draft SA Standard (DSS) through editing into required Standard format by SABS
- Publication by SABS for public comment; incorporating response to comment
- Publication as SA National Standard after approval by Standards Board.

ACKNOWLEDGEMENTS

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Finally, the members of the SANS 10100-3 Working Group deserves special gratitude, not only from the authors, but from the entire South African Civil Engineering Community, for their valuable contributions towards the creation of SANS 10100-3: *Design of concrete liquid retaining structures.*

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LIST OF ABBREVIATIONS

BS	British Standard
CD	Committee Draft
DSS	Draft South African Standard
EN	European Norms
LRS	Liquid Retaining Structures
NWIP	New Work Item Proposal
SA	South Africa
SABS	South African Bureau of Standards
SANS	South African National Standard
TC	Technical Committee
UK	United Kingdom
WG	Working Group
WRC	Water Research Commission

SANS 10100-3 (Draft)	Draft standard for the design of concrete liquid retaining structures, originating from WRC project K5/1764. It is an adapted version of EN 1992-3 (2006) incorporating some information and clauses from BS 8007.
SANS 10100-3 (TC Draft)	Draft standard accepted as SABS Technical Committee Draft by SABS TC98-02 through an official review and voting process. This document is ready for typesetting and distribution for public comment.
SANS 10100-3 (WG Draft)	Draft standard produced by the SANS 10100-3 Working Group.

1 INTRODUCTION

The technical background to the standard for the design of liquid retaining structures (LRS), for convenience referred to as SANS 10100-3 (WG Draft) *Design of concrete liquid retaining structures*, as compiled by the SABS Working Group and submitted to SABS TC98-02, is provided in this report. The technical background is compiled to assist future Working Groups in assessing SANS 10100-3 as input to future revisions of the Standard.

The technical background serves to report and record the technical basis for the decisions of the WG and records the critical input, motivations and decisions on which the published standard will be based. It serves the dual purpose of providing the information required for understanding the intentions of the standard and to allow for future development of subsequent editions of the standard.

A specific characteristic of SANS 10100-3 (WG Draft) is that for various reasons it is compiled as a single standard out of a number of reference standards. The point of departure was to base it on the relevant Eurocode Standards; although there is not a single self-contained Eurocode standard for liquid retaining structures. At the same time the standard should also be consistent with other local standards, particularly the general standard for structural concrete and the loading code. The Background Report therefore serves as a road map to referenced and related standards for structural design.

The Background Report concisely compiles information on which SANS 10100-3 (WG Draft) is based, consisting of:

- **EN 1992-3:2006** which is the primary Eurocode Standard providing for the design of concrete liquid retaining structures;
- **BS 8007**, the standard which serves as the *de facto* South African standard for liquid retaining structures;
- **EN 1992-1-1:2004 / SANS 51992-1-1 (WG Draft)**, the related general structural concrete standards; nominally also BS 8110;
- **EN 1991-4:2006**, the Eurocode Standard which provides for actions on liquid retaining structures and silos;
- **SANS 10160:2011**, the South African Loading Code, with specific reference to the basis of structural design (SANS 10160-1:2011);
- **WRC Project K5-1764 Final Report (2010)** serving as a general source of background information on design procedures for liquid retaining structures; and
- **WRC Project K5-2154-1 Guidelines for the Working Group (2012)** which was compiled to motivate the New Work Item Proposal for a standard on the design of concrete liquid retaining structures and launching of a Working Group also provides some general background information.

This report presents the background to SANS 10100-3 (WG Draft) consecutively in more detail, consisting of:

1. An overview of the relevant scope of the various reference documents and the way in which information from these references have been incorporated in SANS 10100-3 (WG Draft).
2. Reference is made at a more detailed level of the basis of the various sections and where justified, the specific clauses of SANS 10100-3 (WG Draft) and the corresponding standard or source of information which is invoked in formulating the respective requirements or procedures.
3. Extracts from the reference standards are provided for convenience in an appendix, where practical; alternatively the scope of relevant contents is provided.

The main stages of development of SANS 10100-3 consist of the following:

- **Pre-normative Draft**, as compiled during WRC Project K5-1764 – Completed.
- **Working Group Draft (WG Draft)**, as modified and refined by the WG and submitted to SABS TC98-02 *Concrete Structures.* This stage represents the main task of the WG – Completed.
- **Committee Draft (CD)** as voted by TC98-02 – Completed.
- **Draft South African Standard (DSS)** obtained through editing into required Standard format by SABS and checked for technical contents by TC98-02.
- **Published DSS** through publication by SABS for public comment and incorporating response to comments.
- **South African National Standard SANS 10100-3** publication as a SA National Standard after approval by the Standards Board.

2 OUTLINE OF REFERENCE STANDARDS AND SUPPORTING DOCUMENTS

The way in which the reference standards and documents are used or are related to SANS 10100-3 (WG Draft) is briefly reviewed here. Additional information on the standards is provided in the appendix; indicating the general scope of the standard, with emphasis on the section relevant to liquid retaining structures.

2.1 EN 1992-3 as primary reference

Following the replacement of BS 8007 by the equivalent Eurocode Standards, the approach taken was that Eurocode should also serve as primary reference for a future South African Standard for the design of liquid retaining structures. However, Eurocode does not provide a dedicated standard for this class of structure, but combine it with standards for silos for storage of granular solids and for general containment structures for storage of materials over the range -40°C to +200°C.

The most important task was therefore to extract only the requirements relevant to liquid retaining structures from EN 1992-3 in a logical and consistent manner. Liquid retaining structures generally require severe performance requirements as an important class of specialist structure, particularly with regard to serviceability. Nevertheless, EN 1992-3 primarily focusses on the complications deriving from silo design and temperature effects.

An issue to consider was whether the Eurocode standard format was going to be maintained, or to formulate the standard according to SANS format and layout, as was done. Format change is not allowed for adopted CEN / EN standards, but this restriction does not apply to the SANS 10100-3 standard, which is an adaptation of the above mentioned standard.

2.2 Provisions from BS 8007 for continuity with local practice

Important features from BS 8007 that have proven satisfactory and essential to local practice have been incorporated in the current draft of SANS 10100-3. In addition to the adapted procedures from EN 1992-3 and the various other reference standards, the extracts from BS 8007 represent quite a substantial portion of SANS 10100-3 procedures. The extracts from BS 8007 can be seen as giving more detailed guidance to the designer, expressly stating various design situations relevant to LRS that should be considered during the planning, design, detailing, construction, testing and operation phases of a project. The scope of SANS 10100-3 is maintained from that of BS 8007, outlining procedures relevant to the storage of liquids. EN 1992-3 on the other hand deals with LRS as part of a larger spectrum of containment structures which focuses mainly on the complex subject of Silos storing granular solids, thereby providing more general design guidance related to LRS. Specific procedures from BS 8007 included in the SANS 10100-3 (WG Draft) are:

- Basic requirements on floatation

- Design working life, durability and quality management
- Design situations (general guidance on load cases and combinations)
- Operational safety considerations
- Maintenance and operation
- Inspection and testing of the structure
- Deflections
- Reinforcement to control restrained shrinkage and thermal movement (Section 7 and Annex L)
- Surface zones in concrete members (Annex M)
- Depiction of details of movement joints given in Annex N
- Cylindrical prestressed concrete structures (Annex P)

2.3 EN 1992-1-1 / SANS 51992-1-1 as general standard

As part of a policy of sparse formulation applied to the Eurocode standards, EN 1992-3 only provides additional requirements and procedures relevant to its scope of structures as an extension to the general requirements and procedures given in EN 1992-1-1. The general standard for structural concrete is therefore an integral part of the design of liquid retaining structures. This is however not dissimilar to the relationship between BS 8007 and BS 8110.

Consistency between EN 1992-3 and EN 1992-1-1 will be transferred to SANS 10100-3 due to the process of adopting the Eurocode general standard for structural concrete EN 1992-1-1 as new South African standard SANS 51992-1-1 to replace SANS 10100-1. This removes any potential inconsistencies between SANS 10100-3 (WG Draft) and SANS 10100-1, which represents the conditions under which the draft standard was compiled.

2.4 EN 1991-4 providing basis of design and actions procedures

Provisions for loading on tanks for containment of liquids are included in EN 1991-4:2006 *Actions on structures – Silos and tanks* together with loading on silos containing granular solids. Due to the complicated nature of silo actions, this topic completely dominates the standard. Provisions for the basis of design, referring to performance requirements, design situations, partial load and combination factors; are also included in EN 1991-4:2006 and EN 1992-3:2006. These provisions are extensions of and consistent with the procedures provided in EN 1990:2002 *Basis of structural design*.

2.5 SANS 10160 serving as general loading code

Loads on tanks containing liquids are outside the scope of the South African Loading Code SANS 10160:2011 which is primarily directed towards buildings and *similar* industrial structures. In Part 1 nominal provision is made for *loads from fluids* (levels controlled or uncontrolled) and in Part 5 for hydrostatic loads in the geotechnical context. No explicit provision is however made for determining characteristic load values. Furthermore, the indicated partial factors for hydrostatic loads are not consistent with EN 1991-4.

Consideration of EN 1991-4 therefore provided the opportunity to ensure equivalent consistency and filling in of the gaps between SANS 10100-3 and SANS 10160 as is the case for EN 1992-3; EN 1991-4; EN 1990; EN 1991 in general.

Partial load and combination factors and definition of characteristic load values were taken from EN1991-4 and incorporated in Section 2 of SANS 10100-3 (WG Draft).

2.6 Considerations from WRC Project K5-1764

The WRC K5-1764 project set out to develop and calibrate a South African national standard for the design of LRS. The main investigations conducted towards the establishment of SANS 10100-3 procedures could be classified under: (1) *Basis of design*, (2) *Materials*, (3) *Detailing*, and (4) *Construction methods*. Given the various developmental and calibration exercises undertaken, much research is still required to either properly calibrate design models (especially for cracking), better or newly characterise material models to local data, and capture locally preferred details and construction methods. Where full development and calibration has not been achieved, prima facie procedures based on sound engineering judgement should be adopted in the interim, with research needs clearly identified and incorporated in future code revisions as appropriate. Some pertinent issues considered during the selection of the procedures for SANS 10100-3 (WG Draft) are reflected in the discussions that follow.

Basis of design

Basis of design is concerned with the methods that establish the requirements for safety, durability and serviceability of structures, with due regard to aspects of reliability. The selection of the partial and combination factors for hydraulic loads, calibration of the cracking model for the Serviceability Limit State (SLS), assessment of the performance and subsequent calibration of the design model for the shear design of members with stirrups, and proper calibration of key material models (E-modulus, creep, shrinkage) are the main basis of design issues relevant to the performance of LRS. It is pointed out in the K5-1764 report, however, that although the general principles for the development of reliability based design procedures are presented in Eurocode EN 1990 (consequently SANS 10160-1 as well), these principles are not fully applied to the formulation of design procedures for LRS. Therefore, much engineering judgement has been applied in providing for the basis of design requirements in SANS 10100-3 (WG Draft). In the absence of a rational calibration, Section 2 in SANS 10100-3 (WG Draft) has been extended to specify the normative actions, partial factors and combinations of actions for tanks as derived from EN 1991-4.

The onerous set of rules given in EN 1992-3 regarding cracking and its limits have been omitted in SANS 10100-3 until such a time that the crack width restrictions according to EN 1992-3 can be justified by a local study. Stringency or lack thereof in this regard highly influences and affects the cost of LRS and is thus a critical aspect that should be well defined through proper characterisation and calibration. Preliminary studies by the WG deemed EN 1992-3 provisions too stringent, especially for tension dominated design situations (circular reservoirs). Some possibly suitable adjustments to the EN 1992-3 prediction model needs consideration and are discussed in Section 4 of this report. In the interim, the limits for crack width from BS 8007 are maintained for use in SANS 10100-3. EN 1992-3 tightness classes are incorporated to aid designers in managing client expectations. More details are provided in Section 4 of this report.

Due to some concerns about the performance of EN 1992-1-1's design model for members with links, a note from the Eurocode Bridge code EN 1992-2 (2005) was included in SANS to encourage conservative shear designs thereby avoiding as much as possible the sporadic occurrence of shear cracks in this important class of structures. The WG however, deemed it unnecessary to include Annex QQ of EN 1992-2, providing for the control of shear cracks within webs.

In terms of basis of design procedures, the K5-1764 report mostly provides a general assessment which provides a sound platform for an in-depth investigation into the reliability performance of LRS. It is therein stated that the results of such in-depth investigations are not expected to be available in time for implementation in the proposed design procedures (the SANS 10100-3 WG Draft) but will provide expert knowledge to the support of subsequent specification and use of the procedures.

Materials

Some limited level of characterisation of various material models was achieved according to local data representative of South African conditions and practice. Where data was available, it was compared to either – or any combination of – SANS models, BS models, EN models and other internationally recognised models (CEB-FIP, RILEM). Where no test data was available, the predictions of the various models were compared through parametric analyses to gauge the differences in the design outcomes of the different models. In terms of the applicability and suitability of material models, an assessment for LRS provides limited research capacity in support of the models to be adopted in the general concrete standard. Hence, recommendations on material models from the K5-1764 report mostly warrant consideration by the WG on the revision of SANS 10100-1 (hereafter renamed to SANS 51992-1-1).

Material models relevant to LRS include compressive and tensile strengths of concrete and their development rates, E-modulus (stiffness) in relation to its associated parameters (strength, curing, temperature etc.), the influence of curing on material properties, the influence of formwork type on the heat of hydration, the relation between aggregate type and the coefficient of thermal expansivity, creep and shrinkage models, as well as the heat of hydration and strength evolution characteristics of various binder compositions. Some of the various materials issues taken into consideration for SANS 10100-3 (WG Draft) are:

- South Africa will maintain the cube strength specification of concrete compressive strength but, like the Eurocode, will provide a Table in the revised SANS 51992-1-1 giving the relationship between cube strengths and cylinder strengths.
- The tensile and compressive strength models from EN 1992-1-1 were found to generally apply and were recommended for use in the revised SANS 51992-1-1.
- Information on the E-modulus and its relation to aggregate type and strength development of concrete were recommended to be maintained in the revised versions of SANS 51992-1-1 as based on work by Alexander and Davis (1989, 1992a & b) on locally available aggregates for concrete.
- EN 1992-1-1's models for creep and shrinkage were found to generally apply but with a note not to consider curing and loading ages beyond 14 days.
- Recommended coefficients of thermal expansion of concrete are based on Bamforth (2007), as the same typical rock groups are found in SA and are extensively used for aggregate for concrete.

A concise treatment of all outstanding material model and characterisation issues for the current and future development are provided in *Guidelines for the Working Group (2012)*. In some instances where local data is scarce or not traceable, the K5-1764 report states that informative Annexes may be incorporated in SANS 10100-3 from comparable international research, as was done in Annex L. Aspects for incorporation in future revisions are discussed in Section 5 of this report.

Detailing and construction methods

Following an industry survey to capture the salient aspects of local conditions and practice, it was noted that designers tend to use in-house methods or experience as guidance for the determination and specification of some critical parameters. The K5-1764 report establishes that designers use parameters for temperatures (coefficient of thermal expansivity, heat of hydration) restraint factors and material parameters which they have accumulated from experience, or from experienced designers in their companies. A very similar situation exists for certain construction details which designer's specify on their drawings. Although joint details may have originated from the British code, there may be slight variances for local preferences. This information is accumulated by designers through experience. The need for information on some design parameters to be used in South Africa therefore exists and was considered by this WG. The joint details from BS 8007 have been included in Annex N of SANS 10100-3, with guidance on application and local preferences. T1 temperature rise values need to be validated through local studies, but in the interim are based on UK research reported in CIRIA C660 (2007). For the cases of coefficient of thermal expansivity and heat of hydration, UK research conducted by Bamforth (2007) has been suggested for use in SA. This decision is motivated mainly by the fact that the same base rock groups commonly used for aggregates in SA also exist in the UK; such referencing would also be in-line with the tradition of adopting British standards for local use.

3 BASIS FOR SANS 10100-3 (WG DRAFT) SECTIONS AND CLAUSES

The general formulation of SANS 10100-3 can be viewed to systematically consist of first identifying the procedures relevant for the design of LRS as extracted from the general EN 1992-3 standard for containment structures. Thereafter, additional procedures applicable to the design of LRS from various other sources, primarily BS 8007 to maintain consistency with local practice, are incorporated in a logical format to give rise to a competent design standard to aid in the design of local LRS's. Table 3.1 presents the basis of the pertinent issues considered during the establishment of the procedures in SANS 10100-3 (WG Draft).

Table 3.1 Basis of various design procedures included in SANS 10100-3 (WG Draft)

SECTION	CLAUSE	ISSUE / HEADING	SOURCE, TREATMENT & COMMENTS
1 General	1.1.3 (104)	Scope of design temperatures for liquids	Chosen to be in-line with local practice, somewhat increased compared to BS 8007.
2 Basis of Design	2.1.3	Design working life, durability and quality management	Taken from BS 8007. Considered as relevant guidance to the designer for LRS.
	2.3.1	Actions and environmental influences	Taken from EN 1991-4: Loads on tanks from liquids, as it is not treated in SANS 10160. In future it should be added to SANS 10160. Includes basis of design paragraphs for tanks, as well as characteristic values for actions; Supplementary to SANS 10160.
	2.3.1.12	Floatation	Taken from BS 8007. Considered as relevant guidance to the designer for LRS. Considered as an accidental load case, with partial and combination factors derived from EN 1991-4
	2.3.2	Materials and product properties	Taken from BS 8007. Considered as relevant guidance to the designer for LRS.
	2.4.2.6	Partial factors for actions	Taken from EN 1991-4: Loads on tanks from liquids, as it is not treated in SANS 10160.
	2.8	Design situations	Taken from BS 8007. Considered as relevant guidance to the designer for LRS.

Table 3.1(cont'd)

SECTION	CLAUSE	ISSUE / HEADING	SOURCE, TREATMENT & COMMENTS
2 Basis of Design	2.9	Structural considerations	Joints, Deflections and Testing of the structure taken from BS 8007. Considered as relevant guidance to the designer for LRS.
3 Materials	3.1.11	Heat evolution and temperature development due to hydration	Importance of heat evolution established but with little design guidance. The WG provided guidelines on concrete mix proportions to control heat of hydration (Section 4) and T1 design values (Annex L), but further research is required to improve on these.
4 Durability		Concrete mix proportions to control heat of hydration	General provisions based on practical experience. Guidelines on extension with fly ash or GGBS to control the heat of hydration are based on Fulton's Concrete Technology (1986 & 2009). The following reference extended binder was used as a benchmark, being a typical choice of reputable readymix producers: 70% CEM II A-M(V-L) 42.5R : 30% FA. The following rules of thumb for temperature rise per 100 kg material were used to calculate the percentage extender required to produce the same temperature rise as the benchmark binder: • 0ºC for limestone (own assumption). • 4ºC for FA (Fulton's 6th edition). • 6ºC for GGBS (Fulton's 6th edition). • 12-15ºC for SF (own assumption). • 12ºC for standard fineness clinker (Fulton's 6th edition) – CEM I 42.5. • 15ºC for high fineness clinker (own assumption) – CEM I 52.5.
		Durability indexes	General provisions based on practical experience. Guidelines on durability indexes and limits based on Alexander et al (2008).
6 Ultimate limit states	6.2.3 (109)	Conservatively apply $cot\ \theta = 1$ for shear design of members with links	Taken from the Bridge code EN 1992-2 to promote designing conservatively to avoid the sudden brittle shear cracking of LRS due to shear (diagonal tension).

Table 3.1(cont'd)

SECTION	CLAUSE	ISSUE / HEADING	SOURCE, TREATMENT & COMMENTS
7 Serviceability limit states	7.3.1	General considerations for cracking	The onerous set of rules for crack widths from EN 1992-1-1 are omitted pending justification from local investigation. BS 8007 limits are maintained and tied to EN tightness classes based on engineering judgment and practical experience. More details can be found in Section 4 of this background report. Choice of tightness class is currently left to the client/designer, but should in future be linked to exposure classes and other considerations. Exposure classes should be incorporated in the revised editions of SANS 10100-1, CC1 and CC2 on durability.
	7.3.2	Minimum reinforcement areas	Taken from BS 8007. Considered as relevant guidance to the designer for LRS.
	7.3.3	Control of cracking without direct calculation	Ditto.
	7.3.4	Calculation of crack width	The prediction model for crack widths from EN 1992-1-1 are omitted pending further research and local adjustment. Investigations by Kruger and McLoad showed conservative predictions compared to that of BS 8007, with significant economic implication especially for tension dominated design situations. BS8007 crack width prediction model is maintained. More details can be found in Section 4 of this background report. Concrete stiffening of 0.75MPa and 1.0MPa are respectively assumed for crack widths of 0.2mm and 0.1mm (Equations 7.108 & 7.109) Recommended coefficients of thermal expansion of concrete to be based on Bamforth (2007), as the same typical rock groups are found in SA and are extensively used for aggregate for concrete.

Table 3.1(cont'd)

SECTION	CLAUSE	ISSUE / HEADING	SOURCE, TREATMENT & COMMENTS
7 Serviceability limit states	7.3.5	Minimising cracking due to restrained imposed deformations	Taken from BS 8007. Considered as relevant guidance to the designer for LRS.
8 Detailing provisions	8.10	Prestressing	Taken from BS 8007. Considered as relevant guidance to the designer for LRS.
9 Detailing of members and particular rules	9.1 (104)	Reinforcement to control restrained shrinkage and thermal movement	Ditto.
	9.6	Reinforced concrete walls	Ditto.
	9.11	Prestressed walls	Ditto.

Table 3.1(cont'd)

SECTION	CLAUSE	ISSUE / HEADING	SOURCE, TREATMENT & COMMENTS
Annex L		Calculation of strains and stresses in concrete sections subject to restrained imposed deformations	Taken largely from BS 8007. Considered as relevant guidance to the designer for LRS. T1 design values were updated using the charts from CIRIA C660 (2007). Research needs to confirm these for SA concretes. A preliminary study (Harmse, 2014) found that these are acceptable for SA conditions. T1 values for concrete extended with Corex slag is needed. Alexander (2003) recommends that Corex slag extension should not be assumed to improve T1 values, i.e. 100% OPC mix T1 values should be assumed.
Annex M		Surface zones in concrete members	Taken from BS 8007. Considered as relevant guidance to the designer for LRS..
Annex N		Figure of joint details from BS 8007	Taken from BS 8007. Considered as relevant guidance to the designer for LRS. Substantial additional information regarding best practice provided based on practical experience.
Annex O		Effect of temperature on the properties of concrete	Taken from EN1992-3, to provide for increased temperature range of SANS 10100-3 compared to BS 8007.
Annex P		Cylindrical prestressed concrete structures	Taken from BS 8007. Considered as relevant guidance to the designer for LRS.
	P.1.(d)	Minimum circumferential compression	Taken from BS5337 (Previous British code for design of LRS). WG decision based on practical experience, to allow for tolerances in cable extensions (3-6%).
	P.1.(g)	Prestressing wires outside of walls	Discouraged based on practical experience (corrosion).
Annex Q		Guidelines for good construction practice	Guidelines provided by members of the working group based on practical experience.

4 SERVICEABILITY CONSIDERATIONS

Serviceability considerations as provided for in Section 7 and Annex L of SANS 10100-3 (WG Draft) typically govern the design of LRS. The current WG compared the provisions of BS 8007 to that of EN 1992 and concluded that EN 1992 provisions are unnecessarily conservative, especially for tension dominated design situations. It was thus decided to keep the BS 8007 provisions until the EN 1992 provisions could be validated or adjusted to reflect local practice and economic preferences.

This section discusses the relevant reference documents, local studies and experience, the provisions adopted by this WG and considerations for future revisions, respectively for provisions on crack width limits and crack width prediction models

4.1 Crack width limits

Overview of provisions in BS8007 and EN 1992-3

The British design code BS8007 simply specifies limits 0.2 mm for general purposes, and 0.1 mm for aesthetic reasons, developed from experimental and industry experience.

EN1992-3 first specifies a tightness class defined by the requirements for protection against leakage. Crack width limits (wk1) are then recommended depending on the tightness class required. Table 7.105 of EN 1992-3 defines the tightness classes as follows:

Class 0 Some degree of leakage acceptable, or leakage of liquids irrelevant.
Class 1 Leakage to be limited to a small amount. Some surface staining or damp patches acceptable.
Class 2 Leakage to be minimal. Appearance not to be impaired by staining.
Class 3 No leakage permitted

Class 0 does not apply to LRS. Class 1 tightness class would be the typical design situation for LRS. Class 2 would be used if the client requires. Class 3 applies in the case of harmful contents, or when ground water should be prevented from entering.

Class 1 structures may have some leakage, although crack healing is expected to occur where the range for service load strain is less than 150 x 10-6. There may be some cracks through the full section. Cracks are to be assumed to pass through the full section if alternate actions are applied to the section. The recommended maximum crack width for this class depends on the ratio of the hydrostatic pressure (h_D, expressed as head of water) to wall thickness (h). The crack width limits as determined by the hydraulic ratio for sections cracked through the full depth of section are:

$h_D / h \leq 5$ w_{k1} is 0.2 mm
$h_D / h \geq 35$ w_{k1} is 0.05 mm.

Autogenous healing of any cracks is expected to take place if these crack width limits are adhered to. For intermediate values of h_D/ h, crack widths may be interpolated.

Class 2 and 3 structures are expected to have cracks that do not pass through the full section. To achieve this, the depth of the compression zone is limited to a recommended value, x_{min}, which is the lesser of 50 mm or 0.2h (h being the section thickness). If Class 2 sections do have cracks passing through the section, then it is expected that appropriate measures are taken, such as prestressing and using liners. Class 3 structures require that special measures are taken (such as liners), but no specific guidance is given on the specification of those liners.

The crack width limits so specified are based largely on research done by Edvardsen (1999): Autogenous healing of cracks of 0,3 mm width and less was investigated for static and dynamic cracks under a direct tensile load and various water pressure heads. The static tests showed healing occurred over the test period. In the case of the dynamic tests on cracked sections 40 mm in thickness, crack width was varied over a one day cycle. Crack width was kept at a minimum value for 14 hours, and then increased by 30% for six hours. The EN 1992-1-1 crack width limit based on these 30% cycle findings is found to be very conservative. However, other researchers have found a link between hydraulic ratios and self-healing (for example, Jones, 2008). A reliability analysis by McLeod (2012) confirmed that decreasing the limiting crack width to 0,05 mm, with an associated negative economic implication, would be unnecessarily conservative without proper justification. Future incorporation of crack width limits that accounts for pressure head should be positively considered, but it is suggested that such future revision should consider basing crack width limits on the 10% cycle findings.

Feedback from practicing engineers was that EN 1992-1-1 Tightness classes would be useful to manage client expectations. Engineering judgment based on experience with the BS 8007 provisions and the above tightness application were used to provide crack width limits to correspond to the different tightness classes.

Provisions of SANS 10100-3

Practicing engineers noted that the EN 1992-1-1 Tightness classes would be useful to manage client expectations. For this purpose the EN 1992-1-1 Tightness classes were incorporated into Section 7 of SANS 10100-3, but related to BS 8007 crack width limits based on engineering practice and judgment. Tightness class 1 (surface staining and damp patches acceptable) was considered the typical design situation, corresponding to a crack width limit of 0.2 mm. Tightness class 2 (Appearance not to be impaired by staining) was related to the BS 8007 crack width limit of 0.1 mm, corresponding to critical aesthetic appearance.

Practicing engineers further noted that leakage problems in practice are often encountered in tension dominated designs. This may point to the BS 8007 crack width limit of 0.2mm not being stringent enough. However, it was the opinion of the WG that modelling of footing restraint may be the real culprit here: When determining load effects (by structural analysis or from tables), designers must ensure that the assumed boundary conditions reflect the actual boundary conditions.

For example: In circular tanks with a fixed wall-footing connection, wall footing rotation due to the elasticity of the founding material is typically enough to significantly increase the axial tension in the walls (compared to the values obtained for a fully fixed condition). A small increase in tension can result in a significant increase in predicted crack width for the same reinforcement configuration. The following sample of calculated values illustrates the effect (assuming Y10-300 reinforcing):

Table 4.1 Influence of soil stiffness on axial wall tension and predicted crack widths

Assumed soil stiffness	Axial wall tension	Predicted crack width
Infinite (fully clamped)	214 kN/m	0.21 mm
500 kPa	230 kN/m	0.28 mm
300 kPa	244 kN/m	0.34 mm
100 kPa	266 kN/m	0.44 mm
Hinged	316 kN/m	

4.2 Crack width prediction models

Serviceability cracking in LRS consists of restrained cracking (thermal and shrinkage) and load-induced cracking respectively, controlled primarily by means of a specified maximum crack width limit.

Overview of provisions in BS8007 and EN 1992

Comparing the crack width prediction models to BS8007 and EN 1992, both have been developed according to the cause of cracking, namely, load-induced cracking and deformation-induced cracking (which includes early-age shrinkage cracking). BS8007 has separate crack prediction equations for load-induced cracking in mature concrete (Appendix B) and that caused by temperature and moisture effects (Appendix A). These models were developed empirically using parameters specific to the United Kingdom, and are thus not always applicable to South African conditions, for example, climatic factors. Local practicing engineers have through experience adapted relevant parameters.

EN1992's crack prediction model is more rationally based on a bond-slip model and was developed from the compatibility relationship for cracking in the stabilised cracking phase,

$$w_m = S_{rm} \,.\, \varepsilon_m$$

where w_m is mean crack width, S_{rm} is mean crack width and ε_m is the mean strain. Mean crack width is calculated using:

$$S_{rm} = k.c + 0{,}25\ k_1 k_2\ \varphi/\rho$$

where φ is the bar diameter (mm), c is the cover to the longitudinal reinforcement, k_1 is a coefficient taking into account of the bond properties of the bonded reinforcement, k_2 is a coefficient allowing for the distribution of strain, and k is a factor allowing for the influence of concrete cover on the crack spacing. Mean strain is the difference between the mean tensile strain in the reinforcement and in the concrete, allowing for tension stiffening, and determined according to whether cracking is load-induced or deformation-induced. EN1992-1-1 gives the formulation for strain due to load-induced cracking, whilst EN1992-1-3 defines equations for strain due to restrained cracking.

The design crack width ($w_{k,max}$) is taken as a maximum characteristic value having a probability of exceedence of 5%, such that

$$w_{k,max} = 1{,}7\ w_m = (1{,}7\ S_{rm})\ .\ \varepsilon_m = S_{r,max}\ .\ \varepsilon_m$$

where $S_{r,\ max}$ is the maximum crack spacing, determined from

$$S_{r,max} = k_3.c + k_1 k_2 k_4 \varphi\ /\rho_{p,eff}$$

The values of k_3 and k_4 are Nationally Determined Parameters. EN 1992 uses the same formulation for crack spacing for both load-induced and restrained cracking due to imposed deformations.

There has been much debate in Europe regarding the EN 1992 crack width equations. Countries such as Germany and France have proposed changes to the coefficients in the crack spacing formulation, $S_{r,max}$, which are tabled below.

Table 4.2 Summary of EN 1992 k_i values: as applied to maximum crack spacing

Factor	EN1992 (UK)	Germany	France
Bond k_1 (ribbed bars)	0,8	1,0	0,8
Loading k_2 (tension) (flexure)	1,0 0,5	1,0	1,0 0,5
k_3	3,4 = 1,7 x 2	0	c ≤ 25: 3,4 c > 25: $3{,}4(25/c)^{2/3}$
k_4	0,425 = 1,7 x 0,25	0,278 = 1.112 x 0,25	0,425

Relevant research

Research by Caldentey *et al* (2013) showed that the influence of concrete cover on crack spacing is overestimated by the factor k_3. Germany proposes that this influence is zero. However, research shows that concrete cover does have an influence on crack spacing.

Recent research led to the release of the model code MC2010 (Balazs, 2013) which constitutes the fundamental philosophy behind Eurocode. Changes to the crack width model are proposed which reflect updated information on crack width prediction models.

Further to the Master's research by McLeod (2012), an investigation on load-induced cracking is currently being carried out by McLeod into an updated EC crack prediction model applicable to South African conditions; leading to a PhD publication which should be available for consideration at the next revision of SANS 10100-3. Key issues identified to date for investigation are:

- Model uncertainty of the EN 1992 crack prediction model
- Influence of concrete cover
- Tension stiffening model, especially for long term loading
- Influence of stirrups and transverse reinforcement
- Crack width limit

Provisions of SANS 10100-3

Design crack width calculations were performed by McLeod (2012) and Kruger (2013) using both codes for typical LRS and load-induced cracking. For limiting crack widths 0.2 mm, 0.1 mm and 0.05mm, the quantity of reinforcement was determined for each code. It was found that the EN 1992 crack model is conservative compared to that of BS8007, particularly for direct tension where EN 1992 required more than twice the reinforcement of BS 8007 to satisfy the same crack width.

The EN 1992 crack model limits the tension stiffening effect that is accounted for in predictions. According to Mr. Robin Atkinson (2012), applying a lesser reduction of the tension stiffening effect may be one way to improve the seemingly over conservative predictions of EN 1992, especially in tension dominated designs.

Based on the above comparisons (of load induced cracking) by McLeod and Kruger, the WG decided to keep the prediction models (including the restrained crack models) of BS 8007 in the current development. However, positive consideration should be given in future revisions to adopt or adapt the more rationally based EN 1992 provisions for local use. The EN 1992 crack model for restrained cracking especially seems to provide predictions comparable to that of BS 8007, but with a much improved rational basis, as described in CIRIA C660 (2007).

The BS8007 prediction model for cracking due to restrained deformations, currently adopted in SANS 10100-3 focus on thermal effects, provision for creep and shrinkage being made by a fixed value. The EN 1992 model differentiates between early age and long term restrained deformation and allows better definition of thermal, shrinkage and restraint input parameters.

Information on the influence of formwork type and binder composition on the heat of hydration provided in Annex L of SANS 10100-3 was taken from the CIRIA C660 (2007) report (Annex L). These values are based on UK cements and extenders. An initial investigation (Harmse, 2014) found the T1 values to be acceptable for SA conditions. However, further validation of the values for South African materials is needed. Harmse provided possible adjustments to account for placing temperature, wind speed etc. Corex slag extension does not provide similar reductions in the heat of hydration achieved by

GGBS. Alexander (2003) advises that T1 values for pure OPC should be used for Corex extended mixes.

5 POSSIBLE NATIONAL ANNEXES FOR FUTURE REVISIONS OF SANS 10100-3

In addition to the National Annexes that have already been established as part of SANS 10100-3 (WG Draft), numerous other National Annexes dealing with various issues may be included in future revisions of the code. The recommendations for additional National Annexes stem from the K5-1764 report and from needs identified by the WG which could not be addressed in the current cycle. The additional aspects to consider for future incorporation into SANS 10100-3 as NA's include:

- Guidance on the construction of precast reservoirs outlining all relevant design, construction, operation and maintenance issues to be considered.
- The influence of binder composition or aggregate type on E-modulus.
- The influence of curing on E-modulus.
- The influence of humidity on drying shrinkage. Drying shrinkage have been shown to play an important role in design for long term restrained deformation, with relative humidity being the driving force behind this type of shrinkage. The current BS 8007 crack prediction model does not account for this explicitly, but assumes a drying shrinkage value implicitly. The BS 8007 model also does not distinguish between short- and long term strains. The EN crack prediction model explicitly takes drying shrinkage and the effect of humidity into account. A future move to an adapted version of the EN crack prediction model should allow SA to improve on provisions for drying shrinkage as well. Humidity within buildings is typically low, which should be considered when basements are designed to exclude water. On the other hand, Gaylard (2013) has proposed a method to calculate shrinkage for South African concretes. The findings of this study were that "international models generally over-predict the shrinkage of South African concretes." The model proposed by EC2 was amongst those found to over-predict
- South African conditions, particularly highlighting the problems that can occur due to pure water found in mountain streams and rain water.
- Updating and/or confirming the T1 temperature rise values in Annex L for South African concretes.

6 FUTURE UPDATING OF BACKGROUND REPORT

Provision is made in the activities and record keeping of the WG for the ultimate preparation of the final version of the Background Report:

- The WG will be responsible for addressing issues raised by public comment prior to publication.
- The WG must record all public comments which result in modifications of SANS 10100-3 (WG Draft) and the background to such decisions.
- An updated version of this report must be compiled after publication of SANS 10100-3.
- The contents of this report must be placed on public record through an appropriate form of publication, such as a WRC report, and/or summarised in a local journal publication, such as the Concrete Beton journal published by CSSA.

7 CONCLUSIONS

The technical background to the WG draft standard for the design of liquid retaining structures (SANS 10100-3 (WG Draft)) has been reviewed in this report. The report can be considered as operational material for use by future WG's to assist in its systematic review and updating. It serves to highlight the main references as well as the way in which they were considered in deriving the current provisions of SANS 10100-3 (WG Draft).

In retrospect, many issues still require proper calibration and characterisation not only on a national, but international platform as well, mostly concerning the establishment of rational design procedures for LRS based on the principles of structural reliability. Further characterisation of material models to local data is warranted, particularly concerning information on the strength evolution of concrete exposed to different curing regimes, the heat evolution of concretes comprising different local binder compositions as well as the coefficient of thermal expansivity in relation to the respective aggregate used locally in South Africa. However, in the interim, sound engineering judgement was used to select appropriate procedures for critical design parameters for incorporation in SANS 10100-3 where no credible or convincing local data is available.

8 REFERENCES

Alexander, M.G., & Davis, D.E., (1989). *Properties of aggregates in concrete, Part 1.* Hippo Quarries Technical Publication, 44p.

Alexander, M.G., & Davis, D.E., (1992a). *Properties of aggregates in concrete, Part 2.* Hippo Quarries Technical Publication, 48p.

Alexander, M.G., & Davis, D.E., (1992b). *The influence of aggregates on the compression strength and elastic modulus of concrete*, The Civil Engineer in South Africa, May 1992, Vol. 34, No. 5, pp 161-170

Alexander, M.G., Ballim, Y., & Stanish, K., (2008). *A framework for use of durability indexes in performance-based design and specifications for reinforced concrete structures*. Materials & Structures, Vol. 41, No. 5, pp. 921-936.

Alexander, M.G., Jaufeerally, H. & Mackechnie, J.R., (2003). *Structural and durability properties of concrete made with Corex slag*. Department of Civil Engineering, University of Cape Town.

Bamforth, P.B., (2007). *Early-age thermal crack control in concrete*. CIRIA 660. CIRIA London, MWL Digital, UK.

Balazs et al., (2013). *Design for SLS according to fib Model Code 2010.* Structural Concrete Vol. 14, No. 2.

Caldentey A.P., Peiretti H.C., Iribarren J.P. & Soto A.G., (2013). *Cracking of RC members revisited: influence of cover, $\varphi/\rho_{s,ef}$ and stirrup spacing – an experimental and theoretical study.* Structural Concrete, Vol. 14, No. 1.

Collins, M.P., & Mitchell, D., (1987). *Prestressed Concrete Basics.* Canadian prestressed concrete.

Edvardsen, C., (1990). *Water permeability and autogenous healing of cracks in concrete*, ACI Materials Journal, August 1999, Vol. 96, No. 4, pp 448-454

EN 1990 (2002). *Eurocode – Basis of structural design*. European Committee for Standardisation (CEN), Brussels.

EN 1991-4 (2006). *Eurocode 1: Actions on structures – Part 4: Silos and tanks*. European Committee for standardisation (CEN), Brussels.

EN 1992-1-1 (2004). *Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings.* European Committee for Standardisation (CEN), Brussels.

EN 1992-5 (2005). *Eurocode 2: Design of concrete structures – Part 2: Concrete bridges – Design and detailing rules*. European Committee for Standardisation (CEN), Brussels.

EN 1992-3 (2006). *Eurocode 2: Design of concrete structures – Part 3: Liquid retaining and containment structures*. European Committee for Standardisation (CEN), Brussels.

Fulton's Concrete Technology, 6th edition, (1986). *Chapter 14: Manufacture of concrete – Heat of hydration*, pp 701-735.

Fulton's Concrete Technology, 9th edition, (2009). *Chapter 15: Thermal properties of concrete and temperature development at early ages in large concrete elements,* pp 273-286.

Gaylard, P., Ballim, Y. and Fatti, P., (2013) *A model for the drying shrinkage of South African Concretes*, Journal of the South African Institution of Civil Engineering, Vol. 55, Nr. 1.

K5-1764 (1000841): Water Retaining Structures, (2010). *Water Research Commission – The development and calibration of South Africa's National Standards for water retaining structures*. Institute of structural engineering (ISI), University of Stellenbosch.

K5-2154-1: Guidelines for the Working Group, (2012). *Water Research Commission – The implementation of a South African National Standard for the design of water retaining structures.* Institute of structural engineering (ISI), University of Stellenbosch.

Kruger, H.G., (2013). *Report on EC 2 clause 7: Crack control.* Report to the WG on SANS 10100-3.

Kruger, H.G., (2013). *EC2 crack width calculation method – A South African perspective.* Presentation at the Advanced Seminar: Design of liquid retaining structures, University of Stellenbosch, Midrand, August 2013.

McLeod, C., (2012). *Investigation into cracking in reinforced concrete water retaining structures.* MSc Eng. thesis, University of Stellenbosch.

SANS 10100-1 (2000). *The structural use of concrete – Part 1: Design.* South African Bureau of Standards, Pretoria.

SANS 10100-3: Draft, *SANS 10100 Part 3 – Design of concrete liquid retaining structures*.

SANS 10160-1 (2010). *Basis of structural design and actions for buildings and industrial structures. Part 1 to 7*. South African Bureau of Standards, Pretoria.

SANRAL (2011). *Concrete durability specification.* Available on www.sanral.co.za

Nganga, G. and Alexander, M.G., (2011). *Evaluation of the implementation of durability index based performance specifications*. RILEM International Conference on Advances in Construction Materials through Science and Engineering. Hong Kong, RILEM Publications s.a.r.l., Paris, 7 pp.

Alexander, M.G., (2004). *Durability indexes and their use in concrete engineering*. (2004) Proceedings, International RILEM Symposium: Concrete Science and Engineering, a Tribute to Arnon Bentur, Eds. K Kovler, J Marchand, S Mindess, and J Weiss, Evanston, Illinois, RILEM, PRO 36, pp. 9-22.

APPENDIX A: Outline of Reference Documents for SANS 10100-3 (WG Draft)

EN 1992-3:2006 ***Design of concrete structures: Liquid retaining and containment structures***

SCOPE OF STANDARD

Consider the general scope of EN 1992-3:2006 as defined in clause 1.1.2, providing for liquids (although for leakage and durability, this code mainly covers aqueous liquids) and granular soils (silos):

1.1.2 Scope of Part 3 of Eurocode 2

(101)P Part 3 of EN 1992 covers additional rules to those in Part 1 (EN 1992-1-1) for the design of structures constructed from plain or lightly reinforced concrete, reinforced concrete or prestressed concrete for the containment of liquids or granular solids.

CONTENTS OF STANDARD

The table of contents provides a summary of the contents of EN 1992-3.

Table of Contents

EN 1991-4:2006 *Actions on structures: Silos and tanks*

Scope of Standard: Consider the general scope of EN 1991-4:2006 as defined in clause 1.1.2, providing for silos for particulate solids and tanks for liquids; with the standard dominated by procedures for silo related actions.
An extract of the sections relevant to tanks is provided below, with the sections indicated in an abbreviated table of contents.

ABBREVIATED TABLE OF CONTENTS

EXTRACT OF SECTIONS RELEVANT TO TANKS

The sections specifically addressing actions related to the design of tanks are presented below. In a few cases, the general clauses which apply to both silos and tanks are also presented. The bulk of the standard is however concerned with the complex actions on silos.

1.1.2 Scope of EN 1991-4 actions on structures: silos and tanks

(1)P This part provides general principles and actions for the structural design of silos for the storage of particulate solids and tanks for the storage of fluids and shall be used in conjunction with EN 1990, other parts of EN 1991 and EN 1992 to EN 1999.

(2) This part includes some provisions for actions on silo and tank structures that are not only associated with the stored solids or liquids (e.g. the effects of thermal differentials, aspects of the differential settlements of batteries of silos)

(8) The design rules for tanks apply only to tanks storing liquids at normal atmospheric pressure.

(9) Actions on the roofs of silos and tanks are given in EN 1991-1-1, EN 1991-1-3 to EN 1991-1-7 and EN 1991-3 as appropriate.

2.2 Representation of actions on tanks

(1)P Loads on tanks due to liquids shall be represented by a hydrostatic distributed load.

(2) The characteristic value of actions on tanks defined in this standard are intended to correspond to values that have a probability of 2 % that they will be exceeded within a reference period of 1 year.

NOTE: The characteristic values are not based on a formal statistical analysis because such data is not currently available. Instead they are based on historical values used in earlier standards. The above definition corresponds to that given in EN 1990.

Section 3 Design situations

3.1 General

(1)P Actions on silos and tanks shall be determined using the general format for each relevant design situation identified in accordance with EN 1990.

NOTE: This does not mean that the paragraphs and values specified for buildings and bridges in EN 1990, A.1 and A.2 are applicable to silos and tanks.

(2)P Selected design situations shall be considered and critical load cases identified. For silos, the design situations shall be based on the flow characteristics of the stored particulate solid, as determined in accordance with Annex C.

(3)P For each critical load case the design values of the effects of actions in combination shall be determined.

(4)P The combination rules depend on the verification under consideration and shall be identified in accordance with EN 1990.

NOTE: Relevant combination rules are given in Annex A.

(5) The actions transferred from adjoining structures should be considered.

3.5 Design situations for stored liquids in tanks

(1)P Loads on tanks from the stored liquid shall be considered both when the tank is in operation and when it is full.

(2) Where the operational liquid level is different from the level when the tank is full, the latter should be considered as an accidental design situation.

Section 7 Loads on tanks from liquids

7.1 General

(1)P The following rules shall be used to determine the characteristic values of pressure loads from the liquid stored in tanks.

NOTE 1: These rules are valid for static conditions in all types of tanks, but tanks in which dynamic phenomena may occur are not included.

NOTE 2: A list of relevant actions, partial factors and combinations of actions on tanks may be found in Annex B.

7.2 Loads due to stored liquids

(1) Loads due to liquids should be calculated after considering:

- a defined range of liquids to be stored in the tank;
- the geometry of the tank;
- the maximum possible depth of liquid in the tank.

(2) The characteristic value of pressure p should be determined as:

$p(z) = \gamma z$ … (7.1)

where:

z is the depth below the liquid surface;

γ is the unit weight of the liquid.

7.3 Liquid properties

(1) The densities given in EN 1991-1-1, Annex A should be used.

7.4 Suction due to inadequate venting

(1)P Where the venting system to a tank may be susceptible to blockage or impediment, a rational analysis shall be used to determine the suction pressures arising during tank discharge at the peak rate. This analysis shall consider the possible adiabatic nature of the process.

Annex A (Informative) **Basis of design – supplementary paragraphs to EN 1990 for silos and tanks**

EDITORIAL NOTE: This annex is for information only and will be transferred to EN 1990 after Formal Vote.

A.1 General

(1) In principle the general format given in EN 1990 for design procedures is applicable. However silos and tanks are different to many other structures because they may be subjected to the full loads from particulate solids or liquids for most of their life.

(2) This annex provides supplementary guidance applicable to silos or tanks regarding partial factors on actions (gF factors) and on combinations on silos and tanks with other actions; and the relevant y factors.

(3) Thermal actions include climatic effects and the effects of hot solids. Design situations that should be considered include:

- hot solid or liquid filled into a partly filled silo or tank. The effects of heated air above the stored material should be considered;
- resistance of the stored solid to silo wall contraction during cooling.

(4) Determination of the effect of differential settlements of batteries of silo or tank cells should be based on the worst combination of full and empty cells.

A.2 Ultimate limit state

A.2.1 Partial factors γ

(1) The values given in EN 1990, A.1 may be used for the design of silos and tanks.

(2) If the maximum depth of liquid and the unit weight of the heaviest stored liquid are defined, the value of the partial factor γ_F may be reduced from 1,50 to 1,35.

A.2.2 Combination factors Ψ

(1) For the combination factors Ψ for silo loads and tank loads and combination factors with other actions, see A.4.

Annex B (Informative) **Actions, partial factors and combinations of actions on tanks**

EDITORIAL NOTE: This annex is for information only and will be transferred to EN 1990 after Formal Vote.

B.1 General

(1)P The design shall take account of the characteristic values of the actions listed in B.2.1 to B.2.14.

(2) The partial factors on actions according to B.3 and the action combination rules according to B.4 should be applied to these characteristic values.

B.2 Actions

B.2.1 Liquid induced loads

(1)P During operation, the load due to the contents shall be the weight of the *product to be stored from maximum design liquid level* to empty.

(2)P During test, the load due to the contents shall be the weight of the *test medium from maximum test liquid level* to empty.

B.2.2 Internal pressure loads

(1)P During operation, the internal pressure load shall be the load due to the specified minimum and maximum values of the internal pressure.

(2)P During test, the internal pressure load shall be the load due to the specified minimum and maximum values of the test internal pressure.

B.2.3 Thermally induced loads

(1) Stresses resulting from restraint of thermal expansion may be ignored if the number of load cycles due to thermal expansion is such that there is no risk of fatigue failure or cyclic plastic failure.

B.2.4 Self-weight loads

(1)P The self-weight loads on the tank shall be considered as those resulting from the weight of all component parts of the tank and all components permanently attached to the tank.

(2) Numerical values should be taken from EN 1991-1-1, Annex A.

B.2.5 Insulation

(1)P The insulation loads shall be those resulting from the self-weight of the insulation.

(2) Numerical values should be taken from EN 1991-1-1, Annex A.

B.2.6 Distributed imposed load

(1) The distributed imposed load should be taken from EN 1991-1-1 unless specified by the client.

B.2.7 Concentrated imposed load

(1) The concentrated imposed load should be taken from EN 1991-1-1 unless specified by the client.

B.2.8 Snow

(1) The loads should be taken from EN 1991-1-3.

B.2.9 Wind

(1) The loads should be taken from EN 1991-1-4.

(2) In addition, the following pressure coefficients may be used for circular cylindrical tanks, see figure B.1:

a) internal pressure of open top tanks and open top catch basin: c_p = -0,6.

b) internal pressure of vented tanks with small openings: c_p = -0,4.

c) where there is a catch basin, the external pressure on the tank shell may be assumed to reduce linearly with height.

(3) Due to their temporary character, reduced wind loads may be used for erection situations according to EN 1991-1-4 and EN 1991-1-6.

B.2.10 Suction due to inadequate venting

(1) The loads should be taken from section 7 of this standard.

B.2.11 Seismic loadings

(1)P The loads shall be taken from EN 1998-4, which also sets out the requirements for seismic design.

B.2.12 Loads resulting from connections

(1)P Loads resulting from pipes, valves and other items connected to the tank and loads resulting from settlement of independent item supports relative to the tank foundation shall be taken into account. Pipework shall be designed to minimize loadings applied to the tank.

B.2.13 Loads resulting from uneven settlement

(1)P Settlement loads shall be taken into account where uneven settlement can be expected during the lifetime of the tank.

B.2.14 Accidental actions

(1) The loads should include the consequences of events such as external blast, impact, adjacent external fire, explosion, leakage from the inner tank, roll over and overfilling of the inner tank.

NOTE: These loads may be specified in the National Annex, or by the client for the individual project.

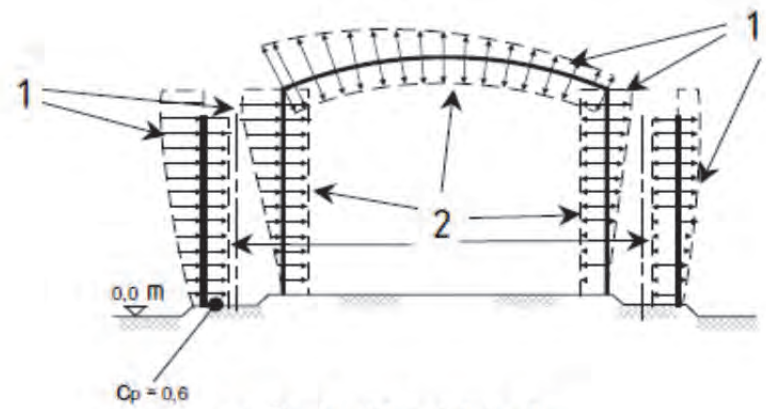
B.3 Partial factors for actions

(1)P The partial factors according to EN 1990 shall be applied to the actions B.2.2 to B.2.14.

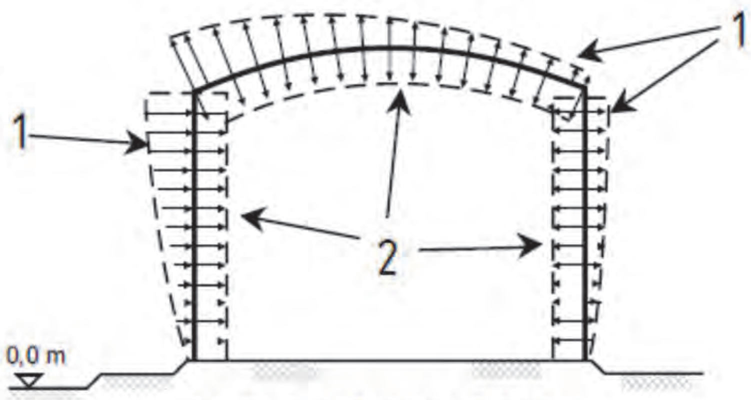
(2) The recommended value of the partial factor for the liquid induced loads during operation (see B.2.1(1)) is γ_F = 1,20.

(3) The recommended value of the partial factor for the liquid induced loads during test (see B.2.1(2)) is γ_F = 1,00.

(4) For accidental design situations, the recommended value of the partial factor for the variable actions is γ_F = 1,00.



a) Tank with catch basin



b) Tank without catch basin

Key

1 C_p according to EN 1991-1-4

2 C_p = 0,4 vented tank only

Figure B.1: Pressure coefficients for wind loading on a circular cylindrical tank

B.4 Combination of actions

(1)P The general requirements of EN 1990, Section 6 shall be followed.

(2) It is recommended that imposed loads and snow loads need not be considered to act simultaneously.

(3) It is recommended that seismic actions need not be considered to act during test conditions.

(4) It is recommended that accidental actions need not be considered to act during test conditions, but that the combination rules for accidental actions given in EN 1990 are applied