Background to the Draft SA National Standard for the design of water retaining structures

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ABSTRACT

The technical background to the draft standard for the design of water retaining structures is provided in this paper. SANS 10100-3 (Draft) Design of concrete water retaining structures, has been developed under a WRC project (K5-1764) and serves as input to a SABS TC98 Working Group (WG) to draft the National Standard. The background information serves the purpose of providing the information required by the WG for understanding the technical basis and intentions of the draft standard. Modification of the draft standard into a South African National Standard (SANS) will require an extension of the present background to record the motivation for the decisions of the WG. This information will allow for effective future development of subsequent editions of the standard.

An overview is provided of the scope of the various reference documents containing the technical basis and the way in which information from these references have been incorporated in SANS 10100-3 (Draft). Reference is then made at a more detailed level to the basis of the various sections of the draft standard. Specific clauses and those of the corresponding standard or reference source of information which are invoked in formulating the respective requirements or procedures are emphasised where justified.

1. INTRODUCTION

A draft standard for the design of concrete water retaining structures was developed as part of a Water Research Commission Project. For convenience this draft standard is referred to as SANS 10100-3 (Draft) Design of concrete water retaining structures. The final project report (WRC 1764 2010) presents both the draft standard and the technical basis for its formulation consisting of both the critical assessment of related reference standards an research particularly directed to provision for local conditions.

SANS 10100-3 (Draft) is intended to serve as the point of departure for the formal standards development process under the appropriate SABS Technical Committee structure ultimately to be approved and published as a South African National Standard (SANS). This paper extracts and summarises the technical basis for the draft standard from the investigations reported in WRC 1764 (2010) to serve as a background report for the present draft. This provides both the motivation for the procedures of the draft standard and an appreciation of its intentions.

Although the background report to the draft standard is primarily aimed at the intended Working Group (WG) who will have the responsibility for developing the final version, it also provides a summary of critical issues related to the design of water retaining structures in South Africa, which should be of general interest. The subsequent stages of development of the draft standard should consist of expert input by the WG and public comment of the Draft South African Standard (DSS). The present background report will need to be modified to reflect the final technical basis for modifications following from this development and review process. The final background report should serve as archive for future updating of the standard, provide some insight to designers, and may serve as input to a commentary for a guidance document.

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

The reference standards and supporting documents on which SANS 10100-3 (Draft) is based, consists of:

(i) **EN 1992-3:2006**, which is the primary Eurocode Standard providing for the design of concrete water retaining structures, as part of the more general scope of silos and tanks (EN 1992-3, 2006);

(ii) **BS 8007:1987**, the standard which serves as the de facto South African standard for water retaining structures (BS 8007, 1987);

(iii) **EN 1992-1-1:2004**, which is at an advanced stage of being adopted as the new South African standard for structural concrete design (EN 1992-1-1, 2004);

(iv) **SANS 51992-1-1 (WG Draft)** (SANS 51992-1-1 WGD, 2013), similar to the relationship between BS 8007 and the general structural concrete standards and BS 8110;

(v) **EN 1991-4:2006**, the Eurocode Standard which provides for actions on water retaining structures and silos (EN 1991-4, 2006);

(vi) **SANS 10160:2011**, the South African Loading Code, with specific reference to the basis of structural design (SANS 10160-1:2011);

(vii) **WRC Project K5-1764 Final Report (2010)**, serving as a general source of background information on design procedures for water retaining structures (WRC K5-1764, 2010); and

(viii) **Guidelines for the Working Group**, a document which was compiled to motivate the New Work Item Proposal for a standard on the design of concrete water retaining structures and launching of a Working Group, also provides some general background information (WRC K5-2154-1, 2012).

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

(i) An overview of the scope of the various reference documents and the way in which information from these references has been incorporated in SANS 10100-3 (Draft).

(ii) The basis of the various sections and, where justified, the specific clauses of SANS 10100-3 (Draft) and the corresponding standard or source of information which is invoked in formulating the respective requirements or procedures.

The process of the development of a South African National Standard on the design of concrete water retaining structures consists of a number of stages as follows, with this paper providing the background at the completion of stage (i):

(i) **Pre-normative Draft**, as compiled during WRC Project K5-1764 – Completed.

(ii) **Working Group Draft (WGD)**, as modified and refined by the WG – to be submitted to SANS TC98 SC-2 Concrete Structures.

(iii) **Committee Draft (CD)** to be approved by ballot by SC-2, before submission to SABS for final review and approval.

(iv) **Draft South African Standard (DSS)** obtained through editing into required Standard format by SABS and checked for technical content by TC98 SC-2.

(v) **Published DSS** through publication by SABS for public comment and incorporating response to comments.

(vi) **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 (D) is briefly reviewed herein.

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 water retaining structures. However, Eurocode does not provide a dedicated standard for this class of structure, but combines this class 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 is therefore to extract only the requirements relevant to water retaining structures from EN 1992-3 in a logical and consistent manner. Water 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 is whether the Eurocode standard format is to be maintained, or to formulate the standard according to the SANS format and layout. Format change is not allowed in adopted CEN / EN standards, but this restriction will not apply to the intended SANS 10100-3 standard, which will be an adaptation of the aforementioned 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 WRS 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 at ambient temperatures below 35 °C (commonly found in swimming pools and industrial structures). EN 1992-3 on the other hand deals with WRS 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 WRS. Specific procedures from BS 8007 included in the SANS 10100-3 draft are:

- Basic requirements on flotation
- 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
- Surface zones in concrete members (Annex C)
- Depiction of details of movement joints given in Annex N

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 water 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 the future 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 (D) and the present 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 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 provides the opportunity to ensure equivalent consistency and filling in 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.

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 WRS, of which SANS 10100-3 (Draft) was one of the outcomes. 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. Where full development and calibration have 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 (Draft) are reflected in the discussions that follow.

2.6.1 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 (elastic modulus, creep, shrinkage) are the main basis of design issues relevant to the performance of WRS. It is pointed out in the K5-1764 report (WRC K5-1764 2010) 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 WRS. Therefore, much engineering judgement has been applied in providing for the basis of design requirements in SANS 10100-3 (Draft). In the absence of a rational calibration, Annex B in SANS 10100-3 (Draft) has been established to specify the 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 (Draft) until such a time that appropriate crack width criteria can be justified by a local study. Stringency or lack thereof in this regard highly influences and affects the cost of WRS and is thus a critical aspect that should be well defined through proper characterisation and calibration. In the interim, the limits for crack width from BS 8007 (related to EN 1992-1-1 exposure class) are incorporated for use in SANS 10100-3 (Draft).

In terms of basis of design procedures, the K5-1764 report mostly provides a general assessment which gives a sound platform for an in-depth investigation into the reliability performance of WRS. 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 but will provide expert knowledge to the support of subsequent revisions.

2.6.2 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 were available, it was compared to either SANS models, BS models, EN models and other internationally recognised models (CEB-FIP, RILEM), or a combination thereof. 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 WRS 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). If not incorporated in SANS 51992 1 1, a separate procedure may be incorporated specifically for WRS in an informative Annex of SANS 10100-3.

Material models relevant to WRS include compressive and tensile strengths of concrete and their development rates, elastic modulus (stiffness) in relation to its associated parameters (strength, curing 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 expansion, 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 (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 elastic 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.
- The EN 1992-1-1 models for creep and shrinkage were found to generally apply but with a note not to consider curing and loading ages beyond 14 days.

A concise treatment of all outstanding material model and characterisation issues for the current and future development are provided in the Guidelines for the Working Group. In some instances

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

SECTION	CLAUSE	ISSUE / HEADING	SOURCE, TREATMENT AND COMMENTS
1 General	1.1.2 (104)	Scope of design. Temperatures for liquids	Kept in-line with local practice, as derived from BS 8007.
2 Basis of Design	2.1.1 (105)	Flotation	Taken from BS 8007. Considered as relevant guidance to the designer for WRS, consistent with present practice for South African structural standards.
	2.1.3	Design working life, durability and quality management	
	2.8	Design situations	
	2.9	Operational safety considerations	
	2.10	Maintenance and operation	
	2.11	Inspection and testing of the structure	
	2.12	Deflections	
3 Materials	3.1.1 (103)	General. Reference is made to Annex K	Annex K will be deleted as it deals with concrete properties at temperatures outside the scope of SANS 10100-3. Delete reference to Annex K
	3.1.11	Heat evolution and temperature development due to hydration	Importance of heat evolution established but with no design guidance. The WG should consider providing a NA.
6 Ultimate limit states	6.2.3 (109)	Suggestion to conservatively apply cot h = 1for 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 WRS due to shear (diagonal tension).
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 but tied to EN exposure classes. The exposure classes are to be incorporated in the revised editions of SANS 10100-1, CC1 and CC2 on durability.
9 Detailing of members and particular rules	9.1 (104)	Reinforcement to control restrained shrinkage and thermal movement	Taken from BS 8007. Considered as relevant guidance to the designer for WRS.
Annex A		Basis of design - supplementary paragraphs to SANS 10160 for tanks: Loads on tanks from liquids	Normative stipulations for the treatment of actions are provided in annexes. Stipulations are taken from EN 1991-4; as it is not treated in EN 1990. In future it could be added to SANS 10160-1 although it is outside the general scope of SANS 10160.
Annex B		Actions, partial factors and combinations of actions on tanks	
Annex C		Surface zones in concrete members	Taken from BS 8007. Considered as relevant guidance to the designer for WRS. Requires better presentation and labelling of Figures as well as better referencing from the main SANS 10100-3 procedures.
Annex K		Effect of temperature on the properties of concrete.	To be deleted. Outside of SANS 10100-3 scope.
Annex N		Figure of joint details from BS 8007	Taken from BS 8007. Considered as relevant guidance to the designer for WRS. The figure should be labelled properly.

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. Some of these aspects are discussed under Possible National Annexes for SANS 10100-3 (Draft).

2.6.3 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 expansion, 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 designers 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 should be considered by this WG. In the interim, however, the joint details from BS 8007 have been included in Annex N of SANS 10100-3. For the cases of coefficient of thermal expansion 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. Further investigation is needed in this regard, specifically regarding the heat of hydration of newer South African cements.

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

The general formulation of SANS 10100-3 can be viewed to consist systematically of first identifying the procedures relevant for the design of WRS as extracted from the general EN 1992-3 standard for containment structures. Thereafter, additional procedures applicable to the design of WRS from various other sources, primarily BS 8007 to maintain consistency with local practice, are incorporated in a logical format to give rise to a concise and competent design standard to aid in the design of local WRS's. Table 3.1 presents the basis of some of the pertinent issues considered during the establishment of the procedures in the current version of SANS 10100-3 (Draft). Sections and clauses not included in Table 3.1 are taken from EN 1992-3 without amendment. Note that clause numbers are consistent with EN 1992-1-1, resulting in intermittencies in the numbering sequence.

4. POSSIBLE ANNEXES FOR SANS 10100-3 (DRAFT)

4.1 Reorganisation of Annexes in Draft

In the present version of SANS 10100-3 (Draft) additional provision for the basis of design for tanks and stipulations for actions, partial factors and combinations of actions are given in separate annexes, as extracted from EN 1991-4:2006. Justification for the treatment of these topics is based on the premise that they should be included in the overall basis of design standard, which is EN 1990 for Eurocode and could be SANS 10160-1 for South Africa.

However, since this material is presented in a normative manner and the Eurocode arrangement is not followed strictly for this standard; the integral presentation of these stipulations in Section 2 would both simplify the standard and ensure that there is no misunderstanding of its normative status.

4.2 Additional Annexes

In addition to the Annexes that have already been established as part of the current version of SANS 10100-3 (Draft), numerous other Annexes dealing with various issues have been recommended to be included in the code. The recommendations for additional Annexes stem mainly from the K5-1764 report. The additional aspects to consider for tentative incorporation into SANS 10100-3 as National Annexures include:

- The coefficient of thermal expansion of concrete should be considered, borrowing from Bamforth (2007), as the same typical rock groups are found in SA and are extensively used for aggregate for concrete. Bamforth further gives design considerations for early-age concrete and heat of hydration.
- 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 elastic modulus.
- The influence of curing on elastic modulus.
- Relative humidity and its regional characteristics.
- South African conditions, particularly highlighting the problems that can occur due to pure water found in mountain streams and rain water.

4.3 National Annex in accordance with Eurocode

Since SANS 10100-3 will be an adapted standard, based not only on Eurocode but also including other material, there is no need to stipulate the selected Nationally Determined Parameters (NDP) in a separate South African National Annex. Where these NDP's are relevant, they are included directly in the normative stipulations. This arrangement is in contrast to that for SANS 51992-1-1 which represents a direct adoption of EN 1992-1-1.

5. CHARACTERISATION OF WRS PERFORMANCE

This background paper is presented primarily from the perspective of the compilation of a South African Standard for the design of WRS from existing standardised procedures. It is implied that the final standard will be based on pragmatic decisions on how best to provide for local needs and conditions. However, such decisions should take account of the previous WRC project on which the proposed approach to be taken is based and the first draft of such a standard is compiled. A number of topics and issues can be identified for which further investigation can contribute to proper characterisation of the performance of WRS.

5.1 Reliability basis of design

The differentiation of the serviceability limit state (SLS) into irreversible, reversible, long term and appearance design situations is the most notable element of the reliability framework relevant to WRS. The following aspects of the serviceability performance of WRS require attention:

(i) Performance level for cracking of concrete: In EN 1992-1-1 concrete cracking is treated as a reversible SLS for which the least severe action combination scheme applies. The implication is also that a low level of reliability performance would apply when reliability analysis and calibration is done.

  a. The importance of WRS as specialist structures may justify a higher reliability classification, with associated performance levels. Generally, WRS should be classified at the equivalent SANS 10160-1 Reliability Class 3, requiring upwards adjustment of partial factors and/or levels of quality management.
  b. Similarly the performance requirement for cracking should be set at a higher reliability level due to the importance of this specific limit state. When stating performance levels in terms of target reliability index values (b_T) (Retief & Dunaiski, 2009), typical values of b_T = 0,5 applies to cracking in buildings and b_T= 1,5 – 2,0 apply to the irreversible SLS.

(ii) A reliability assessment of crack prediction based on the EN 1992-1-1 procedures for representative WRS confirms the importance of a number of factors (McLeod et al., 2012):

  a. Reliability based design outcomes are more economical than the stipulated procedures, even when a high level of performance is set. Refined calibration of the design procedures can therefore result in more economical structures.
  b. The design outcome for the cracking SLS is significantly sensitive to the target level of reliability set as a performance requirement: The amount of tensile steel for b_T = 1,5 and 2,0 is respectively 10% and 15% more than for b_T = 0,5 as default value.
  c. Nevertheless, the more stringent crack width limits stipulated in EN 1992-3 for WRS often result in a substantial increase in tensile steel required to satisfy performance requirements: When the crack width limit stipulated by BS 8007 of 0,2 mm is reduced to 0,1 mm or 0,05 mm, the amount of tensile steel for a representative case is increased by a factor of 1,4 and 2 respectively.

(iii) Crack limit: The rational basis for the more onerous crack limits stipulated in EN 1992-3 as compared to BS 8007 needs to be established. Probability-based economic optimisation could provide such a rational basis, but would require input on the likelihood of self-healing for a range of crack widths, in addition to quantification of the consequences of SLS failure.

(iv) Reliability of structural resistance and accompanying quality management: Although the current version of the SANS 10100-3 (Draft) omits the onerous set of rules pertaining to cracking proposed by EN 1992-3 pending the results of a local support study, it appears likely that Tightness Classes will be prescribed in future and accompanied by locally suitable limits. Such action would call for a revised scheme of quality measures relating to Tightness Classes and allowable crack width limitations to ensure adequate performance of WRS in South Africa.

5.2 Structural performance

5.2.1 Shear resistance

Due to its sudden and brittle mode of failure, shear failures are not desirable in any structure, especially WRS for which cracking limitations represent a fundamental design requirement. The design for shear stresses is to be carried out with the available procedures of the future general South African concrete design standard SANS 51992-1-1. SANS 51992-1-1, as does EN 1992-1-1, will foreseeably enforce the Variable Strut Inclination Method (VSIM) for the provision of shear reinforcement to reinforced concrete members.

The VSIM brings about some economy of link design – it allows notably higher shear stresses as compared to the additive semi-empirical approach employed in the currently operational SANS 10100-1 as adopted from BS 8110 – but has portrayed some inconsistent and potentially unsafe behaviour against the amount of shear reinforcement provided in design Caldera & Mari, 2007; Mensah, 2012). The unbiased and uncalibrated VSIM has been shown generally to have a large conservative bias (particularly at low amounts of shear reinforcement), associated with a large spread and variability. The results of a parametric correlation and regression investigation of laboratory tests have indicated that the VSIM progresses to become marginally safe to unsafe when relatively high amounts of shear links are provided in design.

As a result of these findings, a limitation has been placed on the application of the Eurocode shear design method in the Draft Standard SANS 51992-1-1. For elements where shear reinforcement in elements exceed a certain limit, designers are referred to other methods, such as the shear design method in SANS 10100-1.

5.3 Materials

As described in Section 2.6.2, evaluation of the suitability of relevant material models to South African practice and conditions stopped short of full characterisation and calibration. Nevertheless, the recommendation has been that the general provisions in BS EN 1992-1-1:2004, in combination with the WRS-specific BS EN 1992-3:2006, are suitable for use in a South African WRS given the adaptations and notes in Section 2.6.2.

Research and characterisation needs include early-age properties of concrete and reinforcing steel. Specialist literature on early-age development of concrete properties exists (e.g. Bamforth, 2007), but is not based on specific South African conditions, practice, or materials. Heat of hydration, strength and stiffness evolution, bleeding, capillary pressure, plastic and settlement shrinkage may dominate early age-behaviour, which in turn may determine eventual crack patterns and width in hardened concrete of WRS. Of particular significance are local cements and cement replacement materials, but also chemical additives which are known and intended to alter fresh behaviour and early-age behaviour.

Characterisation of reinforcing steel available in South Africa is essential to enable WRS structural designers to use the various steel design material models included in the envisaged SANS 51992-1-1, adopted from Eurocode. Whereas a linear elastic perfect plastic stress-strain material model remains available, two more categories of reinforcing steel are allowed, for which post-yield strain-hardening is considered up to threshold strain levels. Furthermore, mild steel bars (SANS920), typically used in the form of smooth round bars for stirrups in South Africa, typically fall outside the scope of steels considered in Eurocode, for which minimum yield strengths are between 400 and 600 MPa.

5.4 Detailing and construction methods

The critical parameter for reinforcement quantities, spacing and bar sizes, is, in general, crack width limitations under serviceability conditions. The draft standard provides simplified limitations on minimum percentage of reinforcement as a provision for restrained cracking due to temperature and moisture effects. These numbers were taken from BS8007, seeing that simplified rules such as these are not given in EN 1992-1-3. In addition, experience has shown that these values have served the industry well over the years.

Also, deemed to satisfy rules from BS 8007 are given for reinforcement stresses to limit crack widths under externally applied direct tension or flexure. These would in general result in conservative results.

A section in the Draft Standard addresses the arrangement of prestressing tendons and ducts, as well as anchorages and couplers. These sections were taken directly from EN 1992-1-3. However, an Annexure on the design of cylindrical prestressed concrete structures was taken directly from BS 8007.

The Draft Standard does not include a section on construction methods and on appropriate quality control procedures. This aspect may need attention when a final version of the Standard is developed.

6. CONCLUSIONS

Standards for structural design represent acceptable design practice and the resulting performance of the structures designed in accordance with the stipulated procedures. The final judgement on a standard is therefore made by the profession when a draft standard is published for public comment. The technical background to the draft allows for such judgement to be made not only at face value, but also from considerations on which the formulation is based. The technical basis of design standards typically derives from two main sources, the assessment of research information and experience from practice. In the development of design standards, the use of previous standards serves as a rich source of information consisting of the synthesis of the two sources of input. Most design standards are not fully self-contained, but need to be used in conjunction with related standards, for instance a loading code to be used together with a materials-based standard.

This paper records the pre-normative stages of the development of a South African standard for the design of concrete water retaining structures. Following a wide range of related investigations, reported extensively in the final report of a WRC Project (WRC 1764, 2010), a summary of the main considerations on which a draft standard is based is presented. The two main features of the pre-normative investigations are the need to consider a number of related standards and the need to provide for local conditions, practice, and experience. The main driver to the process was the replacement of the British Standards (BS 8007 & BS 8110) by Eurocode Standards. This was complemented by the need to have a local standard that provides for an important class of structure.

The design of water retaining structures is primarily controlled by the serviceability limit states. The technical background consequently focusses on design requirements for cracking and related provisions for detailing, materials specification and construction practice. A decisive consideration was that the requirements and procedures stipulated by Eurocode for crack control were significantly more stringent than those of BS 8007. It was also concluded that BS 8007 provided useful information not included in Eurocode. It was decided to formulate the draft standard in accordance with Eurocode but with insertions extracted from BS 8007.

The next step consisting of the conversion of the Draft Standard into a South African National Standard requires full appreciation of both the justification for proposed treatment and the identified critical issues. Experienced-based judgement is applied to resolve remaining issues, modify, or extend the draft as deemed necessary to ensure that the final product represents acceptable design practice. The present background will need to be updated to include all the considerations on which the final standard is based.

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 WRS based on the principles of structural reliability.

Further characterisation of material models for 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 binder compositions, as well as the coefficient of thermal expansion in relation to the respective aggregate used locally in South Africa.

However, in the interim, sound engineering judgement should be applied in selecting appropriate procedures for critical design parameters for incorporation in SANS 10100-3 where no credible or convincing local data are available.

Guidelines are not included on construction procedures in the Draft Standard, but a follow up project for the development of a construction manual is recommended. The important parameter would be to define the relevant quality control procedures to ensure correct implementation of the design.

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