

Code of practice for

Design of concrete structures for retaining aqueous liquids

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Committees responsible for this British Standard

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- Department of the Environment (Property Services Agency)
- Health and Safety Executive
- Institution of Civil Engineers
- Institution of Structural Engineers
- Water Authorities Association

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Foreword

This British Standard has been prepared under the direction of the Civil Engineering and Building Structures Standards Committee. It replaces BS 5337, which is withdrawn.

Following the withdrawal of CP 114 the alternative method of design allowed in BS 5337 has been omitted in this British Standard. Secondly, the withdrawal of CP 110 and its replacement by BS 8110 have led to the updating of this code to align with BS 8110. One important change is that the crack width equations have been modified to align with the recommendations of BS 8110 and now include a crack width equation for direct tension. Other changes include a more logical arrangement of objectives and general recommendations for design, the introduction of a restraint factor, the introduction of recommendations for partially prestressed concrete structures, improved recommendations for joints, updating of guidance on jointing materials, an elaboration of the recommendations for concrete and reinforcement (including special reinforcement), and a revision of the inspection and testing recommendations for the structure.

For the first time in a British Standard civil engineering design code the designer is recommended to consider operational safety and to provide appropriately at the design stage.

It has been assumed in the drafting of this code that the design of liquid-retaining reinforced and prestressed concrete structures is entrusted to chartered civil or structural engineers experienced in the use of reinforced or prestressed concrete, and that site construction is carried out under the direction of a competent person.

This code, which is a type 1¹⁾ design code, has been prepared by a Technical Committee consisting of chartered engineers nominated by the organizations represented (see the back cover). The members of the Drafting Panel, convened by the Institution of Structural Engineers, were as follows.

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NOTE The numbers in square brackets used throughout the text of this standard relate to the bibliographic references given in appendix D.

¹⁾ Type 1 codes are defined in PD 6501-1 as "those detailing professional knowledge or practices".

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv pages 1 to 30, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1.1 Scope

This British Standard provides recommendations for the design and construction of normal reinforced and prestressed concrete structures used for the containment or exclusion of aqueous liquids. The term “liquid” in this code includes any contained or excluded aqueous liquids but excludes aggressive liquids. The code does not cover dams, pipes, pipelines, lined structures, or the damp-proofing of basements. The term “structure” is used herein for the vessel that contains or excludes the liquid, and includes tanks, reservoirs, and other vessels.

NOTE 1 The design of structures of special form or in unusual circumstances is a matter for the judgement of the designer.

NOTE 2 The titles of the publications referred to in this standard are listed on the inside back cover.

1.2 Field of application

This British Standard applies particularly to UK conditions, and although the principles are applicable to design in other parts of the world, the designer should take account of local conditions, particularly variations in climate and the possibility of earthquakes, which have not been considered for UK conditions. Consideration has been given to the storage of liquids at ambient temperatures or at temperatures up to approximately 35 °C such as are found in swimming pools and industrial structures.

Recommendations are given for structures in aggressive soils and for structures in areas liable to settlement and subsidence. No recommendations have been made for the effect of any dynamic forces nor for the effect of ice formation on the structure, and the designer should refer to specialist literature for information.

1.3 Symbols

For the purposes of this British Standard the symbols given in BS 8110-1:1985 apply.

1.4 Operational safety

The code includes recommendations for design to provide for operational safety.

1.5 Statutory requirements

Designers should check compliance with any statutory requirements.²⁾

²⁾ Reference should be made to the Reservoirs Act 1975 for structures that have a capacity of more than 25 000 m³.

Section 2. Design: objectives and general recommendations

2.1 Design objectives

The purpose of design is the achievement of acceptable probabilities that the structure being designed will not become unfit in any way for the use for which it is intended. This code provides for a method of design based on limit state philosophy that is generally in accordance with the methods employed in BS 8110. Structural elements that are not part of the liquid-retaining structure should be designed in accordance with BS 8110.

2.2 Structural design

2.2.1 Limit state recommendations

The design of the whole structure and all individual members should be in accordance with the recommendations given in BS 8110 as modified by the recommendations of this code. When all relevant limit states are considered, the design should lead to an adequate degree of safety and serviceability.

It is recommended that the size of the elements and the amounts of reinforcement are assessed on the basis of the serviceability crack width limit state, and that other limit states, including the ultimate limit states, are checked.

2.2.2 Ultimate limit states (ULS)

The partial safety factor, γ_f , for retained liquid loads should be taken as 1.4 (as given in Table 2.1 of BS 8110-1:1985) for load combinations 1 and 2 and as 1.2 for load combination 3, as appropriate.³⁾

2.2.3 Serviceability limit states (SLS)

2.2.3.1 General. The partial safety factor, γ_f , for all loads should be taken as unity as implied in 3.3 of BS 8110-2:1985.

2.2.3.2 Flotation. A structure subject to groundwater pressure should be designed to resist flotation. The deadweight of the empty structure with any anchoring devices should provide a safety factor of not less than 1.1 against uplift pressures during construction and in service. A factor of 1.1 should be used only where the maximum groundwater level can be assessed accurately; otherwise the factor should be assessed by the designer. The uplift may be reduced by:

- a) providing effective drainage to prevent a build-up of external water as far as local conditions permit;

- b) providing pressure relief devices discharging into the vessel (where the entry of external groundwater is acceptable).

2.2.3.3 Cracking. For the purpose of defining the serviceability crack width limit state, the maximum design surface crack widths for the exposure conditions defined in 2.7.3 should be taken to be the following.

- a) *Reinforced concrete.* The maximum design surface crack widths for direct tension and flexure or restrained temperature and moisture effects are:

- 1) severe or very severe exposure: 0.2 mm;
- 2) critical aesthetic appearance: 0.1 mm.

- b) *Prestressed concrete.* Except for the special recommendations for the design of cylindrical prestressed structures (see 4.3), the tensile stress in the concrete should be limited for prestressed concrete structures in accordance with the recommendations of 2.2.3.4.2 of BS 8110-1:1985.

A statically determinate member nominally subjected to axial prestressing should be assumed to have a minimum eccentricity of prestressing of 20 mm or 0.05 times the overall thickness in the plane of bending, whichever is less. For statically indeterminate structures, including cylindrical prestressed structures, this minimum eccentricity recommendation can be ignored.

The required exposure conditions for the surfaces of all members should be clearly defined at the outset of the design process and each member designed in accordance with the crack width limit state recommendations in this section.

Guidance on assumptions and methods that may be used for calculating crack widths are given in 2.6 and appendices A and B.

³⁾ In exceptional circumstances where it is envisaged that the height of the liquid can greatly exceed the height of the wall, factors derived from 2.2.2 of BS 8110-2:1985 should be considered.

2.2.3.4 Deflections. The recommendations for span/effective depth ratios given in BS 8110-1:1985 apply to horizontal members carrying uniformly distributed loads. For a cantilever wall which tapers uniformly away from the support and which is loaded with a triangular pressure, a net reduction factor should be applied to the above ratios if the thickness at the top is less than 0.6 times the thickness at the base. This reduction factor can be assumed to vary linearly between 1.0 and 0.78 where the thickness at the top varies between 0.6 and 0.3 times the thickness at the bottom. In addition, allowance should be made for the significant additional deflection which occurs at the top of the wall due to rotation, if the pressure distribution under the base is triangular or very asymmetrically trapezoidal. Limits for deflections will normally be those for non-liquid-retaining structures since only in exceptional circumstances will deflections be more critical with regard to freeboard, drainage or redistribution of load. Retaining walls should be backfilled in even layers around the structure, the thickness of the layers being specified by the designer. Overcompaction adjacent to the wall should be avoided otherwise large differential deflections (and sliding) of the wall may occur.

At least 75 % of the liquid load should be considered as permanent when calculating deflections.

2.3 Loads

All structures required to retain liquids should be designed for both the full and empty conditions, and the assumptions regarding the arrangement of loading should be such as to cause the most critical effects. Particular attention should be paid to possible sliding and overturning.

Liquid loads should allow for the actual density of the contained liquid and possible transient conditions, e.g. suspended or deposited silt or grit where appropriate. For ultimate limit state conditions, liquid levels should be taken to the tops of walls assuming that the liquid outlets are blocked. For serviceability limit state conditions the liquid level should be taken to the working top liquid level or the overflow level as appropriate to working conditions.

Allowance should be made for the effects of any adverse soil pressures on walls, according to the compaction and/or surcharge of the soil and the condition of the structure during construction and in service. No relief should be given for beneficial soil pressure effects on the walls of containment structures in the full condition. Thermal expansion of a roof should be minimized by reflective gravel or other protection against solar radiation. An example of a critical adverse loading effect occurs when thermal expansion of a roof forces the walls of an empty structure into the surrounding backfill. In this case the passive soil pressure on the walls may be limited by insertion of a thickness of compressible and durable material and/or by providing a sliding joint between the top of the wall and the underside of the roof. This can be either a temporary free sliding joint that is not cast into a fixed or pinned connection until reflective gravel or other solar protective material is placed on the roof, or a permanently sliding joint of assessed limiting friction. Movement of a roof may occur also where there are substantial variations in the temperature of the contained liquid. Where a roof is rigidly connected to a wall this may lead to additional loading in the wall that should be considered in the design. Earth covering on reservoir roofs may be taken as dead load, but due account should be taken of construction loads from plant and heaped earth, which may exceed the intended design load.

2.4 Analysis of walls and junctions

The liquid pressure on plane walls may be resisted by a combination of horizontal and vertical bending moments. An assessment should be made of the proportions of the pressure to be resisted by bending moments in the vertical and horizontal planes. Allowance should also be made for the effects of direct tension in walls induced by flexural action in adjacent walls. Reinforcement should be provided to resist horizontal bending moments at all corners where walls are rigidly joined.

Cylindrical structures may be constructed with a fixed, pinned or sliding joint between the walls and the foundation slab. Allowance should be made for the calculated flexural actions and hoop tensions. Sections should be checked for shear resistance.

2.5 Site conditions

2.5.1 Ground movement

Ground movement leading to displacement and cracking of liquid-retaining structures may cause severe leakage. The designer should therefore consider the possibility of geological faults, mining and other conditions giving rise to foundation conditions where the bearing strata have varying degrees of compressibility. When it is not possible to avoid sites where such conditions occur, the designer should consider adopting one or more of the following measures:

- a) dividing the whole structure into smaller compartments in order to reduce the likely differential movement in each compartment;
- b) providing specially designed joints in the structure to facilitate movement;
- c) using prestressing techniques to act as a safeguard against cracking;
- d) providing flexible sections in service pipes;
- e) in mining areas, providing a form of foundation that will reduce any horizontal forces from ground movement;
- f) providing underfloor drainage to prevent possible uplift pressures on floors and wall bases where groundwater is not considered in the design, for example, where only one compartment of a two-compartment structure is filled and leakage occurs.

Other measures may also be necessary depending on the predicted degree of subsidence.

2.5.2 Aggressive soils and chemical deterioration

Chemical analyses of the soil and groundwater are essential where aggressive substances are suspected. Some waters containing dissolved free carbon dioxide, natural acids or salts may be aggressive, and it will be necessary to take special precautions. Dissolved salts may cause serious deterioration in the concrete and corrosion of the steel. Reference should be made to **6.2** of BS 8110-1:1985 concerning concrete exposed to sulphate or other attack or susceptible to alkali-silica reaction, and for the use of special cements to resist the action of certain aggressive substances. In other and more serious conditions, an impermeable protective coating of a suitable bituminous or other composition may be used on the surface of the concrete.

2.6 Causes and control of cracking

2.6.1 Applied loading effects

Direct or flexural tension in the concrete arising from applied external service loads, from temperature gradients due to solar radiation, or from the containment of liquids at temperatures above ambient, may cause cracking in the concrete. The limitation of cracking from applied loading is dealt with in **2.2.3.3** and in the appropriate design sections. Crack widths arising from flexure and direct tension in mature concrete may be calculated as indicated in appendix B.

2.6.2 Temperature and moisture effects

2.6.2.1 Origins. Changes in the temperature of the concrete and reinforcement and in the moisture content of the concrete cause dimensional changes which, if resisted internally or externally, may crack the concrete. The distribution and width of such cracks can be controlled by reinforcement, together with the provision of movement joints. In this clause, i.e. **2.6.2**, temperature and moisture changes and methods for their control in relation to the particular problems of liquid-retaining structures are considered; it supplements information given in BS 8110-2:1985.

Heat is evolved as cement hydrates, and the temperature will rise for a day or more after casting and then fall towards ambient. Cracking usually occurs at this time while the concrete is still weak. Subsequent lower ambient temperatures and loss of moisture when the concrete is mature will open these cracks, although the loss of moisture at the surface under external drying conditions is usually low. A structure built in the summer but not filled or an external structure standing empty will usually be subjected to greater drops in temperature than the same structure filled. Structures constantly full and protected from climatic effects (e.g. by earth cover, shading or reflective treatment) will have a temperature near that of the liquid stored.

The designer should allow for both the greatest drop in temperature below the peak temperature arising from the heat of hydration and the maximum drying that can be expected, bearing in mind the effects of delays in construction and of conditions that may occur when structures are emptied for maintenance or repair.

2.6.2.2 Methods of control. Cracking arising from temperature and moisture changes in concrete structures can be controlled by reinforcement, by prestress, by movement joints, by temporary open sections closed with subsequent short infill strips, or by a combination of these methods. Cracking arising from minor uneven settlement may also be controlled by the provision of movement joints and by reinforcement or prestress (see **2.5.1**).

In order to minimize and control cracking that may result from temperature and moisture changes in the structure it is desirable to limit the following factors:

- a) the maximum temperature and moisture changes during construction by:
 - 1) using aggregates having low or medium coefficients of thermal expansion and avoiding the use of shrinkable aggregates,
 - 2) using the minimum cement content consistent with the requirements for durability and, when necessary, for sulphate resistance,
 - 3) using cements with lower rates of heat evolution,
 - 4) keeping concrete from drying out until the structure is filled or enclosed,
 - 5) avoiding thermal shock or over-rapid cooling of a concrete surface;
- b) restraints to expansion and contraction by the provision of movement joints (see **5.3**);
- c) restraints from adjacent sections of the work by using a planned sequence of construction or temporary open sections (see **5.5**);
- d) localized cracking within a particular member between movement joints by using reinforcement or prestress;
- e) rate of first filling with liquid (see **9.2**);
- f) thermal shock caused by filling a cold structure with a warm liquid or vice versa.

2.6.2.3 Reinforcement to control restrained shrinkage and thermal movement cracking. The reinforcement referred to in **2.6.2.2** to control cracking arising from restrained shrinkage and thermal movement should be placed in all slabs (floors, walls, roofs) as near to the surface of the concrete as is consistent with the requirement for cover. Prestressed slabs should be provided with reinforcement in any lateral direction in which there is no significant prestress.

The reinforcement should be calculated in accordance with **5.3.3** and appendix A. Except as provided for in option 3 in Table 5.1 and **5.3.3**, the amount of reinforcement in each of two directions at right angles within each surface zone should be not less than 0.35 % of the surface zone cross section, as defined in Figure A.1 and Figure A.2 for deformed grade 460 reinforcement⁴⁾ and not less than 0.64 % for plain grade 250 reinforcement. In wall slabs less than 200 mm in thickness the calculated amount of reinforcement may all be placed in one face. For ground slabs less than 300 mm thick (see **A.2**), the calculated reinforcement should be placed as near to the upper surface as possible consistent with the nominal cover. Bar spacings should generally not exceed 300 mm or the thickness of the section, whichever is the lesser. Where welded fabric⁴⁾ only is used bar spacings should not exceed 1.5 times the thickness of the section.

2.7 Design life and serviceability

2.7.1 General

The life of a completed structure depends on the durability of its components. For a correctly designed structure and good-quality materials and workmanship, the design life of the structure should be between 40 years and 60 years. Some components of the structure (such as jointing materials) have a shorter life than the structural concrete and may require renewal during the life of the structure.

⁴⁾ Deformed grade 460 bars complying with BS 4449 or BS 4461 and high-yield wire fabric complying with BS 4483 having a guaranteed yield or proof stress and guaranteed weld strength.

2.7.2 Maintenance and operation

The completed structure should be inspected regularly. The designer should provide the user with a statement listing the items requiring examination during such maintenance inspections, and stating the recommended frequency of such inspections. The inspection should include examination of the concrete for cracking, leakage, surface deterioration and settlement. Particular attention should be paid to any rust stains that might indicate corrosion of the reinforcement. Any defects should then be corrected. Movement joints should be cleaned and the joint materials replaced if necessary.

The designer should also prepare a schedule of precautions to be taken by the user in order to prevent the structure being damaged or the design life shortened during use. The schedule should be included in the commissioning documentation.

2.7.3 Exposure and appearance

For the purposes of this code, both faces of a liquid-containing or liquid-excluding structural member, together with any internal walls and columns of a containment structure, are to be considered as subject to severe exposure as defined in 3.3.4 of BS 8110-1:1985.

Surfaces subjected to very severe exposure as defined in 3.3.4 of BS 8110-1:1985 should be designed for a maximum design crack width of 0.2 mm (see 2.2.3.3) and concrete cover and mix complying with the recommendations of BS 8110-1:1985, as well as 2.7.6 and 6.3.

Where significant efflorescence and staining of the surface of the structure would be considered to be unacceptable, the recommendations for critical aesthetic appearance should be satisfied (see 2.2.3.3).

2.7.4 Durability

The recommendations in this code for cover, concrete grade, cement content, maximum free water/cement ratio and the means of ensuring a low permeability of the concrete are intended to meet the durability recommendations that correspond generally with the recommendations in Table 3.4 of BS 8110-1:1985 for severe exposure (see 6.3). Consideration should be given to the effect of the liquid to be stored on the durability of all the materials of construction, e.g. concrete, reinforcement or prestressing steel and jointing materials: this is especially pertinent to process liquids and some sewage effluents, although the latter are usually deficient in oxygen and not particularly aggressive. Similar considerations apply to groundwaters (see 2.5.2). Attention is also drawn to the possibility of biological attack, especially on the jointing materials.

The protection afforded by the specified cover and a correctly designed and fully compacted concrete mix is satisfactory for the majority of constructions, but where extended design life is required for a structure, consideration may be given to increasing the cement content (see the next paragraph), increasing the cover (see 2.7.6) or using special reinforcement (see 7.2).

A concrete mix with an increased cement content will provide extra protection for the reinforcement, but a higher cement content will cause more heat of hydration and require extra reinforcement in accordance with appendix A.

2.7.5 Impermeability of the concrete

The concrete should have low permeability. This is important not only for its direct effect on leakage but also because it is one of the main factors influencing durability, resistance to leaching, chemical attack, erosion, abrasion, frost damage and the protection from corrosion of embedded steel. The recommendations in this code for concrete mixes, aggregates, minimum cement content and strength, curing and admixtures generally ensure an adequately impermeable concrete, but it is essential that complete compaction without segregation is obtained on site. In some cases an increased cement and water content may be required in order to obtain adequate workability to ensure complete compaction without increasing the water/cement ratio, but in no case should the maximum cement content be exceeded. Alternatively, adequate workability may be achieved by using a lower water/cement ratio for the same cement content: for this a water-reducing agent is employed.