British Standard

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BRITISH STANDARD

BS 5328-1:1997

Incorporating Amendments Nos. 1 and 2 and Corrigendum No. 1

Concrete —

Part 1: Guide to specifying concrete

ICS 91.100.30

British Standards

Committees responsible for this British Standard

The preparation of this British Standard was entrusted to Technical Committee B/517, Concrete, upon which the following bodies were represented:

British Aggregate Construction Materials Industries
British Cement Association
British Precast Concrete Federation Ltd.
British Ready Mixed Concrete Association
Building Employers Confederation
Cement Admixtures Association
Department of Transport (Highways Agency)
Federation of Civil Engineering Contractors
Federation of Resin Formulators and Applicators (Ferfa)
Institute of Concrete Technology
National House-Building Council
Sand and Gravel Association Limited
Society of Chemical Industry

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

Association of Lightweight Aggregate Manufacturers
British Civil Engineering Test Equipment Manufacturers Association
Cementitious Slag Makers Association
Chartered Institution of Water and Environmental Management
Concrete Society
County Surveyors' Society
Department of the Environment (Building Research Establishment)
Electricity Association
Federation of Piling Specialists
Institution of Structural Engineers
Quality Ash Association

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14163 Corrigendum No. 1	17 October 2002	Correction to reference in Clause **10**, Note 1

Contents

Foreword

This Part of BS 5328 has been prepared by Technical Committee B/517. This Part, which includes designated mixes, is a new edition of BS 5328-1:1991, which is withdrawn, and, together with BS 5328-2, BS 5328-3 and BS 5328-4, forms a comprehensive standard for the specification of concrete to which codes of practice and contractual documents can refer. It includes recommendations originating from BS 8110-1:1985.

This edition introduces technical changes but does not reflect a full review or revision of the standard. This edition makes provision for the use of Portland limestone cement conforming to BS 7583 and incorporates amendments 7174 and 8758.

Amendment number 1 takes account of the recent consensus reached by experts on provisions to resist damaging ASR in the UK. These recommendations are published in the BRE Digest 330:1999. The technical content of this amendment has been derived from these recommendations.

Amendment number 2 takes account of the guidance given in BRE Special Digest 1 [1]. The changes introduced by this amendment are limited and should therefore be used in conjunction with the comprehensive guidance given in BRE Special Digest 1 [1]. Part 2 of the Special Digest describes the procedure to be used to determine the design chemical class for in-situ concrete construction and, where necessary, it details the number of additional protective measures that are needed. BRE Special Digest 1 [1] Part 4 gives design guides for special precast products. This Part of BS 5328 gives the recommendations for the concrete quality that is required for the design chemical class to resist the ACEC class.

BS 5328 is due to be withdrawn in December 2003 and consequently BSI have decided not to revise this Standard to reflect the new cement descriptions given in BS EN 197-1. Where traditional cements are specified, the producer may use the equivalent BS EN 197-1, *Cement — Composition specifications and conformity criteria for common cements,* see national annex NA to BS EN 197:2000 for guidance on equivalents.

As this standard involves selection by the specifier from a number of options and, in certain instances, agreement on requirements between the purchaser and producer, any requirement for conformity to BS 5328 or any claim of compliance with it has to be qualified by reference to the selection and to any such agreements.

This standard covers the methods for specifying and producing concrete as a construction material up to the point of delivery into the construction. The standard is in four Parts:

- Part 1 *Guide to specifying concrete;*
- Part 2 *Methods for specifying concrete mixes;*
- Part 3 *Specification for the procedures to be used in producing and transporting concrete;*
- Part 4 *Specification for the procedures to be used in sampling, testing and assessing compliance of concrete.*

Part 1 provides guidance to the specifier and purchaser of concrete on the selection of requirements for materials and concrete mixes. Part 2 provides a choice of methods by which the purchaser can convey the selected requirements to the producer. Part 3 specifies for the producer the procedures to be used in producing and transporting the concrete. Part 4 specifies the procedures to be used in sampling, testing and assessing concrete for conformity.

This standard provides methods for specifying concrete mixed on site or in a precast concrete factory and for the purchase and supply of ready-mixed concrete. It takes account of the distinct and different responsibilities of the purchaser and the producer. There are a number of instances in which the purchaser has to select from the various options given in this standard in order to specify the concrete required. The purchaser is responsible for passing on to the producer the requirements of the specifying body, e.g. the engineer's or architect's specification, together with any additional requirements. Throughout this standard the terms 'specify' and 'specification' are used in relation to both sets of requirements. There may be occasions where it is advantageous for economic or technical reasons to propose changes to the specification. In such cases the producer and purchaser should agree the proposed amendments for approval and sanction by the specifying body.

Precautions need to be taken when working with cement and fresh concrete and attention is drawn to these in BS 5328-3 and BS 5328-4.

This standard covers concrete produced by normal methods, but it does not apply to precast concrete products where the concrete is specified in other British Standards. Many of the requirements of this standard, e.g. the use of materials and the control of production, apply equally to precast concrete and to in situ concrete. However, some of the requirements concerning the responsibilities of the purchaser and producer may not apply in the case of precast concrete. The specification of designated mixes is unlikely to be appropriate for factory produced precast concrete products.

It is necessary for the purchaser to take into account the requirements of specialized codes of practice and any influences of the construction process. Provisions are made in this standard for the inclusion of any special requirements.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its 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 27 and a back cover.

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Introduction

This Part of BS 5328 gives advice on the selection of the quality of concrete suitable for many general purposes not covered by other British Standard specifications or codes of practice.

This Part of BS 5328 is primarily a guide for the specifier in choosing the appropriate materials and mix. It gives the range of constituent materials that can be used. It describes the properties of fresh and hardened concrete, with considerable emphasis on durability. Distinction is made between structural and non-structural concrete and between unreinforced, reinforced and prestressed concrete. Also included is guidance on sampling for strength conformity testing and action to be taken in the event of non-conformity.

Account is taken of standard specifications relating to ground granulated blastfurnace slag or pulverized-fuel ash used in composite cements or in equivalent combinations.

Purchasers ordering in accordance with this standard are advised to specify quality assurance requirements for materials or for concrete in their purchasing contracts to assure themselves that products specified in accordance with BS 5328 consistently achieve the required level of quality. Purchasers of ready-mixed concrete are advised to specify certification meeting the requirements of the United Kingdom Accreditation Service, National Accreditation Certification Bodies, for product conformity.

Purchasers ordering designated mixes in accordance with BS 5328-2:1997 need not specify quality assurance requirements for concrete, as it is obligatory that the producer holds current product conformity certification based on product testing and surveillance coupled with approval of the producer's quality system to BS EN ISO 9001 by a certification body accredited by the Secretary of State (or equivalent), for the relevant areas of product and systems conformity certification. Purchasers are similarly advised to specify that, where they are available, constituent materials should be obtained from suppliers operating quality systems in accordance with BS EN ISO 9000.

1 Scope

This Part of BS 5328 gives guidance on the selection of materials for concrete and on the mixes to be specified to produce concrete having the required properties in the fresh and hardened state. It also gives guidance on sampling for strength conformity testing and action to be taken in the event of non-conformity.

2 References

2.1 Normative references

This Part of BS 5328 incorporates, by dated or undated reference, provisions from other publications. These normative references are made at the appropriate places in the text and the cited publications are listed on page 26. For dated references, only the edition cited applies; any subsequent amendments to or revisions of the cited publication apply to this Part of BS 5328 only when incorporated in the reference by amendment or revision. For undated references, the latest edition of the cited publication applies together with any amendments.

2.2 Informative references

This Part of BS 5328 refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

3 Definitions

For the purposes of this Part of BS 5328, the definitions given in BS 6100 apply, together with the following.

3.1
batch
quantity of concrete mixed in one cycle of operations of a batch mixer, or the quantity discharged during 1 min from a continuous mixer, or the quantity of concrete conveyed ready-mixed in a vehicle.

3.2
cement
hydraulic binder that sets and hardens by chemical interaction with water and is capable of doing so under water.

NOTE The cements covered by this standard are listed in Table 1.

3.3
cement content
mass of cement contained in a cubic metre of fresh, fully compacted concrete, expressed in kg/m^3.

3.4
cement type
classification of a cement on its main constituents.

3.5
alkali content

3.5.1
certified average alkali content
the average of 25 consecutive determinations of equivalent alkali content carried out on samples each of which is representative of a day's production.

3.5.2
declared mean alkali content
the mean alkali content, expressed as the sodium oxide equivalent, which will not be exceeded without prior notice from the manufacturer. This is the certified alkali content plus a margin that reflects the manufacturer's variability of production.

3.5.3
guaranteed alkali limit
the alkali limit, expressed as the sodium oxide equivalent, which the constituent material supplier guarantees will not be exceeded by any test result, on any spot sample.

3.6
characteristic strength
that value of strength below which 5 % of the population of all possible strength measurements of the specified concrete are expected to fall.

3.7
density of fresh concrete
mass of quantity of compacted fresh concrete divided by its volume, expressed in kg/m^3.

NOTE For the method of determining the density of fresh concrete, see BS 1881-107. Compaction by the method described in BS 1881-107 is not appropriate for semi-dry concrete mixes. The method for determining the density of partially compacted semi-dry concrete is described in BS 1881-129.

3.8
lightweight concrete
hardened concrete having an oven-dried density not greater than 2000 kg/m^3.

NOTE For the method of determining oven-dried density, see BS 1881-114.

3.9
normal-weight concrete
hardened concrete having an oven-dried density greater than 2000 kg/m^3 but not exceeding 2600 kg/m^3.

NOTE For the method of determining oven-dried density, see BS 1881-114.

3.10
heavyweight concrete
hardened concrete having an oven-dried density greater than 2600 kg/m^3.

NOTE For the method of determining oven-dried density, see BS 1881-114.

3.11
designed mix
mix for which the purchaser is responsible for specifying the required performance and the producer is responsible for selecting the mix proportions to produce the specified performance.

3.12
prescribed mix
mix for which the purchaser specifies the proportions of the constituents and is responsible for ensuring that these proportions produce a concrete with the required performance.

3.13
standard mix
mix selected from the restricted list given in Section **4** of BS 5328-2:1997 and made with a restricted range of materials.

3.14
designated mix
mix produced in accordance with the specification given in Section **5** of BS 5328-2:1997 and requiring the producer to hold current product conformity certification based on product testing and surveillance coupled with approval of the producer's quality system to BS EN ISO 9001.

3.15
free water/cement ratio
ratio of the mass of free water (that is, excluding the water absorbed by the aggregate to reach a saturated surface dry condition) to the mass of cement in a concrete mix.

3.16
grade (of concrete)
numerical value of 28 day characteristic strength, expressed in N/mm^2, preceded by the letter C (compressive) or F (flexural) to denote the type.

3.17
equivalent grade
grade of concrete selected to provide reasonable assurance of conformity to parameters such as minimum cement content or maximum free water/cement ratio.

NOTE See **8.5**.

3.18
laitance
thin layer comprising water, cement and fine particles of aggregate that may form on the surface of concrete.

3.19
producer
person or authority entering a contract to supply concrete.

NOTE For example, a producer of ready-mixed or precast concrete supplying a contractor or a contractor supplying a client.

3.20
purchaser
person or authority entering a contract to buy concrete.

NOTE For example, a client purchasing from a contractor or a contractor purchasing from a subcontractor or material supplier.

3.21
ready-mixed concrete
concrete mixed in a stationary mixer or in a truck-mixer and supplied in the fresh condition to the purchaser, either at the site or into the purchaser's vehicles.

3.22
standard strength class (of cement)
classification of a cement based on its compressive strength at 28 days measured on mortar prisms in accordance with BS EN 196-1.

NOTE 1 There are five standard classes, 22.5, 32.5, 42.5, 52.5 and 62.5. British Standard specifications for cements incorporate one or more of these classes. There are in addition two intermediate standard strength classes, 37.5 and 47.5, for mixer combinations of Portland cement (PC) conforming to BS 12 with ground granulated blastfurnace slag (ggbs) conforming to BS 6699.

NOTE 2 The standard strength classes for some cements are subdivided according to their early strength development. The letters L (low), N (normal) and R (rapid) are added to the standard strength class to indicate the early strength. Specifications for cement indicate which, if any, of these subclasses are available.

3.23
time of loading
time of first contact between cement and aggregates or, when the latter are surface dry, between cement and added water.

3.24
aggressive chemical environment for concrete (ACEC)
classification used to describe the aggressiveness of the ground conditions that takes account of the design sulfate class, the type of ground (natural or brownfield) and the mobility and pH of the groundwater.

3.25
design chemical class (DC-class)
designation used to describe a concrete quality capable of resisting the selected aggressive chemical environment for concrete (ACEC), provided any specified additional protective measures (APMs) are correctly applied to the structure.

3.26
design sulfate class
classification for sites based on the sulfate content of the soil and/or groundwater, taking into account the presence or absence of minerals that may oxidize to sulfates (e.g. pyrite), magnesium ions and, for brownfield sites with pH <5.5, chloride and nitrate ions.

3.27
additional protective measure
measure taken in addition to concrete quality in order for the structure to resist the ACEC class.

3.28
structural performance level
classification of a structure based on the intended working life and the consequence of failure.

Table 1 — Cements

Type	Standard
Portland cements:	
Portland (PC)	BS 12
Low heat (LHPC)	BS 1370
Sulfate-resisting (SRPC)	BS 4027
Low alkali sulfate-resisting (LASRPC)	BS 4027
Cements containing: ground granulated blastfurnace slag (ggbs), pulverized-fuel ash (pfa) or limestone:	
Portland blastfurnace (PBFC)	BS 146
High slag blastfurnace	BS 4246
Portland pulverized-fuel ash (PPFAC)	BS 6588
Pozzolanic pulverized-fuel ash	BS 6610
Portland limestone (PLC)[ab]	BS 7583
Combinations manufactured in the concrete mixer from Portland cement and ggbs or pfa:	Combination of which the proportions and properties conform to clauses **6** to **9**[cd] of:
PC conforming to BS 12 with ggbs conforming to BS 6699	BS 146:1996[e](except **6.3**)
	BS 4246:1996[e](except **6.2**)
PC conforming to BS 12 with pfa conforming to BS 3892:Part 1	BS 6588:1996 (except **6.3**)
	BS 6610:1996 (except **6.2**)
Other cements:	
High alumina cement (HAC)[fg]	BS 915
Supersulfated cement (SSC)[f]	BS 4248
Modified Portland cements, e.g. coloured, ultra-high early strength, water-repellent, hydrophobic	Conforming to the physical properties for Portland cement in BS 12

[a] Portland limestone cement should not be used in concrete containing embedded metal exposed to a chloride-bearing environment, e.g. most severe and chloride-bearing very severe environments.

[b] Portland limestone cement should not be used in concrete exposed to conditions of freezing and thawing, unless the concrete is air-entrained in accordance with **5.3.3**

[c] The combination should be subject to procedures to demonstrate conformity.

[d] For the purposes of demonstrating equivalence, conformity to strength classes 37.5 or 47.5 of BS 6699 is deemed to be conformity to strength classes 32.5 or 42.5 of BS 146 respectively.

[e] As an alternative to conforming to the strength requirements in Clause **7** of these standards, the combinations may conform to the standard strength classes in Table 7 of BS 6699.

[f] High alumina cement conforming to BS 915 or supersulfated cement conforming to BS 4248 should not be mixed with any other type of cement in the production of concrete.

[g] High alumina cement should be used with caution (see **4.2.4**). The hydrated cement undergoes chemical changes, including a process known as conversion, which lead to loss of concrete strength and reduced resistance to aggressive chemicals. The precise way in which conversion occurs and the effects on concrete properties depend on the initial free water/cement ratio, the temperature and/or humidity of the concrete during curing and throughout its subsequent life. Guidance on the correct use of high alumina cement should be sought from the manufacturers and current specialized publications.

NOTE 1 Not all cements may be readily available. For example, supersulfated cement has not been produced in Britain since 1969, and specifiers should check for availability.

NOTE 2 The abbreviations OPC and RHPC are no longer used. The corresponding cements are PC 42.5 and PC 52.5 respectively. The abbreviation PC is now adopted for all cements conforming to BS 12.

4 Constituent materials of concrete

4.1 Choice and approval of materials

4.1.1 Materials used should satisfy the requirements for the safety, structural performance, durability and appearance of the finished structure, taking full account of the environment to which it will be subjected. In selecting the materials to be used, account should be taken of the cumulative effect of impurities, the construction process, the likely standards of supervision and workmanship and the possible technical and cost implications of using non-standard materials.

4.1.2 Where non-standard materials are used, there should be satisfactory data on their suitability and assurance of quality control. Records of the details and performance of such materials should be maintained.

4.1.3 Account should be taken of possible interactions between the materials used.

4.2 Cements

4.2.1 Generally, cements should conform to the British Standards listed in Table 1. Other cements or other combinations of Portland cement with ground granulated blastfurnace slag (ggbs) and pulverized-fuel ash (pfa) may be used provided that there are satisfactory data on their suitability, such as performance tests on concrete containing them. Other British Standards may restrict the type of cement to be used in particular cases.

NOTE During the remaining life of BS 5328, some of the British cement standards will be replaced by European standards. For equivalent European cements, see national annex NA to BS EN 197-1:2000.

4.2.2 British Standard specifications for cement contain standard strength classes and some also contain subclasses of early strength (see **3.22**). For most designed and designated mixes, it should not be necessary to specify the standard strength classes or subclasses of the cement.

4.2.3 Where used for special purposes, the cement may need to have additional requirements specified. For example, for certain classes of sulfate resistance it is necessary to stipulate the proportions of ggbs or pfa in composite cements and combinations.

4.2.4 Not all standard cements are suitable for all uses in concrete.

Examples include:

a) High alumina cement conforming to BS 915 should not normally be permitted for structural concrete.

b) Portland limestone cement should not be used in concrete containing embedded metal where the concrete is exposed to a chloride-bearing environment, e.g. most severe and chloride-bearing very severe environments.

c) Portland limestone cement should not be used in concrete exposed to conditions of freezing and thawing unless the concrete is air-entrained in accordance with **5.3.3**.

4.3 Aggregates

4.3.1 Generally, aggregates should conform to the British Standards listed in Table 2. In making reference to aggregates conforming to these standards, there may be a need to specify or approve certain characteristics including size, grading, aggregate carbonate range, impurities, durability and other properties. Other aggregates may be used provided there are satisfactory data on the properties of concrete made with them.

4.3.2 For most work, 20 mm nominal maximum size aggregate is suitable. Where there are no restrictions to the flow of concrete into sections, 40 mm or larger sizes should be permitted. In concrete elements with thin sections, closely spaced reinforcement or small cover, consideration should be given to the use of 10 mm nominal maximum size.

4.3.3 Separate coarse and fine aggregates should be used in concrete of grades C20 and above. Either separate coarse and fine aggregates or all-in aggregate may be used in concrete of grades C15 and below.

4.3.4 Most aggregates have low moisture movement (e.g. flint, quartzite, limestone). Aggregates having a high moisture movement, such as some dolerites and basalts, and gravels containing these rocks, produce concrete having an above average initial drying shrinkage. When the drying shrinkage exceeds certain values this can result in deterioration of exposed concrete and excessive deflections of reinforced concrete. A method of test and classification of aggregates on the basis of their drying shrinkage is given in BS 812-120. Guidance on design recommendations for satisfactory use of high drying shrinkage aggregates in concretes for structures is given in BRE Digest 357 [2].

4.3.5 The elastic modulus of concrete depends mainly on the types of aggregate used and the compressive strength of the concrete.

4.3.6 Where appearance is important, the aggregate should not contain surface-marring materials such as pyrites (see Annex B of BS 882:1992).

4.3.7 Where high strength concrete is required, the source as well as the type of aggregate may need careful selection based on results of previous use or trial mixes.

4.3.8 To select the appropriate requirements for resisting the thaumasite form of sulfate attack (TSA), the combination of the aggregates in the concrete needs to be classified into one of three aggregate carbonate ranges, A (high), B (medium) or C (low), on the basis of the carbonate content. See BRE Special Digest 1:Part 2 [1] for the classification of the aggregate carbonate ranges A, B and C.

Table 2 — Aggregates for general use

Type	Designation	Standard
Lightweight	Foamed or expanded blastfurnace slag lightweight aggregate for concrete	BS 3797
	Lightweight aggregates for concrete	BS 3797
	Clinker and furnace bottom ash aggregates for use in concrete (Not to be used in concrete containing embedded metal)	BS 3797
Normal weight	Aggregates from natural sources for concrete	BS 882
	Air-cooled blastfurnace slag aggregate for use in construction	BS 1047

4.3.9 Aggregate type can affect the fire resistance provided by concrete. Selection of aggregates with lower thermal expansion such as lightweight aggregates or limestone may be advantageous. Aggregates with low coefficients of thermal expansion are also beneficial in reducing the risk or extent of early-age thermal cracking.

4.3.10 A heavy duty grade of aggregate for surfaces expected to withstand moderately abrasive traffic, for example industrial floors, is included in BS 882.

4.4 Admixtures

4.4.1 Generally, admixtures should conform to BS EN 934-2.

Table deleted

4.4.2 Admixtures should not impair the durability of the concrete nor combine with the constituents to form harmful compounds nor increase the risk of corrosion of the reinforcement.

Calcium chloride and chloride-based admixtures should never be added to concrete which is to be reinforced, prestressed or is to contain embedded metal or cement conforming to BS 915 or to BS 4248.

4.4.3 If two or more admixtures are to be used in the same concrete mix, data should be obtained to assess their interaction and to ensure their compatibility.

4.4.4 Admixtures are permitted in designed and prescribed mixes and, with certain restrictions, in designated mixes but are not permitted in standard mixes.

4.5 Pigments

Generally, pigments should conform to BS EN 12878. Other pigments may be used provided there are satisfactory data on the properties of concrete made with them.

4.6 Additional materials

Pfa conforming to BS 3892 and ggbs conforming to BS 6699 may be used as additional materials.

NOTE For the specific use of pfa conforming to BS 3892-1 and of ggbs as part of the cement content, see Table 1.

4.7 Water

Mixing water should be free from materials in quantities deleterious to concrete in the fresh or hardened state (see Annex A of BS 3148:1980). In general, water fit for drinking is suitable for making concrete.

5 Durability of concrete

5.1 General

A durable concrete is one that performs satisfactorily in the working environment during its anticipated service life. The materials and mix proportions specified and used should be such as to maintain its integrity and, if applicable, to protect embedded metal from corrosion.

To achieve this it is necessary to consider many interrelated factors at various stages in the design and construction process. Thus the structural form and cover to steel are considered at the structural design stage, involving consideration of the environmental conditions. If these are particularly aggressive, it may be necessary to consider the type of cement at the structural design stage.

Characteristics influencing the durability of concrete include its permeability and resistance to the ingress of potentially deleterious substances. These are governed by the constituents, their proportions and the procedures used in making the concrete. A suitably low permeability is achieved by having an adequate cement content, a sufficiently low free water/cement ratio, by complete compaction of the concrete and by sufficient hydration of the cement through proper curing methods.

The factors influencing durability include:

a) the shape and bulk of the concrete;

b) the cover to embedded steel;

c) the environment (see **5.3**);

d) the type of cement (see **4.2** and **5.3.4**);

e) the type of aggregate (see **4.3** and **5.2**);

f) the type and dosage of admixture (see **4.4** and **5.3.3**);

g) the cement content and free water/cement ratio of the concrete (see **5.4**);

h) workmanship, to obtain full compaction, correct finishing and effective curing.

The degree of exposure anticipated for the concrete during its service life, together with other relevant factors relating to mix composition, workmanship and design, should be considered. To provide adequate durability under these conditions, the concrete should be specified taking account of the accuracy of current testing regimes for control and conformity as described in this standard.

Where they exist, use should be made of suitable quality assurance schemes.

5.2 Mix constituents

5.2.1 *General*

For concrete to be durable, careful selection of the mix and materials is necessary.

5.2.2 ***Chlorides in concrete***

Whenever there are chloride ions in concrete containing embedded metal there is an increased risk of corrosion. The higher the chloride content and the higher the curing temperature, or subsequent exposure to warm moist conditions, the greater the risk of corrosion. All constituents may contain chlorides and the concrete may be contaminated by air-borne salt spray either from vehicles or the sea.

The chloride limit in BS 12 is 0.10 %, and therefore for prestressed concrete it will be necessary to use the measured chloride content of the cement when assessing the conformity of the concrete.

Marine aggregates and some inland aggregates contain chlorides and may require careful selection and efficient washing to achieve the 0.10 % chloride ion limit for prestressed and heat-cured concrete given in Table 4. Limited information relating to these and other impurities is given in BS 882.

Table 4 — Limits of chloride content of concrete

Type or use of concrete	Maximum total percentage of chloride ion by mass of cement
Prestressed concrete Heat-cured concrete containing embedded metal	0.10
Concrete containing embedded metal made with cement conforming to BS 4027 Concrete made with cement conforming to BS 4248 with or without embedded metal	0.20
Concrete containing embedded metal and made with cement conforming to BS 12, BS 146, BS 1370, BS 4246, BS 6588, BS 6610, BS 7583 or combinations conforming to Table 1	0.40
Other concrete	No limit

Calcium chloride and chloride-based admixtures should never be included in concrete which is to be reinforced or prestressed or is to contain embedded metal or cement conforming to BS 915 or BS 4248.

The total chloride content of the concrete mix arising from the mix constituents should not exceed the limits given in Table 4.

Wherever possible, the total chloride content should be calculated from the mix proportions and the measured chloride contents of each of the constituents.

5.2.3 ***Sulfates in concrete***

Sulfates are present in most cements and in some aggregates. After hardening of the concrete, excessive amounts of mobile sulfate from these or other mix constituents can cause expansion and disruption. To prevent this, the specifications for cements, ggbs, pfa, lightweight aggregates and blastfurnace slag aggregates have limits on the sulfate level. At present there are no sulfate limits for natural aggregates conforming to BS 882. Within the United Kingdom sulfate problems caused by natural aggregates are rare. However, world-wide there are natural aggregates with sulfate levels of sufficient magnitude to cause disruption of concrete. When the source of aggregate is new or is suspected of containing sulfate, tests on the aggregates for sulfate content prior to acceptance are advised.

NOTE As no tests exist to determine mobile sulfate content, it is usual to measure the acid soluble sulfate contents of the constituents. The relationship between such measurements and the mobile sulfate content in the hardened concrete is variable and therefore no universal sulfate limit can sensibly be applied to concrete. For example, a 4 % or 5 % limit would exclude supersulfated cement conforming to BS 4248 and many lightweight and blastfurnace slag aggregates with long histories of satisfactory use.

5.2.4 ***Alkali-silica reaction***

Some aggregates containing particular forms of silica may be susceptible to attack by alkalis originating from the cement or other sources, producing an expansive reaction which can cause cracking and disruption of concrete. Damage to concrete from this reaction will normally occur only when all the following are present:

a) there is a high moisture level within the concrete;

b) the concrete has a high reactive alkali content, or there is another source of reactive alkali;

c) the aggregate contains an alkali reactive constituent.

NOTE BS 812-123 describes a method for testing aggregate.

BS 5328-2:1997 contains requirements for the producer to minimize the risk of damaging alkali-silica reaction (ASR). This applies to all types of concrete (designed, prescribed, standard and designated) and in all but special circumstances, no further requirements need to be specified.

5.2.5 ***Other considerations***

Aggregates liable to be adversely affected by the action of freezing and thawing should not be used in concrete that may be exposed to such conditions. Records of satisfactory use are the best guide for selection of suitable materials.

5.3 Durability and external environment

5.3.1 ***General environment***

The general environment to which the concrete will be exposed during its working life is classified into six levels of severity, i.e. mild, moderate, severe, very severe, most severe and abrasive (see Table 5).

Table 5 — Classification of exposure conditions

Environment	Exposure conditions
Mild	Concrete surfaces protected against weather or aggressive conditions
Moderate	Exposed concrete surfaces but sheltered from severe rain or freezing whilst wet Concrete surfaces continuously under non-aggressive water Concrete in design chemical class DC-1 (see Table 7a) Concrete subject to condensation
Severe	Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing or severe condensation
Very severe	Concrete surfaces occasionally exposed to sea-water spray or de-icing salts (directly or indirectly) Concrete surfaces exposed to corrosive fumes or severe freezing conditions whilst wet
Most severe	Concrete surfaces frequently exposed to sea-water spray or de-icing salts (directly or indirectly) Concrete in sea water tidal zone down to 1 m below lowest low water
Abrasive[1)]	Concrete surfaces exposed to abrasive action, e.g. machinery, metal tyred vehicles or water carrying solids

[1)] For flooring see BS 8204:Part 2

NOTE 1 For aggressive soil and water conditions see **5.3.4**.

NOTE 2 BS 8110 and BS 6349 give conflicting recommendations on mix design for similar exposure conditions. The classification 'very severe' uses the definition from BS 8110 with the addition of the word 'occasionally'; the classification 'most severe' includes the tidal zone definition from BS 6349 together with its reference to sea-water spray. To distinguish the exposure to sea-water spray from that in the 'very severe' class the word 'frequently' has been added. Also included in this class is frequent exposure to de-icing salts.

5.3.2 ***Minimum concrete quality***

The quality of concrete required to give satisfactory performance depends on the severity of exposure and other factors, particularly the cover to steel. The relationships between the cover to steel and concrete quality for reinforced concrete and for prestressed concrete subjected to these exposure conditions are given in relevant codes of practice.

Table 6 gives recommended values for the maximum free water/cement ratio, the minimum cement content and the minimum grade of concrete to ensure long service life under the appropriate conditions of exposure. The minimum grades will generally ensure that the limits on free water/cement ratio and cement content will be met without further checking.

5.3.3 ***Exposure to freezing and thawing***

Where freezing and thawing occurs under wet conditions, enhanced durability can be obtained by the use of suitable air-entraining admixtures.

When concrete lower than grade C50 is used under these conditions, the mean total air content by volume of the fresh concrete at the time of delivery into the construction should be:

a) 7.5 % for 10 mm nominal maximum aggregate size;

b) 6.5 % for 14 mm nominal maximum aggregate size;

c) 5.5 % for 20 mm nominal maximum aggregate size;

d) 4.5 % for 40 mm nominal maximum aggregate size.

When air-entrained concrete is specified with a grade of C40 or over, or with a cement content of more than 350 kg/m^3, problems may be encountered in achieving the required strength, compaction and surface finish. The inclusion of air in concrete reduces the compressive strength and adjustments to the cement content may be necessary to achieve the specified characteristic strength. Air contents greater than 5.5 % by volume may lead to cement contents in excess of 400 kg/m^3 and the mix should be checked in respect of the guidance relating to alkali–silica reaction (see **5.2.4**).

Table 6 — Guidance on mix design limits for durability of concrete made with normal weight aggregates of 20 mm nominal maximum size[1)]

Condition of exposure	Type of concrete	Maximum free w/c ratio	Minimum cement content	Minimum grade
Mild	Unreinforced non-structural	—	—	—
	Unreinforced structural[2)]	0.80	220	C20
	Reinforced	0.65	275	C30
	Prestressed	0.60	300	C35
Moderate	Unreinforced non-structural	—	—	—
	Unreinforced structural[2)]	0.65	275	C30
	Reinforced and prestressed	0.60	300	C35
Severe	Unreinforced	0.60	300	C35
	Reinforced and prestressed	0.55	325	C40
Very severe	All[3)]	0.55	325	C40
Most severe	Unreinforced[3)]	0.50	350	C45
	Reinforced and prestressed[3)]	0.45	400	C50
Abrasive	All[3)]	0.50	350	C45

[1)] Adjustments to minimum cement content should be made for aggregates of nominal maximum size other than 20 mm in accordance with Table 8.

[2)] For concrete in design chemical class DC-1 (see Table 7a) made with normal-weight aggregate and used in foundations and slabs to low rise structures, a minimum grade of C10 may be used provided the minimum cement content is not less than 175 kg/m^3 for designated mixes and 210 kg/m^3 for other types of concrete.

[3)] Where concrete is subject to freezing whilst wet, air entrainment should be used. In the case of air entrained concrete the grade may be reduced by 5.

NOTE For concrete containing embedded metal, the values represent the minimum quality recommended and depend upon the provision of adequate cover. The relationships between quality of concrete and cover are given in relevant codes of practice. Concrete quality alone may not provide sufficient protection for long–term durability in the presence of de-icing salts.

5.3.4 ***Exposure to aggressive chemicals***

5.3.4.1 Deterioration of concrete by chemical attack can occur by contact with gases or solutions of many chemicals, but it is generally the result of exposure to acidic solutions or to solutions of sulfate salts.

Solutions of naturally occurring sulfates of sodium, potassium, calcium or magnesium can be present in some soils and groundwater. Soluble sulfates can also be present in some mining spoil, industrial wastes or contaminated ground. Soluble sulfates can also result from the oxidation of sulfide minerals, particularly pyrite, found in some unweathered clays, some types of alluvium and unburnt colliery spoil. These sulfates can attack concrete causing softening or expansion and disruption. The attack can take the more usual ettringite and gypsum form or, in the presence of carbonate and cool temperatures, the thaumasite form. Both forms require a plentiful supply of water in order to proceed.

5.3.4.2 Recommendations given in this British Standard for concrete qualities to avoid all forms of sulfate attack are based upon the concept of a design chemical class (see **3.24**). The derivation of the design chemical class is described in detail in BRE Special Digest 1:Parts 2 and 4 [1].

The broad principle of this derivation is as follows.

An initial classification of the sulfate conditions is made from analysis of the sulfate content of the soil and/or groundwater samples, taking into account the possibility of oxidation of sulfides to sulfates and the magnesium ion concentration and, for brownfield sites with pH <5.5, chloride and nitrate ions. This gives the design sulfate class. Account is then taken of the mobility and pH of the groundwater and the type of ground (natural or brownfield) to give the aggressive chemical environment for concrete (ACEC) classification for the site. This classification, the width of the element, the structural performance level and the hydrostatic head are then used to determine the basic design chemical class (DC-class) and the number of additional protective measures needed.

The five additional protective measures are:

— enhanced concrete quality;

— use of controlled permeability formwork;

— provision of surface protection;

— sacrificial concrete layer;

— addressing the site drainage.

BRE Special Digest 1:Parts 2 and 4 [1] gives guidance on what additional protective measures are recommended in which circumstances. Where the additional protective measure "enhanced concrete quality" is applied, the basic DC-class is increased and the specification to the producer should contain this enhanced DC-class. Where the design chemical class is DC-3, DC-4 or DC-4m, the number of additional protective measures may be reduced if the concrete comprises aggregate carbonate range B or C. In the case of in-situ construction, the specifier has to assess whether this is an economic option and, if selected, the starred or double starred class (e.g. DC-4**) needs to be specified to the producer (see Table 7a). In a few highly aggressive conditions, only the use of aggregate carbonate range C is recommended. This is specified using the double starred classes.

Table 7a gives recommendations for the type of cement, minimum cement or combination content and maximum water/cement ratio appropriate to each design chemical class and aggregate carbonate range. The cement groups given in Table 7a are described in Table 7b.

NOTE During the remaining life of BS 5328, some of the British cement standards will be replaced with European standards. For equivalent European cements, see national annex NA to BS EN 197-1:2000.

5.3.4.3 Strong acids will attack concrete made with all Portland cement types. A high concrete quality can in some situations give an acceptably slow rate of attack, but in other situations the concrete should be protected with an acid-resisting barrier, see BRE Special Digest 1:Parts 2 and 4 [1] for guidance. As the rate of erosion of concrete surfaces in acidic conditions is affected less by the type of cement or the aggregate carbonate range than by the quality of the concrete, no limitations on the type of cement or aggregate carbonate range to resist acidic conditions are given.

5.3.4.4 For guidance on selection of concretes to be exposed to attack by milk, silage, slurry and other agricultural agents see BS 5502-21. For concrete floors subject to acid spillage in industrial processes consult an expert, a specialist producer of acid resistant finishes and BS 8204-2.

5.4 Limitation on mix parameters

5.4.1 *General*

The free water/cement ratio is an important factor in governing the durability of concrete and should always be the lowest value compatible with producing fully compacted concrete while minimizing segregation or bleeding. An appropriate minimum cement content is required to help ensure a long service life under particular exposure conditions. Appropriate values for the maximum free water/cement ratio, minimum cement content and minimum grade are given in Table 6 and Table 7a.

The cement content required for a particular free water/cement ratio can vary significantly for different mix constituents. Where adequate workability is difficult to obtain at the maximum free water/cement ratio allowed, an increased cement content, the use of ggbs, pfa, superplasticizing admixtures or water-reducing admixtures should be considered.

Cement contents in excess of 550 kg/m^3 should not be used unless special consideration has been given in design to the increased risk of cracking due to drying shrinkage in thin sections or to thermal stresses in thicker sections, and to the increased risk of damage due to alkali–silica reaction (see **5.2.4** and specialist publications).

The purchaser is responsible for providing the producer with all the necessary details to enable the correct mix to be supplied (see BS 5328-2:1997).

5.4.2 *Mix adjustments in Table 6*

The cement contents given in Table 6 apply to 20 mm nominal maximum size aggregate. For other sizes of aggregate they should be changed in accordance with table 8. Different aggregates require different water contents to produce concrete of the same workability and therefore at a given cement content, different free water/cement ratios are obtained. In order to achieve a satisfactory workability at the specified maximum free water/cement ratio, it may be necessary to modify the mix as described in **5.4.1**.

5.4.3 *Use of ground granulated blastfurnace slag or pulverized-fuel ash*

The concrete mix guidance given in Table 6 applies also when Portland blastfurnace cement or Portland pulverized-fuel ash cement is used, or when combinations of Portland cement conforming to BS 12 with ggbs or pfa are used (see **4.2** and **5.4.1**). The durability of the concrete made with these materials can be considered as being equal to that of concrete made with cement conforming to BS 12, provided that the ggbs or pfa concrete conforms to the same grade as would be achieved by the Portland cement concrete. In order to achieve concrete of equal strength at 28 days, depending on the combination used, it may be necessary to increase the total mass of Portland cement plus ggbs or pfa compared with the mass of Portland cement in the concrete without ggbs or pfa. For pfa the increase in the combined mass of Portland cement plus pfa may be about 10 % by mass. When using pfa, the quantity of water required to produce the same workability as concrete made with Portland cement conforming to BS 12 is likely to be less.

Table 7 — Sulfate and acid resistance

a) Concrete qualities for resisting sulfate attack				
Design chemical class[1)]	**Aggregate carbonate range**	**Cement or combination group**[2)]	**Dense fully compacted concrete made with aggregates conforming to BS 882 or BS 1047**	
			Minimum cement or combination content kg/m^3	**Maximum free water/cement ratio**
DC-1	A, B, C	1, 2, 3	—	—
DC-2	A[3)], B, C	1[4)]	340	0.50
	A[3)], B, C	2, 3	300	0.55
DC-2z[5)]	A, B, C	1[4)], 2, 3	300	0.55
DC-3[6)]	A	2a	400	0.40
	A	2b, 3	380	0.45
	B, C	2, 3	340	0.50
DC-3*[6)]	B, C[7)]	2, 3	380	0.45
DC-3**[6)]	C	2, 3	380	0.45
DC-3z[5)]	A, B, C	1[4)], 2, 3	340	0.50
DC-4[6)]	A	2a	400	0.35
	A	2b, 3	400	0.40
	B, C	2, 3	380	0.45
DC-4*[6)]	B, C[7)]	2, 3	400	0.40
DC-4**[6)]	C	2, 3	400	0.40
DC-4z[5),6)]	A, B, C	1[4)], 2, 3	380	0.45
DC-4m[6)]	A	2b[8)], 3	400	0.40
	B, C	3	380	0.45
DC-4m*[6)]	B, C[7)]	3	400	0.40
DC-4m**[6)]	C	3	400	0.40

1) See **3.25**, **5.3.4.2** and BRE Special Digest 1:Part 2 [1].
2) See Table 7b for description of cement groups.
3) In addition a minimum grade of C35 is required.
4) Portland-limestone cement may only be used where the sulfate classification (design sulfate class for the site) does not exceed DS-1.
5) Design chemical classes DC-2z, DC-3z and DC-4z apply where chemical resistance is required primarily to resist acidic conditions.
6) Additional protective measures might be necessary for mobile water conditions, depending upon the type and performance level of the structure. See BRE Special Digest 1:Part 2 [1] for guidance.
7) Where aggregate carbonate range C is used, the concrete will also conform to the double starred class.
8) The aggregate carbonate range shall be strictly determined on the basis of carbonate content and not by "declaration".

NOTE This table is intended for use in conjunction with the guidance given in BRE Special Digest 1 [1].

Table 7 — Sulfate and acid resistance

b) Cement groups for use in table 7a	
Group	**Description**
1	a) Portland cement conforming to BS 12 b) Portland blastfurnace cements conforming to BS 146 c) High slag blastfurnace cement conforming to BS 4246 d) Portland pulverized-fuel ash cements conforming to BS 6588 e) Pozzolanic pulverized-fuel ash cement conforming to BS 6610 f) Portland limestone cement conforming to BS 7583 g) Combinations of Portland cement conforming to BS 12 with ggbs conforming to BS 6699 h) Combinations of Portland cement conforming to BS 12 with pulverized-fuel ash conforming to BS 3892-1
2	a) Portland pulverized-fuel ash cements conforming to BS 6588, containing not less than 26 % of pfa by mass of the nucleus or combinations of Portland cement conforming to BS 12 with pfa conforming to BS 3892-1, where there is not less than 25 % pfa and not more than 40 % pfa by mass of the combination b) High slag blastfurnace cement conforming to BS 4246, containing not less than 74 % slag by mass of nucleus or combinations of Portland cement conforming to BS 12 with ggbs conforming to BS 6699 where there is not less than 70 % ggbs and not more than 85 % ggbs by mass of the combination
	NOTE 1 For group 2b cements, granulated blastfurnace slag with alumina content greater than 14 % should be used only with Portland cement having a tricalcium aluminate (C_3A) content not exceeding 10 %. NOTE 2 The nucleus is the total mass of the cement constituents excluding calcium sulfate and any additives such as grinding aids.
3	Sulfate-resisting Portland cement conforming to BS 4027

Tables 7c and 7d deleted

Table 8 — Adjustments to minimum cement contents given in Table 6 for aggregates other than 20 mm nominal maximum size

Nominal maximum aggregate size mm	Adjustments to minimum cement contents in Table 6 kg/m^3
10	+40
14	+20
20	0
40	−30

NOTE The cement content should be not less than 240 kg/m^3 for reinforced concrete or 300 kg/m^3 for prestressed concrete, except as indicated by footnote 2 to Table 6.

6 Other properties of hardened concrete

6.1 Strength grades

The strength grade of concrete should be selected from Table 9 and Table 10 as appropriate. Minimum grades for particular types of work such as reinforced concrete, prestressed concrete and for durability under particular environmental conditions are given in the appropriate code of practice. Where there is no appropriate code of practice the grades in Table 6 should be used.

NOTE Guidance on the selection of an equivalent grade is given in **8.5**.

Table 9 — Compressive strength grades

Grade	Characteristic compressive strength at 28 days N/mm^2 (= MPa)
C7.5	7.5
C10	10.0
C15	15.0
C20	20.0
C25	25.0
C30	30.0
C35	35.0
C40	40.0
C45	45.0
C50	50.0
C55	55.0
C60	60.0

Table 10 — Flexural strength grades

Grade	Characteristic flexural strength at 28 days N/mm^2 (= MPa)
F3	3.0
F4	4.0
F5	5.0

6.2 Concrete to meet special requirements

Most concrete is specified to meet the requirements of strength, workability and durability under normal conditions of exposure. In some cases concrete is required to have special properties or to resist more severe conditions of exposure. This may call for the specification of particular constituent materials and/or limits on mix proportions; examples of such requirements are:

a) minimum density or maximum density of the hardened concrete and the method of test;

NOTE Three conditions for concrete specimens and the method of test are described in BS 1881-114. The condition and the method used to measure it should be stated.

b) very high strength;

c) improved fire resistance;

d) wear resistance;

e) resistance to thermal cracking;

f) surface finishes;

g) lightweight aggregate concrete.

Specialist literature or suitably qualified people should be consulted before specifying concrete in such circumstances.

7 Properties of fresh concrete

7.1 General

The requirements of concrete in the fresh state, particularly its workability, should take account of the conditions and procedures to be used at the site. The properties of the fresh concrete may be modified by the use of admixtures.

In specifying the properties of fresh concrete to the producer, the purchaser of the fresh concrete should take account of the possibility of changes in the properties during transport under the purchaser's control up to the point of delivery into the construction.

7.2 Workability

The workability of fresh concrete should be suitable for the conditions of handling and placing, so that, after compaction, concrete surrounds all reinforcement, tendons and ducts and completely fills the formwork. Table 11 provides guidance on the workabilities appropriate to different uses (see also Table 13 for workability of concrete for general purposes).

The selection of workability should normally be made by the purchaser of the fresh concrete who will need to specify the chosen test method and value to the producer, taking account of the permitted tolerance (see BS 5328-2 and BS 5328-4). Cohesive mixes may give adequate placeability at lower values of slump than those given in Table 11.

For standard mixes, the cement content to be adopted depends upon the workability specified (see BS 5328-2).

Table 11 — Workabilities suitable for different uses of in situ concrete

Use of concrete	Form of compaction	Workability	Nominal slump[1)] mm
Pavements placed by power operated machines	Heavy vibration	Very low	See note 1
Kerb bedding and backing	Tamping		
Floors and pavements not placed by power-operated machinery	Poker or beam vibration	Low	50
Strip footings Mass concrete foundations Blinding Normal reinforced concrete in slabs, beams, walls and columns Sliding formwork construction Pumped concrete Vacuum processed concrete Domestic general purpose concrete	Poker or beam vibration and/or tamping	Medium	75
Trench fill In situ piling	Self-weight compaction	High	125
Concrete sections containing congested reinforcement	Poker		
Diaphragm walling Self-levelling superplasticized concrete	Self-levelling	Very high	See note 2

[1)] Cohesive mixes may give adequate placeability at lower values of slump than those given here.

NOTE 1 In the "very low" category of workability where strict control is necessary, e.g. pavement quality concrete placed by 'trains', measurement of workability by determination of compacting factor or Vebe time (see BS 1881-103 and BS 1881-104) will be more appropriate than slump.

NOTE 2 In the 'very high' category of workability, measurement and control of workability by determination of flow is appropriate (see BS 1881-105).

7.3 Air content

The air content required for concrete subjected to freezing and thawing is given in **5.3.3**

7.4 Temperature

7.4.1 *Work in cold weather*

In cold weather consideration should be given to the following:

a) prevention of freezing of the immature concrete;

b) extended stiffening times which may lead to increased formwork pressures and delays in finishing;

c) low rate of concrete strength development which may lead to delays in subsequent construction operations such as striking formwork.

As part of the overall approach to working in cold weather, consideration should be given to taking steps outside the scope of this standard such as insulation of the fresh concrete. The following steps modify the concrete in ways which may counter the effects of cold weather:

1) increasing the cement content to increase the heat of hydration and early strength;

2) using a cement which gains strength more rapidly;

3) using admixtures that reduce the setting time and/or increase the rate of strength gain;

4) specifying a minimum temperature of fresh concrete greater than that given in **4.9.1** of BS 5328-3:1990.

7.4.2 *Work in hot weather*

In hot weather consideration should be given to the following:

a) avoiding reductions in the working life of the fresh concrete due to loss of mix water by evaporation and accelerated hydration;

b) preventing a high temperature rise in the concrete element leading to unacceptable levels of early-age thermal cracking and reductions in the ultimate quality of the concrete.

As part of the overall approach to working in hot weather, consideration should be given to modifying the concrete, using one or more of the following:

1) using admixtures to retard the hydration and/or increase the initial workability. A retarder will not compensate for stiffening by moisture loss;

2) using a cement or combination that has a low heat evolution;

3) specifying a maximum temperature of fresh concrete less than that given in **4.9.2** of BS 5328-3:1990.

7.5 Density of fresh concrete

It is not normally necessary to specify the density of fresh concrete.

Where necessary, the minimum or maximum density of fresh concrete may be specified as an alternative to the density of hardened concrete.

7.6 Other properties of fresh concrete

There are some circumstances in which other properties of the fresh concrete, not covered in **7.1**, **7.2**, **7.3**, **7.4** and **7.5** are important. In such cases the purchaser should make the requirements known to the producer (see BS 5328-2). Examples of such qualitative performance requirements include:

a) enhanced cohesion for certain placing conditions;

b) suitability for pumping;

c) required finished appearance by intended method of finish.

8 Basis for specifying concrete

8.1 General

To specify concrete to meet strength, durability or any other special requirements, it is necessary to select its characteristic strength together with any limits required on the mix proportions, the requirements of fresh concrete and the type of materials that may or may not be used. In order to specify concrete having some particular properties, it may be necessary to specify certain types of material and/or specific limits on mix proportions.

Where applicable, use should be made of appropriate quality assurance schemes.

8.2 Types of concrete mix

8.2.1 *General*

Details of the concrete mix needed to meet the end-use requirements are specified in the form of one of the following types of mix:

a) designed;

b) prescribed;

c) standard;

d) designated.

These four types of mix are fully described in **8.2.2**, **8.2.3**, **8.2.4** and **8.2.5** and are summarized in Table 12.

8.2.2 *Designed mix*

The mix is specified by its required performance in terms of a grade, subject to any special requirements for materials, minimum or maximum cement content, maximum free water/cement ratio and any other properties. Strength testing forms an essential part of the assessment of conformity.

8.2.3 ***Prescribed mix***

The mix is specified by its constituent materials and the properties or quantities of those constituents to produce a concrete with the required performance. The assessment of the mix proportions forms an essential part of the conformity requirements. Strength testing is not used to assess conformity.

A prescribed mix should be specified only when there is reliable previous evidence or data, established from trial mixes, that with the materials and workmanship available the concrete produced will have the required strength, durability and other characteristics. This type of mix may be required to produce concrete having particular properties, e.g. to obtain a special finish.

8.2.4 ***Standard mix***

The mix is selected from the restricted range given in Section **4** of BS 5328:Part 2:1997. The assessment of the mix proportions forms an essential part of the conformity requirements. Strength testing is not used to assess conformity.

These mixes have been developed to give assurance that generally they will produce concrete of the required characteristic strength except where there is poor control of production or where poor materials are used. Where strength is important, a designed mix should be specified and where the producer operates suitable quality assurance arrangements a designated mix should be specified.

Standard mixes are applicable for the site batching of concrete for housing and similar construction. They should be specified only where the scale of work or economy does not justify the application of mix design procedures, or to enable work to start where there is insufficient time for the collection of data to support mix design proposals.

Table 13 gives typical applications for general purposes. When specifying a standard mix, the equivalent designated mix should be permitted as an alternative. Table 13 also recommends workabilities which are generally suitable and these workabilities should be specified unless the purchaser has alternative requirements which should be discussed with the producer. Table 11 shows typical slump values and forms of compaction applicable to different workabilities.

Standard mixes should not be used where sulfates or other aggressive chemicals are present in the ground, the ground water, or any adjacent material, other than as blinding or similar applications. For sulfate conditions see **5.3.4**. Cast-in-situ concrete for house drives and similar external areas should resist damage by freezing and thawing which is made worse by de-icing salts carried in from highways. Where these conditions are likely to occur, it is essential that the concrete contains entrained air (see **5.3.3**). Air-entrained concrete is outside the scope of standard mixes.

Where the concrete is laid on a slope, a low workability may be required.

8.2.5 ***Designated mix***

The mix is specified by identifying fromTable 13 the application for which the concrete is to be used, or the application that most closely resembles it, and citing the corresponding designation. It is the purchaser's responsibility to select the appropriate designated mix and Table 13 is only for guidance. Where the soil contains sulfates or sulfides, the guidance in BRE Special Digest 1:Part 1 [1] should be followed.

The purchaser also specifies:

a) whether the concrete is to be unreinforced, reinforced, reinforced and heated, or prestressed;

b) the nominal maximum aggregate size if it is not 20 mm.

The purchaser of the fresh concrete specifies the workability and informs the producer of the method of placing and finishing.

In general, this is all that is required but Section **5** of BS 5328-2:1997 permits some of the specification requirements to be relaxed or restricted and also permits certain options to be selected by the purchaser. If the purchaser requires these options, they have to be specified.

The effects of aggregate carbonate range are taken into account by the provisions in Table 6 of BS 5328-2:1997. However, there are a few extreme situations where BRE Special Digest 1:Part 2 [1] recommends that only aggregate carbonate range C is used. In these situations, the specifier should specify FND4** or FND4M** as appropriate.

In conditions that require DC-3, DC-4 or DC-4m concrete and additional protective measures, the number of additional protective measures may be reduced if the concrete quality is enhanced and aggregate carbonate ranges B or C are used, see BRE Special Digest 1:Part 2 [1]. Prior to selecting these options, the availability of these aggregate carbonate ranges should be checked. Where one of these options is selected by the specifier, it is essential to specify the appropriate starred or double starred DC-class.

Designated mixes are not intended to cover every use of concrete or every potential concreting material. In general, the specifications for the mixes are based on the requirements given in other British Standards. The intention is that these mixes are potentially fit for the designated end uses, subject to good practice in the process of placing, compacting, finishing, and curing, which are not within the scope of this standard. A concept incorporated in the designated mix system is that, no matter what selection of materials is used, a designated mix will have broadly similar properties in the fresh and early stages of its development.

A major difference between the specification of designated mixes and the other methods of specifying concrete is the requirement that producers hold current product conformity certification based on product testing and surveillance, coupled with approval of their quality system to BS EN ISO 9001, as this is the prime means for controlling conformity.

8.3 Selection of constituent materials

Subject to satisfying all the requirements for the concrete and the type of mix specified, unnecessary restrictions should not be imposed upon the materials that may be used.

In order to specify concrete having some particular properties, it may be necessary to specify types of material and/or specific limits on mix proportions. Guidance is given in Clause **4** and in specialist literature.

Table 12 — Summary of different types of mix

Aspect	Type of mix			
	Designed	Prescribed	Standard	Designated
Range of characteristic strength	All	All	7.5 N/mm^2 to 25 N/mm^2	7.5 N/mm^2 to 50 N/mm^2
Mix specified in terms of	Strength grade and limiting mix proportions	Mix proportions	Section **4** of BS 5328:Part 2:1997	Section **5** of BS 5328:Part 2:1997
Responsibility for selection of mix proportions	Producer	Purchaser	Purchaser	Producer
Permitted materials	Conforming to a wide range of British Standards or other specifications (see **4.1**)	Purchaser to specify	Conforming to a restricted range of British Standards (Table 4 of BS 5328-2:1997)	Conforming to a restricted range of British Standards (Clause **5.4** of BS 5328-2:1997)
Main parameter used for judgement of conformity	Strength	Mix proportions	Mix proportions	Quality assurance

8.4 Limits on specifying mix parameters

8.4.1 *General*

Limitations on the mix parameters of minimum cement content, maximum cement content and maximum free water/cement ratio are described in **5.4**.

Minimum cement contents and maximum free water/cement ratios to help ensure durability in various types of environment for reinforced concrete and prestressed concrete are given in table 6 and in relevant codes of practice.

Minimum cement contents and maximum free water/cement ratios for concrete not containing embedded metal are given in table 6, and for concrete exposed to sulfate attack in Table 7a.

Warnings against the use of high cement contents are given in **5.4**.

When prescribed mixes or standard mixes (see BS 5328-2) are specified, the values should also conform to the above requirements.

8.4.2 *Cement content for handling, placing and finishing*

Where necessary, cement content limits should take account of factors associated with the handling, placing and finishing of the concrete. Some of the factors to be considered are:

a) the characteristics of the constituent materials;

b) the workability required;

c) other special placing requirements, e.g. pumping;

d) surface finish;

e) susceptibility of bleeding, settlement and grout loss.

Table 13 — Guide to the selection of designated and standard mixes

Application[1] [2]	Designated mix	Standard mix	Recommended workability (nominal slump)[3]
Foundations requiring design chemical class DC-1 concrete			
Blinding and mass concrete fill	GEN 1	ST2	75
Strip footings	GEN 1	ST2	75
Mass concrete foundations	GEN 1	ST2	75
Trench fill foundations	GEN 1	ST2	125
Fully buried reinforced foundations	RC 30	N/A	75
Plain and reinforced foundations with design chemical classes DC-2 to DC-4[1] concrete requirements			
Design chemical class DC-2	FND 2	N/A	75
Design chemical class DC-2z	FND 2Z	N/A	75
Design chemical class DC-3	FND 3	N/A	75
Design chemical class DC-3*	FND 3*	N/A	75
Design chemical class DC-3**	FND 3**	N/A	75
Design chemical class DC-3z	FND 3Z	N/A	75
Design chemical class DC-4	FND 4	N/A	75
Design chemical class DC-4*	FND 4*	N/A	75
Design chemical class DC-4**	FND 4**	N/A	75
Design chemical class DC-4z	FND 4Z	N/A	75
Design chemical class DC-4m	FND 4M	N/A	75
Design chemical class DC-4m*	FND 4M*	N/A	75
Design chemical class DC-4m**	FND 4M**	N/A	75
General applications			
Kerb bedding and backing	GEN 0	ST1	Very low (nominal 10)
Drainage works to give immediate support[4]	GEN 1	ST2	Very low (nominal 10)
Other drainage works[4]	GEN 1	ST2	50
Oversite below suspended slabs[4]	GEN 1	ST2	75
Floors			
House floors with no embedded metal (see note 1 of **5.3.3** of BS 5328:1997)			
— Permanent finish to be added, e.g. a screed or floating floor	GEN 1	ST2	75
— No permanent finish to be added, e.g. carpeted garage floors with no embedded metal	GEN 2 GEN 3	ST3 ST4	75 75
Wearing surface: light foot and trolley traffic	RC 30	ST4	50
Wearing surface: general industrial	RC 40	N/A	50
Wearing surface: heavy industrial	RC 50	N/A	50
Paving			
House drives, domestic parking and external parking	PAV 1	N/A	75
Heavy-duty external paving for rubber tyre vehicles[5]	PAV 2	N/A	50
Other reinforced and prestressed concrete applications			
Reinforced or prestressed concrete: mild exposure	RC 30	N/A	75
Reinforced or prestressed concrete: moderate exposure	RC 35	N/A	75
Reinforced or prestressed concrete: severe exposure	RC 40	N/A	75
Reinforced or prestressed concrete: most severe exposure	RC 50	N/A	75

[1] The derivation of the design chemical is given in BRE Special Digest 1:Part 2 [1].
[2] Concrete containing embedded metal should be treated as reinforced.
[3] Unless otherwise specified.
[4] In conditions where the design chemical class DC-1 concrete is appropriate.
[5] For extreme applications, seek specialist advice.

8.5 Equivalent grades

8.5.1 *General*

It is good practice to specify a designed mix with a grade as the controlling criterion in a mix design because assessing the conformity to specified cement contents and water/cement ratios is relatively difficult and expensive. Specification of an equivalent grade gives a high probability that strength will control the mix design and thereby reduces the need for conformity checking of cement content or water/cement ratio.

8.5.2 *Selection of equivalent grade*

The equivalent grade may be selected from Table 14 provided that the following apply.

a) The nominal maximum size of the aggregate is between 10 mm and 40 mm.

b) The specified slump is in the range 50 mm to 150 mm.

c) Admixtures providing water reduction are not included.

Table 14 — Equivalent grades for cement content and free water/cement ratio

Minimum cement content	Maximum free water/cement ratio	Equivalent grade for concretes containing cements of standard strength classes		
		32.5	37.5 or 42.5	47.5, 52.5 or 62.5
kg/m^3				
200 to 210	—	C10	C15	C20
220 to 230	—	C15	C20	C25
240 to 260	0.70	C20	C25	C30
270 to 280	0.65	C25	C30	C35
290 to 310	0.60	C30	C35	C40
320 to 330	0.55	C35	C40	C45
340 to 360	0.50	C40	C45	C50
370 to 390	0.45	C45	C50	C55

In all cases the grade to be specified should be at least equal to that required for structural design and durability (see table 6 and the appropriate codes of practice).

When conditions other than those above apply, an equivalent grade may be established from the relationship between cement content, free water/cement ratio and mean strength established from records or trial mixes for the materials to be used. The equivalent grade should be calculated by deducting a margin not exceeding 10 N/mm^2 from the mean strength agreed between the producer and purchaser.

9 Sampling for conformity testing

9.1 General

To avoid duplication of sampling and testing in normal circumstances, when the effects of time and transporting are judged to be of no practical significance, it should be acceptable for representative samples taken at discharge from the concrete mixer to be used for assessment of conformity of concrete delivered into the construction.

When the effects of time and transporting are judged likely to be of significance, it may also be possible to permit such samples to be used by agreement on nominal adjustments to the specified values or by using adjustments based on laboratory or site trials (see also **3.2** of BS 5328-4).

9.2 Rate of sampling for strength conformity testing

The rate of sampling adopted by the purchaser should be notified to the producer by quoting from table 15 the average quantity of concrete, either in cubic metres or as the number of batches (whichever represents the lesser volume), from which a representative sample should be taken from a randomly selected batch. At least one sample should be taken of each grade of concrete on each day that concrete is placed. The rate of sampling may be increased in appropriate circumstances, e.g. for critical elements. Higher rates of sampling and testing would be appropriate at the start of the work so that there are at least two results (see BS 5328-4) to establish the level of quality quickly, during periods of production when quality is in doubt or when conditions change. Conversely, sampling rates may be reduced when consistent quality has been established or when the concrete is supplied from a plant for which the quality control system has third party accreditation for product conformity.

Table 15 — Recommended minimum rates of sampling

Average rate of sampling: one sample per	Maximum quantity of concrete at risk under any one decision	Examples of structures to which applicable
10 m^3 or 10 batches	40 m^3	Masts, columns, cantilevers
20 m^3 or 20 batches	80 m^3	Beams, slabs, bridges, decks
50 m^3 or 50 batches	200 m^3	Solid rafts, breakwaters

10 Action to be taken in the event of non-conformity of the concrete with its specification

The action to be taken in respect of the concrete which is represented by test results that fail to meet the requirements of specifications prepared in accordance with this standard should be determined by the purchaser. This may range from qualified acceptance in less severe cases to rejection and removal in the most severe cases. In determining the action to be taken, due regard should be given to the technical consequences of the kind and degree of non-conformity and to the economic consequences of alternative remedial measures, either replacing the substandard concrete or ensuring the integrity of any work in which the concrete has been placed.

The validity of the test results should be confirmed by checking that the sampling and testing have been carried out in accordance with BS 1881 or such other document as has been specified.

In estimating the quality of the substandard concrete indicated by valid test results and in determining the action to be taken, the following should be established wherever possible:

a) the mix proportions actually used in the concrete under investigation which may affect durability;

b) the selection of the work represented by the test results;

c) the possible influence of any reduction in concrete quality on the strength and durability of the work.

NOTE 1 The purchaser may wish to carry out tests on the hardened concrete. These may include non-destructive methods (see BS 1881-201) or the taking of cored samples (see BS EN 12504-1). The results of any such test should not annul the establishment of non-conformity with the requirements provided that establishment was based on valid test results.

NOTE 2 Advice on the interpretation of non-destructive test results and the strength of concrete cores taken from structures is given in BS 6089. This British Standard also gives further factors to be considered when deciding the action to be taken with regards to structural concrete, and further information is given in the relevant codes of practice.

List of references (see clause 2)

Normative references

BSI publications

BRITISH STANDARDS INSTITUTION, London

BS 12:1996, *Specification for Portland cement.*

BS 146:1996, *Specification for Portland blastfurnace cement.*

BS 882:1992, *Specification for aggregates from natural sources for concrete.*

BS 915, *Specification for high alumina cement.*

BS 915-2:1972, *Metric units.*

BS 1047:1983, *Specification for air-cooled blastfurnace slag aggregate for use in construction.*

BS 1370:1979, *Specification for low heat Portland cement.*

BS 1881, *Testing concrete.*

BS 1881-103:1993, *Method for determination of compacting factor.*

BS 1881-104:1983, *Method for determination of Vebe time.*

BS 1881-105:1984, *Method for determination of flow.*

BS 1881-107:1983, *Method for determination of density of compacted fresh concrete.*

BS 1881-114:1983, *Methods for determination of density of hardened concrete.*

BS 1881-129:1992, *Method for determination of density of partially compacted semi-dry fresh concrete.*

BS 1881-201:1986, *Guide to the use of non-destructive methods of test for hardened concrete.*

BS 3148:1980, *Methods of test for water for making concrete (including notes on the suitability of the water).*

BS 3797:1990, *Specification for lightweight aggregates for masonry units and structural concrete.*

BS 3892, *Pulverized-fuel ash.*

BS 3892-1:1997, *Specification for pulverized-fuel ash for use with Portland cement.*

BS 3892-2:1996, *Specification for pulverized-fuel ash to be used as Type 1 addition.*

BS 4027:1996, *Specification for sulfate-resisting Portland cement.*

BS 4246:1996, *Specification for high slag blastfurnace cement.*

BS 4248:1974, *Specification for supersulfated cement.*

BS 5328, *Concrete.*

BS 5328-2:1997, *Methods for specifying concrete mixes.*

BS 5328-3:1990, *Specification for the procedures to be used in producing and transporting concrete.*

BS 5328-4:1990, *Specification for the procedures to be used in sampling, testing and assessing compliance of concrete.*

BS 5502, *Buildings and structures for agriculture.*

BS 5502-21:1990, *Code of practice for selection and use of construction materials.*

BS 6100, *Glossary of building and civil engineering terms.*

BS 6588:1996, *Specification for Portland pulverized-fuel ash cements.*

BS 6610:1996, *Specification for Pozzolanic pulverized-fuel ash cement.*

BS 6699:1992, *Specification for ground granulated blastfurnace slag for use with Portland cement.*

BS 7583:1996, *Specification for Portland limestone cement.*

BS 8204, *Screeds, bases and in situ floorings.*

BS 8204-2:1999, *Concrete wearing surfaces — Code of practice.*

BS EN 196, *Methods of testing cement.*

BS EN 196-1:1995, *Determination of strength.*

BS EN 197, *Cement.*

BS EN 197-1:2000, *Composition, specifications and conformity criteria for common cements.*

BS EN 934, *Admixtures for concrete, mortar and grout.*

BS EN 934-2:1998, *Concrete admixtures — Definitions and requirements.*

BS EN 12504, *Testing concrete in structures — Cored specimens.*

BS EN 12504-1:2000, *Taking, examining and testing in compression.*

BS EN 12878:1999, *Pigments for the colouring of building materials based on cement and/or lime — Specifications and methods of test.*

Informative references

BSI publications

BRITISH STANDARDS INSTITUTION, London

BS 812, *Testing aggregates.*

BS 812-120:1989, *Method for testing and classifying drying shrinkage of aggregates in concrete.*

BS 812-123:1999, *Method for the determination of alkali-silica reactivity — Concrete prism method.*

BS 6089:1981, *Guide to assessment of concrete strength in existing structures.*

BS 6349, *Maritime structures.*

BS 8110, *Structural use of concrete.*

BS 8110-1:1997, *Code of practice for design and construction.*

BS EN ISO 9000, *Quality management and quality assurance standards.*

BS EN ISO 9001:1994, *Quality systems. Model for quality assurance in design, development, production, installation and servicing.*

Other publications

[1] BRE Special Digest 1:Parts 1 to 4[1)] *Concrete in aggressive ground:*

Part 1 Assessing the aggressive chemical environment;

Part 2 Specifying concrete and additional protective measures;

Part 3 Design guides for common applications;

Part 4 Design guides for specific precast products.

[2] BRE Digest 357[1)] *Shrinkage of natural aggregates in concrete.*

[3] BRE Digest 330[1)] *Alkai-silica reaction in concrete*, 1999.

Text deleted.

1) Available from CRC Ltd, 151 Rosebery Avenue, London EC1R 4QX or online from www.brebookshop.com.
Text deleted.

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