DESIGN OF NORMAL CONCRETE MIXES

SECOND EDITION

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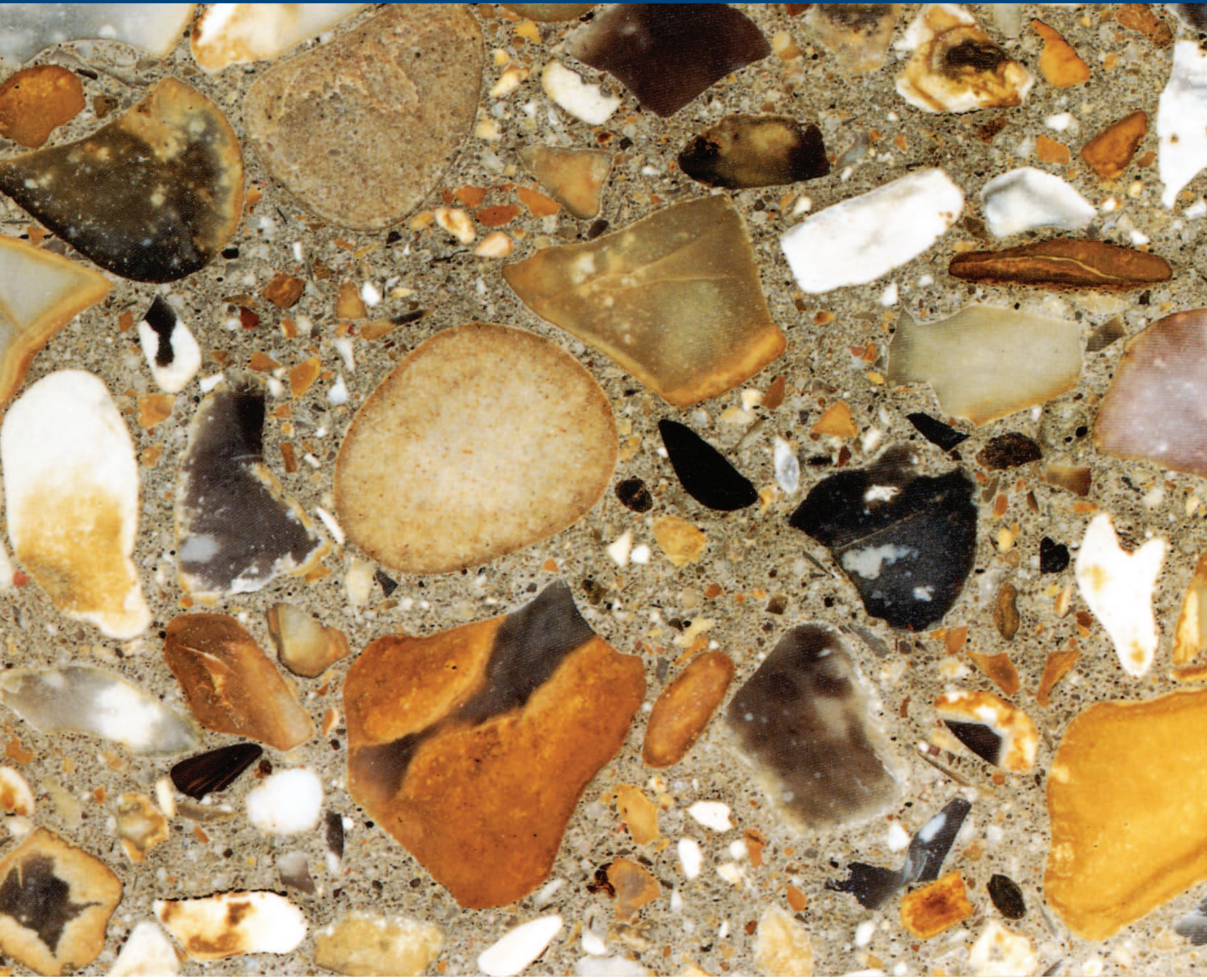

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This second edition replaces the first which was revised in 1988. The design of conrete mixes for most purposes, including roads, is covered in this combined work by Building Research Establishment Ltd, where it was prepared for publication, the Transport Research Laboratory and the British Cement Association.

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Foreword

The method of concrete mix design described in this publication is the same as that used in the first edition, which was published in 1975[1] and revised in 1988[2]. In this second edition, minor amendments have been made to allow for changes in the terminology and properties of the materials used and for changes in various British Standard Specifications.

The basic procedure for this mix design method is applicable to concrete for most purposes including pavements. It is restricted to designing concrete mixes to meet workability, compressive strength and durability requirements using Portland cements complying with BS 12[3] or BS 4027[4] and natural aggregates complying with BS 882[5], or coarse air-cooled slag complying with BS 1047[6]. It does not deal with special materials or special concretes such as lightweight aggregate concrete, or with flowing or pumped concrete. Guidance is given on the application of the method to mixes incorporating pulverised-fuel ash (pfa) for material complying with BS 3892:Part 1[7], or using Portland pulverised-fuel ash cement complying with BS 6588[8]. Guidance is also given on the design of mixes incorporating ground granulated blastfurnace slag (ggbs) complying with BS 6699[9] or using Portland-blastfurnace cements complying with BS 146[10] or BS 4246[11].

As in the first edition, the general principles and basic concepts are given in the Introduction. After this the publication is divided into three parts. Part one gives the background information which is required to understand the mix design procedure.

Part two describes the mix design process and contains all the basic information in the form of tables and graphs for the application of the method to most concretes designed for compressive strength. A standardised form has been developed for use with this method, and some worked examples are given.

Part three deals with modifications to the mix design method to deal with air-entrained concrete, and for the design of mixes incorporating pfa or ggbs.

This method is based on data obtained at the Building Research Establishment, the Transport Research Laboratory (formerly the Transport and Road Research Laboratory), and by the British Cement Association (formerly the Cement and Concrete Association).

1 Introduction

1.1 Principles of proposed method

Basically, the problem of designing a concrete mix consists of selecting the correct proportions of cement, fine and coarse aggregate and water to produce concrete having the specified properties. Sometimes additional ingredients such as ground granulated blastfurnace slag (ggbs), pulverised-fuel ash (pfa), or admixtures, are used as shown in Part three. There are many properties of concrete that can be specified, eg workability, strength, density, thermal characteristics, elastic modulus and durability requirements. The properties most usually specified are:

- The workability of the fresh concrete
- The compressive strength at a specified age
- The durability, by means of specifying the minimum cement content and/or the maximum free-water/cement ratio and, in some cases, requiring the use of selected types of materials

The mix design process must take account of those factors that have a major effect on the characteristics of the concrete, but can, at least at the first stage, ignore those which only have a minor effect on the concrete. There is little point in devising a complex method of mix design which takes into account factors which are difficult to measure or which are unlikely to remain constant during the progress of the job. The effects of various factors on the properties of concrete are described in Sections 2 and 3.

The principle behind the method described in this publication is that from the restricted data usually available at the mix design stage, mix proportions are derived in an attempt to produce a concrete having the required workability and strength. Typical data are given in Part two but where there is more appropriate information available related to local materials, this can be used instead. A trial mix is then made, but because of the assumptions made at this stage in the design it is probable that this trial mix will not completely comply with the requirements. If necessary it is possible, from the trial mix results and information given in this publication, to adjust the mix proportions and to use these for actual production or to prepare a revised trial mix.

1.2 Basic concepts

1.2.1 Strength margin

Because of the variability of concrete strengths[12] the mix must be designed to have a considerably higher mean strength than the strength specified. The method of specifying concrete by its minimum strength has been replaced in British Standards and Codes of Practice such as BS 5328[13] and BS 8110[14] by a ‘characteristic strength’. The difference between the specified characteristic strength and the target mean strength is called the ‘margin’ and is explained more fully in Section 4.

This margin is based on knowledge of the variability of the concrete strength obtained from previous production data expressed as a standard deviation, or alternatively a substantial margin is applied until an adequate number of site results is obtained.

1.2.2 Measurement of workability

In this publication two alternative test methods are used, the slump test[15] which is more appropriate for the higher workability mixes, and the Vebe time test[16] which is particularly appropriate for those mixes which are to be compacted by vibration. The compacting factor[17] is not used in this method since it is not possible to establish consistent relationships between it and the slump or Vebe time tests. If required, it can be used as a control test.

1.2.3 Free-water

The total water in a concrete mix consists of the water absorbed by the aggregate to bring it to a saturated surface-dry condition, and the free-water available for the hydration of the cement and for the workability of the fresh concrete. In practice aggregates are often wet and they contain both absorbed water and free surface water so that the water added at the mixer is less than the free-water required. The workability of concrete depends to a large extent on its free-water content; if the same total water content were used with dry aggregates having different absorptions, then the concrete would have different workabilities. Similarly the strength of concrete is better related to the free-water/cement ratio since on this basis the strength of the concrete does not depend on the absorption characteristics of the aggregates.

The water / cement ratios referred to in this publication are the ratios by mass of free-water to cement in the mix and these, as well as the free-water contents, are based on the aggregates being in a saturated surface-dry condition.

1.2.4 Types of aggregate

Early mix design methods used in the UK[18,19] classified the shape of aggregate as rounded, irregular or angular. There is insufficient difference between the behaviour of rounded and irregular aggregates in concrete to justify the use of separate classifications for these two shapes of aggregate, both of which are usually uncrushed, smooth-textured aggregates. There are however significant differences between these aggregates and angular aggregates which are usually rough in texture and invariably produced by a crushing process.

Two of the characteristics of aggregate particles that affect the properties of concrete are particle shape and surface texture. Particle shape affects the workability of the concrete, and the surface texture mainly affects the bond between the matrix and the aggregate particles and thus the strength of the concrete. Generally, crushed aggregates consist of rather angular particles having a rough surface texture resulting in a concrete of lower workability but higher strength compared with a similar mix made with uncrushed aggregates. There are naturally some exceptions to these generalisations, for example crushed flint has an extremely smooth surface texture whereas uncrushed rounded gritstone has a rough surface texture. However, in line with the principles of this publication of taking only major factors into account to design the initial trial mix, only two types of aggregate are considered, ie crushed and uncrushed.

The type of aggregate becomes of greater importance for concrete having a high specified strength. If the specified strength at 28 days is 50 N / mm^2 or more it may become necessary to use a crushed aggregate rather than an uncrushed gravel. The higher the specified strength the more critical is the selection of the source of the aggregate.

1.2.5 Aggregate grading

This publication deals with concrete made with aggregates having three nominal maximum sizes, ie 40 mm, 20 mm and 10 mm.

Early methods of mix design[18,19] used in the UK specified grading curves for the combined fine and coarse aggregates. These required the use of fine aggregates having a rather restricted range of gradings compared with the limits specified in BS 882. In many parts of the country fine aggregates having such restricted gradings are not available, although the gradings of the available fine aggregates are still suitable for making good quality concrete. Combined aggregate grading curves are not used in this method of mix design which refers instead to the percentage of fine aggregate passing the 600 µm test sieve. The higher the percentage passing the 600 µm test sieve, the finer the fine aggregate. This is a development from the previous edition of this publication which used the grading zones given in the 1973 edition of BS 882.

Fine aggregates should comply with the C, M, or F grading requirements of BS 882:1992[5], but these limits overlap and are too wide for mix design purposes. The method for deriving a suitable fines content takes into account the many relevant factors, ie the type and maximum size of coarse aggregate, the grading of the fine aggregate, characterised by the percentage passing the 600 µm test sieve, and the cement content and workability of the concrete.

1.2.6 Mix parameters

It was previously the general custom in the United Kingdom to specify concrete by a system of proportions or ratios, eg 1:2:4 (being the proportions of cement:fine aggregate:coarse aggregate) either by mass or by volume, or as cement / aggregate ratio, water / cement ratio and fine aggregate / coarse aggregate ratio, usually by mass.

Such systems have certain merits in terms of simplicity of expression. However, they are not so convenient when discussing the effect of mix parameters on the characteristics of the concrete, nor do they adequately describe the quantity of cement required to cast a given volume of concrete.

The most fundamental way to specify mix parameters is in terms of the absolute volumes of the different materials required in a concrete mix. A more practical method, based on similar principles, which has been adopted in this publication is to refer to the mass of materials in a unit volume of fully compacted concrete. This method of referring to concrete mix proportions has been in use for a long period in Europe and in the United States of America, and is becoming the general practice in the United Kingdom.

In order to use this approach, knowledge is required of the expected density of the fresh concrete. This depends primarily on the relative density* of the aggregate and the water content of the mix. The effect of changes in the cement content produces at the most about a 2% change in the expected density and thus, for the purpose of this publication, is ignored. The small quantity of air normally entrapped in compacted concrete is also ignored. Data are given from which an estimate of the wet density of the fresh concrete can be made.

The method of mix design given in this publication results in the mix being specified in terms of the mass in kilograms of the different materials required to produce one cubic metre of finished concrete.

1.2.7 Durability

A durable concrete is one which gives a satisfactory performance during an adequate life in a given environment; this includes providing protection of the steel against corrosion in reinforced concrete and prestressed concrete. There are some durability problems

*The internationally known term 'relative density' used in this publication is synonymous with 'specific gravity' and is the ratio of the mass of a given volume of substance to the mass of an equal volume of water.

associated with the constituent materials, and others due to the effect of hostile environments.

A major factor in providing durable concrete is the production of a dense, impermeable concrete, having an adequate cement content and low free-water / cement ratio, which is fully compacted and properly cured. To be durable in hostile environments, Codes and Standards may specify the use of particular materials, or limits on the cement content or free-water / cement ratio. Provision is made in the mix design method for these to override the values obtained from strength and workability requirements.

The problems of providing protection against corrosion of steel in concrete are discussed in BRE Digest 263[20]. To ensure adequate protection, BS 8110 requires higher strength grades of concrete as the severity of the exposure increases; it also specifies minimum cement contents and maximum free-water / cement ratios, depending on the degree of exposure. Corrosion problems are aggravated by the presence of chlorides in either aggregates or admixtures. Limits are specified in BS 882 and BS 8110 and materials complying with these requirements should be used.

Concrete in the ground may be subject to attack by sulfates as described in BRE Digest 363[21]. To minimise the effect of such attack requires the use of sulfate-resisting Portland cement or other materials, and the mix proportions should comply with the requirements given in BRE Digest 363 or in BS 5328[13].

Concrete that is exposed to freezing when wet and to the action of de-icing salts is liable to spall and deteriorate. The resistance of concrete to such deterioration is greatly improved if it contains entrained air as required in BS 5328. The method of mix design described in Part two requires modifications for air-entrainment which are given in Part three, Section 8.

Concrete that retains a high moisture content and that is made with certain aggregates may react with the alkalis from the cement to cause cracking and expansion, owing to the alkali–silica reaction as described in BRE Digest 330[22]. Measures to avoid such disruption are described in BRE Digest 330 and in an independent Working Party Report published by the Concrete Society[23]. These may require the use of a low-alkali Portland cement available under BS 4027 or the use of other materials.

Many of the measures described previously to give assurance of durability in adverse environmental conditions involve the specification of minimum cement contents or maximum free-water / cement ratios. Owing to the difficulties of testing for compliance with such requirements during concrete construction, an alternative approach is to specify a high strength requirement for durability[24]. However, the more fundamental requirements can be checked if required by using rapid analysis techniques, such as that provided by the RAM equipment available from Wexham Developments.