British Standard

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BRITISH STANDARD

BS 5400-8:
1978

Steel, concrete and composite bridges —

Part 8: Recommendations for materials and workmanship, concrete, reinforcement and prestressing tendons

UDC 624.21.01:624.012.45

Cooperating organizations

The Steel and Concrete Standards Committee, under whose direction this British Standard was prepared, consists of representatives from the following Government departments and scientific, technical and professional organizations:

Association of Consulting Engineers
Association of County Councils
British Constructional Steelwork Association
British Precast Concrete Federation Ltd.
British Railways Board
British Steel Industry
Cement and Concrete Association
Concrete Society Limited
Constructional Steel Research and Development Organization
Department of the Environment (Building Research Establishment)
Department of the Environment (Transport and Road Research Laboratory)
Department of Transport
Federation of Civil Engineering Contractors
Greater London Council
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Institution of Highway Engineers
Institution of Municipal Engineers
Institution of Structural Engineers
London Transport Executive
Ministry of Defence
Sand and Gravel Association Ltd.
Scottish Development Department
Welding Institute

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Contents

NOTE The numbering of the clauses and subclauses in this Part is similar to that in Part 7 for ease of cross-reference.

Foreword

BS 5400 is a document combining codes of practice to cover the design and construction of steel, concrete and composite bridges and specifications and recommendations for the loads, materials and workmanship. It comprises the following Parts:

— *Part 1: General statement;*

— *Part 2: Specification for loads;*

— *Part 3*[1]*: Code of practice for design of steel bridges;*

— *Part 4: Code of practice for design of concrete bridges;*

— *Part 5*[1]*: Code of practice for design of composite bridges;*

— *Part 6*[1]*: Specification for materials and workmanship, steel;*

— *Part 7: Specification for materials and workmanship, concrete, reinforcement and prestressing tendons;*

— *Part 8: Recommendations for materials and workmanship, concrete, reinforcement and prestressing tendons;*

— *Part 9*[1]*: Code of practice for bearings;*

— *Part 10*[1]*: Code of practice for fatigue.*

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

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 28, an inside back cover and a back cover.

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

[1] In course of preparation

NOTE The numbering of the clauses and subclauses of this Part is similar to that in Part 7 for ease of cross-reference. In this context "See Part 7" instructs the user to refer to the corresponding clause or subclause in Part 7.

1 Scope

This Part of this British Standard is in the form of notes for the guidance of engineers using the detailed specification clauses covered by Part 7 and gives a greater understanding of the reasons for their choice.

2 References

The titles of the standards publications referred to in this Part of this British Standard are listed on the inside back cover.

3 Concrete

3.1 Specification of concrete. In this British Standard the concept of concrete as a single material has been adopted. It is therefore the responsibility of the engineer to specify the type of concrete he requires to ensure both the strength and the durability of the finished structure.

3.1.1 ***Classification of concrete mixes.*** When specifying concrete, the following terms should be used to describe the class of concrete required.

3.1.2 ***Ordinary structural concrete.*** Ordinary structural concrete is concrete of any grade that is used in reinforced, prestressed or plain concrete construction and that does not contain admixtures or materials other than those specified in **3.2** of Part 7.

3.1.3 ***Special structural concrete.*** The structural concrete should be considered as special when it contains admixtures or materials other than those specified in **3.2** of Part 7.

3.1.4 and **3.1.5** ***Designed mix and prescribed mix.*** When a designed mix is specified, the contractor or manufacturer should be responsible for selecting the mix proportions in accordance with **3.6** to achieve the required strength and workability, but the engineer should be responsible for specifying the minimum cement content and other properties required to ensure durability.

When a prescribed mix is specified, the engineer should specify the mix proportions and the contractor or manufacturer should undertake to provide a properly mixed concrete containing the constituents in the specified proportions in accordance with the appropriate provisions of **3.7**. The engineer should be responsible for ensuring that the mix proportions prescribed provide the strength and durability he requires. The class of concrete mix required is covered by one of the following descriptions:

Designed mix for ordinary structural concrete

Prescribed mix for ordinary structural concrete

Designed mix for special structural concrete

Prescribed mix for special structural concrete

These descriptions may be used to describe in broad terms the type of concrete required, but they do not in any way constitute a complete specification.

3.1.6 ***Form of specification.*** The engineer should decide the class and grade designation of the concrete required for each part of the work and determine suitable limitations on the constituent materials and mix proportions in accordance with the recommendations of **3.5**. On the basis of these data, together with any other requirements of the work, the engineer should specify the concrete in accordance with **3.1.2** or **3.1.3,** and **3.1.4** or **3.1.5,** of Part 7 as appropriate. For constructional convenience the number of types and grades of concrete used on one site or in one factory should be kept as few as possible.

Recommendations regarding the assessment of compliance with the specified requirements are given in **3.9**.

3.1.7 ***Designed mix for ordinary structural concrete.*** By the definition given in **3.1.2**, limitations on the constituent materials are already established and therefore the engineer need only specify the following:

Designed mix for ordinary structural concrete	Clause in Part 7
Grade designation	**3.5.1**
Type of cement	**3.2.1**
Minimum cement content	**3.5.2**
Nominal maximum size of aggregate	**3.2.2**

Unless specified otherwise, the contractor should decide the workability of the fresh concrete (see **3.9.4** of Part 7).

3.1.8 ***Prescribed mix for ordinary structural concrete***

3.1.8.1 When the engineer intends to adopt one of the prescribed mixes given in Table 2 of Part 7 that are relatively rich in cement and are intended for use where the cost of trial mixes or of acceptance cube testing is not justified, the limitations on constituent materials are defined in **3.2** of Part 7, and therefore the engineer need only specify the following:

Prescribed mix in accordance with Table 2 of Part 7	Clause in Part 7
Grade designation	**3.5.1**
Type of cement	**3.2.1**
Nominal maximum size of aggregate	**3.2.2**

Provided that the materials used are those described, the weights given in Table 2 of Part 7 are appropriate for the large majority of cases except where poor control is allied to the use of poor materials.

3.1.8.2 When the engineer intends to adopt a prescribed mix for ordinary structural concrete other than those given in Table 2 of Part 7, the limitations on constituent materials and mix proportions should be fully described in the specification. Before prescribing such a mix he should be sure that with the materials and workmanship available in the particular locality a concrete of the required standard can be readily obtained. For this purpose he should arrange for preliminary strength tests to be carried out unless satisfactory evidence is available from previous use of the mix. He may also arrange for strength tests to be carried out during the progress of the work in accordance with **3.9.2.2** to satisfy himself that his specified mix proportions are suitable. Admixtures should not be specified or used.

The information to be given in the specification should include the following:

Prescribed mix for ordinary structural concrete not specified in Table 4 of Part 7	Clause in Part 7
Grade designation	**3.5.1**
Proportion of cement : fine aggregate : coarse aggregate	**3.2.2**
Nominal maximum size of aggregate	**3.2.2**
Types of cement that may be used	**3.2.1**
Types of aggregate that may be used	**3.2.2**
Required workability	**3.9.4**

3.1.9 ***Designed mix for special structural concrete.*** This broad class of concrete mixes includes those using admixtures, those using cements other than Portland, lightweight aggregates, heavyweight aggregates etc., and those specially designed to have a special property or to produce a particular surface finish. It is important, therefore, to specify the requirements in detail and, where possible, to state the reasons for any special requirements so that the the contractor can more fully appreciate the object of the work.

In appropriate circumstances any of the following information may be included, but great care should be taken to ensure that the requirements specified do not conflict with each other.

Designed mix for special structural concrete	Clause in Part 7
Grade designation	**3.5.1**
Minimum cement content	**3.5.2**
Nominal maximum size of aggregate	**3.2.2**
Required workability	**3.9.4**
Maximum cement content	**3.5.3**
Required brand or type of cement	**3.3.1**
Required source or special type of aggregate	**3.3.2** or **3.4.2**
Required admixture	**3.3.4**
Air content of fresh concrete	**3.9.6**
Min. or max. temperature of fresh concrete	**3.11.8** or **3.11.9**
Rate of sampling and testing	**3.9.2.1**
Other requirements	**3.9.1** and **3.10.2**

Unless specified otherwise, the contractor should decide the workability and the mix should be designed in accordance with the provisions of **3.9.4** of Part 7.

3.1.10 ***Prescribed mix for special structural concrete.*** Mixes in this class should only be specified when the engineer is confident that, with the materials and workmanship available, a concrete of the required standard can be readily obtained.

An engineer with expert knowledge or previous experience of mix design using particular cements, special aggregates or unusual gradings (such as gap grading) may wish to specify the ingredients for a special mix.

An engineer may wish to use a prescribed mix to obtain a special finish. Strength may be of secondary importance.

When an engineer intends to specify, or allow, the use of an admixture in what would otherwise be an ordinary structural concrete, it becomes a special structural concrete and should be treated as such (see **3.3.4**).

3.1.11 ***Requirements for fresh concrete.*** The requirements for the concrete in the fresh or plastic state, particularly its workability (see **3.9.4** of Part 7), should be decided by or in consultation with the contractor.

It may be necessary when working in cold or hot weather to control the temperature of fresh concrete (see **3.11.6** and **3.11.7**).

Where the minimum dimension of concrete to be placed at a single time is greater than 600 mm and especially where the cement content is likely to be 400 kg/m^3 or more, measures to reduce the temperature, such as the selection of a cement type with a slower release of heat of hydration, should be considered. In exceptional cases other measures to reduce the temperature or to remove evolved heat may be necessary.

3.2 Constituent materials of ordinary structural concrete

3.2.1 ***Cement.*** Where cements other than those complying with the requirements of BS 12 and BS 146 are used, account should be taken of their properties and any particular conditions of use.

Supersulphated cement should not be mixed with any other type of cement.

3.2.2 ***Aggregates***

3.2.2.1 *General.* The engineer may specify or approve on request the use of aggregates other than those specified in **3.2.2, 3.3.2** or **3.4.2** of Part 7, including types or gradings not covered by the appropriate British Standards, provided that there are satisfactory data on the properties of concrete made with them.

When high strength concrete is required, the source as well as the type of aggregate may need careful selection based on the results of trial mixes.

Where it is known that any property of any aggregate is likely to have an unusual effect on the strength, density, shrinkage, moisture movement, thermal properties, creep, modulus of elasticity or durability of concrete made with it, the engineer should take account of these factors in the design and workmanship requirements.

Aggregates having a high drying shrinkage, such as some dolerites and whinstones, and gravels containing these rocks produce concrete having a higher drying shrinkage than that normally expected. This can result in deterioration of exposed concrete and excessive deflections of reinforced concrete unless special measures are taken. For further information see BRS Digest 35.

3.2.2.2 *Nominal maximum size.* The preferred nominal maximum sizes of aggregate are 40 mm and 20 mm, but if a smaller size is necessary it should be either 14 mm or 10 mm.

3.2.2.3 *Marine aggregates.* Marine aggregates may be used provided that the total chloride content of the concrete mix arising from the aggregate and any other source does not exceed the following limits, expressed as a percentage relationship between chloride ion and weight of cement in the mix.

Table 1 — Limits on total chloride content

Type or use of concrete	Maximum total chloride content (expressed as percentage of chloride ion by weight of cement)
	%
Concrete for any use made with cement complying with BS 4027 or BS 4248	0.06
Reinforced concrete with cement complying with BS 12	0.35 for 95 % of test results with no result greater than 0.50
Plain concrete made with cement complying with BS 12 and containing embedded metal	(as above)

NOTE % chloride ion × 1.648 = % equivalent sodium chloride; % chloride ion × 1.565 = % equivalent anhydrous calcium chloride.

The shell content of the aggregate included as calcium carbonate should not exceed the following amounts:

Nominal size (mm)	%
40	2
20	5
10	15
fine	30

Hollow shells or other shells of unsuitable shape in quantities that may adversely affect the quality of, or cause permeability to, the concrete should not be permitted.

3.2.3 ***Water.*** See Part 7.

3.3 Constituent materials of special structural concrete

3.3.1 ***Cement.*** See **3.2.1**.

3.3.2 ***Aggregates.*** See **3.2.2**.

3.3.3 ***Water.*** See Part 7.

3.3.4 ***Admixtures***

3.3.4.1 *General.* Admixtures may be specified by type and effect or by brand and dosage.

For admixtures for which there is no British Standard, the type and/or proprietary brand may be specified.

Admixtures should never be regarded as replacement for good concreting practice and should never be used indiscriminately.

Many admixtures are highly active chemicals and may impart undesirable as well as desirable properties to the concrete; their suitability should generally be verified by trial mixes. The trial mix should contain cement of the same make and from the same source as that intended to be used for the permanent works. If two or more admixtures are thought to be required in any one mix, the manufacturers of each should be consulted. The engineer should satisfy himself that the admixture is compatible with all of the other constituents of the concrete mix and ascertain whether it accelerates or retards the setting time and loss of workability.

In particular the behaviour of admixtures with supersulphated cements may differ from that with Portland cements, and advice should be sought before use.

3.3.4.2 *Pulverized-fuel ash.* The grading zone and the maximum sulphate content of pulverized-fuel ash in accordance with BS 3892 should be specified. Where pulverized-fuel ash is used, the total sulphate content, expressed as sulphuric anhydride (SO_3) of the concrete mix, should never exceed 4 % by weight of the cement. The sulphate content should be calculated from the known sulphate content of the cement, aggregates (where applicable) and pulverized-fuel ash as determined by tests carried out in accordance with BS 4550, BS 1047 and BS 3892 respectively.

Pulverized-fuel ash should not be used in conjunction with a cement complying with the requirements of BS 4027 in concrete required to be resistant to sulphates.

3.3.4.3 *Air-entraining agents.* The admixture should be of such a type that the air content (see **3.5.6**) can be maintained within the limits specified (see **3.9.6**) irrespective of extension of mixing time to 30 min.

3.4 Miscellaneous aggregates

3.4.1 ***Sands for mortar.*** See Part 7.

3.4.2 ***Aggregate for concrete wearing surface.*** See Part 7.

3.5 Requirements for hardened concrete

3.5.1 ***General.*** The minimum requirements for the strength and durability of the concrete in the hardened state should be decided by the engineer from considerations of the limit state requirements of Part 4, but if in addition a special property or a particular surface finish is required, these minimum requirements may have to be considerably exceeded.

The grade of concrete required depends partly on the particular use and the characteristic strength needed to provide the structure with adequate ultimate strength (Table 2) and partly on the exposure conditions and the cover provided to any reinforcement or tendons (see **6.8.2, 7.9.2** and Table 11 of Part 4).

Table 2 — Grades of concrete and appropriate uses

Grade	Characteristic strength	Lowest grade for compliance with appropriate use
	N/mm^2	
15	15.0	Plain concrete or reinforced concrete with lightweight aggregate
20	20.0	Reinforced concrete with normal aggregate
25	25.0	Concrete with post-tensioned tendons Concrete with pretensioned tendons
30	30.0	
40	40.0	
50	50.0	
60	60.0	

3.5.2 ***Minimum cement content.*** The engineer should state in the contract the minimum cement content required for each concrete mix. One of the main characteristics influencing the durability of any concrete is its permeability. With strong dense aggregates, a suitably low permeability is achieved by having a sufficiently low water/cement ratio, by ensuring sufficient hydration of the cement through proper curing methods, and by ensuring maximum compaction of the concrete. Therefore for given aggregates the cement content should be sufficient to provide adequate workability with a low water/cement ratio so that the concrete can be fully compacted with the means available.

Table 3 gives the minimum cement content required, when using a particular size of aggregate in a Portland cement concrete, to provide acceptable durability under the appropriate conditions of exposure. The reduced minimum cement contents given in Table 3 should only be used when trial mixes (see **3.6.3**) have verified a) that a concrete with a maximum free water/cement ratio not greater than that given for the particular condition can be consistently produced and b) that it is suitable for the conditions of placing and compaction.

Table 4 gives the minimum cement content required when using a particular size of aggregate and a particular type of cement to provide a concrete having acceptable durability under exposure to a particular degree of sulphate attack. It should be noted that this durability is only obtained if the appropriate maximum free water/cement ratio is not exceeded, in addition it should be noted that the table gives the absolute minimum requirements for the average case and that additional recommendations for rather more severe conditions are given in the notes to the table.

3.5.3 ***Maximum cement content.*** Cement contents in excess of 550 kg/m^3 should not be used unless special consideration has been given in design to the increased creep, risk of cracking due to drying shrinkage in thin sections, and higher thermal stresses in thicker sections. In order to make the higher grades of lightweight aggregate concrete, cement contents in excess of 550 kg/m^3 may be used provided that the engineer is satisfied that the concrete produced is suitable in all respects.

3.5.4 ***Type of cement.*** The type of cement used in the concrete mix affects the properties of the hardened concrete. Table 4 indicates how the resistance of concrete to attack by sulphate solutions depends on the type of cement used.

It should be noted that special care is needed in the storage of supersulphated cement as it deteriorates rapidly in poor storage conditions. The rate of strength development of concrete made with supersulphated cement is considerably reduced at low temperatures. Unless adequately cured, the surface of supersulphated cement concrete is liable to become friable or dusty. This concrete should be kept moist for at least 4 days after placing; this is essential during hot weather.

3.5.5 ***Type of aggregate.*** The type of aggregate used in the concrete may affect the creep, shrinkage, durability and other properties (see **3.2.2.1**) of the hardened concrete.

3.5.6 ***Type of admixture.*** Certain admixtures have a considerable effect on the properties of hardened concrete and great care should be taken when specifying or allowing their use in special concretes.

Air-entraining agents used to entrain controlled percentages of air in the concrete generally improve its durability and in particular its resistance to frost damage.

When a concrete of grade 40 or lower is required to provide resistance to the effects of salt used for de-icing, it should contain entrained air and the appropriate admixture should be used for the special concrete required. The average air content of the fresh concrete should be specified as follows:

for natural aggregates of 10 mm nominal maximum size: 7 %

for natural aggregates of 14 mm nominal maximum size: 6 %

for natural aggregates of 20 mm nominal maximum size: 5 %

for natural aggregates of 40 mm nominal maximum size: 4 %

Table 3 — Minimum cement content required in Portland cement concrete to ensure durability

Exposure		Prestressed concrete: Nominal maximum size of aggregate (in mm)				Reinforced concrete: Nominal maximum size of aggregate (in mm)				Plain concrete: Nominal maximum size of aggregate (in mm)			
		40	**20**	**14**	**10**	**40**	**20**	**14**	**10**	**40**	**20**	**14**	**10**
		kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3
Moderate	Surfaces sheltered from severe rain and against freezing whilst saturated with water, e.g. 1) surface protected by a waterproof membrane 2) internal surfaces, whether subject to condensation or not 3) buried concrete and concrete continuously under water	300	300	320	340	260	290	320	340	220	250	280	300
Severe	1) soffits 2) surfaces exposed to driving rain, alternate wetting and drying (e.g. in contact with backfill) and to freezing whilst wet	300	300	320	340	260	290	320	340	240	280	310	330
Very severe	1) surfaces subject to the effects of de-icing salts or salt spray, e.g. roadside structures and marine structures 2) surfaces exposed to the action of sea water with abrasion or moorland water having a pH of 4.5 or less	320	360	390	410	320	360	390	410	270	310	330	350

When the maximum free water/cement ratio can be strictly controlled, these may be reduced to:

Exposure	Prestressed concrete: Nominal maximum size of aggregate (in mm)				Prestressed concrete: Maximum free water/cement ratio	Reinforced concrete: Nominal maximum size of aggregate (in mm)				Reinforced concrete: Maximum free water/cement ratio	Plain concrete: Nominal maximum size of aggregate (in mm)				Plain concrete: Maximum free water/cement ratio
	40	**20**	**14**	**10**		**40**	**20**	**14**	**10**		**40**	**20**	**14**	**10**	
Moderate	300	300	300	310	0.55	240	260	290	310	0.55	200	230	250	270	0.60
Severe	300	300	300	310	0.55	240	260	290	310	0.55	220	250	280	300	0.55
Very severe	300	330	350	370	0.45	290	330	350	370	0.45	240	280	300	320	0.50

Table 4 — Requirements for the durability of concrete exposed to sulphate attack

Class	Concentration of sulphates expressed as SO_3			Requirements for dense, fully compacted concrete made with aggregates complying with BS 882 or BS 1047				
	In soil		In ground water (Parts per 100 000)	Types of cement	(a) Minimum cement content: Nominal maximum size of aggregate (in mm)			(b) Maximum free water/cement ratio
	Total SO_3	SO_3 in 2 : 1 water extract			40	20	10	
	%	g/l			kg/m^3	kg/m^3	kg/m^3	
1	< 0.2	—	< 30	Ordinary Portland or Portland-blastfurnace	240	280	330	0.55
2	0.2 < 5.0	—	30 < 120	Ordinary Portland or Portland-blastfurnace	290	330	380	0.50
				Sulphate-resisting Portland	240	280	330	0.55
				Supersulphated	270	310	360	0.50
3	0.5 < 1.0	1.9 < 3.1	120 < 250	Sulphate-resisting Portland or supersulphated	290	330	380	0.45
4	1.0 < 2.0	3.1 < 5.6	250 < 500	Sulphate-resisting Portland or supersulphated	330	370	420	0.45
5	> 2.0	> 5.6	> 500	Sulphate-resisting Portland or supersulphated plus adequate protective coatings	330	370	420	0.45

NOTE 1 Requirements (a) and (b) both apply.

NOTE 2 This table applies only to concrete made with aggregates complying with the requirements of BS 882 or BS 1047 placed in near-neutral groundwaters of pH 6 to 9, containing naturally occurring sulphates but not contaminants such as ammonium salts. Concrete prepared from ordinary or sulphate-resisting Portland cement should not be recommended in acidic conditions (pH 6 or less).

NOTE 3 The cement contents given in class 2 are the minimal recommended by the manufacturers. For SO_3 contents near the upper limit of class 2, cement contents above these minima are advised.

NOTE 4 Where the total SO_3 in column 2 exceeds 0.5 %, a 2 : 1 water extract may result in a lower site classification if much of the sulphate is present as low-solubility calcium sulphate. Reference should be made to BRS Digest 174:1975.

NOTE 5 For severe conditions (e.g. thin sections, sections under hydrostatic pressure on one side only and sections partly immersed) consideration should be given to a further reduction of the water/cement ratio and, if necessary, an increase in cement content to ensure the degree of workability for full compaction and thus minimum permeability.

NOTE 6 The prescribed mixes given in Table 2 of Part 7 may be used where appropriate to meet the requirements of this table, and for this purpose the free water/cement ratios of grades 20, 25 and 30 shall be taken as 0.55, 0.50 and 0.45 respectively.

3.6 Requirements for designed mixes

3.6.1 ***Target mean strength.*** See Part 7.

3.6.2 ***Evidence of suitability of proposed mix proportions.*** Evidence should be submitted to the engineer for each grade of concrete showing that, at the intended workability, the proposed mix proportions and manufacturing method will produce concrete of the required quality.

Mix proportions having the required minimum cement content and recommended by the producer of a particular lightweight aggregate as complying with the strength requirements of grades 15, 20, 25 or 30 may be accepted in lieu of trial mixes where the engineer is satisfied that the results can be achieved. For higher grades of concrete, trial mixes should be made.

3.6.3 ***Trial mixes.*** If trial mixes are required to demonstrate that the maximum free water/cement ratio is not exceeded (see **3.5.2**), two batches should be made in a laboratory with cement and surface dry aggregates known to be typical from past records of the suppliers of the material. The proposed mix proportions should not be accepted unless both batches have a free water/cement ratio below the maximum specified value at the proposed degree of workability. For this purpose existing laboratory test reports may be accepted instead of trial mixes only if the engineer is satisfied that the materials to be used in the structural concrete are likely to be similar to those used in the tests. The workability of a trial mix should be checked by casting a trial panel representing the most congested part of the work (see **3.10.1**).

3.6.4 ***Additional trial mixes.*** See Part 7.

3.7 Requirements for prescribed mixes

3.7.1 ***Prescribed mixes for ordinary structural concrete.*** The minimum cement contents for these prescribed mixes are given in Table 2 of Part 7 together with the total weights of dry aggregate to produce approximately 1 m^3 of concrete. Depending upon the specific gravity of the aggregates, slight adjustments may be required to the quantity of aggregates to produce this volume of concrete having the required workability, strength and minimum cement content. Table 2 of Part 7 also gives the approximate proportions of fine aggregate to be used, although small adjustments may be required on the site depending on the properties of the local materials. For grade 15 a range of fine aggregate proportions is given, the lower percentage being applicable to finer material such as zone 3 sand and the higher percentage being applicable to coarser material such as zone 1 sand. Where single-sized coarse aggregates are used, the proportions should be chosen to produce a combined grading within the limits of BS 882 or BS 1047 for graded coarse aggregate of the appropriate size.

The actual batch weights should be calculated to suit the size of the mixer from the values given in Table 2 of Part 7 for the appropriate grade of concrete. Allowance should be made for the water content of the fine and coarse aggregates.

Where necessary the aggregates for grade 15 may be batched by volume, in which case the bulk density of the damp aggregate may be taken as 1 500 kg/m^3. One whole bag of cement may be taken as weighing 50 kg.

3.7.2 ***Prescribed mixes for special structural concrete.*** See Part 7.

3.8 Production of concrete

3.8.1 ***General.*** The engineer should be afforded all reasonable opportunity and facility to inspect the materials and the manufacture of concrete and to take any samples or to make any tests. All such inspection, sampling and testing should be carried out with the minimum of interference with the process of manufacture and delivery.

3.8.2 ***Cement.*** See Part 7.

3.8.3 ***Aggregate.*** Separate fine and coarse aggregates should be used except for grade 15, where all-in aggregate may be used.

For the grades of concrete other than 15, the grading of each size of aggregate from each pit, quarry or other source of supply should be determined at least once weekly. The results of such tests should be reported to the engineer and should be used to check whether the gradings are similar to those of the samples used in the establishment of the mix proportions. The results of routine control tests carried out by the aggregate producer should be accepted for this purpose.

3.8.4 ***Batching and mixing.*** The mixing time should be not less than that used by the manufacturer in assessing the mixer performance. In the case of mixes of low workability or high cement content, this may not ensure maximum strength, and it may be advisable to determine a satisfactory mixing time by comparing the strength of samples mixed for different times.

It is advisable to check the accuracy of the batching plant measuring equipment at intervals not exceeding 1 month.

The water content of each batch of concrete should be adjusted so as to produce a concrete of the workability to accord with the trial mixes or Table 2 of Part 7 as appropriate.

3.8.5 ***Control of strength of designed mixes***

3.8.5.1 *Adjustments to mix proportions.* During production adjustments of mix proportions will be made in order to minimize the variability of strength and to approach more closely the target mean strength. Such adjustments are regarded as part of the proper control of production, but the specified limits of minimum cement content and maximum water/cement ratio should be maintained. Changes in cement content may have to be declared (see **3.6.2**).

3.8.5.2 *Change of "current margin".* A change in the "current margin" used for judging compliance with the specified characteristic strength becomes appropriate when the results of a sufficiently large number of tests show that the previously established margin is significantly too large or too small. Recalculation of the margin should be carried out in accordance with **3.6.1**, but although a recalculated margin is almost certain to differ numerically from the previous value, the adoption of the recalculated value is not generally justified if the two values differ by less than 18 % when based on tests on 40 separate batches, or less than 11 % when based on tests on 100 separate batches, or less than 5 % when based on tests on 500 separate batches.

3.8.6 ***Ready-mixed concrete.*** See Part 7.

3.9 Compliance with specified requirements

3.9.1 ***General.*** Provided that the engineer is satisfied that the materials used are in accordance with **3.2** or **3.3** and that correct methods of manufacture (see **3.8**) and practices of handling raw materials and manufactured concrete have been used, the compliance of

a) a designed mix for ordinary structural concrete should be judged by the strength of the hardened concrete in comparison with the specified characteristic strength (see **3.9.2**), together with the cement content in comparison with the specified minimum (see **3.9.3**);

b) a prescribed mix for ordinary structural concrete should, unless otherwise specified, be judged on the basis of the specified mix proportions and required workability. The engineer should, however, satisfy himself that the concrete is likely to have sufficient strength (see **3.1.8**);

c) a designed mix for special structural concrete should be judged in a manner similar to a) above except that, in addition when it is applicable, compliance with any specified special requirements should be judged by the standards set out in **3.9.3**, **3.9.4**, **3.9.5** and **3.9.6**;

d) a prescribed mix for special structural concrete should be judged in a manner similar to b) above.

When requirements not described in detail in this British Standard are specified (e.g. density or modulus of elasticity of concrete), compliance with those requirements should be determined only in association with a detailed description of the method of test and with tolerances that take appropriate account of variability due to sampling, testing and manufacture.

3.9.2 ***Strength***

3.9.2.1 *General.* A minimum rate of sampling should be decided taking into account the nature of the work. Higher rates of sampling and testing may be required at the start of work to establish the level of quality quickly or during periods of production when quality is in doubt; conversely, rates may well be reduced when high quality has been established. The cost of implementing a suitable system of sampling and testing is not negligible, but this has to be set against the volume of concrete normally put at risk, i.e. 30 m^3, 60 m^3 and 150 m^3 for rates 1, 2 and 3 respectively under any one decision. For example, sampling within rate 1 as given in Table 3 of Part 7 would be suitable for highly stressed structural elements, whereas rate 3 would be suitable for mass concrete not subjected to high stresses. For ordinary structural work, rate 2 is appropriate.

3.9.2.2 *Testing plan A.* This should be the normal method of testing the concrete production. It achieves a good balance between the consumer's risk of accepting concrete that does not meet the strength requirements and the producer's risk of having satisfactory concrete rejected.

3.9.2.3 *Testing plan B.* This should be specified where the engineer requires assurance that the concrete placed in a particular part of the works is of adequate strength. It should not, however, be applied to every batch as this would be expensive and would provide no better overall assurance to the consumer than plan A.

3.9.2.4 *Action to be taken in the event of non-compliance with the testing plans.* When the average strength of four consecutive test cubes fails to meet the recommendation of **3.9.2.2**, the mix proportions of subsequent batches of concrete should be modified to increase the strength.

The action to be taken in respect of the concrete that is represented by the test cubes that fail to meet the recommendations of **3.9.2.2** or **3.9.2.3** should be determined by the engineer. 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, the engineer should have due regard for the technical consequences of the kind and degree of non-compliance, and for the economic consequences of alternative remedial measures either to replace the substandard concrete or to ensure the integrity of any structure in which the concrete has been placed.

In estimating the concrete quality and in determining the action to be taken when the conditions of **3.9.2.2** or **3.9.2.3** are not satisfied, the engineer should establish the following wherever possible:

a) the validity of the test results, and confirmation that specimen sampling and testing have been carried out in accordance with BS 1881;

b) the mix proportions actually used in the concrete under investigation;

c) the actual section of the structure represented by the test cubes;

d) the possible influence of any reduction in concrete quality on the strength and durability of this section of the structure.

The engineer may wish to carry out additional tests on the hardened concrete in the structure to confirm its integrity or otherwise; These may include non-destructive methods or the taking of cored samples (see appendix A).

3.9.3 ***Cement content.*** The observation of batching in relation to the indicated batch weights is one way of ensuring this.

As an alternative the cement content may be determined from samples representative of any batch of concrete, provided that a suitable testing regime is used to measure the cement content of fresh concrete to an accuracy of ± 5 % of the actual value with a confidence of 95 %.

3.9.4 ***Workability.*** See Part 7.

3.9.5 ***Water/cement ratio.*** If a maximum water/cement ratio has been specified, the ability to comply with that requirement, at a suitable level of workability, will have been determined by means of trial mixes. Provided that the constituent materials and mix proportions are not substantially different from those used in the trial mixes, a maximum water/cement ratio may be judged from workability tests.

As an alternative the water/cement ratio may be determined from samples representative of any batch of concrete, provided that a suitable testing regime (including errors due to sampling) is used to measure the water/cement ratio of fresh concrete to an accuracy of ± 5 % of the actual value with a confidence of 95 %.

3.9.6 ***Air content of fresh concrete.*** It should be noted that the method of measuring air content described in BS 1881 is not applicable to concrete made with lightweight aggregate.

3.9.7 ***Additional tests on concrete for special purposes.*** Additional cubes may be required for various purposes. These should be made and tested in accordance with BS 1881, but the methods of sampling and the conditions under which the cubes are stored should be varied according to the purpose for which they are required. For determining the cube strength of prestressed concrete before transfer or of concrete in a member before striking formwork or removing cold weather protection, sampling should preferably be at the point of placing, and the cubes should be stored as far as possible under the same conditions as the concrete in the members. The extra cubes should be identified at the time of making and should not be used for the normal quality control or compliance procedures.

3.10 Surface finish of concrete

3.10.1 ***General.*** The type of surface finish required depends on the nature of the member (column, beam, slab or unit, staircase), its final position in the structure, and whether or not it is to receive an applied finish. The appropriate finish, which may vary from face to face, should be carefully chosen and clearly specified. The use of terms such as "fair faced" and "blemish free" should be avoided. Wherever possible, samples of surfaces of adequate size (preferably incorporating a horizontal and vertical joint) should be made available and agreed before work commences. All the factors affecting the quality of the surface finish from formwork should be carefully studied. For detailed descriptions of these factors and their interrelationship, attention is directed to the pamphlet *Recommendations for the production of high quality concrete surfaces,* Cement and Concrete Association Technical Advisory Series, 47.019.

Texture, colour and durability are affected by curing (see **3.11.6**). Where appearance is important, curing methods and conditions including the time of removal of formwork require careful consideration. Components that are intended to have the same surface finish should receive the same treatment.

3.10.2 ***Control of colour.*** Where uniformity of colour is important, all materials should be obtained from single consistent sources. In formwork the replacement of individual plywood sheets or sections of timber in large panels should be avoided. Colour can be affected by curing.

3.10.3 ***Release agents.*** Release agents for formwork should be carefully chosen for the particular conditions they are required to fulfil. Where the surface is to receive an applied finish, care should be taken to ensure the compatibility of the release agent with the finish.

3.10.4 ***Surface finishes for formwork or moulds***

Type "A" finish. The surfaces will be imprinted with the grain of the sawn boards and their joints. In addition small blemishes caused by entrapped air or water may be expected, but the surface should be free from voids, honeycombing or other large blemishes.

Type "B" finish. The surfaces will be imprinted with the slight grain of the wrought boards and their joints. Small blemishes caused by entrapped air or water may be expected, but the surface should be free from voids, honeycombing or other large blemishes.

It should be noted that finishes of type "A" and "B" do not necessarily provide a suitable surface to receive in-situ concrete or applied finishes, nor do they include special board-marked finishes. Consideration should be given to the type of connection or applied finish and, if necessary, other types of treatment should be specified for the appropriate faces.

Type "C" finish. This finish can only be achieved by the use of high quality concrete.

Type "D" finish. Care should be taken, in the choice of any release agent used, to ensure that the finished concrete surface is not permanently stained or discoloured.

Other types of finish. These should be fully specified in each case and should, if possible, be related to samples that are readily available for comparison. Included under this heading is any finish that requires the coarse aggregate to be permanently exposed, the use of special forms or linings, the use of a different concrete mix near the surface, grinding, bush-hammering or other treatment.

3.10.5 ***Protection.*** High quality surface finishes are susceptible to subsequent damage, and special protection may have to be provided in vulnerable areas.

3.11 Construction with concrete. Absolute accuracy exists only in theory; tolerable degrees of inaccuracy have to be accepted in practice. If dimensional tolerances are specified, they should be as large as possible without rendering the finished structure or any part of it unacceptable to the purpose for which it is intended.

3.11.1 ***Construction joints.*** The number of construction joints should be kept as few as possible consistent with reasonable precautions against shrinkage. Concreting should be carried out continuously up to construction joints.

Where it is necessary to introduce construction joints, careful consideration should be given to their exact location, which should be indicated on the drawings. Alternatively the location of joints should be subject to agreement between the engineer and the contractor before any work commences. Construction joints should be at right angles to the general direction of the member and should take due account of shear and other stresses.

The use of shutter paint retarding agents should be discouraged because they tend to migrate into the concrete under the action of vibration.

Concrete should not be allowed to run to a "feather edge" and vertical joints should be formed against a stop board. The top surface of a layer of concrete should be level and reasonably flat unless design considerations make this undesirable. Joint lines should be so arranged that they coincide with features of the finished work.

If a kicker (i.e. a starter stub) is used, it should be at least 70 mm high and carefully constructed. Where possible, the formwork should be designed to facilitate the preparation of the joint surface, as the optimum time for treatment is usually 2 h to 4 h after placing.

Particular care should be taken in the placing of the new concrete close to the joint. This concrete should be particularly well compacted and if possible a vibrator should be used.

3.11.2 ***Formwork***

3.11.2.1 *Design and construction.* The engineer should satisfy himself that all permanent or temporary formwork, including supports, is adequate for the proper construction of the permanent work.

3.11.2.2 *Form lining.* See **3.10**.

3.11.2.3 *Cleaning and treatment of forms.* See **3.10.3**.

3.11.2.4 *Projecting reinforcement, fixing devices.* Special care should be taken when demoulding in order not to break off the edge of the concrete adjacent to the projecting reinforcement.

3.11.3 ***Transporting, placing and compacting of concrete.*** The contractor should submit to the engineer details of the method of transporting and placing concrete. Concrete should be transported from the mixer to the formwork as rapidly as practicable by methods that will prevent the segregation or loss of any of the ingredients and maintain the required workability. It should be deposited as nearly practicable in its final position to avoid rehandling.

All placing and compacting should be carried out under the direct supervision of a competent member of the contractor's (or manufacturer's) staff. Concrete should normally be placed and compacted soon after mixing, but delays in placing may be permitted provided that the concrete can still be placed and effectively compacted without the addition of further water.

The depth of lift to be concreted should be determined by the contractor or manufacturer in consultation with the engineer. A cohesive concrete mix that does not segregate may be allowed to fall freely through any distance provided that special care is taken to avoid displacement of reinforcement or movement of formwork, and damage to faces of formwork, in massive sections it is necessary to consider the effect of lift height on the temperature rise due to the heat of hydration.

Concrete should be thoroughly compacted by vibration, pressure, shock or other means during the operation of placing to produce the required surface finish when the formwork is removed.

Whenever vibration has to be applied externally, the design of formwork and disposition of vibrators should receive special consideration to ensure efficient compaction and to avoid surface blemishes.

The mix should be such that there will not be excess water on the top surface on completion of compaction. It may be necessary to reduce the water content of batches at the top of deep lifts to compensate for water gain from the lower levels, but this can be avoided by designing the mix, checking with preliminary trials and accurately controlling the mix proportions throughout the work.

3.11.4 ***Striking of formwork***

3.11.4.1 *General.* The time at which formwork is struck is influenced by the following factors:

a) concrete strength;

b) stresses in the concrete at any stage in the construction period, which in the case of precast units includes the stresses induced by disturbance at the casting position and subsequent handling;

c) curing (see **3.11.6**);

d) subsequent surface treatment requirements;

e) presence of re-entrant angles requiring formwork to be removed as soon as possible after concrete has set to avoid shrinkage cracks;

f) requirements of any deflection profile.

The formwork should be removed slowly, as the sudden removal of wedges is equivalent to a shock load on the partly hardened concrete.

3.11.4.2 *Striking period for cast in-situ concrete.* In the absence of control cubes, reference should be made to the specialist literature, e.g. *The assessment of formwork striking times and Formwork striking times* prepared by CIRIA, for appropriate guidance.

The periods given in Table 4 of Part 7 are not intended to apply where accelerated curing or slip forms are used. Where it is not practicable to ascertain the surface temperature of concrete, air temperatures may be used though these are less precise. In cold weather the period should be increased according to the reduced maturity. For example, for soffit formwork it would be appropriate to increase the value for 7 °C by half a day for each day on which the concrete temperature was generally between 2 °C and 7 °C, and a whole day for each day on which the concrete temperature was below 2 °C.

When formwork to vertical surfaces such as beam sides, walls and columns is removed in less than 12 h, care should be exercised to avoid damage to the concrete, especially to arrises and features. The provision of suitable curing methods should immediately follow the removal of the vertical formwork at such early ages, and the concrete should be protected from low or high temperatures by means of suitable insulation (see **3.11.6**).

3.11.5 ***Curing of concrete***

3.11.5.1 *Curing methods.* The contractor should submit to the engineer details of the proposed methods of curing and protecting the concrete. The methods of curing and their duration should be such that the concrete will have satisfactory durability and strength and the member will suffer a minimum of distortion, be free of excessive efflorescence and will not cause, by its shrinkage, undue cracking in the structure. To achieve these objectives it may be necessary to insulate the concrete so that it is maintained at a suitable temperature, or so that the rates of evaporation of water from the surfaces are kept to appropriate values, or both. Different curing or drying treatments are appropriate to different members and products. Where necessary, special care should be taken to ensure that similar components are cured as far as possible under the same conditions.

The various factors influencing curing, including admixtures, are given in appendix B.

Curing usually consists of maintaining the formwork in place and covering the concrete with a material such as polyethylene sheet or a curing compound or with an absorbent material that is kept damp for a period of time.

Where structural members are of considerable depth or bulk or have an unusually high proportion of cement or are precast units subjected to special or accelerated curing methods, the method of curing should be specified in detail. Some special cases are cited as examples in appendix B.

The higher the rate of development of strength in concrete, the greater the need to prevent excessive differences in temperature within the member and too rapid a loss of moisture from the surface. Alternate wetting and drying should be avoided, especially in the form of cold water applied to hot concrete surfaces. In order to avoid surface cracking, cold water should not be applied to relatively massive members immediately after striking the formwork while the concrete is still hot.

3.11.5.2 *Accelerated curing.* Accelerated curing (which includes steam curing) consists of curing the concrete in an artificially controlled environment, in which the humidity and the rate of temperature rise and fall are controlled, to speed up the rate of increase in strength.

For supersulphated cement, curing in low-pressure steam up to a maximum temperature of 50 °C is acceptable. Curing above 50 °C should only take place if evidence of satisfactory performance is available.

3.11.6 ***Cold weather work***

3.11.6.1 *General.* Special precautions should be taken to prevent the temperature of the concrete falling to 0 °C during the early stages of hardening.

The contractor should submit to the engineer details of the proposed method for raising and maintaining the temperature of the concrete.

Before placing concrete, the formwork, reinforcement, prestressing steel and any surface with which the fresh concrete will be in contact should probably be at a temperature close to that of the freshly placed concrete. Special care should be taken where small quantities of fresh concrete are placed in contact with larger quantities of previously cast concrete at a lower temperature. Any concrete damaged by frost should be removed from the work.

Concrete temperatures should be measured at the surface at the most unfavourable position.

3.11.6.2 *Concrete temperature.* The raising of the temperature of the concrete may be achieved in a number of ways including the following:

a) by heating the mixing water and aggregate. If the water is heated above 60 °C, it is advisable to mix the water with the aggregate before adding the cement;

b) by increasing the cement content of the mix or by using a more rapid hardening cement;

c) by covering the top face of slabs and beams with adequate insulating material;

d) by providing wind breaks to protect newly placed concrete from cold winds;

e) by using a heated enclosure, completely surrounding the freshly placed concrete or using heated formwork panels. In either event care should be taken to prevent excessive evaporation of water from the concrete.

3.11.7 ***Hot weather work.*** See Part 7.

3.11.8 ***Handling and erection of precast concrete units***

3.11.8.1 *Manufacture off the site.* The contractor should submit to the engineer details of the proposed method of manufacture.

3.11.8.2 *Storage.* Indelible identity, location and orientation marks should be put on the member end where necessary.

The engineer should in all cases specify the points of support during storage, and these should be chosen to prevent unacceptable permanent distortion and lack of fit of the units. In order to minimize the stresses induced, supporting arrangements that permit only small settlements are to be preferred. When a stack is several units high, packings should be vertically above each other to prevent additional bending stresses in any unit. Where disfigurement would be detrimental, packing pieces should not discolour or otherwise permanently damage the units.

The accumulation of trapped water and rubbish in the units should be prevented. The freezing of trapped water can cause severe damage.

Where necessary, precautions should be taken to avoid rust stains from projecting reinforcement and to minimize efflorescence.

3.11.8.3 *Handling and transport.* Precast units should resist, without permanent damage, all stresses induced by handling and transport. The minimum age for handling and transport should be related to the concrete strength, the type of unit and other relevant factors.

The position of lifting and supporting points, the method of lifting, the type of equipment, the minimum age for handling, and transport to be used should be as specified or agreed by the engineer.

Care should be taken to ensure that lifting details are practicable and can be used safely, and that no damage results from the lifting equipment.

During transport the following additional factors require consideration:

a) distortion of the transporting vehicles;

b) centrifugal force due to cornering;

c) oscillation. A slim member may flex vertically or horizontally sufficiently to cause damage;

d) the possibility of damage due to chafing.

3.11.8.4 *Assembly and erection.* Where the method of assembly and erection is part of the design, it should be specified.

3.11.8.5 *Temporary supports during construction.* Temporary supports should be designed for all construction loads, including wind, likely to be encountered during the completion of joints between any combination of precast and in-situ concrete structural elements. When appropriate, temporary supports should take account of movements, including those due to shrinkage of concrete and any post-tensioning. In addition the arrangement and design of temporary supports should be such that, if a unit breaks or accidentally strikes against another during erection, the temporary supports of adjacent units are sufficient to prevent any local damage leading to progressive collapse.

The supports should be arranged in a manner that permits the proper finishing and curing of any in-situ concrete, mortar or grout. Temporary supports should not be removed or released until the required strength is attained in the in-situ position.

Attention is directed to the requirements of various factory acts and regulations governing temporary works, stagings, scaffolding, lifting equipment and the like.

Reference should be made to The British Standard code of practice on falsework at present being drafted.

3.11.8.6 *Forming structural connections.* The precast units should be inspected to ensure that the design requirements of the structural connection can be met.

The precast units should be free from irregularities of such size and shape as to lead to damaging stress concentrations. When reliance is placed on bond between the precast and in-situ concretes, the contact surface of the present unit should have been suitably prepared. If frictional resistance is assumed to be developed at a bearing, the construction should be such that this assumption can be realized. Particular care should be given to checking the accurate location of reinforcement and any structural steel sections in the ends of precast members, and to introducing any additional reinforcement needed to complete the connection.

a) *Concrete or mortar packing.* When joints between units, particularly the horizontal joints between successive vertical lifts, are load-bearing and are to be packed with mortar or concrete, tests should be carried out to prove that the material is suitable for the purpose and that the proposed method of filling results in a solid joint.

b) *Other packing materials.* Packing materials other than grout, mortar or concrete (e.g. resinous adhesives, lead, bituminous compounds) may be used provided that they fulfil all the necessary requirements of strength, appearance, fire resistance and durability, and are compatible in all respects with the concrete components being joined together.

The composition and water/cement ratio of the in-situ concrete or mortar used in any connection should be as specified by the engineer.

Care should be taken to ensure that the in-situ material is thoroughly compacted. The use of an expanding agent may be considered advantageous.

The manufacturer's recommendations as to the application and methods should be strictly followed.

The contractor should submit to the engineer, details of the proposed methods for removing levelling devices such as nuts and wedges.

3.11.8.7 *Protection.* The degree and extent of the protection to be provided should be sufficient for the surface finish and profile being protected, bearing in mind its position and importance. This is particularly important in the case of permanently exposed concrete surfaces, especially arrises and decorative features. The protection can be provided by timber strips, hessian, etc. but should not be such as will damage, mark or otherwise disfigure the concrete.

3.12 Grouting of prestressing tendons

3.12.1 ***General.*** The two main objectives when grouting the ducts of post-tensioned concrete members are

a) to protect the prestressing tendons, and

b) to provide efficient bond between the prestressing tendons and the concrete member so as to control the spacing of cracks at heavy overload and increase the ultimate moment of resistance of the member.

Both of these objectives make it desirable that the whole of the void space within the duct should be filled. The success of this operation is dependent on the production of a grout mix having the desired properties, together with efficient equipment for its injection, and careful workmanship and supervision on the site.

The important properties of a satisfactory grout for the injection of ducts in post-tensioned members are (1) good fluidity and low sedimentation or bleeding in the plastic state, and (2) durability and density with low shrinkage in the hardened state in order to bond with the steel and the sides of the duct and to provide protection for the prestressing tendons. The methods to be adopted should be capable of being carried out on the site reasonably easily and effectively.

Grouting trials should be required by the engineer if necessary to ensure that the above objectives are met.

3.12.2 ***Materials***

a) Cement should normally be ordinary Portland cement or Portland-blastfurnace cement. Rapid hardening Portland cement may be used but it is not recommended for general use. The cement should be fresh but not hot, should contain no lumps and preferably should be bagged.

b) Sand is not recommended for general use but it may be specified for short, large-diameter ducts.

c) Admixtures, normally plasticizers or expanding agents, should be used where experience has shown that their use improves the quality of the grout. They should contain no chlorides, nitrates, sulphates or sulphides, and the free expansion of the grout should not exceed 10 %.

3.12.3 ***Ducts.*** It is important that the whole volume of the duct should be filled with grout. Grout entries to the duct or anchorage should provide a secure grout-tight connection to the grout pump.

3.12.4 ***Grouting equipment.*** The mixing equipment should be of a type capable of producing a homogeneous grout by means of high local turbulence while imparting only a slow motion to the body of the grout. If small lumps remain on the sieve, the cement is too old and the mix should not be used. It is not recommended to use the sieve to eliminate lumps from the grout.

3.12.5 ***Mixing.*** See Part 7.

3.12.6 ***Injecting grout.*** The volume of the spaces to be filled by the injected grout should be compared with the quantity of grout injected.

3.12.7 ***Grouting during cold weather.*** The grout materials may be warmed within the limits recommended for concrete (see **3.11.6**).

3.12.8 ***Strength of grout.*** See Part 7.

4 Reinforcement

4.1 Material

4.1.1 to **4.1.4** ***Characteristic strength of reinforcement.*** The characteristic strengths of reinforcement are given in the appropriate British Standards.

4.1.5 ***Bond classification.*** The engineer should state in the contract the type of deformed bar required. (See **6.8.6.1** of Part 4.)

4.2 Bar schedule dimensions. Bars should be scheduled in accordance with the requirements of BS 4466.

Generally reinforcement should be detailed so that tolerances are not critical. However, where reinforcement is to fit between two concrete faces, the dimension on the bending schedule may be determined as the nominal dimension of the concrete less the nominal cover on each face and less the deduction for tolerance on member size and on bending given in Table 5.

Table 5 — Bar schedule dimensions: deduction for tolerances

Distance between concrete faces	Type of bar	Total deduction
m		mm
0 to 1	Links and other bend bars	10
1 to 2		15
Over 2		20
Any length	Straight bars	40

These deductions apply to most reinforced concrete construction, but where the tolerance on member size is greater than 5, 5,10 and 10 mm for the four categories respectively, larger deductions should be made or the cover increased.

4.3 Cutting and bending. Where the temperature of the steel is below 5 °C, special precautions may be necessary such as reducing the speed of bending or, with the engineer's approval, increasing the radius of bending. If necessary, reinforcement may be warmed to a temperature not exceeding 100 °C.

Where it is necessary to bend reinforcement projecting from concrete, the radius of the bend should be not less than that specified in BS 4466, and the concrete should not be damaged.

Where it is necessary to reshape steel previously bent, this should only be done with the engineer's approval, and each bar should be inspected for signs of fracture.

4.4 Fixing. Spacers should be of such materials and designs as will be durable, will not lead to corrosion of the reinforcement, and will not cause spalling of the concrete cover.

Spacer blocks made from cement, sand and small aggregate should match the mix proportions of the surrounding concrete as far as is practicable with a view to being comparable in strength, durability and appearance.

Non-structural connections for the positioning of reinforcement should be made with steel wire or tying devices or by welding (see **4.7**). Care should be taken to ensure that projecting ends of ties or clips do not encroach into the concrete cover.

The position of reinforcement should be checked before and during concreting, particular attention being paid to the position of top reinforcement in cantilever sections.

4.5 Surface condition. Normal handling prior to embedment in the concrete is usually sufficient for the removal of loose rust and scale from reinforcement; otherwise wire-brushing or sand-blasting should be used.

4.6 Laps and joints

4.6.1 ***General requirements.*** Where continuity of reinforcement is required through the connection, the jointing method used should be such that the assumptions made in analysing the structure and critical sections are realized. The following methods may be used to achieve provided continuity of reinforcement:

a) lapping bars;

b) sleeving;

c) threading of bars;

d) mechanical connections;

e) welding (see **4.7**).

4.6.2 ***Lapping of bars.*** Where straight bars passing through the joint are lapped, the recommendations of **6.8.8.6** of Part 4 apply. When reinforcement is grouted into a pocket or recess, an adequate shear key should be on the inside of the pocket.

Where continuity over a support is achieved by having dowel bars passing through overlapping loops of reinforcement, which project from each supported member, the bearing stresses inside the loops should be in accordance with **6.8.6.9** of Part 4.

4.6.3 ***Sleeving.*** Two principal types of sleeve jointing may be used, provided that the strength and deformation characteristics have been determined by tests:

a) grout- or resin-filled sleeves capable of transmitting both tensile and compressive forces;

b) sleeves that mechanically align the square-sawn ends of two bars to allow the transmission of compressive forces only.

The detailed design of the sleeve and the method of manufacture and assembly should be such as to ensure that the ends of the two bars can be accurately aligned into the sleeve. The concrete cover provided for the sleeve should be not less than that specified for normal reinforcement.

4.6.4 ***Threading.*** The following methods may be used for joining threaded bars.

a) The threaded ends of bars may be joined by a coupler having left and right hand threads. This type of threaded connection requires a high degree of accuracy in manufacture in view of the difficulty of ensuring alignment.

b) One set of bars may be welded to a steel plate that is drilled to receive the threaded ends of the second set of bars; the second set of bars is fixed to the plate by means of nuts.

c) Threaded anchors may be cast into a precast unit to receive the threaded ends of reinforcement.

Where there is a risk of the threaded connection working loose, e.g. during vibration of in-situ concrete, a locking device should be used.

Where there is difficulty in producing a clean thread at the end of a bar, steel normally specified for black bolts (see BS 4190) having a characteristic strength of 430 N/mm^2 should be used.

The structural design of special threaded connections should be based on tests. Where tests have shown the strength of the threaded connection to be at least as strong as the parent bar, the strength of the joint may be based on 80 % of the specified characteristic strength of the joined bars in tension and on 100 % for bars in compression, divided in each case by the appropriate γ_m factor.

4.6.5 ***Mechanical connections.*** Couplers may be used to transfer loads in bars both in tension and compression.

Where reinforcing bars carrying tensile forces are being spliced, the coupler should have a characteristic strength at least as great as the characteristic strength of the connected bars and, where alternating loads predominate, should have an adequate fatigue life. Couplers should be staggered.

The stress in compression reinforcement may be transmitted by bearing of the ends of the bars held in concentric contact by a sleeve or other mechanical device. The ends or bars should be square-sawn cut or square-flame cut and ground, and the coupling device should ensure that the bars are held concentrically and in bearing contact during fixing of steel and placing of concrete.

A coupler may be used that transmits the compressive stress by means of mechanical bond within the connection. In such cases the coupler should have a characteristic strength at least equal to that of the connected bars. The ends of the bars should also be square cut.

4.7 Welding

4.7.1 ***General.*** Welding on site should be avoided if possible, but where suitable safeguards, supervision and techniques are employed and provided that the types of steel (including high-yield steels in accordance with BS 4449 and BS 4461) have the required welding properties, it may be undertaken. Generally, however, all welding should be carried out under the engineer's supervision under controlled conditions in a factory or workshop. The competence of the operators should be demonstrated prior to, and periodically during, welding operations.

Where the effects have been taken into account in the design, welding may be considered for

a) fixing in position, e.g. by welding between crossing or lapping reinforcement or between bars and other steel members. Metal-arc welding or electric-resistance welding may be used on suitable steels;

b) structural welds involving transfer of load between reinforcement or between bars and other steel members. Butt welds may be carried out by flash butt welding or metal-arc welding.

The manual metal-arc process is used on site or in fabrication shops for making joints of every configuration. In particular it is the only process available for making tee joints between bars and anchorage plates and lapped joints between bars. It is emphasized that operators should be trained and possess sufficient skill for producing good welded joints. The flash butt welding process is restricted to fabrication shops where it can produce sound butt welds more rapidly than manual metal-arc welding. The resistance welding process for cross bar joints can be used on site or in fabrication shops, though for on-site work it is more usual to use manual metal-arc welding. Relatively unskilled men after a short period of training are normally competent to operate the equipment used for flash butt and resistance welding.

4.7.2 ***Flash butt welding.*** This is carried out by clamping the reinforcing steel bars in water-cooled copper shoes which introduce a large current to the bars. The bar faces are moved slowly towards each other and, when in close proximity, arcing or flashing occurs at those parts of the two faces in closest contact. The arcing or flashing results in intense heating of the bars. This flashing period can be extended to further preheat the joint before completing the weld which is performed by forcing the hot faces together, metal being forced from the hot faces during the actual welding stage to form a collar. Advice on the correct combination of flashing, heating, upsetting and annealing should be obtained from the reinforcement manufacturer.

4.7.3 ***Manual metal-arc welding.*** This is a form of fusion welding in which heat for welding is obtained from an arc struck between a consumable stick electrode and the joint faces. The stick electrode consists of a metal core and a flux covering, the flux forming a protective shield for the molten metal in the weld pool protecting it from atmospheric contamination. In addition the flux includes constituents that can slag off some harmful contaminants that may be present in the joint prior to welding.

4.7.4 ***Other methods.*** Resistance welding for forming butt welds is a similar operation to flash butt welding, contact of the bar faces creating intense heat due to electrical resistance at the interface. After a predetermined period sufficient to heat the bar faces into a plastic state, the current is turned off, the bar faces are pressed together under great pressure and a welded joint made with less material upset than arrises in flash butt welding.

It is, however, necessary to have cleaner bar faces for resistance butt welding than for flash butt welding.

Resistance welding is rarely used for butt welding of reinforcing steel bars, but resistance spot welding finds wide application for joining wires and bars in cross weld configurations. Large automatic machines with multiple pairs of electrodes are used for simultaneously welding many wires and smaller diameter bars to form mesh. In addition portable guns with single pairs of electrodes are used for tack welding bars of smaller diameter.

Should fabricators wish to use other processes, reference should be made to the reinforcement manufacturer for guidelines in developing satisfactory procedures.

5 Prestressing tendons

5.1 Material

5.1.1 *Characteristic strength of prestressing tendons.* The specified characteristic strengths of prestressing tendons are given in **7.1.4.3** of Part 4.

5.2 Handling and storage. Protective wrappings for tendons should be chemically neutral, and suitable protection should be provided for the threaded ends of bars.

When prestressing tendons have been stored on site for a prolonged period, the engineer should ensure by tests that the quality of the prestressing tendons has not been significantly impaired either by corrosion, stress corrosion, loss of cross-sectional area, or by changes in any other mechanical characteristic.

5.3 Surface condition. All prestressing tendons and internal and external surfaces of sheaths or ducts should be free from loose mill scale, loose rust, oil, paint, grease, soap or other lubricants, or other harmful matter at the time of incorporation in the structural member. A film of rust is not necessarily harmful and may improve the bond. It may, however, also increase the loss due to friction.

Cleaning the tendons may be carried out by wire brushing or by passing through a pressure box containing carborundum powder. Solvent solutions should not be used for cleaning without the approval of the engineer.

5.4 Straightness

5.4.1 *Wire.* In cases where straight as-drawn wire is not essential, wire in small-diameter coils corresponding to the diameter of the blocks in the drawing machine may be used.

5.4.2 *Strand.* See Part 7.

5.4.3 *Bars.* See Part 7.

5.5 Cutting. In post-tensioning systems the heating effect on the tendon should be kept to a minimum.

5.6 Positioning of tendons and sheaths. The method of supporting and fixing the tendons (or the sheaths or duct formers) in position should be such that they will not be displaced by heavy or prolonged vibration, by pressure of the wet concrete, by workmen or by construction traffic. The means of locating prestressing tendons should not unnecessarily increase the friction when they are being tensioned.

Sheaths and extractable cores should retain their correct cross section and profile and should be handled carefully to avoid damage. Extractable cores should be coated with release agent only with the approval of the engineer and should not be extracted until the concrete has hardened sufficiently to prevent its being damaged. Joints in sheaths should be securely taped to prevent penetration of the duct by concrete or laitance, and ends of ducts should be sealed and protected after the stressing and grouting operations. Joints in adjacent sheaths should be spaced at least 300 mm apart. Damage can occur during the concreting operation, and if the tendon is to be inserted later, the duct should be dollied during the concreting process to ensure a clear passage for the tendon. Inflatable rubber ducts are not suitable for this purpose.

5.7 Tensioning the tendons

5.7.1 *General.* Tendons may be stressed either by pretensioning or by post-tensioning according to the particular needs of the form of construction. In each system different procedures and types of equipment are used, and these govern the method of tensioning, the form of anchorage and, in post-tensioning, the protection of the tendons.

5.7.2 *Safety precautions.* A tendon when tensioned contains a considerable amount of stored energy which, in the event of any failure of tendon, anchorage or jack, may be released violently. All possible precautions should be taken during and after tensioning to safeguard persons from injury, and equipment from damage, that may be caused by the sudden release of this energy. Guidance on the precautions to be taken is given in appendix C.

5.7.3 *Tensioning apparatus.* See Part 7.

5.7.4 *Pretensioning.* The transfer of stress should take place slowly to minimize shock that would adversely affect the transmission length.

5.7.5 *Post-tensioning*

5.7.5.1 *Arrangement of tendons.* Tendons, whether in anchorages or elsewhere, should be so arranged that they do not pass around sharp bends or corners likely to provoke rupture when the tendons are under stress.

5.7.5.2 *Anchorages.* The anchorage system in general comprises the anchorage itself and the arrangement of tendons and reinforcement designed to act with the anchorage. The form of anchorage system should facilitate the even distribution of stress in the concrete at the end of the member and should be capable of maintaining the prestressing force under sustained and fluctuating load and under the effect of shock.

Provision should be made for the protection of the anchorage against corrosion.

5.7.5.3 *Deflected tendons.* See Part 7.

5.7.5.4 *Tensioning procedure.* The measured tendon force should be compared with that calculated from the extension, using the *E* value for the tendon obtained by measuring the load-extension relationship in a calibrated testing machine with an extensometer of 1 m gauge length. This provides a check on the accuracy of the assumption made for the frictional losses at the design stage; if the difference is greater than 6 %, corrective action should be taken.

Where a large number of tendons or tendon elements are being tensioned and the full force cannot be achieved in an element because of breakage, slip or blockage of a duct, and if the replacement of that element is not practicable, the engineer should consider whether a modification in the stress levels can still comply with the relevant limit state.

The engineer should specify the order of loading and the magnitude of the load for each component of the tendon.

5.8 Protection and bond prestressing tendons

5.8.1 ***General.*** It is essential to protect prestressing tendons from both mechanical damage and corrosion. Protection may also be required against fire damage.

It may also be an important design requirement for the stressed tendon to be bonded to the structure.

5.8.2 ***Protection and bond of internal tendons.*** Internal tendons may be protected and bonded to the member by either cement grout or sand cement grout in accordance with **3.12**. Alternatively the tendons may be protected by other materials such as bitumen or petroleum-based compounds, epoxy resins, plastics and the like, provided that bond is not important.

5.8.3 ***Protection and bond of external tendons.*** A tendon is considered external when, after stressing and incorporation in the work but before protection, it is outside the concrete section. It does not apply, for example, to a slab comprising a series of precast beams themselves stressed with external tendons and subsequently concreted or grouted in so that the prestressing tendons are finally contained in that filling with adequate cover.

Protection of external prestressing tendons against mechanical damage and corrosion from the atmosphere or other aspects of the environment should generally be provided by an encasement of dense concrete or dense mortar of adequate thickness. It may also be provided by other materials hard enough and stable enough in the particular environment.

In determining the type and quality of the material to be used for the encasement, full consideration should be given to the differential movement between the structure and the applied protection that arises from changes of load and stress, creep, relaxation, drying shrinkage, humidity and temperature in either. If the applied protection is dense concrete or mortar and investigations show the possibility of undesirable cracking, then a primary corrosion protection should be used that will be unimpaired by differential movement.

If it is required that external prestressing tendons be bonded to the structure, this should be achieved by suitable reinforcement of the concrete encasement to the structure.

Appendix A Inspection and testing of structures and components

A.1 General. This appendix indicates methods for inspecting and, where necessary, testing whole structures, finished parts of a structure, or structural components to ensure that they have the required standards of finish, dimensional accuracy, serviceability and strength. Where inspection or results of other tests (see also **A.2**) lead to doubt regarding the adequacy of the structure, loading tests should be made following the procedure set out in **A.6**.

In this section, deflection means the maximum amount of movement under load of the component being tested, relative to a straight line connecting its points of support.

The load tests described in this section may not be suitable for

a) model testing when used as a basis of design,

b) development testing of prototype structures,

c) testing to prove the adequacy of a structure, owing to change of use or loading.

Where a contractor or manufacturer

uses a quality control method, and

maintains records of the entire process of manufacture (subject to these records being certified by a chartered engineer or a laboratory approved by the engineer, and being made available to the engineer) which show that, among other things, the products meet the recommendations of this standard,

such records may be accepted as confirming that the required quality has been reached. This in no way precludes the engineer's specifying such tests as he requires.

It is recommended that, prior to the acceptance of a contract or order, the manufacturer and the purchaser (or their appointed representatives) should agree the extent, loading and methods of physical testing to be applied to the units, and also agree their respective liabilities regarding payment for such tests. Wherever possible, testing requirements should be properly described in the specification and bill of quantities.

A.2 Check tests on structural concrete

A.2.1 ***General.*** The testing of concrete specimens to establish whether the concrete used in the structure complies with the specification as a structural material is described in **3.9**, and additional cube tests for special purposes are dealt with in **3.9.7**.

The tests described in **A.2.2** are applicable to hardened concrete in the finished parts of a structure or in precast units. They may be used in routine inspection and for quality control. They are also of use when concrete is found defective from visual inspection and when low cube strengths are obtained when assessing the strength of the concrete used.

If the results of these check tests show that the quality of the concrete is inadequate or shows other defects, the engineer may require a loading test to be made that should then be carried out in accordance with **A.6**.

A.2.2 ***Types of check tests***

A.2.2.1 *Cutting cores.* In suitable circumstances the compressive strength of the concrete in the structure may be assessed by drilling and testing cores from the concrete. The procedure used should comply with the requirements of BS 1881-4. Such cores may also be cut to investigate the presence of voids in the compacted concrete. Core cutting should, whenever possible, avoid reinforcement.

A.2.2.2 *Gamma radiography.* Gamma radiography may be used to test concrete up to 450 mm thick for the presence of local voids in the concrete and the efficiency of the grouting of ducts in prestressed members; the presence and location of embedded metal may also be determined. The testing should be carried out in accordance with the recommendations in BS 4408-3. Special precautions are necessary to avoid contamination from the radioactive source.

A.2.2.3 *Ultrasonic test.* If an ultrasonic apparatus is regularly used by trained personnel and if continuously maintained individual charts are kept that show, for a large number of readings, the relation between the readings and the strength of cubes made from the same batch of concrete, such charts may be used to obtain approximate indications of the strength of the concrete in the structure.

In cases of suspected lack of compaction or low cube strengths, ultrasonic tests carried out on adjacent suspect and acceptable sections of the structure may provide useful comparative data.

A.2.2.4 *Electromagnetic cover measuring devices.* The position of reinforcement or tendons may be verified to depths of about 70 mm by an electromagnetic cover measuring device in accordance with the recommendations of BS 4408-1.

A.2.2.5 *Rebound hammer test.* If a rebound hammer is regularly used by trained personnel and if continuously maintained individual charts are kept that show, for a large number of readings, the relation between the readings and the strength of cubes made from the same batch of concrete, such charts may be used in conjunction with hammer readings to obtain an approximate indication of the strength of the concrete in a structure or element. An accuracy of ± 3 N/mm^2 could be expected when used by trained personnel in these circumstances.

When making rebound hammer tests, each result should be the average of at least nine individual readings. Readings should not be taken within 25 mm of the edge of concrete members. It may be necessary to distinguish between readings taken on a trowelled face and those taken on a moulded face. When making the test on precast units, special care should be taken to bed them firmly against the impact of the hammer.

A.3 Surface finish. The surface of the concrete should be inspected for defects, for conformity with the specification and, where appropriate, for comparison with approved sample finishes.

Subject to the strength and durability of the concrete being unimpaired, the making good of surface defects may be permitted, but the standard of acceptance should be appropriate to the type and quality of the finish specified and should ensure satisfactory permanence and durability. On permanently exposed surfaces great care is essential in selecting the mix proportions to ensure that the final colour of the faced area blends with the parent concrete in the finished structure.

A.4 Dimensional accuracy. The method of measurements of dimensional accuracy, making allowance for specified tolerances, if any, should be agreed in advance of manufacture.

The effect of temperature, shrinkage and imposed load should be taken into account.

The positions of bars, tendons or ducts should be checked where these are visible or ascertainable by simple means.

In the case of precast units, the checking of twist, bow, squareness and flatness may entail removal of the unit from its stacked position to a special measuring frame. Extensive checking of units in this manner may materially affect the cost. The frequency and scope of measurement checks should therefore be strictly related to the production method, the standard of quality control at the place of casting, and the function that the unit has to fulfil.

When checking the camber or upward deflection due to prestress, the precast unit should be placed on proper bearings at full span and a central reference point should be provided level with the bearings. The amount of upward deflection to be expected at any stage should be assessed as described in **7.3.6.1** of Part 4 of BS 5400. Alternative methods of checking include the use of dial gauges or measurements from a thin wire stretched across the bearings and tensioned sufficiently to take out the sag. Upward deflection is preferably measured on the underside.

A.5 Load tests on individual precast units

A.5.1 ***General.*** The load tests described in this clause are intended as checks on the quality of the units and should not be used as a substitute for normal design procedures. Where members require special testing, such special testing procedures should be in accordance with the specification.

Test loads are to be applied and removed incrementally.

A.5.2 ***Non-destructive test.*** The unit should be supported at its designed points of support and loaded for 5 min with a load equal to the sum of the characteristic dead load plus 1.25 times the characteristic imposed load. The deflection should then be recorded. The maximum deflection measured after application of the load should be in accordance with the requirements that should be defined by the engineer.

The recovery should be measured 5 min after the removal of the applied load and the load then reimposed. The percentage recovery after the second loading should be not less than that after the first loading nor less than 90 % of the deflection recorded during the second loading. At no time during the test should the unit show any sign of weakness or faulty construction as defined by the engineer in the light of a reasonable interpretation of relevant data.

A.5.3 ***Destructive test.*** The unit should be loaded while supported at its design points of support and should not fail at its ultimate design load within 15 min of the time when the test load becomes operative. A deflection exceeding $^1/_{40}$ of the span is regarded as failure of the unit.

A.5.4 ***Special test.*** For very large units or units not readily amenable to tests (such as columns, the precast parts of composite beams, and members designed for continuity or fixity) the testing arrangements should be agreed before such units are cast.

A.6 Load tests of structures or parts of structures

A.6.1 ***General.*** The tests described in this clause are intended as a check on structures other than those covered by **A.5**, where there is doubt regarding serviceability or strength.

Test loads are to be applied and removed incrementally.

A.6.2 ***Age at test.*** The test should be carried out as soon as possible after the expiry of 28 days from the time of placing the concrete. When the test is for a reason other than the quality of the concrete in the structure being in doubt, the test may be carried out earlier provided that the concrete has already reached its specified characteristic strength.

When testing prestressed concrete, allowance should be made for the effect of prestress at the time of testing being above its final value.

A.6.3 ***Test loads.*** The test loads to be applied for the limit states of deflection and local damage are the appropriate design loads, i.e. the characteristic dead and imposed loads. When the ultimate limit state is being considered, the test load should be equal to the sum of the characteristic dead load plus 1.25 times the characteristic imposed load and should be maintained for a period of 24 h. If any of the final dead load is not in position on the structure, compensating loads should be added as necessary.

During the tests, struts and bracing strong enough to support the whole load should be placed in position, leaving a gap under the members to be tested, and adequate precautions should be taken to safeguard persons in the vicinity of the structure.

A.6.4 ***Measurements during the tests.*** Measurements of deflection and crack width should be taken immediately after the application of load and, in the case of the 24 h sustained load test, at the end of the 24 h loaded period, after removal of the load and after the 24 h recovery period. Sufficient measurements should be taken to enable side effects to be taken into account. Temperature and weather conditions should be recorded during the test.

A.6.5 ***Assessment of results.*** In assessing the serviceability of a structure or part of a structure following a loading test, the possible effects of variation in temperature and humidity during the period of the test should be considered.

The following recommendations should be met.

A.6.5.1 For reinforced concrete structures and class 3 prestressed concrete structures, the maximum width of any crack measured immediately on application of the test load for local damage should not be more than two-thirds of the value for the limit state requirement given in **5.1.1.1** of Part 4 of BS 5400. For class 1 and class 2 prestressed concrete structures, no visible cracks should occur under the test load for local damage.

A.6.5.2 For members spanning between two supports, the deflection measured immediately after application of the test load for deflection should be not more than $^1/_{500}$ of the effective span. Limits should be agreed before testing cantilevered portions of structures.

A.6.5.3 If the maximum deflection (in millimetres) shown during the 24 h under load is less than $40L^2/h$ where L is the effective span (in metres) and h is the overall depth of construction (in millimetres), it is not necessary for the recovery to be measured, and **A.6.5.4** and **A.6.5.5** do not apply.

A.6.5.4 If, within 24 h of the removal of the test load for the ultimate limit state as calculated in **A.6.3**, a reinforced concrete or class 3 prestressed concrete structure does not show a recovery of at least 75 % of the maximum deflection shown during the 24 h under load, the loading should be repeated. The structure should be considered to have failed to pass the test if the recovery after the second loading is not at least 75 % of the maximum deflection shown during the second loading.

A.6.5.5 If, within 24 h of the removal of the test load for the ultimate limit state as calculated in **A.6.3**, a class 1 or class 2 prestressed concrete structure does not show a recovery of at least 85 % of the maximum deflection shown during the 24 h under load, the loading should be repeated. The structure should be considered to have failed to pass the test if the recovery after the second loading is not at least 85 % of the maximum deflection shown during the second loading.

Appendix B Curing

B.1 General. The principal reasons and recommendations for curing concrete are given in **3.11.5**. The following clauses are intended to amplify the factors that should be considered in complying with that clause. The recommendations apply particularly to the United Kingdom and countries with similar temperate climates, and are based on the assumption that the concrete temperature during the curing period will not fall below 2 °C. Particular precautions to be taken when concreting at low air temperatures are given in **3.11.7** of Part 7.

B.2 Strength of concrete. The rate of gain of strength is increased by the use of a more rapid hardening cement; hence the curing period can be less for rapid hardening cement than for ordinary Portland and Portland-blastfurnace cements, but should be longer for low-heat and supersulphated cements. Similarly the duration of curing should be related to the use of accelerators or retarders. However, the higher the rate of development of strength of the concrete (and hence of heat of hydration of the cement), the more care should be taken during the early period after casting to prevent excessive differences in temperature within the unit and excessive loss of moisture from the concrete.

The rate of gain of strength is also increased if the temperature of the concrete is raised. Accelerated curing may commence as soon as the concrete has been placed, particularly when high strength is required very early and ultimate strength is not critical. However, the ultimate strength of concrete subjected to accelerated curing is not likely to be affected adversely, provided that

a) the rate of rise in the temperature of the concrete does not exceed about 15 °C/h for the first 3 h;

b) thereafter the rate of rise and fall of temperature of the concrete does not exceed about 35 °C/h; and

c) the temperature of the concrete does not exceed about 80 °C.

An approximate guide to the development of strength at different temperatures can be obtained by using the concept of "maturity", which may be defined as the area under a curve of the concrete temperature (in degrees Celsius) plotted against time (in hours) calculated from a basis of – 10 °C. Knowing the maturity, the corresponding age of concrete cured at normal temperatures can be estimated and the strength then found from data relating the strength of that type of concrete to age at that temperature. An example for accelerated curing is given in Figure 1.

The strength of concrete subjected to accelerated curing for periods up to about 24 h may well be appreciably greater than the value estimated in this way. Some compensation for this effect may be applied by calculating the maturity for both the accelerated curing and the curing at normal temperatures as the difference in average temperatures between the concrete and 0 °C instead of – 10 °C. This adjustment should not be made for average temperatures below normal.

Curing by means of damp absorbent materials is likely to cause a lowering of the temperature of the concrete as a result of the evaporation from the material, and in some circumstances the effect can be significant.

The rate of development of strength diminishes as the concrete dries out; hence excessive evaporation of water from all surfaces may need to be prevented and the factors in clause **3** of Part 7 therefore apply.

B.3 Distortion and cracking. The concrete should be cured so that internal stresses within the member, whether due to differences in temperature or differences in moisture content within the concrete, are not sufficient to cause distortion or cracking. The disposition of reinforcement will affect the restraint to the strains, and hence it will have an effect on any distortion and cracking.

In assessing the likely temperature variation within the concrete, the following factors apply:

rate of heat evolution (related to rate of development of strength; see clause **3** of Part 7);

size and shape of member;

different insulation values of curing media (e.g. wooden moulds or water spray);

external temperature.

For example, surface cracking may occur as a result of variation in temperatures due to applying a cold water spray to a relatively massive member immediately after stripping the moulds while the concrete is still hot.

In assessing the likely variation in moisture content within the concrete, the rate of evaporation from unprotected concrete will be higher with

a) atmospheric conditions encouraging evaporation (e.g. low relative humidity, high wind speed, concrete surface hotter than the air), especially if the rate of migration of water through the concrete is greater than the rate of evaporation from the surface;

b) members of high surface/volume ratio;

c) early age of concrete;

d) lower grade of concrete.

For example, cracking may occur due to varying shrinkage in members with sudden changes in section that affect the surface/volume ratio appreciably, especially if the more massive section is reinforced and the more slender section is not.

If the shrinkage of units after they are built into the structure is likely to lead to undesirable cracking at the ends of the unit, curing aimed at preventing the loss of water from the unit should be continued no longer than is necessary to obtain the desired durability and strength; thereafter the concrete should be given the maximum opportunity to dry out consistent with the limitation of the variation in moisture content as already outlined.

For example, cracks may occur at the ends of precast concrete lintels that have been moist-cured but not allowed to dry sufficiently before being erected in the building.

B.4 Durability and appearance. As deterioration is most likely to occur as a result of the concrete providing inadequate protection for the reinforcement or because of frost attacking the surface concrete, all vulnerable surfaces of concrete should be protected against excessive loss of water by evaporation that would result in a weak, porous surface layer.

Where it is important to prevent the formation of efflorescence, especially in cold weather, the atmosphere adjacent to the surface of the concrete should be maintained at a constant relative humidity approaching 100 % for the time given in Table 4 of Part 7. Concrete should be protected from the wetting and drying cycles produced by rain or condensation and drying winds.

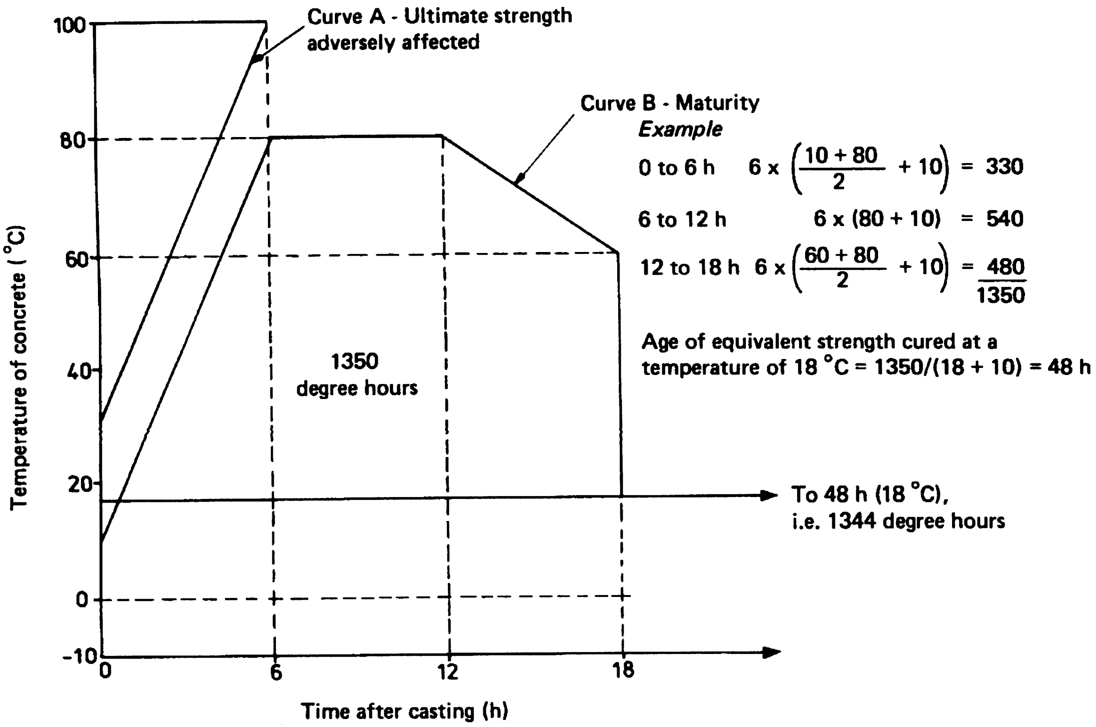

Figure 1 — Temperature/time curves for concrete

Appendix C Safety precautions for prestressing and grouting operations

C.1 Introduction. The purpose of this appendix is to suggest some simple but sensible precautions to ensure that stressing and grouting are carried out with the maximum of safety. The operations involved in tensioning and de-tensioning prestressing tendons are not dangerous provided that sufficient care is taken and the following assumptions have been made.

a) Stressing operations are carried out by experienced personnel under a competent supervisor.

b) The design and construction of the units concerned are of the required high standard.

c) The workmanship is in accordance with clause **5** of Part 7.

d) All equipment is in full working order and properly maintained.

It should be noted that the engineer can only advise the contractor regarding safety and, failing satisfaction, he may refer the particulars to the factory inspector.

C.2 General precautions

a) Erect stout screens at the back of the jack and opposite the anchorage at the non-jacking end to form safety barriers should trouble occur.

b) Display a large sign "ATTENTION–STRESSING IN PROGRESS–KEEP CLEAR" on the side of the safety screens remote from the jack and anchorages to warn workmen, sightseers and passers-by to keep well away.

c) Fence off the area between the safety screens and the unit being stressed so that no one can pass between them during the stressing operations.

d) Never stand behind a jack or anchorage during stressing operations; keep clear of anchorages that have recently been tensioned.

e) Display a notice adjacent to the stressing plant giving the maximum design load of the bed and the upper limit of the position of the centre of gravity of the stressing wires.

f) Always refer to the detailed instructions issued by suppliers of the equipment being used and follow these instructions carefully.

g) Instruct all operatives and supervisors to wear safety helmets during stressing operations. Make sure that operatives wear gloves when handling prestressing tendons and that clear eye-shields are worn during grouting operations.

h) Keep all equipment thoroughly clean and in workmanlike condition; badly maintained equipment always gives rise to trouble, and consequently is dangerous.

i) Do not permit any welding near prestressing tendons; prestressing tendons should not be used for earthing electrical equipment of any kind.

j) Do not allow grips to be exposed to the weather and become rusty.

k) Regular examination of hydraulic hoses is essential, and oil in the pump reservoir should be regularly drained and filtered.

l) Use only self-sealing couplings for hydraulic pressure pipes and ensure that no bending stresses are applied to end connections.

m) It is preferable to use only hydraulic equipment supplied with a bypass valve that is preset to a maximum safety load before stressing. The maximum safety load should not be more than 90 % of the specified characteristic strength of the tendons.

n) Each jack pressure gauge should be checked at frequent intervals against a master gauge and the site engineer furnished with a calibration chart. Alternatively, a suitable calibrated proving ring can be used so that a daily test can be made if required. When large-diameter strand is being used, it is essential that some form of dynamometer or load cell is introduced behind or as an integral part of the jack.

C.3 Precautions to be taken before stressing

a) Check all equipment before use and report any signs of wear or defects.

b) Check to ensure that the handling, storage, surface conditions, etc., of the tendons comply with the requirements of clause **5** of Part 7.

c) Be careful when handling coils of high tensile wire as they may "whip back" with force if not securely bound.

d) When assembling tendons, check each individual wire for obvious flaws.

e) See that the wedges and the inside of barrels or cones are clean so that wedges are free to move inside the taper.

f) The threads of bars, nuts and couplers should be cleaned and oiled, and thread-protecting wrappings should be removed at the last moment before use. Threaded bars for preformed ducts should have suitable protection to the thread to avoid damage by abrasion.

g) Ensure that adequate precautions have been taken to restrain any possible skewing or lifting of the stressing equipment during stressing or release.

h) When tensioning is being carried out from scaffolding, both jack and pump should be securely lashed to prevent them falling in the event of a tendon breaking.

i) Arrange for stressing to take place as soon as possible after the grips have been positioned.

C.4 Precautions to be taken during stressing

C.4.1 *Using a prestressing jack*

a) Double-check the grips or fixings of tendons to the prestressing jack before stressing. Keep the wedges clean and free from dirt.

b) In systems where more than one wire is gripped at a time around the body of the jack, make sure the wedge pieces are not worn. A slip of one wire may well cause overloading of the other wires, which may lead to failure.

c) Tension tendons to a low initial stress (say 60 N/mm^2) and recheck wedges, fixings and position of jack. Zero the extension gauge at this stage.

d) Do not strike the equipment with a hammer to adjust the alignment of the jack when the load is on.

e) Ensure that a competent person is always available at the non-jacking end to check on anchorages before and during stressing.

f) Double-check all fixings before releasing tensions.

g) Check hydraulic pressure pipes for flaws or bubbles after each stressing operation.

C.4.2 *Using a cross-head*

a) Pin up the top wires first and, on completion, check that they have been pulled straight and are not tangled or caught up in the forms. A pinning-up force of 2.25 kN is recommended for 5 mm diameter wire, and one of 4.5 kN for 12.7 mm strand.

b) Before tensioning, ensure that all the tendons are secured against the possibility of flying. The following act as safeguards:

1) shutters and end-plates;

2) stirrups enclosing tendons;

3) heavy timbers laid over tendons;

4) rolls of hessian laid across tendons.

c) Place a protective guard over the grips before starting multi-strand stressing, and immediately after single-strand stressing is completed.

d) For multi-wire or multi-strand stressing, apply a small extension initially and check the line to ensure that there are no loose or caught-up wires or end-plates. Only after this inspection should the full load be applied. In placing the packers care should be taken not to score the ram of the jack.

e) For single-wire stressing, apply the full load and extension to each of the individual wires and lock off. The loads and extensions should be carefully noted by the supervisor.

C.5 Precautions to be taken after stressing

C.5.1 *Using a prestressing jack*

a) After stressing, cut off tendons behind the anchorages in accordance with the recommendations of **4.5**.

b) Check all ducts with compressed air to make sure that they are not blocked before grouting.

c) It is preferable to use only threaded connectors between grout nozzles and grouting points. A sudden spurt of grout under pressure can cause severe injury especially to the eyes.

d) Do not peer into duct bleeders to see if grout is coming through. Grout may jam temporarily and, as pressure is applied, suddenly spurt from the bleeders or the far end of the duct, causing serious injury.

e) When grouting above railways or public roads, take precautions to see that escaping grout does not cause a hazard to traffic below.

C.5.2 *Using a cross-head*

a) Before de-tensioning remove all obstructions to the free movement of the units.

b) Only allow the cross-head to be jacked back a minimum amount, just sufficient to free the packers.

c) Detension slowly and evenly. Any sudden movement may cause damage to the concrete units.

d) Ensure that the supervisor keeps a record book for each line. The following information should be recorded:

1) date into service of all new equipment;

2) dates of exchange of equipment, wedges, barrels, etc.;

3) number of uses to date of wedges, barrels, etc.;

4) confirmation that the inspection as detailed below has been carried out.

e) Inspect and clean all wedges each week, and record the fact in the book provided. Clean the teeth of the wedges with a wire brush in order to remove any dirt or rust accumulated in the valleys of the teeth. Replace worn segments as necessary. Coat the backs of the wedges with graphite or wax, according to the grip manufacturer's instructions.

f) Return all barrels to the stores for cleaning and checking along with the wedges. It is essential to see that the insides of the barrels are clean so that the wedges are free to move inside the taper.

g) Inspect weekly for the following:

1) distorted anchor-plates;

2) distortion of stressing equipment, cross-heads, etc.;

3) any cracked welding on the equipment.

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Publications referred to

BS 12, *Portland cement (ordinary and rapid-hardening).*
BS 146, *Portland-blastfurnace cement.*
BS 882, 1201, *Aggregates from natural sources for concrete (including granolithic).*
BS 1047, *Air-cooled blast furnace slag coarse aggregate for concrete.*
BS 1881, *Methods of testing concrete.*
BS 3892, *Pulverized-fuel ash for use in concrete.*
BS 4027, *Sulphate-resisting Portland cement.*
BS 4190, *ISO metric black hexagon bolts, screws and nuts.*
BS 4248, *Supersulphated cement.*
BS 4408, *Recommendations for non-destructive methods of test for concrete.*
BS 4408-1, *Electromagnetic cover measuring devices.*
BS 4408-3, *Gamma radiography of concrete.*
BS 4449, *Hot rolled steel bars for the reinforcement of concrete.*
BS 4461, *Cold worked steel bars for the reinforcement of concrete.*
BS 4466, *Bending dimensions and scheduling of bars for the reinforcement of concrete.*
BS 4550, *Methods of testing cement.*
BS 4757, *Nineteen-wire steel strand for prestressed concrete.*
BS 5400, *Steel, concrete and composite bridges.*
BS 5400-4, *Code of practice for design of concrete bridges.*
BS 5400-7, *Specification for materials and workmanship, concrete, reinforcement and prestressing tendons.*

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