SERIES 1700
STRUCTURAL CONCRETE

Contents

Note

The Overseeing Organisation is issuing separate interim advice with respect to the introduction of European standards for aggregates. (11/03)

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STRUCTURAL CONCRETE

1701 Concrete - Classification of Mixes

General

1 Unless otherwise described in Appendix 17/4, concrete shall be a designed mix and shall be either ordinary structural concrete or special structural concrete. The mixes for the structural concrete in the Works are given in Appendix 17/1.

Ordinary Structural Concrete

2 Ordinary structural concrete shall contain only materials specified in Clause 1702.

Special Structural Concrete

3 Special structural concrete is concrete containing an admixture or material other than those specified in Clause 1702 or any restriction on the range of material types specified in Clause 1702.

Designed Mix

4 The Contractor shall select the mix proportions and, unless otherwise specified, the workability in order to satisfy the strength and other requirements of the Contract.

1702 Concrete - Ordinary Structural - Constituent Materials

Cement

1 (05/02) Cement shall comply with one of the following:

(i) (05/02) BS EN 197-1:
- CEM I (Portland cement).
- CEM II/A-S and CEM II/B-S (Portland-slag cement).
- CEM III/A (Blastfurnace cement).
- CEM II/A-V and CEM II/B-V (Portland-fly ash cement) provided that the fly ash (pfa) complies with (iv) below.
- CEM IV/A (Pozzolanic cement) with siliceous fly ash only, provided that the fly ash (pfa) complies with (iv) below.

(ii) (05/02) BS 146: 2002 (Blastfurnace cements with strength properties outside the scope of BE EN 197-1 (Type BIIIA)).

(iii) BS 4027 (Sulfate-resisting Portland cement).

(iv) (05/02) A combination of BS EN 197-1 CEM I (Portland cement) and BS 3892 : Part 1 (Pulverized-fuel ash for use with Portland cement) provided that the amount of pfa is not less than 15% nor more than 35% by mass of the total cement. The pfa used shall have a maximum colour index of 7 (Colour comparator disc reference no. 296570) when tested using the Lovibond Colour Comparator system as referred to in Annex A.7 of BS 3892 : Part 1.

(v) (05/02) A combination of BS EN 197-1 CEM I (Portland cement) and BS 6699 (Ground granulated blastfurnace slag for use with Portland cement) provided that the amount of ggbs is not more than 65% by mass of the total cement.

Aggregate

2 (05/01) Unless otherwise specified, aggregates shall comply with one of the following British Standards, as appropriate:

(i) BS 882 (Aggregates from natural sources for concrete).

(ii) BS 1047 (Air-cooled blastfurnace slag coarse aggregate for concrete).

The flakiness index (when determined by the sieve method described in BS 812 : Part 105 : Section 105.1) of the coarse aggregate shall not exceed 35% except when natural, uncrushed aggregates are used for concrete of grades lower than 40, when the flakiness index shall not exceed 50%. No limit is relevant to Grade 15 concrete or below. For concrete Grade 40 or higher the ten per cent fines value of the coarse aggregate, determined in accordance with BS 812 : Part 111, shall be not less than 100 kN and for other grades not less than 50 kN. The test sample shall be in a soaked condition at the time of test.

Chloride levels of the aggregates shall be determined daily, in accordance with BS 812 : Part 117 or less frequently when the long term variability has been established.

The drying shrinkage shall meet the requirements for Category A in accordance with Appendix A of BS 812 : Part 120, namely, not exceeding 0.075%.

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Mixing water (05/01)

3 (05/01) Water for the use in the production of concrete shall be obtained from either:

(i) A public mains supply, which should be of potable quality; or

(ii) Where mains water is not available the Contractor should obtain approval from the Overseeing Organisation for the use of the water from the suggested source. Water from any source other than a mains supply shall be sampled at a frequency determined by the Overseeing Organisation and tested in accordance with the relevant sections of BS 3148. The sodium and potassium contents shall be declared and expressed as equivalent Na_2O, which shall be taken into account when calculating the alkali contribution from other sources in sub-Clause 1704.6, control of alkali-silica reaction.

Water from sea or tidal reaches of rivers shall not be used.

1703 Concrete - Special Structural - Constituent Materials

Cement

1 (05/02) Cement shall comply with sub-Clause 1702.1 or where permitted in Appendix 17/4 with one of the following:

(i) (05/02) BS 1370 (Low heat Portland cement).

(ii) (05/02) BS EN 197-1 CEM III/B (Blastfurnace cement).

(iii) (05/02) BS 146 : 2002 (Blastfurnace cements with strength properties outside the scope of BS EN 197-1 (Type BIIIB)).

(iv) (05/02) BS EN 197-1 CEM I (pigmented Portland cement).

(v) (05/02) A combination of BS EN 197-1 CEM I (Portland cement) and BS 6699 (Ground granulated blastfurnace slag for use with Portland cement) provided that the amount of ggbs is not less than 66% nor more than 80% by mass of the total cement.

Aggregate

2 Aggregate shall comply with the requirements of sub-Clause 1702.2. Unless otherwise described in Appendix 17/4 lightweight aggregate shall comply with BS 3797.

Water

3 Water shall comply with sub-Clause 1702.3.

Admixtures

4 (i) (05/02) General. The quantity and method of using admixtures shall be in accordance with the manufacturer's recommendations. Unless otherwise described in Appendix 17/4 an admixture shall comply with one of the following British Standards:

BS EN 12878 (Pigments for the colouring of building materials based on cement and/or lime).

BS EN 934-2 (Admixtures for concrete, mortar and grout - Part 2: Concrete admixtures).

In all cases the Contractor shall record the following information:

(a) the quantity to be used, in ml per kg of cement or ml per cubic metre of concrete for liquid products and in kilograms per 50 kilograms of cement or kilograms per cubic metre of concrete for solid products;

(b) the detrimental effects caused by adding a greater or lesser quantity;

(c) the chemical name(s) of the main active ingredient(s);

(d) whether or not the admixture leads to the entrainment of air.

The Contractor shall demonstrate the action of an admixture by means of trial mixes.

(ii) Calcium chloride. The use of calcium chloride in any form is prohibited.

1704 Concrete - General Requirements

Concrete Grade and Class

1 For each grade of concrete the specified characteristic strength in N/mm² shall be as given in Table 17/1. The class of concrete shall be defined by its grade followed by the maximum size of aggregate allowed (eg. 30/20).

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TABLE 17/1: (05/01) **Grades of Concrete**

Grade	Characteristic Strength [N/mm²]
7.5	7.5
10	10.0
15	15.0
20	20.0
25	25.0
30	30.0
40	40.0
50	50.0
60	60.0

Minimum Cement Content and Maximum Water/ Cement Ratio

2 The cement content shall be not less than, and the water/cement ratio shall be not greater than described in Appendix 17/1.

Maximum Cement Content

3 The cement content shall not exceed 550 kg/m^3 unless otherwise described in Appendix 17/1.

Maximum Chloride Content

4 The total chloride content of a concrete mix arising from the cement, aggregate and any other source shall not exceed the appropriate limit given in Table 17/2 when determined in accordance with BS 812 : Part 117.

TABLE 17/2: (05/02) **Maximum Total Chloride**

Type or use of cement	Maximum total chloride content expressed as % of chloride ion by mass of cement (inclusive of ggbs or pfa when these are used as cement)
Prestressed concrete, heat-cured concrete containing embedded metal	0.1
Concrete made with cement complying with BS 4027	0.2
Concrete containing embedded metal and made with cement complying with BS EN 197-1, BS 146, BS 1370, or combinations of BS EN 197-1 CEM I with pfa or ggbs	0.3

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

Maximum Sulfate Content

5 The total acid-soluble sulfate content of the concrete mix, expressed as SO_3, shall not exceed 4% of the mass of the cement in the mix. The sulfate shall be calculated as the total from the various constituents of the mix.

Control of Alkali-Silica Reaction

Aggregates

6 (i) (05/01) The Contractor shall use low, normal or high reactivity aggregates (as defined in (ii), (iii) and (iv) below) and restrict the content of sodium oxide equivalent in the mix as specified. Extremely reactive aggregates (as defined in (v)) shall not be used.

(ii) Low reactivity aggregates are natural and other aggregates listed in Table 17/3 or combinations of aggregates listed in Table 17/3. Inclusions of chert, flint, or quartzite shall not be permitted.

TABLE 17/3: (05/01) **Rocks and Minerals Considered to be of Low Reactivity**

Andesite
Basalt
Chalk (as a minor rock type)
Diorite
Dolerite
Dolomite
Feldspar
Gabbro
Gneiss
Granite
Limestone
Marble
Micro granite
Quartz (excluding quartzite, microcrystalline and cryptocrystalline quartz)
Schist
Slate
Syenite
Trachyte
Tuff
Air-cooled blastfurnace slag (BS 1047)
Expanded clay/shale/slate
Sintered pfa

(iii) (05/01) High reactivity aggregates comprise crushed greywacke-type rock (greywacke, greywacke-type sandstones, greywacke-type siltstones or mudstones) from a primary source or combinations of aggregates containing more than 10% of these; and recycled aggregates processed from demolition waste.

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Where a naturally occurring gravel or combination of gravels containing a greywacke-type rock is crushed during processing, except where the testing protocol shows otherwise, it shall be assumed to be a high reactivity aggregate if the crushed greywacke content of the final aggregate combination exceeds 10% by mass of the total aggregate.

(iv) Normal reactivity aggregates are natural aggregates or combinations of aggregates (not included in (ii) and (iii) above and (v) below) that may contain chert, flint or quartzite, and most crushed rock, but excluding those which contain more than 10% crushed greywacke. Aggregate combinations of gravels and sands in which both fractions have a high proportion of flint and the total flint content is greater than 60% by mass shall be classed as normally reactive.

(v) (05/01) Extremely reactive aggregates comprise those aggregates containing detectable quantities of opal, glass and calcined flint and they shall not be used alone or in combination with other aggregates.

(vi) The definition of rock types shall be as in BS 812 : Part 102. Feldspar and quartz are defined in BS 6100 : Section 5.2. The petrographical examination of aggregates for alkali-silica reaction shall be carried out as required in Appendix G.

Cement

(vii) The sodium oxide equivalent contributed to the mix by a Portland cement, expressed in kg/m^3, shall be taken as that calculated as the alkali content of the Portland cement expressed as a percentage (in accordance with paragraph (viii)) multiplied by the proposed quantity of Portland cement in the mix.

The sodium oxide equivalent of the pfa or ggbs shall be taken as that calculated as the alkali content of either pfa or ggbs, expressed in kg/m^3 (in accordance with paragraph (x)) multiplied by the proposed quantity of pfa or ggbs in the mix, and the deemed contribution to the mix shall be taken as that stated in paragraph (xiv).

(viii) (05/01) The acid-soluble alkali content of the Portland cement shall be taken as the manufacturer's declared mean of the 25 daily determinations of sodium oxide equivalent. The Contractor shall keep records of test certificates furnished by the cement manufacturer giving the results of these tests. The acid-soluble alkali content of the Portland cement shall be determined in accordance with BS EN 196 Part 21 National Annex NA or by an x-ray fluorescence technique calibrated against this Standard.

(ix) (05/02) High alkali Portland cement, with an acid-soluble alkali content greater than 0.75% sodium oxide equivalent, shall not be used, except where it is CEM I and used in combination with ggbs or pfa as prescribed in (xv) below.

(x) (05/02) The Contractor shall keep records of test certificates giving, in terms of sodium oxide equivalent, the acid-soluble Alkali Content (AC) of any ggbs or pulverized-fuel ash which is intended for the concrete mixes. The AC of the ggbs or the pulverized-fuel ash shall be taken as the average of 25 weekly determinations for the period immediately preceding the certificate, plus twice the standard deviation of the results. The AC of the ggbs or the pulverized-fuel ash shall be determined in accordance with BS EN 196 Part 21 National annex NA or by an x-ray fluorescence technique calibrated against this Standard.

(xi) The AC of any ggbs used shall not exceed 1.0% sodium oxide equivalent and the AC of any pfa used shall not exceed 5.0% sodium oxide equivalent.

(xii) (05/02) The sodium oxide equivalent in the mix shall be the sum of the sodium oxide equivalent in the BS EN 197-1 CEM I, BS 1370 or BS 4027 Portland cement component, the amount deemed contributed by any ggbs or pulverized-fuel ash, 0.76 times the chloride ion (Cl^- ion) content of the aggregate, measured by the method in BS 812 : Part 117, and the amount of sodium oxide equivalent in any admixtures or water to be used in the mix.

(xiii) (05/02) Where the alkali content of the BS EN 197-1 CEM I, BS 1370 or BS 4027 Portland cement component is less than or equal to 0.75% sodium oxide equivalent and the aggregate combination is classified as low reactivity, the sodium oxide equivalent of the mix, excluding the Portland cement, pfa and ggbs components, shall not exceed 0.60 kg/m^3.

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(xiv) (05/02) Where the alkali content of the BS EN 197-1 CEM I, BS 1370 or BS 4027 Portland cement component is less than or equal to 0.75% sodium oxide equivalent and the aggregate combination is classified as normal reactivity, the following requirements shall apply:

(a) Where pfa is a constituent of the mix, the percentage of the total acid-soluble alkali content of the pfa to be used in calculating the sodium oxide equivalent of the mix shall be as follows:

Group	Proportion of pfa in a Portland cement or combination	Percentage of total acid-soluble alkali content to be used
A	< 20% in a combination < 21% in a Portland cement	100 100
B	20 - 24% in a combination 21 - 25% in a Portland cement	20 20
C	> 24% in a combination > 25% in a Portland cement	0 0

(b) Where ggbs is a constituent of the mix, the percentage of the total acid-soluble alkali content of the ggbs to be used in calculating the sodium oxide equivalent of the mix shall be as follows:

Group	Proportion of ggbs in a Portland cement or combination	Percentage of total acid-soluble alkali content to be used
A	< 25% in a combination < 26% in a Portland cement	100 100
B	25 - 39% in a combination 26 - 41% in a Portland cement	50 50
C	> 39% in a combination > 41% in a Portland cement	0 0

(c) (05/02) For mixes in Groups A and B of paragraphs (a) and (b) above, the sodium oxide equivalent of the cement, including the amount contributed by the pfa or ggbs, shall not exceed 3.5 kg/m^3 less the sodium oxide equivalent of the mix excluding the Portland cement (CEM I), pfa and ggbs components, where this exceeds 0.2 kg/m^3.

(d) (05/02) For mixes containing no pfa or ggbs and for mixes in Group C of paragraphs (a) and (b) above, the sodium oxide equivalent of the mix shall not exceed 3.5 kg/m^3 less the sodium oxide equivalent of the mix excluding the Portland cement and pfa or ggbs component, where this exceeds 0.2 kg/m^3.

Where a normally reactive aggregate is used in conjunction with a Portland cement CEM I)/pfa combination and the pfa content is greater than or equal to 25% but less than 30% by mass, the following cement contents, including the mass of the pfa, shall also not be exceeded.

Sodium oxide equivalent of the mix excluding that contribution from Portland cement (CEM I) and pfa component	**Alkali content of the Portland cement (CEM I)**		
	≤ 0.65% sodium oxide equivalent	**≤ 0.70% and > 0.65% sodium oxide equivalent**	**≤ 0.75% and > 0.70% sodium oxide equivalent**
≤ 0.3 and > 0.2 kg/m^3	550 kg/m^3	540 kg/m^3	530 kg/m^3
≤ 0.4 and > 0.3 kg/m^3	550 kg/m^3	525 kg/m^3	510 kg/m^3
≤ 0.5 and > 0.4 kg/m^3	550 kg/m^3	515 kg/m^3	490 kg/m^3
≤ 0.6 and > 0.5 kg/m^3	550 kg/m^3	505 kg/m^3	470 kg/m^3

(xv) (05/02) Where the alkali content of the BS EN 197-1 CEM I Portland cement component exceeds 0.75% sodium oxide equivalent, the following requirements shall apply:

Group X	
EITHER	A minimum of 25% by mass of the total cement shall be comprised of pfa.
OR	A minimum of 40% by mass of the total cement shall be comprised of ggbs.

Group Y	
EITHER	35% by mass of the total cement shall be comprised of pfa.
OR	A minimum of 50% by mass of the total cement shall be comprised of ggbs.

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(a) (05/02) Mixes with low reactivity aggregates, shall comply with Group X above, and the sodium oxide equivalent of the cement, including the amount contributed by the pfa or ggbs, shall not exceed 5.0 kg/m^3 less the sodium oxide equivalent of the mix, excluding the Portland cement (CEM I) and pfa or ggbs component, where this exceeds 0.2 kg/m^3.

(b) (05/02) Mixes with normal reactivity aggregates shall comply with Group X above, and the sodium oxide equivalent of the cement, including the amount contributed by the pfa or ggbs, shall not exceed 3.0 kg/m^3 less the sodium oxide equivalent of the mix, excluding the Portland cement (CEM I) and pfa or ggbs component, where this exceeds 0.2 kg/m^3.

Mixes with high reactivity aggregates shall comply with Group Y above, and the sodium oxide equivalent of the cement, including the amount contributed by the pfa or ggbs, shall not exceed 2.5 kg/m^3 less the sodium oxide equivalent of the mix, excluding the Portland cement (CEM I) and pfa or ggbs component, where this exceeds 0.2 kg/m^3.

(xvi) (05/02) For mixes with high reactivity aggregates, the following cement requirements shall apply:

Group Z	
EITHER	Portland cement complying with BS EN 197-1 CEM I, BS 1370 or BS 4027 shall be used, with an alkali content less than or equal to 0.75% sodium oxide equivalent.
OR	35% by mass of the total cement shall be comprised of pfa.
OR	A minimum of 50% by mass of the total cement shall be comprised of ggbs.

(a) (05/02) For mixes complying with Group Z above, the sodium oxide equivalent of the cement shall not exceed 2.5 kg/m^3 less the sodium oxide equivalent of the mix, excluding the Portland cement and pfa or ggbs component, where this exceeds 0.2 kg/m^3.

(b) Refer also to paragraph (xv) c) above.

Buried concrete exposed to sulfates (05/01)

7 (05/02) The Contractor shall use a concrete mix designed in accordance with Table 17/4. The following steps are necessary to derive the Design Chemical (DC) Class required for Table 17/4:

(i) The Design Sulfate (DS) Class has been determined on the basis of a ground investigation to classify the site according to the sulfate content of the groundwater and/or of a 2:1 water:soil extract, and the total potential sulfate that may arise from the oxidation of sulfides such as pyrite following ground disturbance and, for DS Classes DS-4 and DS-5, the magnesium ion concentration, in accordance with Table 17/5.

(ii) (05/02) The Aggressive Chemical Environment for Concrete (ACEC) has been determined from the Design Sulfate Class and consideration of the type of soil (natural or brownfield), the mobility of the groundwater and its pH, in accordance with Table 17/5.

(iii) (05/02) The Design Chemical (DC) Class and the required number of Additional Protective Measures shall be determined by the Overseeing Organisation from the ACEC Class, the Structural Performance Level (Table 17/6) required for the structure and the concrete section thickness, in accordance with Table 17/7.

(iv) (05/02) Any Additional Protective Measures shall be selected from the permitted options given in Table 17/8 and incorporated in the Works.

(v) (05/02) For DC Classes DC-3, DC-3*, DC-3**, DC-4, DC-4*, DC-4**, DC-4m, DC-4m* and DC-4m** , the mix design shall make allowance for the carbonate content of the aggregate, expressed as the Aggregate Carbonate Range in accordance with Table 17/9.

(vi) (05/02) The cement and combination groups to be used in accordance with Table 17/4 are detailed in Table 17/10.

Table 17/4: (05/02) **Concrete Qualities to Resist Chemical Attack**

Design Chemical Class [5]	Aggregate Carbonate Range	Cement or combination group [1]	Dense fully compacted concrete made with aggregate conforming to BS 882 or BS 1047	
			Minimum cement content kg/m³	Maximum free water/cement ratio
DC-1	No restriction	1, 2, 3	-	-
DC-2	A[3], B, C	1	340	0.50
	A[3], B, C	2, 3	300	0.55
DC-2z [2]	No restriction	1, 2, 3	300	0.55
DC-3	A	2a	400	0.40
	A	2b, 3	380	0.45
	B,C	2, 3	340	0.50
DC-3* [6]	B	2, 3	380	0.45
DC-3** [7]	C	2, 3	380	0.45
DC-3z [2]	No restriction	1, 2, 3	340	0.50
DC-4	A	2a	400	0.35
	A	2b, 3	400	0.40
	B,C	2, 3	380	0.45
DC-4* [6]	B	2, 3	400	0.40
DC-4** [7]	C	2, 3	400	0.40
DC-4z [2]	No restriction	1, 2, 3	380	0.45
DC-4m	A	2b [5], 3	400	0.40
	B,C	3	380	0.45
DC-4m* [6]	B	3	400	0.40
DC-4m** [7]	C	3	400	0.40

Notes

[1] For cement or combination groups see Table 17/10.

[2] Classes DC-2z, DC-3z and DC-4z apply where chemical resistance is recommended primarily to resist acid attack under conditions described in BRE Special Digest SD1.

[3] In addition to the requirement for a minimum cement content and a maximum free water/ cement ratio, a minimum concrete grade of C35 is recommended when using Range A aggregate combinations.

[4] Bold horizontal lines indicate division of the Table in terms of concrete quality in respect of aggressive ground conditions. Using the option 'Enhance concrete quality' as an Additional Protective Measure can be satisfied by using the recommendations of the next numerically higher DC Class. Where the starting point is a 'starred' DC Class, the step is to a similarly starred higher DC Class, e.g. DC-3** plus a 1 step enhancement of concrete quality leads to a specification of DC-4**.

[5] Use of group 2b cements in DC-4m concrete requires use of Range A aggregate which has been strictly determined on the basis of carbonate content, and not by 'declaration' (see BRE Special Digest SD1, Part 2, Appendix 3).

[6] Using a single-starred DC Class may permit the recommended number of APM to be reduced by 1 (see Note [5] of Table 17/7).

[7] Using a double-starred DC Class may permit the recommended number of APM to be reduced by 2 (see Note [5] of Table 17/7).

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Table 17/5: (05/02) **Aggressive Chemical Environment for Concrete (ACEC) Site Classification**

Refer to BRE Special Digest SD1, Part 1, Sections 4, 5, and 6 before using this Table for ground assessment.

Sulfate and magnesium						Natural soil		Brownfield [3]		
Design Sulfate Class for site	**2:1 water/soil extract**		**Groundwater**		**Potential sulfate[2]**	**Static water**	**Mobile water**	**Static water**	**Mobile water**	**ACEC Class for site**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
	SO_4 g/l	Mg g/l	SO_4 g/l	Mg g/l	SO_4 %	pH	pH	pH [4]	pH [4]	
DS-1	>1.2		>0.4		>0.24	All pH values		All pH values		AC-1s
							>5.5		>6.5	AC-1
							≤5.5		5.5-6.5	AC-2z
									4.5-5.5	AC-3z
									>4.5	AC-4z
DS-2	1.2-2.3		0.4-1.4		0.24-0.6	>3.5		>5.5		AC-1s
							>5.5		>6.5	AC-2
						≤3.5		≤5.5		AC-2s
							≤5.5		5.5-6.5	AC-3z
									4.5-5.5	AC-4z
									>4.5	AC-5z
DS-3	2.4-3.7		1.5-3.0		0.7-1.2	>3.5		>5.5		AC-2s
							>5.5		>6.5	AC-3
						≤3.5		≤5.5		AC-3s
							≤5.5		5.5-6.5	AC-4
									>5.5	AC-5
DS-4	3.8-6.7	≤1.2	3.1-6.0	≤1.0	1.3-2.4	>3.5		>5.5		AC-3s
							>5.5		>6.5	AC-4
						≤3.5		≤5.5		AC-4s
							≤5.5		≤6.5	AC-5
DS-4m	3.8-6.7	>1.2 [1]	3.1-6.0	>1.0 [1]	1.3-2.4	>3.5		>5.5		AC-3s
							>5.5		>6.5	AC-4m
						≤3.5		≤5.5		AC-4ms
							≤5.5		≤6.5	AC-5m
DS-5	>6.7	≤1.2	>6.0	≤1.0	>2.4	>3.5		>5.5		AC-4s
						≤3.5	All pH values	≤5.5	All pH values	AC-5
DS-5m	>6.7	>1.2 [1]	>6.0	>1.0 [1]	>2.4	>3.5		>5.5		AC-4ms
						≤3.5	All pH values	≤5.5	All pH values	AC-5m

Notes

[1] The limit on water-soluble magnesium does not apply to brackish groundwater (chloride content between 12g/l and 18g/l). This allows **m** to be omitted from the relevant ACEC classification.

[2] Applies only to sites where concrete will be exposed to sulfate ions (SO_4) which may result from the oxidation of sulfides such as pyrite, following ground disturbance.

[3] 'Brownfield' is defined as sites which may contain chemical wastes remaining from previous industrial use or from imported wastes.

[4] An additional account is taken of hydrochloric and nitric acids by adjustment to sulfate content - see Section 6.1.2. of BRE Special Digest SD1.

Explanation of suffix symbols to ACEC Class number

- Suffix **s** indicates that, as the water has been classified as Static, no Additional Protective Measures are generally necessary.
- Concrete placed in ACEC Classes which include the suffix **z** have primarily to resist acid conditions and may be made with cements from any of the Groups in Table 17/10.
- Suffix **m** relates to the higher levels of magnesium in Design Sulfate Classes 4 and 5.

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Table 17/6: (05/02) **Structural Performance Level of Buried Concrete**

Refer to BRE Special Digest SD1, Part 2, Section 3 for further guidance on Structural Performance Level.

STRUCTURAL PERFORMANCE LEVEL (SPL)	TYPICAL ATTRIBUTES
Low	Short service life structures less than 30 years; Unreinforced concrete; Non-critical structural details; Temporary structures; Long service life structures, but with associated low stress levels eg house foundations (unreinforced).
Normal	Intermediate service life (30 to 100 years); Not falling in either high or low category.
High	Long service life structures greater than 100 years, eg transport structure foundations; Vulnerable critical details such as slender structural elements, hinges, joints, etc; Structures retaining hazardous materials.

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Table 17/7: (05/02) **Concrete Quality and Number of Additional Protective Measures Recommended for the General Use of In-situ and Precast Concrete**

Refer to BRE Special Digest SD1, Part 2, Section 4 for guidance on the use of this Table.

Design Chemical (DC) Class / Number of Additional Protective Measures (APM) [1],[2]								
	Low Structural Performance Level			Normal Structural Performance Level			High Structural Performance Level [3]	
Section thickness / ACEC class	<140 mm	140-450 mm	>450mm [4]	<140 mm	140-450mm	>450mm [4]	140-450mm	>450mm [4]
AC-1	DC-2/ 0	DC-1/ 0	DC-1/ 0	DC-2/ 0	DC-1/ 0	DC-1/ 0	DC-1/ 0	DC-1/ 0
AC-1s	DC-2/ 0	DC-1/ 0	DC-1/ 0	DC-2/ 0	DC-1/ 0	DC-1/ 0	DC-1/ 0	DC-1/ 0
AC-2	DC-3/ 0	DC-2/ 0	DC-1/ 0	DC-3/ 0	DC-2/ 0	DC-1/ 0	DC-2/ 0	DC-1/ 0
AC-2s	DC-3/ 0	DC-2/ 0	DC-1/ 0	DC-3/ 0	DC-2/ 0	DC-1/ 0	DC-2/ 0	DC-1/ 0
AC-2z	DC-3z/ 0	DC-2z/ 0	DC-1/ 0	DC-3z/ 0	DC-2z/ 0	DC-1/ 0	DC-2z/ 0	DC-1/ 0
AC-3	DC-3/ 2 [5][6]	DC-3/ 1 [5]	DC-2/ 1	DC-3/ 3 [5]	DC-3/ 2 [5]	DC-2/ 2	DC-3/ 3 [5]	DC-2/ 3
AC-3s	DC-4/ 0	DC-3/ 0	DC-2/ 0	DC-4/ 0	DC-3/ 0	DC-2/ 0	DC-3/ 0	DC-2/ 0
AC-3z	DC-4z/ 0	DC-3z/ 0	DC-2z/ 0	DC-4z/ 0	DC-3z/ 0	DC-2z/ 0	DC-3z/ 0	DC-2z/ 0
AC-4	DC-4/ 2 [5][6]	DC-4/ 1 [5]	DC-3/ 1 [5]	DC-4/ 3 [5]	DC-4/ 2 [5]	DC-3/2 [5]	DC-4/ 3 [5]	DC-3/ 3 [5]
AC-4s	DC-4/ 0	DC-4/ 0	DC-3/ 0	DC-4/ 0	DC-4/ 0	DC-3/ 0	DC-4/ 0	DC-3/ 0
AC-4z	DC-4z/ 1 [7]	DC-4z/ 0	DC-3z/ 0	DC-4z/ 1 [7]	DC-4z/ 0	DC-3z/ 0	DC-4z/ 0	DC-3z/ 0
AC-4m	DC-4m/ 2 [5][6]	DC-4m/ 1 [5]	DC-4m/ 0	DC-4m/ 3 [5]	DC-4m/ 2 [5]	DC-4m/ 1 [5]	DC-4m/ 3 [5]	DC-4m/ 2 [5]
AC-4ms	DC-4m/ 0	DC-4m/ 0	DC-3/ 0	DC-4m/ 0	DC-4m/ 0	DC-3/ 0	DC-4m/ 0	DC-3/ 0
AC-5	DC- 4/ 1 [7]	DC- 4/ 1 [7]	DC-3/ 1 [7]	DC- 4/ 3 [5][8]	DC- 4/ 2 [5][8]	DC-3/ 2 [5][8]	DC- 4**/ 1 [7]	DC-3**/ 1 [7]
AC-5m	DC-4m/ 1 [7]	DC-4m/ 1 [7]	DC-4m/ 1 [7]	DC-4m/ 3 [5][8]	DC-4m/ 2 [5][8]	DC-4m/ 1 [7]	DC-4m**/ 1 [7]	DC-4m**/ 1 [7]
AC-5z	DC-4z/ 1 [7]	DC-4z/ 1 [7]	DC-3z/ 1 [7]	DC-4z/ 1 [7]	DC-4z/ 1 [7]	DC-3z/ 1 [7]	DC-4z/ 1 [7]	DC-4z/ 1 [7]

Notes:

[1] Where carbonation of the concrete prior to exposure can be assured, the recommended DC Class/APM (other than those carrying a z suffix to the DC Class), may be relaxed by either 1 DC Class or 1 APM, provided that for AC-5 and AC-5m conditions the resulting package includes APM3.

[2] Where the hydrostatic head of groundwater is greater than 5 times the section thickness one APM over and above the number indicated in the Table should be applied. This should preferably be APM5, but if this is not practicable, then apply either APM1 or APM3.

[3] For High SPL, a Section thickness of less than 140mm is generally not recommended in aggressive ground conditions. Specific precast concrete products (see Part 4 of BRE Special Digest SD1) are an exception.

[4] This column of the Table may be used for concrete elements greater than 450mm thick where other durability and structural considerations permit. Use of this column is inappropriate where the surface of the concrete is required to remain unaffected by aggressive ground, for example in elements such as friction piles.

[5] Where DC-3, DC-4 or DC-4m is given or derived, the number of APM may be reduced (provided that the reduction does not override the recommendation to use or include APM3) by:

- one provided that DC-3*, DC-4* or DC-4m* concrete is specified;
- two provided that DC-3**, DC-4** or DC-4m** concrete is specified.

If, in addition, the concrete quality is to be enhanced as a result of the application of APM1, the step in concrete quality is to the next higher * class, eg DC-4* is specified instead of DC-3* and DC-4** is specified instead of DC-3**.

[6] If APM3 is selected for Low SPL concrete no further APM are necessary.

[7] Only APM3 is recommended (not applicable to bored piles).

[8] To include APM3, where practicable, as one of the recommended number of APM.

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Table 17/8: (05/02) **Options available to provide Additional Protective Measures for buried concrete**

Option Code	Additional Protective Measure (APM) [1]
APM1	**Enhanced concrete quality** (see BRE Special Digest SD1, Part 2, Section 5.3)
APM2	**Use of controlled permeability formwork** (see BRE Special Digest SD1, Part 2, Section 5.4)
APM3	**Provide surface protection** (see BRE Special Digest SD1, Part 2, Section 5.5)
APM4	**Provide sacrificial layer** (see BRE Special Digest SD1, Part 2, Section 5.6)
APM5	**Address drainage of site** (see BRE Special Digest SD1, Part 2, Section 5.7)

Notes:

[1] For options applicable to specific precast concrete products, see Part 4 of BRE Special Digest SD1.

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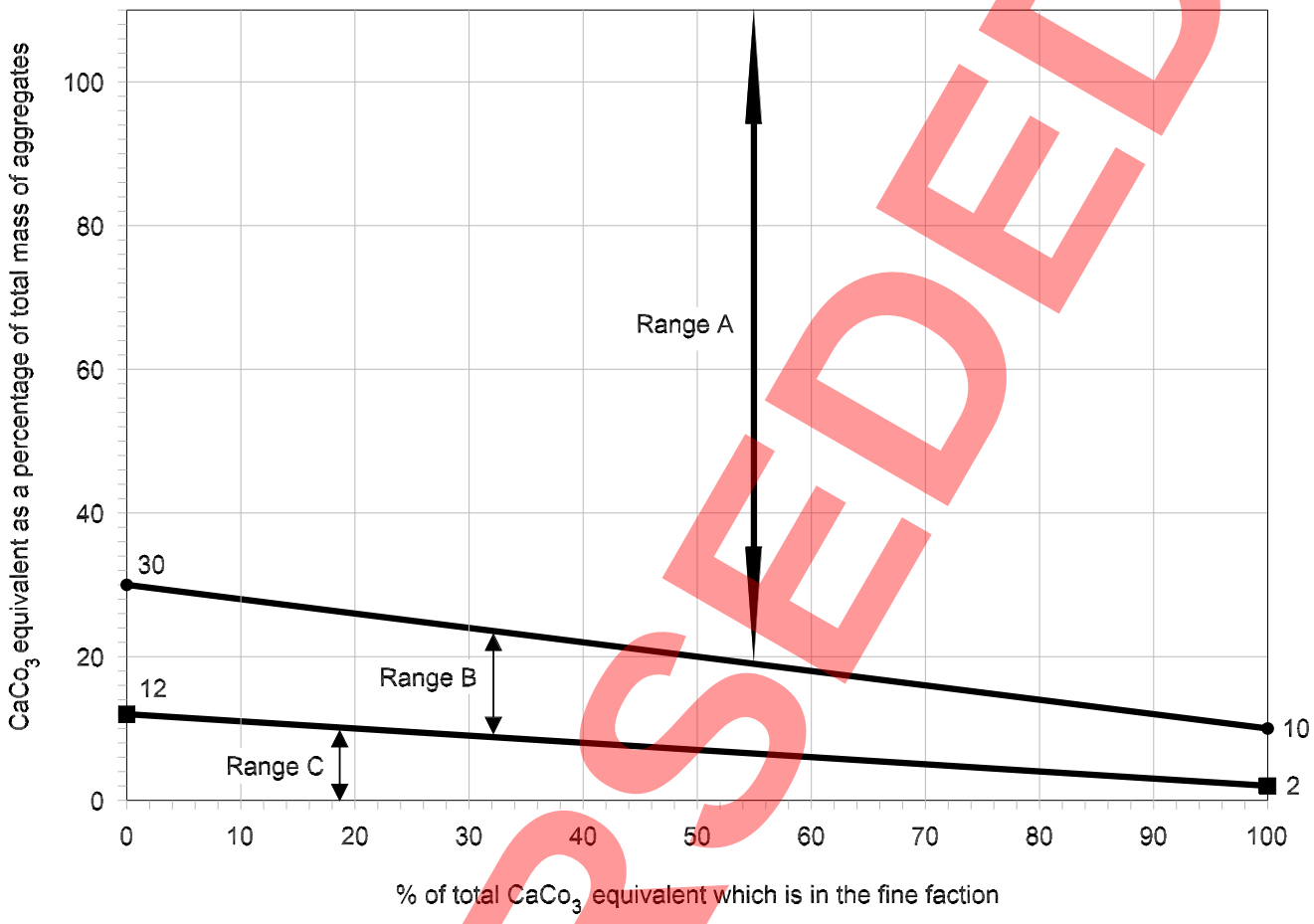
TABLE 17/9: (05/02) **Carbonate Ranges for concrete mix design**



Procedure:

1. Prepare test portions of separate fine (f) and coarse (c) aggregates, as detailed in EN 1744 -1 : 1998, Tests for chemical properties of aggregates, Section 12.3.
2. Determine % of carbon dioxide (CO_2) content of each test portion by a suitable method (eg. BS EN 196-21 : 1992, Clause 5).
3. Convert each concentration of CO_2 to $CaCO_3$ equivalent by multiplying by 100/44 to obtain values for Pcf and Pcc where:

   Pcf = % $CaCO_3$ equivalent in the fine fraction,

   Pcc = % $CaCO_3$ equivalent in the coarse fraction.
4. Calculate % of total $CaCO_3$ equivalent in the fine fraction to give the x-axis value, as:

   100 x (Pcf x F) / {(Pcf x F) + (Pcc x C)}

   where F and C are the mix design values for fine and coarse aggregate respectively (in kg/m3).
5. Calculate total $CaCO_3$ equivalent as a % of the total mass of aggregates to give the y-axis value, as:

   100 x {(Pcf x F) + (Pcc x C)} / (F + C).
6. Identify applicable aggregate Range A, B or C from x-axis and y-axis values.

Note: $CaCO_3$ equivalent may be more than 100% if dolomite is present.

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TABLE 17/10: (05/02) **Cement Groups for use in Table 17/4**

Group	Description	
1	a) b) c) d) e) f) g) h)	Portland cement (CEM I) conforming to BS EN 197-1. Portland-slag cements (CEM II/A-S and CEM II/B-S) conforming to BS EN 197-1. Blastfurnace cement conforming to (CEM III/A and CEM III/B) BS EN 197-1. Blastfurnace cements with strength properties outside the scope of BS EN 197-1 (Types BIIIA and BIIIB) conforming to BS 146:2002. Portland-fly ash cements (CEM II/A-V and CEM II/B-V) conforming to BS EN 197-1. Pozzolanic cement (CEM IV/A)[1] conforming to BS EN 197-1. Combinations of Portland cement (CEM I) conforming to BS EN 197-1 with ggbs conforming to BS 6699. Combinations of Portland cement (CEM I) conforming to BS EN 197-1 with pulverized-fuel ash conforming to BS 3892 : Part 1.
2	a) b)[3]	Portland-fly ash cements (CEM II/B-V)[2] conforming to BS EN 197-1, or Pozzolanic cement (CEM IV/A)[1][2] conforming to BS EN 197-1 or combinations of Portland cement conforming to BS EN 197-1 with pfa conforming to BS 3892 : Part 1, where there is not less than 25% pfa and not more than 35% pfa by mass of the combination. Blastfurnace cement (CEM III/B) conforming to BS EN 197-1 or Blastfurnace cements with strength properties outside the scope of BS EN 197-1 (Type BIIIB) conforming to BS 146:2002, or combinations of Portland cement (CEM I) conforming to BS EN 197-1 with ggbs conforming to BS 6699 where there is not less than 65% ggbs and not more than 80% ggbs by mass of the combination.
3		Sulfate-resisting Portland cement conforming to BS 4027.

Notes:

[1] With siliceous fly ash only.

[2] Minimum 25% fly ash by mass of cement.

[3] For all group 2b cements, ground granulated blastfurnace slag with alumina content greater than 14% should be used only with Portland cement (CEM I) having a tricalcium aluminate (C_3A) content not exceeding 10%.

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1705 Concrete - Requirements for Designed Mixes

Current Margin

1 (05/01) The current margin for a concrete mix shall be determined by the Contractor and shall be taken as the lesser of:

(i) 1.64 times the standard deviation of cube compressive strength test results on at least 100 separate batches of concrete of nominally similar proportions of similar materials and produced over a period not exceeding 12 months, by the same plant under similar supervision, but not less than one sixth of the characteristic strength for concrete up to Grade 15 or 3.75 N/mm² for concrete of Grade 20 or above;

(ii) 1.64 times the standard deviation of cube compressive strength test results on at least 40 separate batches of concrete of nominally similar proportions of similar materials and produced over a period exceeding 5 days but not exceeding 6 months, by the same plant under similar supervision, but not less than one third of the characteristic strength for concrete up to Grade 15 or 7.5 N/mm² for concrete of Grade 20 or above.

Where there is insufficient data to satisfy sub-Clauses (i) or (ii) above, the margin for the initial mix design shall be taken as two thirds of the characteristic strength for concrete up to Grade 15 or 15.0 N/mm² for concrete of Grade 20 or above. This margin shall be used as the 'current margin' only until sufficient data is available to satisfy sub-Clauses (i) or (ii) above. However, when the specified characteristic strength approaches the maximum possible strength of concrete made with a particular aggregate, a smaller margin not less than one third of the characteristic strength up to Grade 15 or 7.5 N/mm² for concrete of Grade 20 or above may be used for the initial mix design.

Suitability of Proposed Mix Proportions

2 (05/01) The Contractor shall record, prior to the supply of any designed mix, the following information:

(i) the nature and source of each material;

(ii) either:

(a) appropriate existing data as evidence of satisfactory previous performance for target mean strength, current margin, workability and water/cement ratio; or

(b) full details of tests on trial mixes carried out in accordance with sub-Clause 3 of this Clause;

(iii) (05/02) the quantities of each material per cubic metre of fully compacted concrete.

Any change in the source of material or in mix proportions (except changes in Portland cement content of not more than 20 kg/m^3 and pro-rata changes in aggregate contents) shall be subject to a re-assessment of the mix in accordance with this sub-Clause.

Where Portland cement (CEM I) to BS EN 197-1 and pulverized-fuel ash to BS 3892 : Part 1 or Portland cement (CEM I) to BS EN 197-1 and ground granulated blastfurnace slag to BS 6699 have been combined by the Contractor then any change in the source of material or in the mix proportions (except changes in Portland cement (CEM I) content of not more than 15 kg/m^3 and changes in pulverised-fuel ash or ground granulated blastfurnace slag of not more than 10 kg/m^3 and pro-rata changes in aggregate contents) shall be subject to a re-assessment of the mix in accordance with this sub-Clause.

Trial Mixes

3 (05/01) The Contractor shall give notice of the making of trial mixes and preliminary testing of the cubes. The Contractor shall prepare trial mixes, using samples of material typical of those he proposes to use in the Works, for all grades, before commencement of concreting.

The Contractor shall ascertain the workability of the trial mixes.

Sampling and testing procedures shall comply with BS 1881.

The concrete production plant and means of transport employed to make the trial mixes and to transport them representative distances shall be similar to the corresponding plant and transport to be used in the Works. A clean dry mixer shall be used and the first batch discarded. Test cubes shall be taken from trial mixes as follows. For each mix a set of six cubes shall be made from each of three consecutive batches. Three from each set of six shall be tested at an age of 28 days and three at an earlier age.

The average strength of the nine cubes tested at 28 days shall exceed the specified characteristic strength by the current margin minus 3.5 N/mm².

Additional Trial Mixes

4 During production the Contractor shall carry out trial mixes and tests before substantial changes are made in the materials or in the proportions of the

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materials to be used, except when adjustments to the mix proportions are carried out in accordance with sub-Clause 1706.4(i).

1706 Concrete - Production

Cement

1 (05/02) Separate silos shall be used for the storage of different cements and additions (ie pfa or ggbs). Cross contamination of cements with additions shall result in immediate removal of the cross contaminated materials. Alternatively these materials may be stored in bags in dry weatherproof sheds with raised floors and each consignment shall be kept separate and distinct. Any cementitious material that has become contaminated by damp or other causes shall be removed immediately. Silos for storing pulverized-fuel ash shall be equipped with aerators to ensure free flow within the silo.

Aggregate

2 (05/01) Sands (ie fine aggregates), single-sized coarse aggregates and graded aggregates shall be used and stored in separate hoppers, or separate stockpiles. Relative proportions of coarse aggregates to be used shall be determined on the basis of the trial mixes.

All aggregates shall be kept free from contact with deleterious matter with adequate provision for drainage, and shall be stored and handled so as to avoid segregation.

The overall grading of the aggregates shall be such as to produce concrete of the specified quality that will work readily into position without segregation or excessive bleeding. The overall grading shall be controlled throughout the work so that it conforms closely to that assumed in the selection of the mix proportions. Each delivery shall be inspected and, if required in Appendix 1/5, testing shall be carried out as specified therein.

The Contractor shall keep records of the results of routine control tests carried out by the aggregate producer.

Batching and Mixing

3 (05/01) The quantities of cement, sand (ie fine aggregate) and the various sizes of coarse aggregate shall be measured by mass.

Separate weighing machines shall be used for cementitious materials and aggregates. Alternatively, cementitious materials may be measured by using a whole number of bags in each mix.

The quantity of water adjusted for the free moisture content of the aggregate shall be measured. Any admixture to be added shall be measured by volume unless solid, in which case it shall be measured by mass. Different types of cement shall not be mixed.

The batch weight of aggregate shall be adjusted to allow for the free moisture content of the aggregate being used.

All measuring equipment shall be maintained in a clean and serviceable condition. Its accuracy shall be checked over the range in use when set up at each site, and maintained thereafter.

The accuracy of equipment shall fall within the following limits:

Measurement of cementitious materials	± 3% of the quantity of cement in each batch
Measurement of water	± 3% of the quantity of water in each batch
Measurement of aggregate	± 3% of the total quantity of aggregate in each batch
Measurement of admixture	± 5% of the quantity of admixture in each batch

The mixer shall comply with BS 1305 where applicable. Care shall be taken to ensure that all constituents are thoroughly mixed and, in particular, any admixtures are uniformly distributed throughout the batch.

The mixing time shall be not less than that recommended by the manufacturer.

Mixers that have been out of use for more than 30 minutes shall be thoroughly cleaned before any fresh concrete is mixed. The first batch of concrete through the mixer shall then contain an appropriate additional quantity of cement. Mixing plants shall be thoroughly cleaned before changing from one type of cement to another.

Control of Strength of Designed Mixes

4 (i) Adjustment to mix proportions. Adjustments to mix proportions shall be made, other than those allowed under sub-Clause 1705.2, in order to minimize the variability of strength and to maintain the target mean strength. Such adjustments shall not be taken to imply any change in the current margin.

(ii) Change of current margin. When appropriate, the Contractor shall recalculate the current margin in accordance with sub-Clause 1705.1. The recalculated value shall be adopted as the current margin for concrete produced subsequently.

Ready Mixed Concrete

5 (05/01) Ready mixed concrete shall comply with this Series and the following special requirements. The concrete shall be carried in purpose-made agitators, operating continuously, or truck mixers. The concrete shall be compacted and in its final position within 2 hours of the introduction of cement to the aggregate. The time of such introduction shall be recorded on the delivery note together with the mass of the constituents of each mix.

When concrete is transported in a truck mixer, water shall only be added by the machine operator, supervised in accordance with an accepted product certification scheme for ready mixed concrete.(Appendix B) on the Site or at the central batching plant, but in no circumstances shall water be added in transit.

1707 Concrete - Compliance

General

1 Sampling and testing of fresh and of hardened concrete shall comply with BS 1881 unless otherwise described in Appendix 17/4.

Strength

2 (i) (05/02) General. Compliance with the specified characteristic strength shall be based on tests made on cubes at an age of 28 days unless there is satisfactory evidence that a particular testing regime is capable of predicting the strength at 28 days for concrete tested at an earlier age.

The rate of sampling shall be as given in Table 17/11 but not less than one sample shall be taken on each day that concrete of that grade is used.

TABLE 17/11: (05/02) **Rates of Sampling and Testing**

Use of concrete	**Sample from one batch selected randomly to represent an average volume of not more than the lesser of:**
Prestressed concrete	10 m³ or 10 batches
Reinforced concrete	20 m³ or 20 batches
Mass concrete	50 m³ or 50 batches

(ii) Testing. Two cubes shall be made from a sample taken from a randomly selected batch of concrete. Samples shall be taken at the point of discharge from the delivery vehicle. The cubes shall be tested and the mean of the two results shall be taken as the test result. When the difference between the results divided by their mean exceeds 15%, the test result shall be deemed invalid.

For compliance purposes:

(a) the average strength determined from any group of four consecutive test results shall exceed the specified characteristic strength by not less than 0.5 times the 'current margin'; and

(b) each individual test result shall be greater than 85% of the specified characteristic strength.

The 'current margin' shall be taken as two thirds of the specified characteristic strength for concrete up to Grade 15, or 15 N/mm² for concrete of Grade 20 or above, unless in accordance with sub-Clause 1705.1 or sub-Clause 1706.4(ii), a smaller margin is applicable.

If only one test result fails to meet the second requirement (b), then that result shall be considered to represent only the particular batch of concrete from which those cubes were taken.

If the average strength of any group of four consecutive test results fails to meet the first requirement (a), then all the concrete in all the batches represented by all such results shall be deemed not to comply with the strength requirements. For the purposes of this Clause the batches of concrete represented by a group of four consecutive test results shall include the batches from which samples were taken to make the first and the last pairs of cubes in the group of four, together with all the intervening batches.

(iii) Special testing. Special testing shall be used if required in Appendix 17/4.

Two test cubes shall be made from each of two independent representative samples taken from every batch of concrete selected for testing. The cubes shall be tested and the mean of the two results shall be taken as the test result. When the difference between the two results divided by their mean exceeds 15%, the test result shall be deemed invalid.

The average strength of the two test cubes taken from the same batch of concrete shall exceed the specified characteristic strength by not less than 2.0 N/mm² or one-tenth of the specified strength, whichever is the smaller.

If the average strength of the test specimens taken to represent a given batch of concrete fails to meet the appropriate requirement, the whole of that batch of concrete represented by those specimens shall be deemed not to comply with the strength requirements of the Specification. Compliance with the average strength requirement in respect of a given batch of concrete shall not be adduced as evidence of compliance in respect of any other batch.

Workability

3 The workability of the fresh concrete shall be such that the concrete is suitable for the conditions of handling and placing as described in sub-Clause 1710.3 so that after compaction as described in sub-Clause 1710.3 it surrounds all reinforcement, tendons and ducts and completely fills the formwork. Workability shall be measured for each batch using one of the following tests in accordance with BS 1881 : Part 102, 103 or 104, and shall be within the following limits of the required values:

Slump	± 25 mm or ± one-third of the required value, whichever is the greater
Compacting factor	± 0.03, where the required value is 0.90 or more ± 0.04, where the required value is between 0.80 and 0.90 ± 0.05, where the required value is 0.80 or less
Vebe	± 3 seconds or ± one-fifth of the required value, whichever is the greater

Air Content of Fresh Concrete

4 (05/01) When air entrainment is required as stated in Appendix 17/1 the average air content of the fresh concrete shall be:

for natural aggregates 10 mm nominal size, 7.5%

for natural aggregates 14 mm nominal size, 6.5%

for natural aggregates 20 mm nominal size, 5.5%

for natural aggregates 40 mm nominal size, 4.5%

The percentage air content determined from individual samples taken at the point of placing the concrete and representative of any given batch of concrete shall be within ± 2.0% of the specified value. The average percentage air content from any four consecutive determinations from separate batches shall be within ± 1.5% of the specified value.

The air content shall be determined as described in BS 1881 : Part 106 for each batch.

1708 Concrete - Surface Finish

Trial Panels

1 (11/03) When required in Appendix 17/3 and before commencing concreting the Contractor shall prepare a trial panel of a suitable size that will demonstrate that the required surface finish can be achieved by the methods proposed.

The panel shall contain representative reinforcement and shall be filled with the proposed concrete mix compacted by the method to be used in the work. As soon as practicable after compaction, the forms shall be removed to check that the required surface finish and compaction has been achieved.

Reference panels have also been produced showing typical Class F2 and F4 Surface finishes made with local materials in each region of the UK and they can be viewed at various sites throughout the UK as described in sub-Clause NG 1708.4(ii).

Control of Colour

2 When stated in Appendix 17/1 each constituent material shall be obtained from a single consistent source. The aggregates shall be free of any impurities that may cause staining. The mix proportions and the grading, particularly of the sand (ie fine aggregate), shall be maintained constant. The same type of plywood or timber shall be used in formwork throughout similar exposed areas.

Release Agents

3 (05/01) Release agents for the formwork shall enable the formwork to be removed without damage to the concrete surface. There shall be no adverse residual effect from the release agent on the concrete surface. Where a concrete surface is to be permanently exposed, only one agent shall be used throughout the entire area. Release agents shall be applied evenly and shall not be permitted to come into contact with reinforcement, prestressing tendons and anchorages. Any such contact areas shall be washed free of contamination.

Where the concrete is to receive an applied finish, or surface impregnation, release agents shall be compatible with that particular process.

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Surface Finishes for Concrete

4 (i) (05/01) Formed Surfaces - Classes of Finish

Formwork as described in sub-Clause 1710.2 shall be capable of producing the following finishes where required in the Works:

Class F1. No extra requirement.

Class F2. The irregularities in the finish shall be no greater than those obtained from the use of wrought thicknessed square edged boards arranged in a uniform pattern. The finish is intended to be left as struck but imperfections such as fins and surface discolouration shall be made good.

Class F3. The resulting finish shall be smooth and of uniform texture and appearance. The formwork lining shall leave no stain on the concrete and shall be so joined and fixed to its backing that it imparts no blemishes. It shall be of the same type and obtained from only one source throughout any one structure. The Contractor shall make good any imperfections in the finish. Internal ties and embedded metal parts shall not be used.

Class F4. The requirements for Class F4 are as for Class F3 except that internal ties and embedded metal parts shall be permitted. The ties shall be positioned only in rebates or in other positions as described in Appendix 17/3.

Class F5. The resulting finish shall be smooth and of uniform texture. Any blemishes and imperfections, such as discolouration and fins, shall be made good. Provision for the embedment of metal parts in the Permanent Works on a regular spacing, shall be allowed.

Other classes. The finishes shall comply with the specific requirements described in Appendix 17/3.

Permanently exposed concrete surfaces to all Classes of finish other than F1 shall be protected from rust marks and stains of all kinds.

Unless otherwise described in Appendix 17/3, all formwork joints for all classes of finish other than F1 shall form a regular pattern with horizontal and vertical lines continuous throughout each structure and all construction joints shall coincide with these horizontal or vertical lines.

(ii) Unformed Surfaces - Classes of Finish

Class U1 finish. The concrete shall be levelled and screeded to produce a uniform surface to the profile shown on the Drawings. No further work shall be applied to the surface unless it is used as a first stage for another class of finish.

Class U2 finish. After the concrete has hardened sufficiently, the Class U1 finish shall be floated by hand or machine sufficiently only to produce a uniform surface free from screed marks.

Class U3 finish. When the moisture has disappeared and the concrete has hardened sufficiently to prevent laitance from being worked to the surface, a Class U1 finish shall be steel-trowelled under firm pressure to produce a dense, smooth uniform surface free from trowel marks.

Class U4 finish. The concrete shall be levelled and screeded to produce a uniform surface. When the concrete has sufficiently hardened and the bleed water evaporated the surface shall be trowelled to produce a hard dense surface free from screed marks and exposed aggregate. Finally the surface shall be lightly textured with a wooden float or equivalent.

Alternatively the concrete shall be levelled, screeded and floated to produce a uniform surface and immediately before the waterproofing operation this surface shall receive surface preparation by water jetting or grit blasting to provide a lightly textured finish.

The finished surface shall not deviate from the required profile by more than 10 mm over a 3 m gauge length or have any abrupt irregularities more than 3 mm.

Class U5 finish. The concrete shall be levelled and screeded to produce a uniform finish. When the concrete has sufficiently hardened to prevent laitance being worked to the surface it shall be floated to produce a surface free from screed marks and exposed aggregate. Finally the surface shall be textured to suit the requirements of the particular waterproofing and surfacing system. The accuracy of the finished surface shall be such that it does not deviate from the required profile by more than 5 mm over a 3 m gauge length or have any abrupt irregularities.

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Other classes. The finishes shall comply with the specific requirements described in Appendix 17/3.

1709 (05/01) Concrete - Surface Impregnation

General

1 Impregnation shall be applied to those surfaces described in Appendix 17/2 in accordance with the manufacturer's instructions unless otherwise directed by Contract Documents or agreed by the Overseeing Organisation. The works shall in addition, be carried out in accordance with Health and Safety requirements, COSHH requirements and Waste Disposal Authority requirements.

Material

2 (i) The material for impregnation shall be monomeric alkyl (isobutyl)-trialkoxy-silane with a minimum active content of 92% delivered to the Site in sealed containers.

(ii) The refractive index of the material shall comply with the value stated in the manufacturer's product specification, within a limit of 0.003 units. The refractive index shall be checked as follows:

(a) Collect samples of the material from a newly opened container and from the spraying nozzle.

(b) Measure the refractive index of three samples from both the container and spray nozzle using a portable refractometer.

(c) Measure the temperature of the samples (portable refractometers have temperature measuring capability).

(d) Correct the refractive index measurements to the temperature stated in the manufacturer's product specification.

(e) If the temperature corrected measured value of the refractive index exceeds the manufacturer's specified value by more than 0.003 units then a laboratory check shall be undertaken to confirm compliance.

(iii) The Contractor shall obtain with each delivery a certificate that the material in that delivery complies with sub-Clause 2(i) of this Clause. No material shall be used in the works until the Certificate of Compliance has been accepted by the Overseeing Organisation.

(iv) The material shall be stored in a secure facility that has a dry frost-free environment protected from direct heat.

(v) The containers shall remain sealed until their contents are required for use. The contents of any opened container shall be used within 48 hours or else disposed of safely, in accordance with sub-Clause 7 of this Clause.

(vi) Materials offering a performance in respect of the protection of concrete and long term durability equivalent to that of monomeric alkyl (isobutyl)-trialkoxy-silane will be accepted. The assessment of the durability of an alternative surface applied hydrophobic pore lining impregnating material will be based on the provision of evidence that it has, in practice, provided an effective water repellent but vapour-permeable layer at the concrete surface for a period of not less than 15 years after application.

Spraying Equipment

3 (i) A power driven continuously circulating pumped system operating at a low nozzle pressure shall be used to apply the material in such a way as to avoid atomisation. Water shall be prevented from entering any part of the equipment.

(ii) A pressure gauge shall be installed between the trigger valve and spray lance to enable the pressure to be monitored.

(iii) A 'kill' switch shall be provided so that the pumping system may be stopped immediately should this be required.

Protective Measures

4 (i) Use and handling of the silane material shall be in strict accordance with the manufacturer's recommendations, and in full compliance with all current Health and Safety legislation. The Contractor shall ensure that only fully trained operatives undertake impregnation operations, and where necessary carry out trials to verify procedures.

(ii) Measures shall be taken to ensure that no impregnation material enters into any drainage system or watercourse. The Contractor shall obtain all necessary written permissions and licences from the appropriate authorities, prior to any silane operations above or adjacent to any watercourse.

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(iii) Measures shall be taken to ensure that no impregnation material comes into contact with any humans, animals, vegetation or vehicular traffic by providing suitable and adequate protection and traffic management. The Contractor shall obtain approval from the Overseeing Organisation and all other authorities' licenses, agreements and permissions associated with traffic safety, management and protective measures in advance of the commencement of impregnation operations.

(iv) Elastomeric bearings, painted steel surfaces, exposed bituminous materials, and joint sealants adjacent to structural elements to be impregnated shall be masked off or covered before and during impregnation operations.

(v) In the case of spillage, action shall immediately be taken to limit the extent of the spillage and the Overseeing Organisation and other relevant authorities shall be informed at once.

(vi) After completion of impregnation operations, all contaminated protective sheeting and materials used for masking or covering, shall be disposed of in accordance with sub-clause 7 of this clause.

Surface Condition

5 (i) Areas to be treated shall be protected from adverse effects of the weather and shall be surface dry for a minimum of 24 hours before application commences. Artificial drying of surfaces shall not be permitted

(ii) Surfaces shall be free from loose or deleterious matter and residues of curing membranes, release agents graffiti and graffiti removal agents. The Contractor shall ensure that any harmful residual effects from the application of curing membranes are not present before impregnation commences. Existing structures shall be hand brushed with a stiff bristle brush to remove surface deposits. Where deleterious surface deposits cannot be removed using a stiff bristle brush they shall be removed by light grit blasting.

(iii) Water jetting or steam cleaning shall not in general be used as a means of surface preparation.

Application

6 (i) The Contractor shall submit a method statement to the Overseeing Organisation and shall obtain the Overseeing Organisation's written approval before commencing impregnation operations.

(ii) Impregnation of the face of a structural element shall be carried out in a single continuous operation for each application.

(iii) Impregnation shall be carried out not less than 7 days after the concrete has been placed, or 3 days after concrete repairs have been completed on a structural element. Particular attention is drawn to compliance with sub-clauses 5(i) & (ii) of this clause.

(iv) The material shall be applied by continuous spray technique giving saturation flooding, working from the lowest level upwards. Two applications shall be made each at a coverage of 300 ml/m² with an interval between each of at least six hours.

(v) Impregnation shall not be carried out in the following conditions:

(a) when the shade temperature is below 5°C;

(b) when the temperature of the concrete surface is greater than 25°C;

(c) When the wind speed is in excess of 8 km/hr unless the working area is fully encapsulated.

(vi) Members shall be protected from rain and spray during application and for at least six hours after completion.

Disposal

7 Disposal of impregnation material, any contaminated materials and protective sheeting or masking, shall be in strict accordance with the requirements of the Waste Disposal Authority. Whilst on site, all such materials must be retained in a safe and secure facility. The Contractor shall obtain all necessary certificates of approval for the disposal of the materials.

Testing and Monitoring

8 Where required in the Contract, the Contractor shall carry out impregnation on trial panels 2m x 2m or equivalent area, one on each of a vertical and horizontal surface. The Contractor shall then demonstrate on these panels, that the proposed method of working will meet the appropriate requirements of this clause.

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1710 Concrete - Construction General

Construction Joints

1 The position of construction joints shall be as shown on the Drawings and at additional positions determined by the Contractor in accordance with the requirements of Appendix 17/4. When concrete is placed in vertical members, walls, columns and the like, the lifts of concrete shall finish level or, in sloping members, at right angles to the axis of the members, and the joint lines shall match features of the finished work, if possible, or be formed by grout checks. Kickers shall be constructed integrally with the lift of concrete below.

Concreting shall be carried out continuously up to construction joints.

Construction joints shall be prepared in either of the following ways:

(i) When the concrete is self-supporting but still sufficiently green, the formwork shall be removed, as necessary to expose the construction joint, subject to the requirements of sub-Clause 5 of this Clause. The concrete surface shall be sprayed with a fine spray of water or brushed with a stiff brush, just sufficiently to remove the outer mortar skin and expose the larger aggregate without disturbing it. Alternatively where this preparation proves impracticable the hardened surface skin and laitance shall be removed by grit blasting or a needle gun. Hardened surfaces shall not be hacked.

(ii) By the use of proprietary steel open-mesh permanent formwork.

Retarding agents shall not be used unless permitted in Appendix 17/4.

The joint surface shall be clean and damp but free of standing water immediately before any fresh concrete is placed against it.

Formwork

2 (i) (05/01) Design and construction. The formwork shall be sufficiently rigid and tight to prevent loss of grout or mortar from the concrete at all stages and for the appropriate method of placing and compacting.

The formwork shall be so arranged as to be readily dismantled and removed from the cast concrete without shock, disturbance or damage. Where necessary, the formwork shall be so arranged that the soffit form, properly supported on props only, can be retained in position for such period as may be required by maturing conditions as described in sub-Clause 1710.4(ii). If the component is to be prestressed whilst still resting on the soffit form, provision shall be made to allow for elastic deformation and any variation in weight distribution.

Where it is intended to re-use formwork it shall be thoroughly cleaned and made good.

Internal metal ties which require to be withdrawn through hardened concrete shall not be used where either face is permanently exposed. Where internal ties are left in, they shall be provided with a mortar cover of at least 50mm. The pocket shall be scabbled and dampened immediately prior to mortar filling.

(ii) Cleaning and treatment of forms. The faces of the forms in contact with the concrete shall be clean and treated with a suitable release agent, where applicable as described in sub-Clause 1708.3.

Immediately before concreting, all forms shall be thoroughly cleaned out. The source of any compressed air used for the clearing of foreign matter from formwork shall be free from oil and other contaminant.

(iii) Projecting reinforcement and fixing devices. Where holes are needed in forms to accommodate projecting reinforcement or fixing devices, care shall be taken to prevent loss of grout when concreting or damage when striking forms.

(iv) Permanent formwork shall comply with Appendix 17/4.

Transporting, Placing and Compacting

3 (05/01) Concrete shall be so transported and placed that contamination, segregation or loss of the constituent materials does not occur.

Concrete, when deposited, shall have a temperature of not less than 5°C and not more than 30°C. Fresh concrete shall not be placed against in situ concrete that has been in position for more than 30 minutes unless a construction joint is formed as described in sub-Clause 1 of this Clause.

Concrete shall not be pumped or discharged through aluminium alloy conduits.

No concrete shall be placed in flowing water. Underwater concrete shall be placed in position by tremies or by pipelines.

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Concreting operations shall not displace reinforcement, tendon ducts, tendon anchorages or formwork, or damage the faces of formwork.

Concrete shall be thoroughly compacted by vibration during the operation of placing, and thoroughly worked around the reinforcement, tendons or duct formers, around embedded fixtures and into corners of the formwork to form a solid mass free from voids. When vibrators are used to compact the concrete, vibration shall be applied continuously during the placing of each batch of concrete until the expulsion of air has practically ceased and in a manner that does not promote segregation of the ingredients.

Particular care shall be taken when concreting bridge decks of substantial thickness to avoid layering of concrete, and the whole thickness shall be placed in one pass. In deck slabs where void formers are used, adequate means to prevent flotation shall be employed and care taken to ensure adequate compaction of the concrete placed beneath the void formers.

A sufficient number of vibrators in serviceable condition shall be on site to ensure that spare equipment is always available in the event of breakdowns.

Vibration shall not be applied by way of the reinforcement. Where vibrators of the immersion type are used, contact with reinforcement and inserts shall be avoided as far as is practicable.

Concrete shall not be subjected to disturbance between 4 hours and 24 hours after compaction except that re-compaction of the upper layers of deep lifts to prevent or anneal settlement cracking may be carried out. Whenever vibration has to be applied externally, the design of formwork and disposition of vibrators shall ensure efficient compaction and the avoidance of surface blemishes.

There shall be no excess water on the top surface on completion of compaction.

Striking of Formwork

4 (i) (05/01) General. Formwork shall be removed in a manner not to damage the concrete, and at times to suit the requirements for its curing and to prevent restraint that may arise from elastic shortening, shrinkage or creep.

(ii) (05/02) Striking period. Where the concrete compressive strength is confirmed by tests on concrete cubes stored under conditions that simulate the field conditions, formwork supporting concrete in bending may be struck when the cube strength is 10 N/mm² or three times the stress to which it will be subjected, whichever is the greater.

For ordinary structural concrete made with Portland cement (CEM I) or sulfate-resisting Portland cement (SRPC) of strength class 42.5 or above, in the absence of control cubes the period before striking shall be in accordance with the minimum periods given in Table 17/12.

TABLE 17/12: (05/02) **Minimum Period Before Striking Formwork (CEM I or SRPC Concrete)**

	Minimum Period Before Striking		
	Surface temperature of concrete:		
	16°C	**7°C**	**t°C (any temperature between 0°C and 25°C)**
Vertical formwork to columns, walls and large beams	12 hours	18 hours	300 hours t + 10
Soffit formwork to slabs	4 days	6 days	100 days t + 10
Props to slabs	10 days	15 days	250 days t + 10
Soffit formwork to Beams	9 days	14 days	230 days t + 10
Props to beams	14 days	21 days	360 days t + 10

Where surface temperatures of concrete fall outside or are likely to fall outside the above temperature ranges agreement should be reached between the Contractor and Overseeing Organisation on appropriate striking times.

Curing of Concrete

5 (i) (05/02) Curing methods. Immediately after compaction and thereafter for the curing time, except where elevated temperature curing is used, concrete shall be protected against harmful effects of weather, including rain, rapid temperature changes, frost, and from drying out. The method of curing shall provide a suitable environment for the concrete to mature and prevent harmful loss of moisture.

The curing time shall be the number of days given in Table 17/13 unless the average surface temperature of the concrete during the required number of days falls below 10°C, in which case the period of curing shall be extended until the maturity of the concrete reaches the value given in the table.

The Contractor shall keep records of all curing liquids, compounds and membranes and their subsequent removal from the areas scheduled in Appendix 17/2. Where the Contractor proposes to use a curing liquid, compound or membrane on surfaces on which a waterproofing system is to be laid, it shall be completely removable.

Where the Contractor proposes the use of a curing liquid, compound or membrane on surfaces scheduled in Appendix 17/2, it shall be of a film type that fully degrades by exposure to ultra-violet light without leaving any residue that is detrimental to the surface impregnation of the concrete.

TABLE 17/13: (05/02) **Minimum Periods of Normal Curing for Different Types of Cement**

Conditions under which concrete is maturing	**Number of days (where the average surface temperature of the concrete exceeds 10°C during the whole period)**			**Equivalent maturity (degree hours) calculated as the age of the concrete in hours multiplied by the number of degrees Celsius by which the average surface temperature of the concrete exceeds -10°C**		
	Other*	SRPC	PC	Other*	SRPC	PC
1. Hot weather or drying winds	7	4	3	3500	2000	1500
2. Conditions not covered by 1	4	3	2	2000	1500	1000

NOTE. Other* includes all permitted cements except PC and SRPC.
(05/02) PC = Portland cement (CEM I).
SRPC = Sulfate-resisting Portland cement.

(ii) (05/02) Accelerated curing. Elevated-temperature curing as described below may be used only with Portland cement (CEM I) or sulfate-resisting Portland cement.

(a) The formwork may be generally heated to no more than 20°C prior to the placing of concrete.

(b) Once placing is complete the concrete shall be left for 4 hours without additional heating. The concrete temperature can then be raised at a maximum rate of 10°C per ½hour.

(c) The concrete temperature shall at no time exceed 70°C.

(d) The rate of subsequent cooling shall not exceed the rate of heating.

(e) Cubes shall be manufactured and cured under identical conditions to those to which the concrete is subjected.

The use of accelerated curing methods for concrete containing other types of cement or any admixture shall not be used.

Cold Weather Work

6 When concrete is placed at air temperatures below 2°C, the following requirements shall be met:

(i) The aggregates and water used in the mix shall be free from snow, ice and frost.

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(ii) The surface temperature of the concrete at the time of placing shall be at least 5°C and shall not exceed 30°C.

(iii) The surface temperature of the concrete shall be maintained at not less than 5°C until the concrete reaches a strength of 5 N/mm² as determined by tests on cubes that were cured under identical conditions to the structural concrete.

(iv) Before placing concrete, the formwork, reinforcement, prestressing steel and any surface with which the fresh concrete will be in contact shall be free from snow, ice and frost.

(v) Cement shall not be allowed to come into contact with water at a temperature greater than 60°C.

Hot Weather Work

7 During hot weather the Contractor shall ensure that the constituent materials of the concrete are sufficiently cool to prevent the concrete from stiffening in the interval between its discharge from the mixer and compaction in its final position.

Cement shall not be allowed to come into contact with water at a temperature greater than 60°C.

Precast Concrete Construction

8 (i) (05/01) Manufacture off the Site. The Contractor shall give reasonable notice to the Overseeing Organisation in advance of the date of commencement of manufacture and casting of each type of member.

A copy of all 28-day cube test results relating to the work shall be made available.

For all prestressed members, the Contractor shall obtain, not more than 7 days after the transfer of stress, a certificate showing the force and extension in the tendons after they were anchored, the strength and age of test cubes cast as described in sub-Clause 1724.4(iv) and the minimum age in hours of the concrete at the time the stress was applied to the member.

For all prestressed pretensioned members the length, cross-section dimensions and straightness of precast concrete shall be measured at 28 ± 2 days after casting. Unless otherwise stated, and notwithstanding the requirements of (iv) below, the allowable dimensional variations shall not exceed the following:

Length	Variation
Up to 3 m	± 6 mm
3 to 4.5 m	± 9 mm
4.5 to 6 m	± 12 mm
Additional for every subsequent 6 m	± 6 mm
Cross section (each direction)	
Up to 500 mm	± 6 mm
500 to 750 mm	± 9 mm
Additional for every subsequent 250 mm	± 3 mm
Straightness or bow (deviation from intended line)	
Up to 3 m	± 6 mm
3 to 6 m	± 9 mm
6 to 12 m	± 12 mm
Additional for every subsequent 6 m	± 6 mm

The above allowable dimensional variations have not been taken into account in the bar schedules (Clause 1713 refers).

Where tests are to be carried out, no members to which the tests relate shall be dispatched to the Site until the tests have been satisfactorily completed.

All members shall be indelibly marked to show the member mark as shown on the Drawings, the production line on which they were manufactured, the date on which the concrete was cast and, if they are of symmetrical section, the face that will be uppermost when the member is in its correct position in the Works. The markings shall be so located that they are not exposed to view when the member is in its permanent position.

Unless otherwise specified the vibrated top surface of precast concrete members which will subsequently receive in situ concrete shall be further prepared by one of the following methods as shown on the Drawings:

Class 1 surface preparation,

The surface finish shall be in accordance with sub-Clause 1 of this Clause.

Class 2 surface preparation,

The hardened surface shall be jetted with air or water to remove laitance and all loose material and no further roughening shall then be carried out (rough as cast).

(ii) Storage. When members are stored, they shall be firmly supported only at the points described in Appendix 17/4. The

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accumulation of trapped water and deleterious matter in the units shall be prevented. Care shall be taken to avoid rust staining and efflorescence.

When a stack is several units high, packings shall be vertically above each other to prevent additional bending stresses in any unit. Where disfigurement would be detrimental, packing pieces shall not discolour or otherwise permanently damage the units.

(iii) Handling and transport. Members shall be lifted or supported only at points described in Appendix 17/4 and shall be handled and placed without impact.

(iv) Assembly and erection. In a composite slab bridge where precast beams are laid side by side with minimal gaps to form a deck:

(a) the difference in soffit level between adjacent units before the in situ concrete is placed shall nowhere exceed 5 mm for units up to 5 m in length or 10 mm for longer units;

(b) the width of the deck soffit shall be within + 25 mm of that shown on the Drawings;

(c) in adjacent spans, the continuity of line of the outside beams shall be maintained;

(d) the width of the gap between individual beams shall not exceed twice the nominal gap shown on the Drawings;

(e) the alignment of transverse holes shall permit the reinforcement or prestressing tendons to be placed without distortion.

The in situ concrete in composite slab bridges shall be placed in such a sequence that the advancing edge of the freshly deposited concrete over the full width of the deck, between longitudinal construction joints, is approximately parallel to the deck supports. Precast beams shall be prevented from moving laterally during the placing of the in situ concrete.

The method of assembly and erection shall comply with any particular requirements in Appendix 17/4.

(v) Forming structural connections. The composition and water/cement ratio of the in situ concrete or mortar used in any connection and in the packing of joints shall be in accordance with the assembly instructions.

Levelling devices shall only be released or removed when the structural connection is complete and has achieved sufficient strength.

(vi) Protection. At all stages of construction, precast concrete units and other concrete associated therewith shall be properly protected to prevent damage to permanently exposed concrete surfaces, especially arrises and decorative features.

1711 (05/01) Concrete - Grouting and Duct Systems for Post-tensioned Tendons

Planning, Trials and Basic Requirements

1 (11/03) Site operations, including duct installation, stressing and grouting, shall be carried out by organisations certificated by CARES in accordance with the requirements of the CARES Scheme for the Supply and Installation of Post-tensioning Systems in Concrete Structures, or an equivalent scheme.

Grouts for protection of prestressing tendons shall be as required in Appendix 17/6 and defined in sub-Clause 1711.2.

The Contractor shall undertake full-scale trials of the grout mix and of the grouting operations as required in the Contract for duct installation, testing, concreting, grouting and any other associated requirements in accordance with the details described in Appendix 17/6. The trials are required to demonstrate that the grouting methods and procedures proposed by the Contractor shall ensure that grout fills the ducts and surrounds the prestressing steel.

The Contractor shall submit for acceptance of the Overseeing Organisation, a detailed method statement, at least 4 weeks prior to use in any trials or in the Works, covering proposed materials, ducts, anchorage and vent arrangements, personnel, equipment, grouting procedures and quality control.

Where full scale trials are required, these shall be commenced at least 56 days before the planned commencement of fixing ducts for prestressing for the permanent works unless specified otherwise in Appendix 17/6. The trials shall incorporate all relevant details of ducts, vents, duct supports, prestressing anchorages and couplers, prestressing strands, grout inlets and outlets. The tendons shall be sufficiently tensioned such that the strands within the duct take up a representative alignment. All systems, methods and materials are to be those proposed for the permanent

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works and shall have been submitted to the Overseeing Organisation as part of the detailed method statement required.

After three days the Contractor shall carefully cut or core the trial section to expose cross sections and longitudinal sections of the duct, anchorages and any other locations where required, or as further directed by the Overseeing Organisation, to demonstrate that the duct is satisfactorily grouted. A report shall be prepared by the Contractor giving full details of the trial, testing results and photographs of the exposed sections.

Grouting of the ducts shall be shown to leave no void which has either a dimension greater than 5% of the duct diameter measured in the radial direction of the duct or greater than 200 mm measured in the longitudinal direction of the duct (or appropriate dimension, in the case of oval ducts, anchorages etc) or which poses a risk to the protective system. The location of any voids with respect to grout vents and their adequate grouting and subsequent sealing, and the disposition of the steel tendons within the body of the grout shall be reported in writing by the Contractor to the Overseeing Organisation within 24 days.

Prestressing for the permanent works shall not be permitted without the prior written acceptance of the Overseeing Organisation to grouting procedures and formal acceptance of the results of the grouting trial.

The Contractor shall carry out a materials suitability assessment in accordance with sub-Clause 1711.2.

Grout Materials

2 (11/03) The properties of the grout, made with the materials, and using the plant and personnel proposed for use on site, shall be assessed for suitability for the intended purpose. This assessment shall be carried out sufficiently in advance of grouting operations to enable adjustments to be made in use of materials or plant or personnel.

Grouts shall comply with the requirements in sub-Clause 1711.8. The materials' assessment shall consist of the preparation of the grout, made with the materials, and using the plant and personnel proposed for use on site, and the testing of it in accordance with sub-Clause 1711.9. The preparation shall be carried out under representative conditions of temperature expected on site. If grouting operations are likely to cover different seasons, the assessment shall be carried out for the expected range of temperatures.

No departures from the sources of the materials and procedures approved as a result of satisfactory trials will be permitted without the written approval of the Overseeing Organisation.

Grouts shall consist only of Portland cement (CEM I) complying with BS EN 197-1 Class 42.5N, admixtures complying with sub-Clause 1711.10 and water complying with BS EN 1008. Where proprietary prebagged grout is used it shall be mixed in accordance with the manufacturer's instructions.

Grouts shall not contain a chloride ion content of more than 0.1% by mass of the cement.

Duct Systems

3 (11/03) The system of ducts, duct connectors, grouting connections, vents, vent connections, drains, transitions to anchorages and caps for anchors shall form a complete encapsulation for the tendons which is resistant to the ingress of air and water. Ducts shall be of proven corrosion resistant durable material. Ducting which may degrade or corrode during the expected life of the structure shall not be permitted. The system shall be fully compatible with the prestressing anchorages, couplers and other details. Where ducts are non-conductive, metal parts of anchorages shall be electrically bonded to the adjacent reinforcement at each end of the tendon and electrical continuity of the structure over the length of the tendon shall be confirmed by testing.

The following air pressure tests shall be carried out on site unless specified otherwise in Appendix 17/6.

Duct Assembly Verification Tests

Each complete duct system including vents, anchorages, anchorage caps, and where appropriate couplers and their connections, shall be air-pressure tested before concreting. Testing to a pressure of 0.01N/mm^2 unless otherwise specified in Appendix 17/6, shall demonstrate that the system is undamaged and has been correctly assembled. The testing shall demonstrate that a loss of pressure no greater than 10% occurs after 5 minutes, unless specified otherwise in Appendix 17/6.

The minimum manufactured wall thickness of ducting for internal tendons shall be 2 mm. The duct rigidity and type and spacing of fixings and supports shall be such as to maintain line, position and cross section shape during concreting. Local deformation of the duct at supports shall be avoided.

For external tendons the minimum wall thickness shall be 4 mm for durability, or such thicker wall as required to withstand grouting pressures of the particular duct configuration.

The Contractor shall provide evidence of testing to demonstrate the following requirements:

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(i) Wall thickness of ducts for tendons after tensioning of the tendons shall be not less than 1.5mm unless specified otherwise in Appendix 17/6.

(ii) (11/03) For internal tendons the duct shall transmit full bond strength from the tendons to the surrounding concrete over a length no greater than 50-100 duct diameters or other such requirement as given in Appendix 17/6.

(iii) (11/03) The duct system shall comply, as a minimum, with the International Federation for Structural Concrete (*fib*) recommendations (Technical Report, Bulletin No. 7) for 'Corrugated plastic ducts for internal bonded post-tensioning', and with other requirements of this Clause.

Vents providing an air passage of at least 15 mm internal diameter shall be provided at the anchorages and in the troughs and crests and beyond each intermediate crest in the direction of flow of the grout at the point where the duct is one half diameter lower than the crest, (but no further than 1m from the crest), unless otherwise described in Appendix 17/6. The maximum spacing of vents shall be 15m unless specified otherwise in Appendix 17/6.

The vent diameter and spacing may be varied in full-scale trials demonstrating the suitability of alternatives. The vents shall be rigidly connected to the ducts, and shall be capable of being closed and re-opened. Holes in the ducts shall be at least the internal diameter of the vents and shall be formed before pressure testing.

For external tendons the arrangement and detailing of the vents at positions within deflectors/diaphragms shall be proven by detailed testing.

Vents on each duct shall be identified by labelling and shall be protected against damage at all times.

Vents at high points shall extend to a minimum of 500 mm above the highest point on the duct profile unless described otherwise in Appendix 17/6.

Grouting Equipment

4 (11/03) Grouting equipment shall consist of a mixer, a storage reservoir and a pump with all the necessary connection hoses, valves, measuring devices for water, dry materials, admixtures and testing equipment.

The mixing equipment shall be capable of producing a grout of homogeneous consistency and shall be capable of providing a continuous supply to the injection equipment. The capacity of the equipment shall be such that each duct can be filled and vented without interruption and at the required rate of injection.

The injection equipment shall be capable of continuous operation and shall include a system for recirculating the grout when grouting is not in progress.

The equipment shall provide a constant delivery pressure; it shall have two pressure gauges and a pressure relief valve to prevent pressures exceeding 1 N/mm^2. All piping to the grout pump shall have as few bends, valves and changes in diameter as possible, and shall incorporate a sampling Tee with a locking-off valve.

The equipment shall be capable of maintaining pressure on completely grouted ducts and shall be fitted with a valve that can be locked off without loss of pressure in the duct.

During the grouting operation the Contractor shall provide adequate flushing-out plant to facilitate complete removal of the grout in the event of a breakdown of the grouting equipment or other disruption before the grouting operation has been completed. The Contractor shall demonstrate that this equipment is in full working order.

All equipment shall be kept free from build-up of adhering materials.

(11/03) **Batching and Mixing of Grouts**

5 (11/03) All materials shall be batched by mass except the mixing water and liquid admixtures which may be batched by mass or by volume. Bagged materials shall be weighed before use, unless clearly weight marked with stated tolerance. The accuracy of batching shall be or have been (in case of pre-bagged materials):

± 2% for dry materials, cement and admixtures

± 1% for mixing water

of the quantities specified. The total amount of mixing water shall include the water content of liquid admixtures.

Depending upon environmental or material influence (eg temperature, configuration of the tendon and properties of the materials used), the water/cement ratio shall be kept as low as possible having regard to the required plastic properties of the grout. Actual water/cement ratios shall be recorded.

The material shall be mixed to produce a homogeneous grout and kept in slow continuous agitation until pumped into the duct. Unless manufacturers specify otherwise, water shall be added to the mixer first, followed by the dry materials which may be added as a whole or in part in sequence until the total quantities are added. The minimum mixing time determined from grouting trials shall be adhered to.

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The temperature of freshly mixed grout shall be between 5°C and 30°C. The maximum temperature may be increased provided trials demonstrate that the grout meets the requirements of sub-Clause 1711.8.

Injecting Grout

6 (11/03) A check shall be made to ensure that the ducts, vents, inlets and outlets are capable of accepting injection of the grout. This check shall be achieved by blowing through the system with dry, oil-free air and testing each vent in turn.

Any water in the ducts shall be removed before grouting operations commence.

Grouting of the ducts shall be carried out within 28 days of installation of the tendon or as soon as is practicable thereafter, in which case additional measures shall be taken to avoid corrosion of the prestressing steel. The Overseeing Organisation's written agreement to commence grouting operations shall be obtained. Injection shall be continuous and the rate of injection slow enough to avoid segregation of the grout.

Grout shall only be injected from one end of the duct.

The method of injecting grout shall ensure filling of the ducts and that the tendons are surrounded by grout. Grout shall be allowed to flow from each vent and the remote end of the duct until its fluidity is visually equivalent to that of the grout being injected. In the event of disagreement, testing may be carried out in accordance with sub-Clause 1711.8.

Following this, a further 5 litres of grout at each vent, or such other requirement of Appendix 17/6, shall be vented into a clean receptacle and then discarded. The opening shall be firmly closed. All vents shall be closed in a similar manner one after another in the direction of the flow except that at intermediate crests the vents immediately downstream shall be closed before their associated crest vent.

The injection tubes shall then be sealed off under pressure with a pressure of 0.5 N/mm^2 being maintained for at least one minute. Grout vents at high points shall be reopened immediately after 1 minute, while the grout is still fluid. Any escape of air, water or grout shall be recorded and reported immediately to the Overseeing Organisation. A further pumping of grout shall then be carried out to expel bleed water – and/or entrapped air. This shall be carried out with the vents open one at a time sequentially in the direction of grouting with a further 5 litres being released at each vent. In the event of disagreement over the quality of the vented grout, testing shall be undertaken immediately by the Contractor.

The injection tubes shall then be sealed off under pressure, with a pressure of 0.5 N/mm^2 being maintained for at least one minute.

The filled ducts shall not be subjected to shock or vibration for at least 24 hours from the time of grouting.

When the grout has set, the grout vents shall be temporarily reopened. If voids are apparent on inspecting vents at end caps, the Overseeing Organisation may require all or some of the end caps to be removed to demonstrate that they are satisfactorily filled with grout. End caps which have been removed shall then be replaced and permanently sealed against ingress of contaminants, such sealing to be proved to the Overseeing Organisation.

If the method of demonstrating filling of the anchorage caps involves their removal, a photographic record shall be made by the Contractor. The record shall clearly identify the individual anchorages, and shall be included in the report to the Overseeing Organisation.

If, in the opinion of the Overseeing Organisation, there is doubt that the ducts or any part of the system are not satisfactorily filled with grout, the Overseeing Organisation may require investigations to be carried out.

The Contractor shall keep full records of grouting for each duct in accordance with the certification scheme requirements for the installation of post-tensioning systems. Copies of these records shall be supplied to the Overseeing Organisation within 24 hours of completing grouting to each duct.

On completion of grouting, grout vents shall be positively sealed and waterproofed by a means separate from the concrete waterproofing.

Grouting During Cold Weather

7 (11/03) When the ambient temperature is expected to fall below 5°C, accurate records shall be kept by the Contractor of the maximum and minimum air temperatures, and the temperatures of the structural elements adjacent to the ducts to be grouted. No materials containing frost or ice shall be used, and the ducts and equipment shall be completely free of frost and ice.

Grout shall not be placed when the temperature of the structural elements adjacent to the ducts is below 4°C, or is likely to fall below 4°C during the following 48 hours, unless the element is heated so as to maintain the temperature of the placed grout above 5°C for at least 48 hours.

Methods of heating shall be to the acceptance of the Overseeing Organisation.

Ducts shall not be warmed with steam.

Properties of Grout

8 (05/02) The following criteria shall apply:

Fluidity

When tested by the method specified in sub-Clause 1711.9, the fluidity of the grout shall meet the criteria given in Table 17/14. Additionally, the fluidity (flow cone passage time) at outlets shall not vary from that of the injected grout by more than 20%.

TABLE 17/14: (11/03) **Test Requirements for Fluidity of Grout**

Test Method	Cone
Fluidity immediately after mixing	≤25 s (see note)
Fluidity at the end of the injection period subject to a minimum of 30 minutes after mixing*	≤25 s (see note)
Fluidity at duct outlet	≥10 s
* Mixing time shall be measured from the time when all of the materials are in the mixer. For pre-bagged grout the minimum time shall be 90 minutes.	
NOTE: For grouts prepared in some mixers which have a high shear mixing action, the upper limits given in Table 17/14 may be increased to 50 s. The mixer and these limits shall be subject to the acceptance of the Overseeing Organisation.	

Bleeding

When tested by the method referred to in sub-Clause 1711.9 the bleeding for grout shall be less than 1% of the initial volume of the grout and the average of 4 successive results shall be less than 0.3%. Testing shall be carried out at 24 hours.

Volume Change

The volume change assessed may be either an increase or decrease. When tested in accordance with the method referred to in sub-Clause 1711.9 the volume change of grout shall be within the range - 0% to + 5%.

Strength

The compressive strength of 100 mm cubes made of the grout shall exceed 27 N/mm^2 at 7 days. Cubes shall be made, cured and tested in accordance with BS EN 12390-1 and BS EN 123900-3.

Sieve Test

The grout shall contain no lumps. This shall be verified by testing as referred to in sub-Clause 1711.9.

Sedimentation Test

When tested by the method referred to in sub-Clause 1711.9 the grout shall not exhibit variation in density from top to bottom of a single test sample in excess of 5%.

Testing of Grout

9 (11/03) General. Suitability and acceptance tests for the properties of grout shall be determined in accordance with the Concrete Society Technical Report 47 “Durable Bonded Post-Tensioned Concrete Bridges” 2nd edition. The testing requirements are summarised in Table 17/15.

TABLE 17/15: (11/03) **Minimum Test Requirements for Grout**

Suitability Testing	
Fluidity	Sampled immediately after mixing, one test. After estimated time to grout duct or minimum of 90 mins from initial mixing. Two tests averaged in both cases.
Bleed Volume change Sedimentation Strength	Each sampled immediately after mixing, 3 tests averaged.
Acceptance Testing	
Fluidity	Sampled immediately after mixing, one test from mixer. After flow through duct, one test from each anchorage outlet. On completion, one test from the mixer.
Bleed Volume Change Strength	One tests per day or one per 1.5 m^3 of grout unless otherwise agreed by the Overseeing Organisation.
Sedimentation	One test per day for site bateched grout, or one test per pre-bagged supplied batch (by manufacturer’s reference number); subject to a minimum of one test per continuous grouting operation.

Admixtures

10 (11/03) The following criteria shall apply:

General

Admixtures shall be used where required to achieve a low water/cement ratio and impart good fluidity, minimum bleed and volume stability or expansion to the grout to comply with sub-Clause 1711.8. For site batched grout admixtures should be added on site during the mixing process and used in accordance with the manufacturer's recommendations. For pre-bagged grout the admixtures shall form a pre-blended component.

Types

Admixtures are divided into two types, expanding and non-expanding and they may be used to obtain the required grout performance. Admixtures used in combination shall be checked for compatibility by the Contractor, and reported to the Overseeing Organisation for acceptance.

Chemical Composition

Admixtures shall not contain substances in quantities that will adversely affect the grout or cause the grout to promote corrosion of the prestressing steel by rusting, pitting, stress corrosion or hydrogen embrittlement.

Material requirements

The admixture shall not segregate and shall be uniform in colour. The composition shall not change and the supplier shall operate a quality system complying with BS EN ISO 9001. The quality system shall be certified by a third party accredited by an appropriate organisation in accordance with sub-Clauses 105.3 and 105.4.

Where appropriate, admixtures shall comply with BS EN 934-4. Other admixtures shall be permitted provided they satisfy Clause 8 of BS EN 934-2 and full account is taken of their effects on the finished product and their fitness for purpose. Data on their suitability, including previous experience with such materials, shall be made available and records of the details and performance of such materials shall be maintained.

It should be noted that additional information beyond that required by Clause 8 of BS EN 934-2 must be provided by the manufacturer for admixtures bearing CE marking (see ZA.2.2 and ZA.3 of BS EN 934-2).

Dosage

The optimum dosage of any admixture shall be determined by trial mixes with the cement to be used in the grout. This dosage shall be expressed as percent by mass of the cement. It shall be within the range recommended by the supplier and shall not exceed 5% by mass of the cement. The method of measuring dosage and checking weights of pre-packed dry materials shall comply with sub-Clause 1711.5 or as otherwise agreed with the Overseeing Organisation.

1712 (05/01) Reinforcement - Materials

(05/02) **Hot Rolled and Cold Worked Carbon Steel Bars**

1 (05/02) All steel reinforcement specified shall comply with BS 4449 or BS 4483 and shall be cut and bent in compliance with BS 8666 and shall be obtained from a firm holding a valid CARES (or fully equivalent scheme) certificate of approval.

2 (05/02) Hot rolled and cold worked carbon steel bars shall comply with BS 4449 except that no bar shall contain a flash weld.

Hard Drawn Steel Wire

3 Hard drawn mild steel wire shall comply with BS 4482.

Steel Fabric

4 Steel fabric reinforcement shall comply with BS 4483 and shall be delivered to the Site in flat mats or pre-bent.

(05/02) **Stainless Steel Reinforcement**

5 (05/02) All stainless steel reinforcement shall comply with BS 6744 and shall be cut and bent in compliance with BS 8666 and shall be obtained from companies holding valid CARES (or fully equivalent scheme) certificares of approval for the production and supply of stainless reinforcement. Manufacturers who have applied for CARES regisration will be acceptable to the end of year 2002, subject to the approval of their quality manual and procedures by CARES.

6 (05/02) Stainless steel reinforcement shall be to the specified material strength grade in BS 6744.

Bond Strength

7 (05/02) The classification of deformed carbon steel bars as Type 1 or 2 for bond strength shall be in

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accordance with BS 4449. The type of deformed carbon steel bar shall be as described in Appendix 17/4.

Stainless steel reinforcement shall be plain or ribbed bar in accordance with BS 6744 and shall be as described in Appendix 17/4.

1713 (05/02) Carbon Steel Reinforcement and Stainless Steel Reinforcement - Bar Schedule Dimensions - Cutting and Bending

1 (05/02) The bar schedules are based on the dimensions of the concrete and the nominal cover to the reinforcement shown on the Drawings. The reinforcement shall be cut and bent within the tolerances given in BS 8666 but this shall not relieve the Contractor of his responsibility for the correct fit of the reinforcement and the achievement of the required cover as described in Clause 1714.

Bending of reinforcement at temperatures below 5°C or in excess of 100°C shall not be carried out.

Re-bending of grade 460 carbon steel bars on site shall not to be permitted. Re-bending of grade 250 bars not exceeding 12 mm may be carried out.

Re-bending of stainless steel reinforcement bars on site shall not be permitted.

Site storage of reinforcement should ensure that it is clear of the ground and covered with a waterproof sheeting or fixed cover, in order to reduce contamination and excess corrosion prior to placement.

1714 Reinforcement - Fixing

1 (05/02) Reinforcement shall be secured against displacement. Unless specified otherwise, the actual concrete cover shall be not less than the required nominal cover minus 5 mm.

The cover to a bar in an outer layer of reinforcement shall not exceed the nominal cover shown on the Drawings by more than 2% of the overall dimension of the member, measured in the same direction, or by more than 20 mm, whichever is the lesser. Bars in inner layers shall be located as shown on the Drawings; they shall be in close contact with the bars of the outer layer, unless otherwise indicated. Welding of carbon steel reinforcing bars for fixing purposes shall be in accordance with Clause 1717.

Welding of stainless steel reinforcement bars shall not be permitted.

Cover blocks shall be of comparable strength, durability and appearance to the surrounding concrete. They shall match the mix proportions of the adjacent material so far as is practicable. They shall ensure that the reinforcement is correctly positioned and shall be as small as possible consistent with their purpose, and designed so that they will not overturn or be displaced when the concrete is placed. Reinforcement spacers and chairs should be produced and fixed in accordance with the Concrete Society report CS 101.

Wire cast in the block for the purpose of tying it to the reinforcement shall be as described below.

Spacer blocks (categorised as heavy in the Concrete Society Report CS101) should be factory produced. Site produced concrete or mortar spacers shall not be used.

Projecting ends of ties or clips shall not encroach into the concrete cover. Tying wires shall be 1.2 mm diameter stainless steel wire throughout the structure excepting any locations as described in Appendix 17/4 where 1.6 mm soft annealed iron wire may be used. Stainless steel tying wire shall be used when tying stainless steel reinforcement.

The Contractor shall provide access and carry out a cover measurement survey of all reinforced concrete surfaces within the 24-hour period following the removal of formwork. The cover measurement survey shall be carried out on a 500 mm grid over the whole structure in general accordance with BA 35/90.

1715 Reinforcement - Surface Condition

1 (05/01) Immediately before concrete is placed around it, reinforcement shall be free from mud, oil, paint, retarder, release agent, loose rust, loose mill scale, snow, ice, grease or any other substance that can be shown to have an adverse chemical effect on the steel or concrete, or to reduce the bond between the steel and the concrete.

1716 (05/01) Reinforcement - Laps and Joints

1 Laps and joints shall be made only where shown on the Drawings, except in the case where additional laps or splice bars are required and the Overseeing Organisation's approval has been obtained.

2 Where reinforcing bars are required to be coupled the coupling system shall have a current British Board of Agrément Roads and Bridges Certificate or CARES Certificate of Product Assessment and shall be sourced from a firm holding relevant valid CARES (or fully equivalent scheme) certificate of approval. Couplers shall comply with cover requirements of sub-Clause 1714.1.

1717 Reinforcement - Welding

General

1 (05/02) Welded reinforcement, other than steel fabric reinforcement, shall not be incorporated in the Permanent Works unless permitted in Appendix 17/4. When required, the Contractor shall demonstrate that at each location the fatigue life, durability and other properties of the member are not adversely affected by the proposal.

Site welding of stainless steel reinforcement bars shall not be permitted.

(05/02) Flash Butt Welding for Carbon Steel

2 (05/01) Flash butt welding shall only be carried out with an appropriate combination of flashing, heating, upsetting and annealing and subject to the demonstration of the satisfactory performance of trial joints. Only those machines that automatically control this cycle of operations shall be used.

(05/02) Manual Metal-arc Welding for Carbon Steel

3 (05/01) Metal-arc welding shall be carried out in accordance with BS 7123 and the recommendations of the reinforcement manufacturer, subject to the demonstration of the satisfactory performance of trial joints.

(05/02) Other Methods of Welding for Carbon Steel

4 (05/01) Other methods of welding may be used subject to the demonstration of the satisfactory performance of trial joints.

Strength of Structural Welded Joints

5 (05/02) The strength of all structural welded joints shall be assessed following tests on trial joints to establish the minimum specified mechanical properties of the joint. Tests shall be carried out by an independent testing body as specified in BS 8666.

1718 Prestressing Tendons - Materials

Steel Wire

1 (05/01) Steel wire shall comply with BS 5896.

Cold Worked High Tensile Alloy Bar

2 Cold worked high tensile alloy steel bars for prestressed concrete shall comply with BS 4486.

Stress-relieved Seven-wire Strand

3 (05/01) Stress-relieved seven-wire strand shall comply with BS 5896 or have properties that are not inferior.

Sampling and Testing

4 (05/01) When it is proposed to use super strand complying with BS 5896 : Table 6, or other than the lowest strength 3, 4, 5, 6 or 7 mm diameter wires complying with BS 5896 Tables 4 or 5 the following shall apply:

(i) A sample shall be taken from each reel of material proposed for use in the Works.

(ii) A reel shall only be accepted if both the breaking load and the 0.1% proof load of the sample exceeds the specified characteristic loads given in Tables 4 or 6. In the case of Table 5 this requirement shall apply to the breaking load and the load at 1% elongation.

5 (11/03) Where scheduled in Appendix 1/5, the Contractor shall arrange for samples of the steel intended for use in the Works to be tested at a testing laboratory appropriately accredited by an appropriate organisation in accordance with sub-Clauses 105.3 and 105.4.

1719 Prestressing Tendons - Handling and Storage

1 Care shall be taken to avoid mechanically damaging, work-hardening or heating prestressing tendons while handling. All prestressing tendons shall be stored clear of the ground and protected from the weather, from splashes from any other materials, and from splashes from the cutting operation of an oxy-acetylene torch, or arc-welding processes in the vicinity.

In no circumstances shall prestressing tendons after manufacture be subjected to any welding operation, or heat treatment or metallic coating such as galvanizing. This does not preclude cutting as described in Clause 1722.

1720 Prestressing Tendons - Surface Condition

1 (05/01) Prestressing tendons and internal and external surfaces of sheaths or ducts shall be clean and free from pitting at the time of incorporation in the work. Slight surface rusting is acceptable.

1721 Prestressing Tendons - Straightness

Wire

1 Low relaxation and normal relaxation wire shall be in coils of sufficiently large diameter to ensure that the wire pays off straight, except that 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.

Strand

2 Prestressing strand, however manufactured, shall be in coils of sufficiently large diameter to ensure that the strand pays off straight.

Bars

3 (05/01) Prestressing bars as delivered shall be straight. Any small adjustments for straightness that are necessary on Site shall be made by hand. Bars bent in the threaded portion shall be rejected. Any straightening of bars shall be carried out cold but at a temperature of not less than 5°C. Any necessary warming shall be by means of steam or hot water.

1722 Prestressing Tendons - Cutting

1 All cutting of wire, strand or bar shall be carried out using either:

(i) a high-speed abrasive cutting wheel, friction saw or equivalent mechanical method at not less than one diameter from the anchor; or

(ii) an oxy-acetylene cutting flame, using excess oxygen to ensure a cutting rather than a melting action, not less than 75 mm from the anchor. The temperature of the tendon adjacent to the anchor shall not be greater than 200°C. Care shall be taken that neither the flame nor splashes come into contact with the anchorages or tendons.

1723 Prestressing Tendons - Positioning of Tendons, Sheaths and Duct Formers

1 Tendons, sheaths and duct formers shall be accurately located and maintained in position both vertically and horizontally as shown on the Drawings. Unless otherwise described in Appendix 17/4 the tolerance in the location of the centre line of sheath or duct shall be ± 5 mm.

Where tendons are described in the Contract as debonded from the concrete they shall be covered with suitable sleeves. The ends of the sleeves shall be taped to the tendon to prevent the ingress of grout.

Joints in sheaths shall be securely taped to prevent penetration of the duct by concrete or laitance, and ends of ducts shall be sealed and protected after the stressing and grouting operations. Joints in adjacent sheaths shall be spaced at least 300 mm apart.

1724 Prestressing Tendons - Tensioning

General

1 All wires, strands or bars stressed in one operation shall be taken, where possible, from the same parcel. Each cable shall be tagged with its number from which the coil numbers of the steel used can be identified. Cables shall not be kinked or twisted. Individual wires and strands for which extensions are to be measured shall be readily identifiable at each end of the member. No strand that has become unravelled shall be used.

Tensioning Apparatus

2 The tensioning apparatus shall meet the following general requirements:

(i) The means of attachment of the tendon to the jack or tensioning device shall be safe and secure.

(ii) Where two or more wires or strands are stressed simultaneously, they shall be approximately of equal length between anchorage points at the datum of load and extension measurement. The degree of variation shall be small compared with the expected extension.

(iii) The tensioning apparatus shall be such that a controlled total force is imposed gradually and no dangerous secondary stresses are induced in the tendons, anchorage or concrete.

(iv) The force in the tendons during tensioning shall be measured by direct-reading load cells or obtained indirectly from gauges fitted in the hydraulic system to determine the pressure in the jacks. Facilities shall be provided for the measurement of the extension of the tendon and of any movement of the tendon in the gripping devices. The load measuring device shall be calibrated to an accuracy within ± 2% and checked at frequent intervals.

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Elongation of the tendon shall be measured to an accuracy within 2% or 2 mm, whichever is the lesser.

(v) The tensioning equipment shall be calibrated before the tensioning operation and subsequently at frequent intervals.

Pretensioning

3 Where pretensioning methods are used, the tension shall be fully maintained by some positive means during the period between tensioning and transfer. The transfer of stress shall take place slowly to minimize shock.

(i) Straight tendons. In the long-line method of pretensioning, sufficient locator plates shall be distributed throughout the length of the bed to ensure that the wires or strands are maintained in their proper position during concreting. Where a number of units are made in line, they shall be free to slide in the direction of their length and thus permit transfer of the prestressing force to the concrete along the whole line.

In the individual mould system, the moulds shall be sufficiently rigid to provide the reaction to the prestressing force without distortion.

(ii) Deflected tendons. Where possible, the mechanisms for holding down or holding up tendons shall ensure that the part in contact with the tendon is free to move in the line of the tendon so that frictional losses are nullified. If, however, a system is used that develops a frictional force, this force shall be determined by test and due allowance made.

For single tendons the deflector in contact with the tendon shall have a radius of not less than 5 times the tendon diameter for wire or 10 times the tendon diameter for strand, and the total angle of deflection shall not exceed 15°.

The transfer of the prestressing force to the concrete shall be effected in conjunction with the release of hold-down and hold-up forces.

Unless otherwise described in Appendix 17/4, concrete shall not be stressed until it has reached at least the age at which 2 test cubes taken from it attain the specified transfer strength. The test cubes shall be made and tested as described in BS 1881 : Part 108 and BS 1881 : Part 116 respectively. They shall be cured in similar conditions to the concrete to which they relate. The Contractor shall cast and test sufficient cubes to demonstrate that the required strength of the concrete at transfer has been reached.

Post-tensioning

4 (i) (05/01) Arrangement of tendons. Where wires, strands or bars in a tendon are not stressed simultaneously, the use of spacers shall be in accordance with the recommendations of the system manufacturer.

(ii) Anchorages. Anchorages shall be tested in accordance with BS 4447.

For each anchorage system used in the Works, the characteristic value for anchorage efficiency shall be not less than 90%.

Proprietary anchorages shall be handled and used strictly in accordance with the manufacturer's instructions and recommendations.

(iii) Deflected tendons. The deflector in contact with the tendon shall have a radius of not less than 50 times the diameter of the tendon, and the total angle of deflection shall not exceed 15°.

(iv) Tensioning procedure. Before tensioning, the Contractor shall demonstrate that all tendons are free to move in the ducts unless the geometry of the ducts makes this impracticable. Tensioning shall be carried out in such a manner that the stress in the tendons increases at a gradual and steady rate. Tensioning shall not be carried out at a temperature below 0°C.

Unless otherwise described in Appendix 17/4, concrete shall not be stressed until it has reached at least the age at which 2 test cubes taken from it attain the specified transfer strength. The test cubes shall be made and tested as described in BS 1881 : Part 108 and BS 1881 : Part 116 respectively. They shall be cured in similar conditions to the concrete to which they relate. The Contractor shall cast and test sufficient cubes to demonstrate that the required strength of the concrete at transfer has been reached.

The Contractor shall ensure that those carrying out the stressing are provided with

particulars of the required tendon loads, order of stressing and extensions. Allowance shall be made during stressing for the friction in the jack and in the anchorage, although the former is not necessary when using load cells, and for draw-in of the tendon during anchoring.

Stressing shall continue until the required extension and tendon load are reached.

The extension shall allow for any draw-in of the tendon occurring at a non-jacking end, but measurement shall not commence until any slack in the tendon has been taken up.

Immediately after anchoring, the forces in the prestressing tendons shall not exceed 70% of their characteristic strength. During stressing the value may exceed 70% of their characteristic strength but shall not exceed 80%.

After the tendons have been anchored, the force exerted by the tensioning apparatus shall be decreased gradually and steadily so as to avoid shock to the tendon or the anchorage. Full records shall be kept of all tensioning operations, including the measured extensions, pressure-gauge or load-cell readings, and the amount of draw-in at each anchorage. When requested copies of these records shall be provided within 24 hours of each tensioning operation.

Tendons shall not be cut within 3 days of their being grouted.

1725 Prestressing Tendons - Protection and Bond

1 The prestressing tendons shall be protected in their permanent positions from both mechanical damage and corrosion as described in Appendix 17/4.

1726 Stainless Steel Dowels - Materials

1 (05/02) Dowels shall be made from Steel Designation 1.4429 or 1.4436 and Grade 200 or 500 steel bars complying with BS 6744.

1727 Inspection and Testing of Structures and Components

General

1 Inspection and testing of structures and components shall be carried out as described in Appendix 17/4.