BRITISH STANDARD

BS 5400-7: 1978

Steel, concrete and composite bridges —

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

UDC 624.21.01:624.012.45

Cooperating organizations

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

Association of Consulting Engineers
Association of County Councils
British Constructional Steelwork Association
British Precast Concrete Federation Ltd.
British Railways Board
British Steel Industry
Cement and Concrete Association
Concrete Society Limited
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Department of the Environment (Building Research Establishment)
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London Transport Executive
Ministry of Defence
Sand and Gravel Association Ltd.
Scottish Development Department
Welding Institute

This British Standard, having been prepared under the direction of the Steel and Concrete Bridges Standards Committee, was published under the authority of the Executive Board on 30 June 1978

The following BSI references relate to the work on this standard:
Committee reference B/116
Draft for comment 73/10842 DC

ISBN 0 580 10219 X

Amendments issued since publication

Amd. No.	Date	Comments

Contents

NOTE The numbering of the clauses and subclauses in this Part is similar to that in Part 8 for ease of cross-reference.

Foreword

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

— *Part 1: General statement;*

— *Part 2: Specification for loads;*

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

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

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

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

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

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

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

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

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

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 16, an inside back cover and a back cover.

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

[1)] In course of preparation

1 Scope

This Part of this British Standard is a specification for the materials and workmanship for concrete, reinforcement and prestressing tendons used in the construction of bridges.

The clauses are suitable for incorporation in construction contracts.

2 References

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

3 Concrete

3.1 Classification of concrete mixes

3.1.1 ***General.*** The class of concrete shall be one of the following:

designed mix for ordinary structural concrete

prescribed mix for ordinary structural concrete

designed mix for special structural concrete

prescribed mix for special structural concrete

3.1.2 ***Ordinary structural concrete.*** This shall contain only materials specified in **3.2**.

3.1.3 ***Special structural concrete.*** This is concrete containing an admixture or material other than those specified in **3.2**.

3.1.4 ***Designed mix.*** 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.

3.1.5 ***Prescribed mix.*** The contractor shall provide concrete that contains constituents in the specified proportions to satisfy the requirements of the contract.

3.2 Constituent materials of ordinary structural concrete

3.2.1 *Cement.* Cement shall comply with the requirements of one of the following British Standards:

BS 12, *(Portland cement (ordinary and rapid-hardening)).*

BS 146, *(Portland-blastfurnace cement).*

BS 4027, *(sulphate-resisting Portland cement).*

3.2.2 *Aggregate.* Unless otherwise specified or agreed by the engineer, aggregate shall comply with the requirements of one of the following British Standards, where appropriate.

BS 882, 1201, *(aggregates from natural sources for concrete, including granolithic).*

BS 1047, *(air-cooled blastfurnace slag coarse aggregate for concrete).*

The nominal maximum size of aggregate shall be 40 mm or 20 mm.

Marine aggregates may only be used with Portland cement or sulphate-resisting cements subject to the agreement of the engineer to the content of chloride salt and shell. Marine aggregates shall not be used in prestressed concrete or steam-cured concrete.

The flakiness index (when determined by the sieve method described in BS 812) of the coarse aggregate shall not exceed 35 % except when natural, uncrushed aggregates are used for concrete of grades lower than C40, when the flakiness index shall not exceed 50 %. No limit is relevant to grade 15 concrete.

3.2.3 ***Water.*** Water shall be clean and free from harmful matter. If taken from a source other than a Public Utility Undertaking, approval shall be subject to tests in accordance with BS 3148.

3.3 Constituent materials of special structural concrete

3.3.1 ***Cement.*** Cement shall comply with the requirements of **3.2.1** or, subject to the approval of the engineer, with the requirements of one of the following British Standards:

BS 1370, *(low heat Portland cement).*

BS 4246, *(low heat Portland-blastfurnace cement).*

BS 4248, *(supersulphated cement).*

BS 12, *(white Portland cement, coloured Portland cement: all requirements) (ultra-high early strength Portland cement, water-repellent Portland cement, hydrophobic Portland cement: the requirements for the physical properties for ordinary Portland cement).*

3.3.2 ***Aggregate.*** Aggregate shall comply with the requirements of **3.2.2** or, unless otherwise specified or agreed by the engineer, with the requirements of one of the following British Standards:

BS 877, *(foamed or expanded blastfurnace slag coarse aggregate for concrete).*

BS 3797, *(lightweight aggregates for concrete).*

For coarse aggregate for concrete wearing surface, see **3.4.2**.

3.3.3 ***Water.*** See **3.2.3**.

3.3.4 ***Admixtures***

3.3.4.1 *General.* The quality and method of use shall be in accordance with the manufacturer's recommendations and in all cases shall be subject to the approval of the engineer. Unless otherwise specified or approved by the engineer, an admixture shall comply with the requirements of one of the following British Standards:

BS 1014, *(pigments for concrete, magnesium oxychloride and concrete).*

BS 3892, *(pulverized fuel ash for use in concrete grading zone B).*

BS 5075, *(except chloride-based admixtures).*

In all cases the contractor shall provide the following information for the engineer's approval:

a) the quantity to be used, in kilograms per kilogram of cement and in kilograms per cubic metre of concrete;

b) the detrimental effects caused by adding a greater or lesser quantity in kilograms per cubic metre of concrete;

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

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

If required by the engineer, the contractor shall demonstrate the action of an admixture by means of trial mixes.

3.3.4.2 *Calcium chloride.* Calcium chloride or admixtures containing calcium chloride shall not be used in structural concrete containing reinforcement, prestressing tendons or other embedded metal.

3.4 Miscellaneous aggregates

3.4.1 ***Sands for mortar.*** The fine aggregate for mortar shall comply with the requirements of one of the following British Standards:

BS 1200, *(building sands from natural sources).*

BS 3797, *(lightweight aggregates for concrete).*

BS 877, *(foamed blastfurnace slag lightweight aggregate for concrete).*

BS 882, *(coarse and fine aggregates from natural sources, grading zones 3 and 4).*

3.4.2 ***Aggregate for concrete wearing surface.*** For concrete wearing surfaces, the coarse aggregate shall be in accordance with **3.2.2**, except that air-cooled blastfurnace slag coarse aggregate (BS 1047) shall not be used for this purpose. Limestone aggregates may be used in the top 50 mm of concrete wearing surfaces only if:

a) fine aggregate does not contain more than 25 % by weight of limestone in either the fraction retained or the fraction passing a 600 μm test sieve (see BS 410).

b) after 50 h abrasive wear on the accelerated wear machine developed by the Transport and Road Research Laboratory, the specimens give a result of not less than 50 when tested with the friction tester described in **10.8** of BS 812-3:1975; and

c) when the specimens in b) have been subjected to polishing on the same machine for a further 5 h, they again give a result of not less than 50 when tested with the friction tester. The test shall be carried out on four specimens; if one specimen fails to comply with the above requirement, the test shall be repeated on a further four specimens of the same concrete mix. The aggregate tested shall be regarded as complying with the specification if, after both abrasion and polishing, either all four of the first group of four specimens give a result not less than 50, or not less than three of the first group of four specimens and all of the second group of four specimens give a result of not less than 50.

3.5 Requirements for hardened concrete

3.5.1 ***Concrete grade.*** For each grade of concrete the specified characteristic strength in N/mm^2 shall be as given in Table 1.

3.5.2 ***Minimum cement content.*** The cement content shall be not less than that described in the contract.

3.5.3 ***Maximum cement content.*** The cement content shall not exceed 550 kg/m^3 unless otherwise described in the contract or agreed by the engineer.

Table 1 — Grades of concrete

Grade	Characteristic strength
	N/mm^2
15	15.0
20	20.0
25	25.0
30	30.0
40	40.0
50	50.0
60	60.0

3.6 Requirements for designed mixes

3.6.1 ***Target mean strength.*** The target mean strength specimen shall exceed the specified characteristic strength by at least the "current margin". The current margin for a concrete mix shall be determined by the contractor and shall be taken as the lesser of

a) 1.64 times the standard deviation of cube tests on at least 100 separate batches of concrete of nominally similar proportion of similar materials and produced over a period not exceeding 12 months by the same plant under similar supervision, but not less than 2.5 N/mm^2 for concrete of grade 15 or 3.75 N/mm^2 for concrete of grade 20 or above;

b) 1.64 times the standard deviation of cube tests 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 5 N/mm^2 for concrete of grade 15 or 7.5 N/mm^2 for concrete of grade 20 or above.

Where there are insufficient data to satisfy a) or b) above, the margin for the initial mix design shall be taken as 10 N/mm^2 for concrete of grade 15 or 15.0 N/mm^2 for concrete of grade 20 or above. This margin shall be used as the "current margin" only until sufficient data are available to satisfy a) or b) above. However, subject to the engineer's approval, when the specified characteristic strength approaches the maximum possible strength of concrete made with a particular aggregate, a smaller margin not less than 5 N/mm^2 for concrete of grade 15 or 7.5 N/mm^2 for concrete of grade 20 or above may be used for the initial mix design.

3.6.2 ***Suitability of proposed mix proportions.*** The contractor shall submit for the engineer's approval, prior to the supply of any designed mix, the following information:

a) the nature and source of each material;

b) either;

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

2) full details of tests on trial mixes carried out in accordance with **3.6.3**, or

3) alternatively for ordinary structural concrete, a statement that, for initial production, the appropriate mix proportions given in Table 2 will be used;

c) 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 cement content of not more than 20 kg/m^3) shall be subject to the engineer's prior

3.6.3 ***Trial mixes.*** The contractor shall give notice to enable the engineer to be present at the making of trial mixes and preliminary testing of the cubes. The contractor shall prepare trial mixes, using samples of approved material typical of those he proposes to use in the works, for all grades to the engineer's satisfaction prior to commencement of concreting.

The contractor shall determine the workability of the trial mixes.

Sampling and testing procedures shall be in accordance with BS 1881.

The concreting 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 batches 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 approved by the engineer. The cubes shall be made, cured, stored, transported and tested in compression in accordance with the specification. The tests shall be carried out in a laboratory approved by the engineer.

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/mm^2.

3.6.4 ***Additional trial mixes.*** During production the contractor shall carry out trial mixes and tests, if required by the engineer, before substantial changes are made in the materials or in the proportions of the materials to be used, except when adjustments to the mix proportions are carried out in accordance with **3.8.5.1**.

3.7 Requirements for prescribed mixes

3.7.1 ***Prescribed mixes for ordinary structural concrete.*** Unless otherwise specified, the concrete mix shall be as detailed in Table 2.

The material shall comply with the requirements of **3.2** and, prior to the production of concrete, the contractor shall submit for the engineer's approval details of the nature and source of each material. Similar details shall be provided before substantial changes are made in the materials to be used and, if required by the engineer, the contractor shall demonstrate the adequacy of the mix by means of trial mixes and tests.

3.7.2 ***Prescribed mixes for special structural concrete.*** The concrete mix shall comply with all the requirements described in the contract.

The material shall comply with the requirements of **3.3** or **3.4**.

3.8 Production of concrete

3.8.1 ***General.*** The contractor shall provide supervision to ensure the required standard of control over materials and workmanship.

3.8.2 ***Cement.*** Cement shall be stored in dry weatherproof sheds with raised floors or in silos. If in sheds, each consignment shall be kept separate and distinct. Any cement that has become injuriously affected by damp or other causes shall be removed from the site immediately.

The contractor shall furnish, as directed by the engineer, test certificates relating to the cement to be used in the works. Each certificate shall indicate results of tests and analysis by an approved firm and shall state that the cement complies in all respects with the requirements of the appropriate specification for the particular type of cement.

Table 2 — Prescribed mixes for general use

Weights of cement and total dry aggregates, in kilograms, to produce approximately one cubic metre of fully compacted concrete, together with the percentages by weight of fine aggregate in total dry aggregates

Concrete grade	Nominal max. size of aggregate (mm)	40		20		14		10	
	Workability	Medium	High	Medium	High	Medium	High	Medium	High
	Slump limit (mm)	50 to 100	100 to 150	25 to 75	75 to 125	10 to 50	50 to 100	10 to 25	25 to 50
15	Cement (kg)	250	270	280	310	—	—	—	—
	Total aggregate (kg)	1 850	1 800	1 800	1 750	—	—	—	—
	Fine aggregate (%)	30 to 45	30 to 45	35 to 50	35 to 50	—	—	—	—
20	Cement (kg)	300	320	320	350	340	380	360	410
	Total aggregate (kg)	1 850	1 750	1 800	1 750	1 750	1 700	1 750	1 650
	Sand[a]								
	Zone 1 (%)	35	40	40	45	45	50	50	55
	Zone 2 (%)	30	35	35	40	40	45	45	50
	Zone 3 (%)	30	30	30	35	35	40	40	45
25	Cement (kg)	340	360	360	390	380	420	400	450
	Total aggregate (kg)	1 800	1 750	1 750	1 700	1 700	1 650	1 700	1 600
	Sand[a]								
	Zone 1 (%)	35	40	40	45	45	50	50	55
	Zone 2 (%)	30	35	35	40	40	45	45	50
	Zone 3 (%)	30	30	30	35	35	40	40	45
30	Cement (kg)	370	390	400	430	430	470	460	510
	Total aggregate (kg)	1 750	1 700	1 700	1 650	1 700	1 600	1 650	1 550
	Sand[a]								
	Zone 1 (%)	35	40	40	45	45	50	50	55
	Zone 2 (%)	30	35	35	40	40	45	45	50
	Zone 3 (%)	30	30	30	35	35	40	40	45

[a] Sand is defined as fine aggregate resulting from the natural disintegration of rock.

3.8.3 ***Aggregate.*** Single-sized coarse aggregates and fine aggregates shall be used, unless otherwise authorized by the engineer, and stored in separate hoppers, or different stacks which shall be separated from each other. 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 and without the use of excessive water. 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 by the engineer, tested in accordance with BS 812.

The contractor shall provide copies of the results of routine control tests carried out by the aggregate producer.

3.8.4 ***Batching and mixing.*** The quantities of cement, fine aggregate and the various sizes of coarse aggregate shall be measured by weight unless otherwise authorized by the engineer.

A separate weighing machine shall be provided for weighing the cement. Alternatively the cement may be measured by using a whole number of bags in each batch.

The quantity of water shall be measured. Any admixture to be added shall be measured and, if solid, shall be measured by weight. Different types of cement shall not be mixed.

The batch weight of aggregate shall be adjusted to allow for a moisture content typical 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 cement	± 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 the requirements of BS 1305 or BS 4251 where applicable. The mixing time shall be not less than that recommended by the manufacturer, subject to the engineer's approval of the trial mixes.

Mixers that have been out of use for more than 30 mm shall be thoroughly cleaned before any fresh concrete is mixed. Unless otherwise agreed by the engineer, the first batch of concrete through the mixer shall then contain only two-thirds of the normal quantity of coarse aggregate. Mixing plant shall be thoroughly cleaned before changing from one type of cement to another.

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

3.8.5.1 *Adjustment to mix proportions.* Adjustments to mix proportions shall be made subject to the engineer's approval, 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.

3.8.5.2 *Change of current margin.* When required by the engineer, the contractor shall recalculate the current margin in accordance with **3.6.1**. The recalculated value shall be adopted as directed by the engineer, and it shall become the current margin for concrete produced subsequently.

3.8.6 ***Ready-mixed concrete.*** Ready-mixed concrete shall comply with the general requirements of this specification 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 h of the introduction of cement to the aggregate, unless a longer time is agreed by the engineer. The time of such introduction shall be recorded on the Delivery Note together with the weight of the constituents of each mix.

When truck-mixed concrete is used, water shall be added under supervision either at the site or at the central batching plant as agreed by the engineer, but in no circumstances shall water be added in transit.

Unless otherwise agreed by the engineer, truck mixer units and their mixing and discharge performance shall comply with the requirements of BS 4251.

3.9 Compliance with specified requirements

3.9.1 ***General.*** All sampling and testing of constituent materials shall be carried out in accordance with the provisions of the appropriate British Standard. In particular, sampling and testing of fresh and of hardened concrete shall be carried out in accordance with the provisions of BS 1881 unless such provision is at variance with this specification.

3.9.2 ***Strength***

3.9.2.1 *General.* Compliance with the specified characteristic strength shall be based on tests made on cubes at an age of 28 days unless there is evidence, satisfactory to the engineer, that a particular testing regime is capable of predicting the strength at 28 days of concrete tested at an earlier age.

Unless otherwise directed by the engineer, the rate of sampling shall be as given in Table 3, but not less than one sample shall be taken on each day that concrete of that grade is used.

Table 3 — Rates of sampling and testing

Rate of Sampling	Sample from one batch selected randomly to represent an average volume of not more than the lesser of:
Rate 1	10 m^3 or 10 batches
Rate 2	20 m^3 or 20 batches
Rate 3	50 m^3 or 50 batches

3.9.2.2 *Testing plan A.* Each cube shall be made from a single sample taken from a randomly selected batch of concrete. The samples shall be taken at the point of discharge from the mixer or, in the case of ready-mixed concrete, at the point of discharge from the delivery vehicle.

At least one sample shall be taken on each day that concrete of that particular grade is used. The times of day at which samples are taken shall be chosen at random.

For compliance purposes

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

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

The "current margin" shall be taken as 10 N/mm^2 for concrete of grade 15 or 15 N/mm^2 for concrete of grade 20 or above, unless in accordance with **3.6.1** or **3.8.5.2** a smaller margin has been established to the satisfaction of the engineer.

If only one cube result fails to meet the second requirement b), then that result may be considered to represent only the particular batch of concrete from which that cube was taken.

If the average strength of any group of four consecutive test cubes fails to meet the first requirement a), then all the concrete in all the batches represented by all such cubes 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 cubes shall include the batches from which samples were taken to make the first and the last cubes in the group of four, together with all the intervening batches.

3.9.2.3 *Testing plan B.* The contractor shall use testing plan B for single batches of concrete as directed by the engineer. One test cube shall be made from each of two independent representative samples taken from every batch of concrete selected for testing using plan B.

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/mm^2 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 this requirement in respect of a given batch of concrete shall not be adduced as evidence of compliance in respect of any other batch.

3.9.2.4 *Action to be taken in the event of non-compliance with testing plans A and B.* The contractor shall take such remedial action as the engineer may order, including the removal of the relevant concrete, and shall, before proceeding with the concreting, submit for the engineer's approval details of the action proposed to ensure that the concrete still to be placed in the works will comply with the requirements of the specification.

3.9.3 ***Cement content.*** The cement content of any batch of concrete shall be not less than the specified minimum value less 5 % of that value, nor more than the specified maximum value plus 5 % of that value.

3.9.4 ***Workability.*** The workability of the fresh concrete shall be such that the concrete is suitable for the conditions of handling and placing (see **3.11.3**) so that after compaction (see **3.11.3**) it surrounds all reinforcement, tendons and ducts and completely fills the formwork. Workability shall be measured at least once a day using one of the following tests in accordance with BS 1881, 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 s or ± one-fifth of the required value, whichever is the greater

3.9.5 ***Water/cement ratio.*** The water/cement ratio of a batch of concrete shall not exceed the specified maximum value by more than 5 % of that value.

3.9.6 ***Air content of fresh concrete.*** 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 ± 1.5 % of the specified value. The average percentage air content from any four consecutive determinations from separate batches shall be within ± 1.0 % of the specified value.

3.9.7 ***Additional tests on concrete for special purposes.*** When required by the engineer, additional cubes shall be made and tested in accordance with BS 1881. The method of sampling, identification and storage of the concrete cubes shall be as directed by the engineer.

3.10 Surface finish of concrete

3.10.1 ***Trial panels.*** When required by the engineer, the contractor shall prepare, prior to concreting, a sample panel of size and surface texture to be agreed by the engineer. The panel shall contain reinforcement fixed to represent the most congested part of the work. The panel 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 side forms shall be removed to enable the engineer to check the surface finish and compaction achieved.

3.10.2 ***Control of colour.*** When specified, the contractor shall obtain each constituent material from a single consistent source. The aggregates shall be durable and free of any impurities that may cause staining. The mix proportions and the grading, particularly of the fine aggregate, shall be maintained constant. In formwork the same type of plywood or timber shall be used throughout similar exposed areas, and individual plywood sheets or sections of timber in large panels shall not be replaced.

3.10.3 ***Release agents.*** Release agents for formwork shall be to the approval of the engineer. 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 contact with reinforcement and prestressing tendons shall be avoided.

3.10.4 ***Surface finishes for concrete.*** Unless otherwise specified, the surface finish shall be one of the following.

Type "A" finish. This finish shall be obtained by the use of properly designed formwork or moulds of closely jointed sawn boards. The surface shall be free from voids, honeycombing or other large blemishes.

Type "B" finish. This finish shall be obtained by the use of properly designed forms of closely jointed wrought boards. Alternatively, steel or other suitable material may be used for the forms. The surface shall be free from voids, honeycombing or other large blemishes.

Type "C" finish. This finish shall be obtained by using properly designed forms having a hard, smooth surface. The concrete surfaces shall be smooth with true, clean arrises. Only very minor surface blemishes shall be permitted and there shall be no staining or discoloration.

Type "D" finish. This finish shall be obtained by first producing a type "B" finish on thoroughly compacted, high-quality concrete cast in properly designed forms. The surface shall then be improved by carefully removing all fins and other projections, thoroughly washing down and then filling the most noticeable surface blemishes with a cement and fine aggregate paste. Consistency of the colour of the concrete shall be to the approval of the engineer.

Type "E" finish. This finish shall be obtained by first producing a type "C" finish and then, while the concrete is still green, filling all surface blemishes with a fresh, specially prepared cement and fine aggregate paste. Consistency of the colour of the concrete shall be to the approval of the engineer. After the concrete has been properly cured, the faces shall be rubbed down where necessary to produce a smooth and even surface.

3.10.5 ***Protection.*** permanently exposed surfaces shall be protected from spillage, stains and damage of any sort.

3.11 Construction with concrete

3.11.1 ***Construction joints.*** The position of construction joints shall be as specified in the drawings or agreed with the engineer before the concrete is placed. 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 member, and the joint lines shall match features of the finished work, if possible, or be formed by grout checks. Kickers, if required, shall be constructed integrally with the lift of concrete below.

Concreting shall be carried out continuously up to construction joints.

Immediately the concrete has achieved sufficient strength to be self-supporting subject to the requirements of **3.11.5**, the stop ends shall be removed and the aggregate exposed by means of a fine water jet or compressed air jet and gentle brushing that does not disturb the aggregate. Shutter paint retarding agents shall not be used unless authorized by the engineer.

Alternatively, sandblasting or a needle gun shall be used to remove the surface skin and laitance. Hardened surfaces shall not be hacked.

Immediately prior to concreting on a joint, the surface of the concrete against which new concrete will be cast shall be free from laitance and shall be roughened to the extent that the largest aggregate is exposed but not disturbed. The joint surface shall be clean and damp but not wet immediately before the fresh concrete is placed against it.

3.11.2 ***Form work***

3.11.2.1 *Design and construction.* The design and construction of formwork shall be carried out by competent persons, taking due account of the surface finish required. 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.

Formwork (including supports) shall be sufficiently rigid to maintain the forms in their correct position, shape and profile within the limits of the dimensional tolerances where specified. The supports shall be designed to withstand the worst combination of self-weight, formwork weight, formwork forces, reinforcement weight, wet concrete weight, construction and wind loads, together with all incidental dynamic effects caused by placing, vibrating and compacting the concrete.

The formwork shall be so arranged as to be readily dismantled and removable 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 or specification. 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.

3.11.2.2 *Form lining.* The type and treatment of any lining (plywood, metal, plastics, etc.) to the forms shall be appropriate to the concrete finish required.

3.11.2.3 *Cleaning and treatment of forms.* All rubbish shall be removed from the interior of the forms before the concrete is placed. The faces of the forms in contact with the concrete shall be clean and treated with a suitable release agent, where applicable (see **3.10.3**).

3.11.2.4 *Projecting reinforcement, 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 demoulding.

3.11.3 ***Transporting, placing and compacting of concrete.*** Concrete shall be so transported and placed that contamination, segregation or loss of the constituent materials does not occur.

Concrete shall not be placed in any part of the works until the engineer's approval has been given. If concreting is not started within 24 h of approval being given, approval shall again be.obtained from the engineer. Concreting shall then proceed continuously over the area between construction joints. Fresh concrete shall not be placed against in situ concrete that has been in position for more than 30 min unless a construction joint is formed in accordance with **3.11.1**.

No concrete shall be placed in flowing water. Underwater concrete shall be placed in position by tremies or by pipeline from the mixer.

All placing shall be carried out under the direct supervision of a competent member of the contractor's staff. Concreting operations shall not be permitted to displace reinforcement, tendon ducts, tendon anchorages or formwork or to damage the faces of formwork.

Concrete shall be thoroughly compacted by vibration, unless otherwise agreed by the engineer, 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.

Internal vibrators shall be capable of producing not less than 10 000 cycles per minute, and external vibrators not less than 3 000 cycles per minute.

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

Concrete shall not be subjected to disturbance between 4 h and 24 h after compaction.

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.

The mix shall be such that there will be no excess water on the top surface on completion of compaction.

3.11.4 ***Striking of formwork***

3.11.4.1 *General.* The removal shall be done in such a manner as not to damage the concrete, and shall take place at times to suit the requirements for its curing and to prevent restraint that may arise from elastic shortening, shrinkage or creep.

3.11.4.2 *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/mm^2 or twice the stress to which it will be subjected, whichever is the greater.

In the absence of control cubes, the periods before striking shall be as the engineer directs.

3.11.5 ***Curing of concrete***

3.11.5.1 *Curing methods.* The method of curing shall prevent loss of moisture from the concrete. Immediately after compaction and for 7 days thereafter, except where elevated temperature curing is used, concrete shall be protected against harmful effects of weather, including rain, rapid temperature changes and frost, and from drying out.

The curing time shall be the number of days given in Table 4 unless the average 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.

Details of all curing methods used shall be subject to the approval of the engineer.

3.11.5.2 *Accelerated curing.* Elevated-temperature curing may be used only with ordinary Portland cement. After the completion of the placing of the concrete, 4 h shall elapse before its temperature is raised. The rise in temperature within any period of 30 min shall not exceed 10 °C and the maximum temperature attained shall not exceed 70 °C. The rate of subsequent cooling shall not exceed the rate of heating.

The use of accelerated curing methods for concrete containing other types of cement or any admixture shall be subject to the engineer's approval.

3.11.6 ***Cold weather work.*** When concrete is placed at air temperatures below 2 °C, the following requirements shall be met.

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

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

c) The surface temperature of the concrete shall be maintained at not less than 5 °C until it reaches a strength of 5 N/mm^2 as determined by tests on cubes that were cured under identical conditions to the structural concrete.

d) 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.

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

3.11.7 ***Hot weather work.*** 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.

3.11.8 ***Precast concrete construction***

3.11.8.1 *Manufacture off the site.* When the method of manufacture has been approved, no changes shall be made without the consent of the engineer.

The contractor shall inform the engineer 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 sent to the engineer as soon as they become available.

Where the engineer requires tests 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 described in the contract, the production line on which they were manufactured, the date on which the concrete was cast and, if they are 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.

3.11.8.2 *Storage.* When members are stored, they shall be firmly supported only at the points described in the contract. The accumulation of trapped water and deleterious matter in the units shall be prevented. Care shall be taken to avoid rust staining and efflorescence.

3.11.8.3 *Handling and transport.* Members shall be lifted or supported only at points described in the contract or otherwise agreed by the engineer and shall be handled and placed without impact.

The method of lifting, the type of equipment and transport to be used, and the minimum age of the members to be handled shall be subject to the approval of the engineer.

Table 4 — Normal curing periods

Conditions under which concrete is maturing	**Minimum periods of protection for different types cement**					
	Number of days (where the average temperature of the concrete exceeds 10 °C during the whole of the 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 temperature of the concrete exceeds –10 °C)		
	LHC or SSC	**OPC, PBFC or SRPC**	**RHPC**	**LHC or SSC**	**OPC, PBFC or SRPC**	**RHPC**
1. Hot weather or drying winds	7	4	2	3 500	2 000	1 000
2. Conditions not covered by 1	4	2	1	2 000	1 000	500

Key:

LHC = Low heat Portland cement or low heat Portland-blastfurnace cement.

SSC = Supersulphated cement.

OPC = Ordinary Portland cement.

RBFC = Portland-blastfurnace cement.

RHPC = Rapid-hardening Portland cement

SRPC = Sulphate-resisting Portland cement.

3.11.8.4 *Assembly and erection.* The method of assembly and erection described in the contract shall be strictly adhered to on site. Immediately a unit is in position, and before the lifting equipment is removed, temporary supports or connections between members, as necessary, shall be provided. The final structural connections shall be completed as soon as is practicable.

3.11.8.5 *Forming structural connections.* No structural connections shall be made until the engineer's approval has been given.

Unless otherwise agreed by the engineer, the composition and water/cement ratio of the in-situ concrete or mortar used in any connection and the packing of joints shall be in accordance with the assembly instructions.

Levelling devices shall only be released or removed with the engineer's approval.

3.11.8.6 *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.

3.12 Grouting of prestressing tendons

3.12.1 ***General.*** The contractor shall undertake grouting trials when required by the engineer.

3.12.2 ***Materials.*** Unless otherwise directed or agreed by the engineer as a result of grouting trials, the grout shall consist only of ordinary Portland cement and water. The water/cement ratio shall be as low as possible consistent with the necessary workability.

The grout shall not be subject to bleeding in excess of 2 % after 3 h or 4 % maximum when measured at 18 °C in a covered cylinder approximately 100 mm diameter with a height of grout of approximately 100 mm, and the water shall be reabsorbed by the grout during the 24 h after mixing.

Admixtures may be used with the written permission of the engineer and shall be applied strictly in accordance with the manufacturer's instructions.

Dry materials shall be measured by weight.

3.12.3 ***Ducts.*** Air vents shall be provided at any crests in the duct profile and elsewhere as specified.

All ducts shall be thoroughly clean before grouting. Ducts formed without metal sheathing shall be provided with effective drainage and, unless otherwise directed by the engineer, shall be flushed with water before grouting. All surplus water shall be removed by compressed air injection. All anchorages shall be sealed or fitted with grouting connections.

3.12.4 ***Grouting equipment.*** The mixing equipment shall produce a grout of homogeneous consistency and shall be capable of providing a continuous supply to the injection equipment.

The injection equipment shall be capable of continuous operation with little variation of pressure and shall include a system for recirculating the grout while actual grouting is not in progress. Compressed air shall not be used.

The equipment shall have a sensibly constant delivery pressure not exceeding 1 N/mm^2. All piping to the grout pump shall have a minimum of bends, valves and changes in diameter. All baffles to the pump shall be fitted with 1.18 mm sieve strainers. All equipment, especially piping, shall be thoroughly washed through with clean water after every series of operations and at the end of use for each day. The interval between washings shall not exceed 3 h.

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.

3.12.5 ***Mixing.*** Water shall be added to the mixer first, then the cement. When these are thoroughly mixed, the admixture, if any, shall be added. Mixing shall continue until a uniform consistency is obtained. The water/cement ratio of the mix shall not exceed 0.45 by weight unless otherwise agreed by the engineer. Mixing shall not be by hand.

3.12.6 ***Injecting grout.*** Grouting shall be carried out as soon as is practicable after the tendons in them have been stressed and the engineer's permission to commence has been obtained. Injection shall be continuous, and it shall be slow enough to avoid producing segregation of the grout. The method of injecting grout shall ensure complete filling of the ducts and complete surrounding of the steel. Grout shall be allowed to flow from the free end of the duct until its consistency is equivalent to that of the grout injected. The opening shall then be firmly closed. Any vents shall be closed in a similar manner one after another in the direction of the flow. After an appropriate time, further injections shall be carried out to fill any possible cavities.

The injection tubes shall then be sealed off under pressure until the grout has set.

The filled ducts shall not be subjected to shock or vibration within 1 day of grouting.

Not less than 2 days after grouting, the level of grout in the injection and vent tubes shall be inspected and made good as necessary.

The contractor shall keep full records of grouting including the date each duct was grouted, the proportion of the grout and any admixtures used, the pressure, details of any interruptions and topping up required. Copies of these records shall be supplied to the engineer within 3 days of grouting.

Where required by the engineer, the contractor shall provide facilities and attendance for the radiographic testing of ducts.

3.12.7 ***Grouting during cold weather.*** When the weather is cold, accurate temperature records shall be kept covering maximum and minimum air temperatures, and temperatures of the structures to be grouted. No materials in which frost or ice is present shall be used, and the ducts and equipment shall be completely free of frost and ice.

No grout shall be placed when the temperature of the structure is below 5 °C, or is likely to fall below 5 °C during the next 48 h, unless the member is heated so as to maintain the temperature of the placed grout above 5 °C for at least 48 h.

Ducts shall not be warmed with steam unless accompanied by general heating of the member or structure externally.

3.12.8 ***Strength of grout.*** The compressive strength of 100 mm cubes made of the grout shall exceed 17 N/mm^2 at 7 days. Cubes shall be cured in a moist atmosphere for the first 24 h, and subsequently in water.

4 Reinforcement

4.1 Material

4.1.1 ***Hot rolled bars.*** Hot rolled mild steel bars and hot rolled high yield bars shall comply with the requirements of BS 4449.

4.1.2 ***Cold worked bars.*** Cold worked steel bars shall comply with the requirements of BS 4461.

4.1.3 ***Hard drawn steel wire.*** Hard drawn mild steel wire shall comply with the requirements of BS 4482.

4.1.4 ***Steel fabric.*** Steel fabric reinforcement shall comply with the requirements of BS 4483 and shall be delivered to the site in flat mats.

4.1.5 ***Bond strength.*** The classification of deformed bars as type (1) or (2) for bond strength shall be in accordance with appendix E of CP 110-1:1972.

4.2 and **4.3 Bar schedule dimensions; cutting and bending.** Reinforcement shall be scheduled in accordance with BS 4466 and shall be cut or cut and bent to the dimensions specified in the contract.

Bending at temperatures below 5 °C or in excess of 100 °C may only be carried out with the engineer's approval and under his supervision.

Any reinforcement bar that has already been bent shall not be rebent at the location of the original bend without the engineer's permission.

4.4 Fixing. 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.

In a member where the nominal cover is dimensioned to the links, spacers between the links and formwork shall be the same dimensions as the nominal cover.

Cover blocks required for ensuring that the reinforcement is correctly positioned shall be as small as possible consistant with their purpose, of a shape acceptable to the engineer and designed so that they will not overturn when the concrete is placed. They shall be made of concrete with 10 mm maximum aggregate size and they shall be of the same strength and material source as the adjacent concrete. Wire cast in the block for the purpose of tying it to the reinforcement shall be as described in the contract. Stainless steel tying wire shall be used in cover blocks to exposed surfaces.

Other types of spacers may be used only with the approval of the engineer. Pieces of wood, metal, tile or porous material shall not be used as cover blocks.

Projecting ends of ties or clips shall not encroach into the concrete cover. Tying wires shall be either

a) 1.6 mm diameter soft annealed iron wire for unexposed surfaces, or

b) 1.2 mm diameter stainless steel wire for in situ exposed surfaces.

The position of reinforcement shall be checked before and during concreting.

4.5 Surface condition. Immediately before concrete is placed around it, reinforcement shall be clean, free from mud, oil, paint, retarders, loose rust, loose mill scale, snow, ice, grease or any other substance that can be shown to affect adversely the steel or concrete chemically, or to reduce the bond.

4.6 Laps and joints. Laps and joints including sleeving, threading and other mechanical connections shall be made only by the methods specified and at the positions shown on the drawings or as agreed by the engineer.

4.7 Welding

4.7.1 ***General.*** Welding of reinforcement shall only be carried out with the engineer's approval.

4.7.2 ***Flash butt welding.*** Flash butt welding shall only be carried out with the combination of flashing, heating, upsetting and annealing to the engineer's approval, and only those machines that automatically control this cycle of operations shall be used.

4.7.3 ***Manual metal-arc welding.*** Metal-arc welding of reinforcement shall be carried out in accordance with BS 5135 and the recommendations of the reinforcement manufacturers, subject to the approval of the engineer and the satisfactory performance of trial joints.

4.7.4 ***Other methods.*** Other methods of welding may be used subject to the approval of the engineer and to their satisfactory performance in trial joints.

4.7.5 ***Location of welded joints.*** Welded joints shall not be made at bends in reinforcement. Unless otherwise agreed by the engineer, joints in parallel bars of the principal tensile reinforcement shall be staggered in the longitudinal direction at a distance not less than the end anchorage length for the bar.

4.7.6 ***Strength of structural welded joints.*** The strength of all structural welded joints shall be assessed following tests on trial joints to demonstrate that they achieve the strength of the bar.

5 Prestressing tendons

5.1 Materials

5.1.1 ***Steel wire.*** Steel wire shall comply with the requirements of BS 2691.

5.1.2 ***Cold worked high tensile alloy bar.*** Cold worked high tensile alloy steel bars for prestressed concrete shall comply with the requirements of BS 4486.

5.1.3 ***Stress-relieved seven-wire strand.*** Stress-relieved seven-wire strand shall comply with the requirements in BS 3617 or have properties that are not inferior.

5.1.4 ***Nineteen-wire strand.*** Nineteen-wire steel strand shall comply with the requirements of BS 4757.

5.1.5 ***Testing.*** Where directed by the engineer, the contractor shall arrange for samples of the steel intended for use in the works to be tested at an approved independent testing laboratory.

5.2 Handling and storage. 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 "on site" heat treatment or metallic coating such as galvanizing. This does not preclude cutting as specified in **5.5**.

5.3 Surface condition. Prestressing tendons and internal and external surfaces of sheaths or ducts shall be clean and free from pitting, loose rust and loose scale at the time of incorporation in the work.

5.4 Straightness

5.4.1 ***Wire.*** Unless otherwise agreed by the engineer, low relaxation and normal relaxation wire shall be in coils of sufficiently large diameter to ensure that the wire pays off straight.

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

5.4.3 ***Bars.*** Prestressing bars as-delivered shall be straight. Any small adjustments for straightness that are necessary on site shall be made by hand under the supervision of the engineer. 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 heating shall be by means of steam or hot water.

5.5 Cutting. All cutting of wire, strand or bar shall be carried out using either

a) a high-speed abrasive cutting wheel, friction saw or any other mechanical method approved by the engineer, or

b) an oxy-acetylene cutting flame, using excess oxygen to ensure a cutting rather than a melting action. Care shall be taken that neither the flame nor splashes come into contact with either the anchorage or other tendons.

In post-tensioning systems, the cutting action as in a) and b) shall be not less than one diameter from the anchor, and the temperature of the tendon adjacent to the anchor shall be not greater than 200 °C.

5.6 Positioning of tendons, sheaths and duct formers. The tendons, sheaths and duct formers shall be accurately located and maintained in position both vertically and horizontally as shown on the drawings. Unless otherwise shown on the drawings, the tolerance in the location of the centre line of sheath or duct shall be ± 5 mm.

5.7 Tensioning the tendons

5.7.1 ***General.*** 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.

5.7.2 ***Tensioning apparatus.*** The tensioning apparatus shall meet the following general requirements.

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

b) 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.

c) 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.

d) 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 intervals to the approval of the engineer. Elongation of the tendon shall be measured to an accuracy within 2 % or 2 mm, whichever is the more accurate.

e) The tensioning equipment shall be calibrated before the tensioning operation and at intervals to the approval of the engineer.

5.7.3 ***Pretensioning.*** 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.

5.7.3.1 *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.

5.7.3.2 *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 a 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 as approved by the engineer.

5.7.4 ***Post-tensioning***

5.7.4.1 *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.

5.7.4.2 *Anchorages.* Anchorages shall be tested in accordance with the requirements of 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.

5.7.4.3 *Deflected tendons.* The deflector in contact with the tendon shall, where possible, have a radius of not less than 50 times the diameter of the tendon, and the total angle of deflection shall not exceed 15°. Where the radius is less than 50 times the diameter of the tendon and the angle of deflection exceeds 15°, the loss of strength of the tendon shall be determined by test and due allowance made.

5.7.4.4 *Tensioning procedure.* Before tensioning, where the design permits, the contractor shall demonstrate that all tendons are free to move in the ducts. Tensioning shall be carried out under competent supervision 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 without the approval of the engineer.

The supervisor in charge of stressing shall be 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.

Any allowance for draw-in of the tendon during anchoring shall be in accordance with the engineer's instructions.

Stressing shall continue until the required extension and tendon load are reached or are to the engineer's satisfaction.

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

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. Copies of these records shall be supplied to the engineer within 24 h of each tensioning operation.

Unless otherwise agreed by the engineer, tendons shall not be cut less than 3 days after grouting.

5.8 Protection and bond of prestressing tendons. The prestressing tendons shall be protected in their permanent positions from both mechanical damage and corrosion in accordance with the requirements of the contract.

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Standards publications referred to

BS 12, *Portland cement (ordinary and rapid-hardening).*
BS 146, *Portland-blastfurnace cement.*
BS 410, *Specification for test sieves.*
BS 812, *Methods for sampling and testing of mineral aggregates, sands and fillers.*
BS 812-3, *Mechanical properties.*
BS 877, *Foamed or expanded blastfurnace slag lightweight aggregate for concrete.*
BS 882, 1201, *Aggregates from natural sources for concrete (including granolithic).*
BS 1014, *Pigments for Portland cement and Portland cement products.*
BS 1047, *Air-cooled blast furnace slag coarse aggregate for concrete.*
BS 1200, *Building sands from natural sources.*
BS 1305, *Batch type concrete mixers.*
BS 1370, *Low heat Portland cement.*
BS 1881, *Methods of testing concrete.*
BS 2691, *Steel wire for prestressed concrete.*
BS 3148, *Tests for water for making concrete.*
BS 3617, *Seven-wire steel strand for prestressed concrete.*
BS 3797, *Lightweight aggregates for concrete.*
BS 3892, *Pulverized-fuel ash for use in concrete.*
BS 4027, *Sulphate-resisting Portland cement.*
BS 4246, *Low heat Portland-blastfurnace cement.*
BS 4248, *Supersulphated cement.*
BS 4251, *Truck type concrete mixers.*
BS 4447, *The performance of prestressing anchorages for post-tensioned construction.*
BS 4449, *Hot rolled steel bars for the reinforcement of concrete.*
BS 4461, *Cold worked steel bars for the reinforcement of concrete.*
BS 4466, *Bending dimensions and scheduling of bars for the reinforcement of concrete.*
BS 4482, *Hard drawn mild steel wire for the reinforcement of concrete.*
BS 4483, *Steel fabric for the reinforcement of concrete.*
BS 4486, *Cold worked high tensile alloy steel bars for prestressed concrete.*
BS 4757, *Nineteen-wire steel strand for prestressed concrete.*
BS 5075, *Concrete admixtures.*
BS 5135, *Metal-arc welding of carbon and carbon manganese steels.*
CP 110, *The structural use of concrete.*
CP 110-1, *Design, materials and workmanship.*

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