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STANDARD SPECIFICATION FOR ROAD WORKS

Section 9: CONCRETE

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FOREWORD

As practices in road construction change over time, it is imperative that Jabatan Kerja Raya (JKR) to continuously update and improve their standard specifications. These new specifications are not only aimed at keeping abreast with current technologies but also to help improve the quality of construction works and its final product. Consequently, these new specifications will ultimately have a significant positive impact on the construction industry especially with the incorporation of new products and technologies.

The JKR Standard Specification for Road Works is an essential document in the road infrastructure construction industry. This Specification provides an improved guidance in the material selection and quality control of workmanship and products, based on current best practices. The purpose of the JKR Standard Specification is to establish uniformity and compliance in road design and construction and to be used by road designers, road authorities, manufacturers and suppliers of road related products.

This particular document, the **"Standard Specification for Road Works – Section 9: Concrete"**, is a part of a series of improved specifications in the JKR Standard Specification for Road Works. The compilation of this document was carried out through a series of discussions that had been held by the technical committee. The draft had also been presented and discussed at length in a specially held workshop to get feedback and comments from relevant parties involved, which were then carefully studied and incorporated into the Specification wherever appropriate or necessary.

The Specification has also gone through different phases of vetting and approval before the production of its final draft and printed copy. It shall be reviewed and updated from time to time to cater for any changes in policies and the inclusion of current requirements, if necessary. Any feedback or improvement to be considered for future revisions should be forwarded to Bahagian Pembangunan Inovasi & Standard, Cawangan Jalan, JKR Malaysia.

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SECTION 9 - CONCRETE

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9.1 GENERAL

This section shall apply to the construction of all structures or parts of structures to be composed of concrete, with or without steel reinforcement. The work shall be carried out all in accordance with this Specification and the lines, levels, grades, dimensions and cross-sections shown in the Drawings and as required by the S.O.

9.1.1 Classification of Concrete Mixes

This subsection describes the classification of concrete mixes to be used in roadworks construction.

9.1.1.1 The concrete mix shall be designed concrete to MS EN 206-1 and MS EN 206-2 unless otherwise stated in the Drawings or in the Tender Related Documents. However, prescribed concrete may be used subjected to the following and as approved by S.O:

(i) The work is of minor nature or involving a small quantity of concrete
(ii) Prior approval is given by the S.O.
(iii) The Contractor shall be responsible for the strength of the concrete
(iv) Only CEM I cement is specified to be used

9.1.1.2 When other than CEM I cement is specified to be used, the concrete mix shall be of designed concrete only.

9.1.1.3 When the composition of concrete consists of additions such as steel or polymer fiber or any advanced cementitious materials, the concrete mix shall be of designed concrete only.

9.1.2 Prescribed Concrete

9.1.2.1 Prescribed concrete shall conform to MS EN 206-1 and MS EN 206-2. Prescribed concrete shall be as detailed in TABLE 9.5. The mix prescribed in the table does not require the use of admixture.

9.1.2.3 For small volume concreting work, volume batching is permitted provided prior approval of the S.O. is obtained. The proportion shall be as specified in TABLE 9.5 A

9.1.3 Designed Concrete

9.1.3.1 Designed concrete shall comply with the recommendations of MS EN 206-1 and MS EN 206-2. The minimum cement content and maximum free water to cement ratio to be used shall be as shown on TABLES 9.6 and 9.6 A.

9.1.3.2 Designed concrete with intended use for High Performance (HPC) and Ultra-High Performance concrete (UHPC) for the purpose of strength and durability shall be in accordance to Subsection 9.14 of this specification. Concrete is deemed as High Performance (HPC) or Ultra-High Performance (UHPC) type when it is mentioned in the Drawings, Bill of Quantities, Tender Documents or whenever required by the S.O. for the purpose of

strength and/or durability or concrete that possesses advanced cementitious-based composites materials which is also described in Subsection 9.14 of this specification.

9.1.3.3 The Contractor shall comply with the following requirements:

(i) Notify the S.O. whether the designed concrete is to be produced as site-mixed or ready-mixed.

(ii) If the Contractor chooses to use ready mix concrete, he shall notify the S.O. the name of the supplier, location of the ready mix plant, journey time taken to transport the concrete to the Site and production capacity of the plant.

(iii) Submit a mix design report covering all concrete mixes to the S.O. for approval. The designed concrete shall comply with the requirements specified in TABLES 9.6 and 9.6A.

(iv) The Contractor shall ensure that the S.O. be permitted to visit or station his representative at the plant at any stage of the concrete production.

9.1.4 Requirements for Concrete

9.1.5.1 Concrete grade

The grade of concrete to be used in the Works shall be as stated in the Drawings, Tender Documents and/or in the Bill of Quantities. Concrete shall be designated as Grade C X/Y where 'X' is minimum characteristic cylinder strength in N/mm^2, and 'Y' is minimum characteristic cube strength in N/mm^2. For prescribed mix, a suffix 'P' shall be added after 'X'.

9.1.5.2 Cement content

(i) Cement content in this Specification shall refer to the total quantity of cement as approved in Subsection 9.2.1, or the total quantity of cementitious materials comprising Portland cement and other constituents complying to MS EN 197-1.

(ii) Minimum cement content

The minimum cement content shall be in accordance with TABLES 9.6 and 9.6 A, unless otherwise shown on the Drawings

(iii) Maximum cement content

The maximum cement content shall not exceed 550 kg/m^3 unless otherwise shown on the Drawings or as approved by the S.O. Cement content for HPC and UHPC shall be in accordance to Subsection 9.14 of this specification.

9.1.5.3 Consistency

(i) The consistency of the fresh concrete shall be judged by its suitability for the condition of handling, workability and placing

so that after compaction, it surrounds all reinforcement, tendons and ducts and completely fills the formwork. Consistency of the concrete shall be within one of the following limits:

(a) Slump classes (Refer to TABLE 9.7)
(b) Compacting classes (Refer to TABLE 9.7A)
(c) Vebe classes (Refer to TABLE 9.7B)
(d) Flow classes (Refer to TABLE 9.7C)

(ii) Unless specified otherwise in the Drawings, consistent values expressed as slump and flow classes appropriate to the different uses of concrete shall be as given in TABLE 9.7D.

9.1.5.4 Total chloride content

The total chloride content of the concrete mix arising from the aggregate or any other source shall not, under any circumstance, exceed the limits in TABLE 9.7E expressed as a percentage of relationship between chloride ions and weight of cement in the mix. When necessary, tests shall be carried out in accordance with BS 1881: Part 124 for each grade of concrete, to demonstrate that these limits are not exceeded.

9.1.5.5 Maximum sulphate content

The total estimated sulphate content of any mix, including that present in the cement shall not exceed 4% by weight of cement in the mix. Where necessary, tests shall be carried out in accordance with BS 1881: Part 124 for each grade of concrete to demonstrate that this limit is not exceeded.

9.1.5.6 Cement Additions

Pulverized Fly Ash (PFA) or Ground Granulated Blast-furnace Slag (GGBS) with or without Silica Fume as approved in Subsections 9.2.4 and 9.2.5 shall be added to the mix to achieve not only the specified strength but also meet the permeability requirement to enhance the durability of the concrete or any other specific requirements.

When cement additions are used for structure close to the sea, exposed to sea water spray or breeze, or subjected to high chloride or sulphate exposure, then permeability requirements as per Subsection 9.3.2.2 shall be carried out or as deemed necessary by the S.O.

9.2 MATERIAL

9.2.1 Cement

9.2.1.1 The cement to be used throughout the Works shall be cement obtained from SIRIM-Certified manufacturer. The cement shall be described and complied with MS EN 197-1 as shown in TABLE 9.1.

9.2.1.2 Certificates of tests

Manufacturers' certificates of tests shall in general be accepted as proof of soundness. Additional tests shall be carried out on any cement which appears to have deteriorated through age, damage to containers, improper storage, or any other reason. The test shall be carried out at any approved laboratory in accordance with MS EN196 at the expense of the Contractor. Any batch of cement that has been sampled and tested and found not to have complied with the requirements shall be rejected and removed from the Site.

The S.O. may, without tests being made, order that any bag of cement, a portion of the contents of which has hardened, or which appears to be defective in any other way, be removed from the Site.

9.2.1.3 Transportation and storage

The cement shall be transported to the Site in covered vehicles adequately protected against water. It shall be stored in a weatherproof cement store to the approval of the S.O. Cement stored in bags shall not be laid directly on the ground. It shall be taken for use in the Works in the order of its delivery into the store. Cement delivered in bulk shall be stored in purposely built silos of an approved design.

9.2.2 Aggregates

9.2.2.1 Aggregates shall be naturally occurring sand, granite or limestone, crushed or uncrushed, except as otherwise specified, and shall comply with MS EN 12620. They shall be obtained from a source approved by the S.O. Marine aggregates shall not be used.

9.2.2.2 Coarse aggregates

Coarse aggregates shall comply with MS EN 12620. For work below ground level, only crushed granite shall be used. Unless otherwise specified in the Drawings, tests shall be carried out according to MS 30. The property limits shall be as specified in TABLE 9.2. The maximum nominal size of aggregate shall be as specified in the Drawings.

9.2.2.3 Fine aggregates

Fine aggregates shall comply with MS EN 12620. In the context of MS EN 12620, the term 'sand' is used to mean 'fine aggregate'. Unless otherwise specified in the Drawings, tests shall be carried out in accordance with MS 30. The property limits shall be as specified in TABLE 9.2.

9.2.2.4 Grading

(i) Coarse aggregates

The grading of coarse aggregates shall be analysed as described in MS 30 and shall be within the limits specified in TABLE 9.3.

(ii) Fine aggregates

The grading of fine aggregates shall be analysed as described in MS 30 and shall be within the limits specified in TABLE 9.3A. However, for prescribed mixes Grading Limit M only shall be used.

9.2.2.5 Sampling and testing of aggregates

Where site mixing is used, samples of fine and coarse aggregates approved by the S.O. shall be kept on Site. These samples shall give a fair indication of the general quality of the aggregates for comparison with the aggregates delivered during the course of executing the work. Tests shall be carried out on samples of the latter, taken at intervals as required by the S.O., or whenever there is a change of source. The appropriate method of sampling and testing shall be in accordance with the standards as specified in TABLE 9.2. Any batch of aggregate rejected by the S.O. shall be removed from the Site.

9.2.2.6 Storage of aggregates

Separate storage facilities with adequate provision for drainage shall be provided for each different size of aggregate used. Aggregate shall be handled and stored so as to minimize segregation and contamination.

9.2.3 Water

Water shall comply with the requirements of MS EN 1008. It shall be clean and free from materials deleterious to concrete in the plastic and hardened state and shall be from a source approved by the S.O. The S.O. may instruct the Contractor to carry out chemical tests at any approved laboratory at the expense of the Contractor. The Contractor shall make adequate arrangement to supply and store sufficient water at the Site to be used in mixing and curing of concrete.

9.2.4 Admixtures

9.2.4.1 Suitable admixtures may be used in concrete mixes with the prior approval of or as directed by the S.O.

9.2.4.2 The admixtures, the sampling and testing of the admixtures and the information to be provided with the admixture supplied shall comply with MS EN 934 Pt. 1- 6.

9.2.4.3 All admixtures shall be used strictly in accordance with manufacturer's recommendation.

9.2.4.4 Before allowing the admixture to be used in the Works, relevant tests based on trial mixes shall be carried out. A control mix shall be made using a conventional trial mix that is without using the admixture in order to determine the free water to cement ratio and mix proportion required to give the specified strength with the required slump. Using the same mix proportion as in the control mix but with a modified water to cement ratio whenever necessary, a test shall be carried out using the recommended dosage of the

admixture. The results of the relevant test obtained from the control mix and test mix shall be compared. The S.O. may allow the use of the admixture only when the results are found to be satisfactory and comparable to the effects as claimed by the manufacturer. The admixture acceptance test shall comply with the requirements specified in TABLE 9.4.

9.2.4.5 The use of admixtures that are of chloride based type are not permitted for structural concrete containing reinforcement, prestressing tendons or other embedded metal. The Contractor shall submit documentary evidence of the contents of the admixture to be used.

9.2.4.6 When the Contractor proposes the use of water reducing admixtures, special control tests shall be carried out with prior approval of the S.O. The tests shall be carried out in accordance with TABLE 9.4 or the latest established standard and with the manufacturer's recommendations, as approved by the S.O.

9.2.4.7 If two or more admixtures are proposed to be used simultaneously in the same concrete mix, the Contractor shall furnish the S.O. with the supporting data on their suitability and compatibility.

9.2.5 Additions

9.2.5.1 Addition Type I, nearly inert addition. General suitability as type I addition is established for:

(i) filler aggregate conforming to MS EN 12620 or BS EN 13055;

(ii) pigments conforming to BS EN 12878; for reinforced concrete, only category B pigments

9.2.5.2 Addition Type II, Pozzolonic or latent hydraulic addition. General suitability as type II addition is established for:

(i) Fly ash (V, W) conforming to MS EN 450-1; Ash obtained by methods other than electrostatic or mechanical precipitation of dust-like particles from the flue gases from furnaces fired with pulverized coal shall not be used in cement that conforms to MS EN 197-1.

(a) Siliceous fly ash is a fine powder of mostly spherical particles having Pozzolanic properties. It consists essentially of reactive silicon dioxide (SiO_2) and aluminium oxide (Al_2O_3). The remainder contains iron oxide (Fe_2O_3) and other compounds. The proportion of reactive calcium oxide shall be less than 10.0 % by mass, the content of free calcium oxide, as determined by the method described in BS EN 451-1 shall not exceed 1.0 % by mass. Fly ash having a free calcium oxide content higher than 1.0 % by mass but less than 2.5 % by mass is also acceptable provided that the requirement on expansion (soundness) does not exceed 10 mm when tested in accordance with MS EN 196-3 using a mixture of 30 % by mass of siliceous fly ash and 70 % by mass of

a CEM I cement conforming to MS EN 197-1. The reactive silicon dioxide content shall not be less than 25.0% by mass.

(b) Calcareous fly ash is a fine powder, having hydraulic and/or Pozzolanic properties. It consists essentially of reactive calcium oxide (CaO), reactive silicon dioxide (SiO_2) and aluminium oxide (Al_2O_3). The remainder contains iron oxide (Fe_2O_3) and other compounds. The proportion of reactive calcium oxide shall not be less than 10% by mass. Calcareous fly ash containing between 10% and 15% by mass of reactive calcium oxide shall contain not less than 25% by mass of reactive silicon dioxide. Adequately ground calcareous fly ash containing more than 15% by mass of reactive calcium oxide, shall have a compressive strength of at least 10.0 N/mm^2 at 28 days when tested in accordance with MS EN 196-1. Before testing, the fly ash shall be grounded and the fineness, expressed as the proportion by mass of the ash retained when wet sieved on a 40μm mesh sieve, shall be between 10% and 30% by mass. The test mortar shall be prepared with ground calcareous fly ash only instead of cement. The mortar specimens shall be demoulded 48hrs after preparation and then cured in a moist atmosphere of relative humidity of at least 90% until tested. The expansion (soundness) of calcareous fly ash shall not exceed 10mm when tested in accordance with MS EN 196-3 using a mixture of 30% by mass of calcareous fly ash grounded as described above and 70% by mass of a CEM I cement conforming to MS EN 197-1.

(ii) Silica fume conforming to BS EN 13263-1; Silica fume originates from the reduction of high purity quartz with coal in electric arc furnaces in the production of silicon and ferrosilicon alloys and consists of very fine spherical particles containing at least 85% by mass of amorphous silicon dioxide. Silica fume shall meet the following requirements:

- The loss on ignition shall not exceed 4% by mass determined in accordance with MS EN 196-2 but using an ignition time of 1 hour.
- The specific surface (BET) of the untreated silica fume shall be at least 15.0 m2/g when tested in accordance with ISO 9277.

For intergrinding with clinker and calcium sulfate the silica fume may be in its original state or compacted or pelletized (with water).

(iii) Grounded Granulated Blast-furnace Slag conforming to MS EN 15167-1.

Burnt shale, specifically burnt oil shale, is produced in a special kiln at temperatures of approximately 800°C. Owing to the composition of the natural material and the production process, burnt shale contains clinker phases, mainly dicalcium silicate

and monocalcium aluminate. It also contains, besides small amounts of free calcium oxide and calcium sulfate, larger proportions of Pozzolanically reacting oxides, especially silicon dioxide. Consequently, in a finely grounded state burnt shale shows pronounced hydraulic properties like that of Portland cement and, in addition pozzolanic properties.

Adequately grounded burnt shale shall have a compressive strength of at least 25,0 N/mm^2 at 28 days when tested in accordance with MS EN 196-1. The test mortar shall be prepared with finely grounded burnt shale only instead of cement. The mortar specimens shall be demoulded 48hrs after preparation and cured in a moist atmosphere of relative humidity of at least 90% until tested.

The expansion (soundness) of burnt shale shall not exceed 10 mm when tested in accordance with MS EN 196-3 using a mixture of 30% by mass of grounded burnt shale and 70% by mass of a CEM I cement conforming to MS EN 197-1.

9.3 CONCRETE CONFORMANCE AND IDENTITY TESTING

9.3.1 Evaluation of Conformity

9.3.1.1 General

The Contractor is responsible for the evaluation of conformity for specified requirements of the concrete. For this purpose, the Contractor shall carry out the following tasks:

(i) Initial test,
(ii) Production control including conformity control

9.3.1.2 Concrete composition and initial testing

(i) Initial test is required for designed mix concrete only.

(ii) In the case of using a new concrete composition, initial testing shall be performed to provide a concrete that achieves the specified properties or intended performance with an adequate margin of strength. The concrete design and design relationships shall be re-established in the case of a prescribed concrete.

(iii) New concrete composition shall be reviewed periodically to provide assurance that all concrete designs are still in accordance with the actual requirements, taking into account of the change in properties of the constituent materials and the results of conformity testing on the concrete compositions.

(iv) Concrete for structures or members of structures in non-abrasive, insignificant chloride attack environment or deemed not to have been exposed to durability risk can be relieved from permeability test requirements in this subsection, subjected to S.O approval. Otherwise, or if it is mentioned in the drawings, the permeability test shall be conducted in full to the S.O.'s approval and acceptance.

(v) Testing and compliances for HPC and UHPC shall be cross-referenced with Subsection clause 9.14 of this specification.

9.3.1.3 Initial tests

(i) Frequency of initial tests

Initial test shall be repeated if there has been a significant change either in the constituent materials or in the specified requirements on which the previous tests were based.

(ii) Test conditions

(a) In general, initial test shall be carried out on fresh concrete with a temperature 27±2ºC

(b) For the initial test of single concrete composition, at least three (3) specimens from each of three (3) batches shall be tested.

(c) The strength of each batch or load shall be taken to be the average of the three (3) specimen test results. The result of the initial test of the concrete is the average strength of all batches or loads.

(iii) Criteria for adoption of initial tests

For assessing the properties of concrete, in particular those of fresh concrete, the differences between the type of mixer and mixing procedure applied during the initial test and those applied during actual production shall be taken into account.

The compressive strength of the concrete with the composition to be adopted for the actual case shall exceed the characteristic strength, f_{ck} values of TABLE 9.8 or TABLE 9.9 by an adequate margin. This margin shall be at least that needs to satisfy the conformity criteria given in Subsection 9.3.2.1(iii). The margin should be twice the expected Standard Deviation (σ) which means at least a margin of 6 N/mm^2 to 12N/mm^2 depending on the production facilities, the constituent materials and the available background information about the variation.

The consistency of the concrete shall be within the limits of the consistence class as in TABLE 9.7 or/ and TABLE 9.7D at the time at which the concrete is likely to be placed or delivered in the case of ready mixed concrete.

For other properties that are specified, the concrete shall meet the specified values with an appropriate margin as approved by the S.O.

9.3.2 Conformity Control for Designed Concrete

9.3.2.1 Conformity control for compressive strength

(i) General

(a) For normal-weight and heavy-weight concrete of strength classes from C8/10 to C55/67 or light-weight concrete from LC8/9 to LC55/60, sampling and testing shall be performed on individual concrete compositions.

(b) In the sampling and testing plan, the conformity criteria of an individual concrete compositions distinction are made between initial production and continuous production. Initial production covers the production until at least 35 test results are available.

(c) Continuous production is achieved after at least 35 test results of initial production are obtained over a period not exceeding 12 months.

(d) Any continuation in the case of production of an individual concrete composition that has been suspended for more than 12 months, the criteria, sampling and testing plan that are given for initial production criteria shall be resorted and adopted.

(e) During continuous production, the sampling and testing plan and the criteria for initial production may be adopted.

(f) If the strength is specified for a different age of concrete, the conformity shall be assessed on specimens tested at that specified age unless stated otherwise.

(g) Identity testing shall be carried out in accordance with Subsection 9.3.4 in order to verify that a defined volume comes from a conforming population.

(h) While work on concreting is in progress, tests on consistency of the mix shall be carried out at suitable intervals and, in addition, whenever any materials or the proportions of the mix are changed, or when directed by the S.O.

(ii) Sampling and Testing

(a) Samples of concrete shall be randomly selected and taken in accordance with EN 12350-1. The minimum rate of sampling and of testing of concrete shall be in accordance with TABLE 9.10 at the rate that gives the highest number of samples for initial or continuous production, as appropriate.

(b) The samples shall be taken after any water or admixtures are added to the concrete, but sampling before adding water reducing agent to adjust the consistence is

permitted where there is proof by initial testing that the water reducing agent to be used has no negative effect on the strength of the concrete.

(c) The test result shall be that obtained from an individual specimen or the average of the results when two or more specimens made from one sample are tested at the same age.

(d) Where two or more specimens are made from one sample and the range of the test values is more than 15% of the mean, the result shall be disregarded unless an investigation reveals an acceptable reason to not justify disregarding of an individual test value.

(e) The initial testing process shall be witnessed by the S.O. representative prior to further production of concrete or as advised by S.O.

(iii) Conformity criteria for compressive strength

(a) Conformance assessment shall be made on test results taken during an assessment period that shall not exceed the last twelve months.

(b) Conformance of concrete compressive strength is assessed on specimens tested at 28 days in accordance with criteria given in TABLE 9.11:

- Groups of n non-overlapping or overlapping consecutive test results f_{cm} (Criterion 1)
- Each individual test result f_{cl} (Criterion 2)

(c) Conformance is confirmed if both the criteria given in TABLE 9.11 for either initial or continuous production are satisfied.

(d) Initially, the standard deviation shall be calculated from at least 35 consecutive test results taken over a period exceeding three months and which is immediately prior to the production period during which conformity is to be checked. This value shall be taken as the estimate of the standard deviation (σ) of the population. The validity of the adopted value shall be verified during the subsequent production using Method 1 as stated below. However, Method 2 may be used if approved by the S.O.

- Method 1

  The initial value of standard deviation may be applied for the subsequent period during which conformity is to be checked, provided the standard deviation of the latest 15 results (σ_{15}) does not deviate significantly from the adopted standard deviation. This is considered valid

provided:

$$0.63\sigma \leq \sigma_{15} \leq 1.37\sigma$$

Where the value of σ_{15} lies outside these limits, a new estimate of σ shall be determined from last available 35 test results.

- Method 2

  The new value of σ may be estimated from a continuous system and this value is adopted. The sensitivity of the system shall be at least that of Method 1.

9.3.2.2 Permeability requirements

(i) Initial Surface Absorption Test (ISAT)

(a) ISAT shall be carried out on samples of different components of the bridge or culvert structures before the mix designs are approved. The samples shall be 150mm x 150mm x 150mm cubes cut from the sample in accordance with BS1881-208 between 28 and 40 days after casting and water cured of the samples. The maximum values shall not exceed the following limits at 10 minutes after starting the test:

- In-situ constructions: less than 0.10ml/m^2/s
- Precast concrete elements: less than 0.10ml/m^2/s

(b) During construction, the ISAT test shall be similarly carried out on test samples and will form one of the basis for rejecting or accepting the concrete elements.

(ii) Rapid Chloride Permeability Test (RCPT)

(a) In addition to ISAT, RCPT shall be carried out using cores taken from the 150mm x 150mm x 600mm samples cast, in accordance with AASHTO T277; “Standard Method of Test for Rapid Determination of the Chloride Permeability of Concrete” and ASTM C1202; “Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration”. The following limits shall not be exceeded:

- In-situ construction: 1000 coulombs
- Precast concrete elements: 800 coulombs

(b) During construction, the ISAT test shall be similarly carried out on test samples and will form one of the basis for rejecting or accepting concrete elements.

9.3.3 Non-conformity of Product

9.3.3.1 The following actions shall be taken by the Contractor in the event of non- conformity:

(i) Check test results and if invalid, take action to eliminate errors;

(ii) If non-conformance is confirmed e.g. by retesting, take corrective actions including a management review of the relevant production control procedures;

(iii) Where it is confirmed of non-conformance with the specification that was not obvious at delivery, immediate notice shall be given to the S.O. in order to avoid any consequential damage;

(iv) Record actions on the items above

9.3.3.2 If the Contractor has given notice of non-conformance of the concrete or if the results of conformance tests do not fulfill the requirements, supplementary testing according to MS EN 12504-1 on cores taken from the structure or components or a combination of tests on cores and non-destructive tests on the structure or in structural components as given in MS EN 13791 shall be instructed by the S.O.

9.3.3.3 For non-conformance on the 28-day compressive strength, the section of work represented by the samples which fail the test carried out in accordance with Subsection 9.3.2.1 shall be removed.

9.3.4 Identity Testing

9.3.4.1 General

Identity testing indicates whether the defined volume of concrete in question belongs to the same population as that verified as conforming to the characteristic strength via conformity assessment.

9.3.4.2 Identity testing for compressive strength

(i) Sampling and testing plan

(a) The sampling rate for identity testing shall be as follows:

- One sample for concrete volume less than 10.0 m^3 of structures e.g. drains, road barriers, sumps, road kerbs, parapet, culverts etc.

- One sample per 10.0 m^3 or every group of 10 batches for critical structures e.g., piled embankment slab, retaining walls, bored piles, deck slabs, abutments, piers, Substructures, pile caps, beams, etc.

- One sample per 20.0 m^3 or every group of 20 batches e.g. rigid pavements, drains, road barriers, sumps, road kerbs, parapet, etc,

- One sample per 50.0 m^3 or every group of 50 batches e.g. raft foundation and mass concrete.

(b) Sample that consist of minimum of three (3) specimens shall be taken from different batches or loads in accordance with BS EN 12350-1. Test specimens shall be prepared and cured in accordance with MS EN 12390-2. The compressive strength of the specimens shall be determined in accordance with MS EN 12390-3. The test result shall be that obtained from the average of the results of two (2) or more specimens made from one sample for testing at the same age. Where the range of test values is more than 15% of the mean, the results shall be disregarded unless an investigation reveals an acceptable reason to not justify disregarding an individual test value.

Cube strength tested at 7 day:

One cube from each sample batch shall be tested for the seven (7) days compressive strength. The cube compressive strength shall not fall below the corresponding values given in TABLE 9.12 for prescribed concrete, and two-third (2/3) of the twenty eight (28) days compressive strength for designed concrete.

9.3.4.3 Identity criteria for compressive strength

(i) Concrete under production control certification

(a) Identity of concrete is assessed for each individual strength test result and the average non-overlapping discrete results as identified in TABLE 9.13.

(b) Concrete is deemed to have come from a conforming population if both the criteria in TABLE 9.13 are satisfied for *n* results derived from strength tests on samples taken from the defined volume of concrete.

(ii) Concrete not under production control certification

From the defined volume of concrete, at least three (3) samples shall be taken for testing. The concrete is deemed to have come from a conforming population if the conformity in Subsection 9.3.2.1(iii) and TABLE 9.11 for initial production is satisfied.

9.3.4.4 Identity testing for slump and flow

(i) Sampling and testing plan

(a) The sampling shall be either:

- In accordance with MS 26-1-1; or
- Measured using a spot sample obtained from the initial discharge, if concrete is delivered in a truck mixer or agitating equipment. The spot sample shall be taken after a discharge of approximately 0.3 m^3 by taking six

(6) increments from the moving stream of concrete in accordance with MS 26-1-1.

(b) The sample shall be remixed on a non-absorbent surface and tested for slump or flow. Slump shall be measured in accordance with MS 26-1-2. Flow shall be measured in accordance with MS 26-1-5.21.

9.3.4.5 Identity criteria for the slump of an individual batch

If the measured slump meets the requirements specified in TABLE 9.14 and/or is within the tolerance specified in TABLE 9.15, the identity test confirms that the batch conforms to MS EN 206: Part 1 with respect to consistency.

For identity criteria for flow, reference shall be made to MS 523-2; Annex B.

9.4 PRODUCTION OF CONCRETE

9.4.1 General

All concrete shall be subjected to production control under the responsibility of the Contractor.

Production control comprises all measures necessary to maintain the properties of concrete in conformance to specified requirements. It includes:

(i) selection of materials.
(ii) concrete design.
(iii) concrete production.
(iv) inspection, sampling and tests.
(v) the use of the results of test on constituent materials, fresh and hardened concrete and equipment.
(vi) for ready-mixed concrete, inspection of equipment used in transporting fresh concrete.

9.4.2 Production Control System

The production control system shall contain adequately documented procedures and instructions. These procedures and instructions shall, where relevant, be established in respect of the control requirement as given in the TABLES 9.10, 9.11 and 9.16.

9.4.3 Supervision

The Contractor shall ensure the required standard of control over materials and workmanship. The S.O. shall be afforded all reasonable opportunities and facilities to inspect the constituent materials and the production of concrete and to take samples for testing as or when necessary.

9.4.4 Site Mixed Concrete

9.4.4.1 Site mixed concrete shall include prescribed mix and designed mix.

9.4.4.2 The quantities of cement, fine aggregate and various sizes of coarse

aggregate shall be measured by weight unless otherwise approved by the S.O. 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 by volume or by weight. Any solid admixtures to be added shall be measured by weight; liquid or paste admixtures shall be measured by volume or weight.

9.4.4.3 The batch weight of aggregate shall be adjusted to allow for the moisture content of the aggregate being used. All measuring equipment shall be calibrated on site or their calibration status established by certificates from accredited laboratories.

9.4.4.4 The mixing time shall be not less than two minutes and not more than five minutes or any other time recommended by the mixer manufacturer after all the ingredients have been placed in the mixer.

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

9.4.4.6 The water content of each batch of concrete may be adjusted so as to produce concrete of the required workability. However care shall be taken to ensure the free water over cement ratio is maintained. The total amount of water added to the mix shall be recorded.

9.4.5 Ready Mixed Concrete

9.4.5.1 Ready mixed concrete are batched, either dry or wet, at a control plant and transported in purpose-made agitators operating continuously or truck mixers to the Site.

9.4.5.2 Ready mixed concrete shall comply with the requirements of designed concrete as in Subsection 9.3.2 and MS EN 206-1. All concrete materials, including water and admixtures shall be mixed in the plant and delivered to Site in purpose made truck mixers. No extra water or admixtures are allowed to be added after the concrete has left the plant.

9.4.5.3 Ready mixed concrete delivered to the Site shall be accompanied by delivery ticket and manufacturer's batching record stating the details of mix proportions by weight, the grade of concrete, type and size of aggregate, date and time of loading at plant, type and dosage of chemical admixtures and other relevant production details in suitable format, failing which the S.O, or his representative, shall immediately reject the total load of the concrete. The S.O. or his representative, and the Contractor shall ensure the information provided in the delivery tickets and the manufacturer's batching record complies with the details of the approved 'designed concrete' and its corresponding consistence as in subsections 9.3.2 and 9.3.4 respectively before discharging the concrete.

9.4.5.4 Rejected concrete shall be removed from the site. The delivery ticket shall be marked 'REJECTED'.

9.4.6 Transporting

Concrete shall be transported from the mixer to the formwork as rapidly as practicable by methods, which will prevent segregation or loss of any constituents or ingress of foreign matter or water and maintain the required workability. It shall be deposited as near as practicable in its final position to avoid re-handling or moving the concrete horizontally by vibration. The concrete shall be conveyed by chutes or concrete pumps only with permission from the S.O.

9.4.7 Placing

9.4.7.1 Placing of concrete in dry condition:

(i) For all concrete, whether mixed on or off the site of the Works, each batch shall be placed and compacted within two (2) hours of adding the cement to the dry aggregates and within 45 minutes (or any other period of time based on the initial test as per Subsections 9.2.4 and 9.3.1.3 and approved by the S.O. if an admixture is used) of adding water to the cement and aggregate. Concrete shall not be placed in any part of the structure until the approval of the S.O. has been obtained. If concreting is not started within 24 hours of approval given, approval shall again be obtained from the S.O.

(ii) All formwork and reinforcement contained in it shall be clean and free from standing water immediately before the placing of concrete. Concreting shall be carried out continuously between and up to the predetermined construction joints in one sequence of operation. It shall be thoroughly compacted by either hand tamping or mechanical vibration, or both and shall be thoroughly worked into the corners. After tamping into place the concrete shall not be subjected to disturbance other than such as incidental to compaction by vibration. In the event of unavoidable stoppage in positions not predetermined, the concreting shall be terminated on a horizontal plane and against vertical surfaces by the use of stop boards. The location for termination shall be subjected to the approval of the S.O.

(iii) Fresh concrete shall not be placed against in-situ concrete which has been in position for more than 45 minutes unless a construction joint is formed in accordance with Subsection 9.5.3. When in-situ concrete has been in place for four hours, no further concrete shall be placed against it for a further 20 hours. Where retarding admixture has been used, the S.O. may approve variation to this limit.

(iv) Except where otherwise approved by the S.O., concrete shall be deposited in horizontal layers to a compacted depth not exceeding 450mm when internal vibrators are used, or 300 mm in all other cases. The surface of the concrete shall be maintained reasonably level during placing.

(v) Concrete shall not be dropped into place from a height exceeding 1.5m. However, drops exceeding 1.5m may be

allowed provided the mix has been well designed and proportioned. When trunking or chutes are used, they shall be kept clean and used in such a manner as to avoid segregation.

(vi) The Contractor shall maintain an experienced steel fixer at the site of reinforced concrete works during the placing of concrete to reposition any reinforcement which may be displaced.

9.4.7.2 Placing of concrete under water

No concrete shall be placed in flowing water. Underwater concrete if deemed unavoidable, shall be placed in position by Tremie pipes from the mixer. During and after concreting under water, pumping or dewatering operations in the immediate vicinity shall be suspended until the S.O. permits them to continue. Where the concrete is placed by a Tremie pipe, the following requirements shall be applicable: -

(i) The hopper and Tremie pipe shall be a closed system. The bottom of the Tremie pipe shall be kept as far as practicable beneath the surface of the placed concrete.

(ii) The Tremie pipe shall be large enough with due regard to the size of aggregate. For 20mm aggregates, the Tremie pipe shall be of a diameter not less than 150mm and for larger aggregates, a bigger diameter Tremie pipe approved by the S.O. shall be used.

(iii) Unless otherwise agreed by the S.O., the first charge of concrete shall be placed with a sliding plug pushed down the Tremie pipe ahead of it to prevent mixing of concrete and water.

(iv) The Tremie pipe shall always penetrate well into the concrete with an adequate margin of safety against accidental withdrawal if the pipe is surged to discharge the concrete.

(v) The concrete shall be deposited wholly by Tremie pipe and the method of deposition shall not be changed part way up to prevent the laitance from being entrapped within the structure.

(vi) All Tremie pipes shall be properly cleaned after use.

9.4.8 Placement Temperature

Placement temperature shall comply with MS EN 206-3 to prevent premature setting, early thermal cracking and loss of water during placing of concrete in the formwork and the following precautions shall be taken:

9.4.8.1 At the time of placing, no part of the concrete shall have a temperature exceeding 36°C. This may be achieved by cooling the water and aggregate prior to mixing.

9.4.8.2 Concrete shall not be placed in forms or around reinforcement whose temperature exceeds 36°C. This can be achieved by providing shading or other means to protect from direct sunlight.

9.4.8.3 Freshly placed concrete shall be protected from direct sunlight and from loss of moisture by covering, shading or other means.

9.4.8.4 No concrete shall be placed when the air temperature at the point of deposition exceeds 36°C.

9.4.8.5 The Contractor shall provide the method statement for temperature control in the case of large volumes of continuously concrete pour exceeding 100m^3 or as deemed necessary by S.O. No concreting shall take place without prior approval from the S.O.

9.4.8.6 In the case of high potential of early thermal cracking may occur, the apparatus and instrumentation for temperature monitoring shall be installed at the location shown in the Drawings or as directed by the S.O.

9.4.9 Compaction

9.4.9.1 Unless otherwise approved by the S.O., concrete shall be thoroughly compacted by vibration and thoroughly worked around the reinforcement, tendons or duct formers, around embedded fixtures and into corners of the formwork to form a dense, homogenous mass, free from voids and which will have the required surface finish when the formwork is removed. 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 which does not promote segregation of the ingredients.

9.4.9.2 The concrete maintained between the two walls of formwork shall be compacted by internal or external vibrators. Concrete in slabs with no formwork on its upper surface shall be compacted either by vibrators of the pan type or by a vibrating screen.

9.4.9.3 The internal vibrators shall be inserted and withdrawn slowly and at a uniform pace of approximately 100mm per second. Compaction shall be deemed to be completed when cement mortar appears in an annulus around the vibrator. Over vibration leading to segregation of the mix must be avoided. The internal vibrators shall be inserted at points judged by the area of mortar showing after compaction, with a certain allowance made for overlapping and they shall not be allowed to come into contact with the formwork or the reinforcement and shall be inserted at a distance of not less than 75mm from the formwork.

9.4.9.4 The pan vibrator shall be placed on the surface of the concrete, which shall have previously been tamped and leveled leaving an allowance in height for compaction until the cement mortar appears under the pan. The vibrator shall then be lifted and placed on the adjoining surface and this operation shall be repeated until the whole surface has been compacted. Alternatively, a vibrating screen spanning the full width of the surface may also be used.

9.4.9.5 Whenever vibration has to be applied externally, the design of formwork and disposition of vibration shall receive special consideration to ensure efficient compaction and to avoid surface blemishes. The vibration shall be such that there will be no excess water on the top surface on completion of compaction.

9.4.9.6 External vibrators shall be firmly secured to the formwork which must be sufficiently rigid to transmit the vibration and strong enough not to be damaged by it. Internal vibrators shall be capable of operating at not less than 10,000 cycles per minute and external vibrators at not less than 3,000 cycles per minute. Sufficient vibrators in serviceable condition shall be on Site so that spare equipment is always available in the event of breakdowns. Vibrators shall be operated by workmen skilled in their use.

9.4.9.7 Concrete shall not be subjected to any disturbance within 24 hours after compaction. No standing or flowing water shall be allowed to come into contact with exposed concrete surfaces during the first two (2) hours after placing and compaction of the concrete.

9.4.9.8 In the event where inadequate or improper compaction is suspected, the S.O. has the right to inspect and to carry out further tests. The tests may include non-destructive and destructive methods. All expenses incurred in carrying out such sampling, testing and remedial works shall be borne by the Contractor irrespective of whether the tests prove the structure to be sound or otherwise.

9.4.10 Curing and Protection

9.4.10.1 The Curing Class 3 in accordance with BS EN 13670 shall apply to all concrete works to avoid premature drying out or any shrinkage type of cracks and shall be cured for the full period of curing which shall not be less than five (5) days for F1, F2, F3 and F4 surfaces, and not less than three (3) days for F11, F12, F13, F14 and F15 surfaces.

9.4.10.2 Curing and protection shall start immediately after compaction of the concrete to protect it from:

(i) Impact damage such as shock, overloading or falling earth which may disrupt the concrete and its bonding interface with the reinforcements.

(ii) Premature drying out from direct sunlight and wind.

(iii) Leaching out by rain and flowing water.

(iv) High internal thermal gradients.

9.4.10.3 Normal curing and protection

Concrete, after it is placed and until the expiration of the curing duration, shall not be allowed to dry out. Provision shall be made for adequate protection against direct sunlight and wind to allow the process of curing to complete within the specified period.

Curing and protection shall be accomplished by covering the exposed concrete surface with an impermeable material such as polyethylene sheet, which should be well sealed and fastened and if required, this treatment can be continued efficiently throughout the whole period of curing.

When the concrete has attained its final set, one of the following curing methods shall be adopted:

(i) Water curing shall be accomplished by keeping the surface of the concrete continuously wet by ponding with water.

(ii) Curing may be accomplished by sealing in the water as specified above by covering with an approved waterproofed curing paper or plastic sheeting laid with airtight joints. It must be securely positioned to prevent displacement by wind and protected from tear or other damage.

The use of other methods of curing may be deemed necessary when the concrete is subjected to high internal thermal gradient, or with large exposed surface area. The Contractor shall submit a method statement to the approval of the S.O.

In the event where the Contractor fails to do proper curing, the S.O. has the right to inspect and to carry out further tests which may include destructive methods. All expenses incurred in carrying out such sampling, testing and remedial works shall be borne by the Contractor irrespective of whether the tests proved the structure to be sound or otherwise.

9.4.10.4 Accelerated curing

Elevated temperature curing may be used only with CEM I Cement and subjected to the approval of the S.O.

Curing can only be started 4 hours (hrs) after completion of the placing of concrete, unless the Contractor is able to prove that curing can start earlier by furnishing all the relevant supporting data to the S.O. The rise in temperature within any period of 30 minutes shall not exceed 10°C and maximum temperature attained shall not exceed 70°C unless it can be proven that any deviation from this provision shall not result in any detrimental effect to the concrete works. The rate of subsequent cooling shall not exceed the rate of heating. The total accelerated curing time shall not cause any detrimental effect to the concrete as approved by the S.O. The use of accelerated curing methods for concrete with CEM I in accordance to MS EN 197-1 or concrete containing other types of any admixture or any additional shall be to the approval of the S.O

9.5 CONSTRUCTION WITH CONCRETE

9.5.1 Geometry Control

9.5.1.1 Geometry Control

(i) The Contractor shall submit to the S.O. for approval a geometric control plan which shall indicate in detail how the survey is to be performed and Contractor's proposed actions to assure proper erection of the structure to the final grade shown in the drawings. The geometric control plan shall

provide for regular monitoring of the structure.

(ii) The Contractor shall check the elevations and alignment of the structure, at every stage of construction, and must maintain record of all these checks and of all adjustments and corrections made. All curves shall be performed at a time that will minimize the influence of temperature.

9.5.1.2 Deflection and Camber Data for Related Bridge Construction

The Contractor shall submit deflection and/ or camber data for each stage of construction as required, prior to constructing the structure to its final grade. The procedure used shall account for the effect of the time dependent prestress losses and creep which will occur during the construction phase.

The camber of the structure will be monitored by the Contractor at each stage of construction and corrective actions as approved by the S.O. shall be performed by the Contractor to assure proper erection of the structure to its final grade.

9.5.2 Dimensional Deviations

9.5.2.1 Deviations arise at three stages of construction, i.e. during initial setting out, during in-situ construction and during erection and assembly. It is important that effective control measures are adopted by the Contractor to ensure that deviations are kept within permissible limits.

9.5.2.2 The following permissible deviations in BS 5606 are given as tolerances values for specific dimensions.

(i) In-situ Concrete

Construction	Location	mm
Walls	Thickness	± 8
	Straightness in 5m	± 9
	Abrupt changes in continuous surface	± 4
	Verticality up to 2m	11
	Up to 3m	17
	Up to 7m	16
Columns	Size on plan up to 1m	± 8
	Verticality up to 3m	12
	Up to 7m	16
	Squareness	9
Beams	Depth	
	(Perimeter beams) up to 600mm	± 13

Construction	Location	mm
	Over 600mm	± 20
	(Internal beams) up to 600mm	± 12
	Over 600mm	± 16
	Level	
	Variation from target plane	± 22
	Straightness in 6m	±10
Structural slab	Level	
	Variation from target plane	± 25
	Structural soffit	± 19
Foundation	Dimensions on plan	± 50
Rigid Pavement	Level and dimensions on plan	± 25
Drainage / Culvert	Level and dimensions on plan	± 25

(ii) Precast Concrete Members

Dimension	Location	mm
Length	Up to 3m	± 6
	3m to 4.5m	± 9
	4.5m to 6m	± 12
	Additional deviation for every subsequent 6m	± 6
Cross section	Up to 500mm	± 6
	500mm to 750mm	± 9
	Additional deviation for every subsequent 250mm	± 3
Straightness	Up to 3m	6
	3m to 6m	9
	6m to 12m	12
	Additional deviation for every subsequent 6m	6

(iii) Control of Accuracy During Construction - Checking by the Contractor shall be systematic and to be undertaken at all stages of construction. Particular attention shall be given to monitoring of construction in areas where the work would seriously affect its appearance or performance.

(a) Dimensional control, i.e. the Contractor shall ensure to achieve dimensional control by:

- Checking that measured results are within the tolerances specified.
- Identifying sources of induced inaccuracy.
- Taking appropriate corrective action subject to the approval of the S.O.

(b) Recording, i.e. the dimensions measured shall be systematically recorded by the Contractor and agreed by the S.O. for the following:

- Checking compliance.
- Preparing as-built drawings showing the measurements achieved in practice and the deviations from the target size.
- Establishing characteristic accuracy.

(c) Corrective action, i.e. corrective action by the Contractor in respect of work that does not comply with the tolerances specified can include:

- Rectification as approved by the S.O. of works already done.
- Increasing Contractor's supervision at identified sources of inaccuracy.
- Adjustment of design and/or details as approved by the S.O.

(d) Preventive action, i.e. systematic checking by the Contractor as the work proceeds is essential to make sure that the monitoring and control systems are in place and adequate. Preventive action shall be ~~T~~aken, based on assessment of the results of the monitoring, particularly at the initial stages of each work. This will allow problems to be identified and addressed at an early stage, subject to the approval of the S.O.

9.5.3 Construction Joints

9.5.3.1 Construction joints shall be made at the location as shown on the Drawings and concreting work shall be carried out continuously up to the construction joints. If the position and detail of any construction joints is not described in the drawings, the Contractor shall propose and obtain the approval of the S.O. prior to commencement of concreting. The construction joints shall be made as few as possible with reasonable precautions against shrinkage. The joints shall be at right angles to the general direction of the member and shall take due account of shear and

other stresses.

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

9.5.3.3 At horizontal construction joints, gauge strips of about 25mm width shall be placed inside the forms along all exposed surfaces to ensure a straight joint on those surfaces. Where a kicker (that is a starter stub) is used for the construction of walls and columns, it shall be at least 75mm high, to be constructed monolithically with the base concrete.

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9.5.3.4 Where vertical construction joints are necessary in mass concrete structures, reinforcing bars shall be placed across the joints so as to make the structure monolithic, all to the approval of the S.O.

9.5.3.5 Prior to recommencement of concreting on a joint, action is to be taken so as to ensure that 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 coarse aggregate is exposed but not disturbed. Care shall be taken to avoid damaging the lines of the joint. Care shall also be taken so that the joint surface is clean and damp but not wet and the exposed adjoining surfaces shall be of consistent colour. Immediately before the fresh concrete is placed against the joint, fresh rich cement mortar (1:2) shall first be applied to the exposed surface.

9.5.3.6 Where the S.O. considers that special preparation is necessary, e.g. for an in-situ structural connection, preparation shall be carried out, preferably when the concrete has set but not hardened, by spraying with a fine spray of air and water or brushing with a stiff brush sufficiently to remove the outer mortar skin and expose the larger aggregates without disturbing them. Where this treatment is impracticable, sand blasting or a needle gun shall be used to remove the surface skin and laitance. Hardened surfaces shall be chipped manually or mechanically to free them from laitance and properly roughened to the extent that the coarse aggregates are being exposed.

9.5.4 Fixing Blocks, Brackets, Built In Bolts, Holes, Chases, etc

9.5.4.1 All fixing blocks, brackets, built in bolts, holes, chases, etc shall be accurately set out and formed and carefully sealed prior to the concrete being placed. It is the responsibility of the Contractor to obtain all such information for these items of work and to obtain the approval of the S.O. before incorporating such works prior to the concrete being placed.

9.5.4.2 Bolts and other inserts to be cast into the concrete shall be securely fixed to the formwork in such a way that they are not displaced during the concreting operations and that there is no

loss of materials from the wet concrete through holes in the formwork.

9.5.4.3 Unless otherwise shown on the Drawings or instructed by the S.O., reinforcement shall be locally moved so that the minimum specified cover is maintained at the locations of inserts, holes, chases, etc. In the event where the minimum cover cannot be maintained, the Contractor shall take all necessary precautions to protect the reinforcements against corrosion by applying approved coating materials to the reinforcements and the concrete cover.

9.5.4.4 Temporary plugs shall be removed and the threads of built in bolts shall be cleaned and greased before handing over any part of the Works.

9.5.5 Movement Joints

9.5.5.1 Movement joints, expansion joints, contraction joints or other permanent structure joints shall be provided in the required positions and constructed and sealed with waterproofing materials as detailed in the Drawings.

9.5.5.2 When forming movement joints, joint filler shall be fixed firmly to the first-placed concrete. If more than one strip is used within a joint, it is essential to butt the ends tightly or tape them together to prevent grout leakage and restricting the closure of the joint.

9.5.5.3 It is essential that the concrete on both sides of the joint, when placed, is thoroughly compacted to form a dense uniform mass. Where stop ends comprise more than one element, particular care is necessary to ensure that joints between elements are sufficiently tight to allow no grout loss through them during compaction of the concrete.

9.5.5.4 Where flexible water stops are used, they shall be fixed so as to ensure that they are not displaced from their intended position during compaction of the concrete and that the concrete surrounding them is fully compacted. The design of the water stop should be practical and take account of the problems often associated with integral water stop construction in difficult placing conditions.

9.5.5.5 Water stops laid horizontally and located within the concrete mass shall be avoided since they attract the greatest risk of local honeycombing.

9.5.5.6 Unless otherwise shown on the Drawings, all exposed expansion joints interface to structure components shall be covered with 0.7mm thick aluminium cover strips fixed with masonry nails at 300mm centers.

9.5.5.7 Polystyrene foam shall not be used as the filler material to form the joints between any elements of the structures unless approved and advised otherwise by the S.O.

9.5.6 Sealants and Special Materials

9.5.6.1 General

The installation method and the selection, mixing, application and curing of all joint waterproofing materials shall be in accordance with the manufacturer's recommendations. The Contractor may propose to use alternative joint waterproofing materials by submitting supporting technical information, test reports and samples of the proposed waterproofing materials to the S.O. for approval.

9.5.6.2 Waterproofing materials

All waterproofing materials used at public access areas shall be protected with non-shrink grout covering.

9.5.6.3 Water stops

(i) Water stops shall be as specified in the Drawings and shall be installed and butt jointed according to BS 8007 & BS EN 1992-3 and the manufacturer's recommendation.

(ii) Water stops shall be securely positioned in the formwork to prevent displacement during concreting.

9.5.6.4 Two-part polysulphide or two-part polyurethane sealant

Two-part polysulphide or two-part polyurethane sealant for external use shall comply with the following requirements:

(i) Conformance to BS 4254
(ii) Minimum joint movement capacity of ± 27.5% of joint width at 27.5ºC
(iii) Shore 'A' Hardness of 25 ± at 27.5ºC
(iv) Resistance to dilute acids, alkali and all kinds of fuel

9.5.6.5 Preformed flexible strip sealant

Preformed flexible strip sealant shall comply with the following requirements:

(i) Shall only be used in horizontal joints and be subjected to pressure throughout its length
(ii) Good adhesion
(iii) Water resistant
(iv) Non-staining

9.5.6.6 Bitumen/rubber cold applied membrane

Bitumen/rubber cold applied membrane shall comply with the following requirements:

(i) Minimum joint movement capacity of ±10% of joint width at 27.5ºC
(ii) 90% solid content
(iii) Resistant to dilute acid and alkali

9.5.6.7 Hot-poured rubber/bitumen sealing compound

Hot-poured rubber/bitumen sealing compound shall comply with BS 2499.

9.5.6.8 Bituminous sheeting

Bituminous sheeting with non-asbestos fiber shall comply with the following requirements:

(i) Resistant to lime water (no visual effect after two (2) weeks immersion)
(ii) Maximum water absorption of 10% of dry weight
(iii) Minimum tensile strength of 50 kg/cm²
(iv) Ozone and ultraviolet resistant

9.5.6.9 Polyurethane foam backing rods

Polyurethane foam backing rods used as sealant stops in panel joints shall have the following properties: -

(i) Minimum compressibility of 75% of original volume at 27.5°C
(ii) Excellent resilient properties
(iii) Density between 35 kg/cm³ and 45 kg/cm³
(iv) Total resistance to common acids, lubricants and detergents
(v) Total resistance to water infiltration by capillary action
(vi) Suitability for up to 70°C

9.6 STEEL REINFORCEMENT

9.6.1 General

The Works shall consist of furnishing and placing reinforcing steel in accordance with this specification and in conformity with the Drawings or as directed by the S.O.

9.6.2 Materials

9.6.2.1 Hot rolled mild steel and high yield bars shall comply with the requirements of MS 146. Cold worked steel bars shall comply with the requirements of BS 4461. Hard drawn mild steel wire shall comply with the requirements of MS 144.

9.6.2.2 Steel fabric reinforcement shall comply with the requirements of MS 145 and shall be delivered to the Site in flat sheets, unless specified otherwise.

9.6.2.3 Dowel bars shall be plain, round bars conforming to the requirements of MS146. They shall be free from burring or other deformations restricting slippage in the concrete. Dowel bar sleeves used for debonding shall be of approved synthetic material. The closed end of the sleeve shall be filled with 25mm thick compressible foam fillers and the sleeve shall fit tightly over the length of the bar to be debonded.

9.6.2.4 Before any reinforcement steel is brought to the site, the Contractor shall furnish the mill certificates of tests and these shall

be submitted for acceptance by the S.O. In addition, the Contractor shall on request, furnish the S.O. with a test sheet from approved laboratories for any batch of bars, giving the results of each of the mechanical tests and/ or chemical composition analysis required under the MS or any equivalent international standards approved by the S.O. The specified characteristic strength of steel reinforcement shall be as given in TABLE 9.17.

9.6.2.5 During the course of the work, any reinforcement found to be not in accordance with the MS or BS may be rejected by the S.O., notwithstanding any previous acceptance on the strength of the test certificates. The S.O. may call for additional tests to be carried out at the Contractor's expense on samples taken from the batch of the defective reinforcement. If the samples do not comply with the MS or BS, then the S.O. may reject the whole batch and instruct its removal from the Site.

9.6.2.6 Steel reinforcement shall be stored in clean and dry conditions. When placed in the work it shall be clean and free from loose rust, mill scale, oil, grease, paint, dirt or anything which may reduce its bond with concrete. If directed by the S.O., the steel bars shall be brushed or otherwise cleaned before use, at the Contractor's expense.

9.6.2.7 Binding wire shall be 1.6mm diameter soft annealed steel wire complying with the requirements of BS 1052.

9.6.3 Construction Methods

9.6.3.1 Cutting and bending of reinforcement

(i) Bars shall be of their correct lengths and bent to the exact shapes required before being fixed in the work.

(ii) Bars shall be cut and bent cold by the application of slow, steady pressure or in an approved bar-bending machine. Bending at temperatures in excess of 100ºC may only be carried out with the S.O.'s approval and under his supervision. Except where indicated otherwise in the Drawings, bars shall be bent and measured in accordance with BS 4449.

(iii) Cold worked and hot rolled bars shall not be straightened or bent again once having been bent. Where it is necessary to bend the free end of mild steel reinforcement already cast in the concrete, the internal radius of the bend shall not be less than twice the diameter of the bar.

(iv) Special care shall be taken so that the overall length of bars with multiple bends is accurate and that after bending and fixing in position the bars remain in place without wrap or twist.

9.6.3.2 Fixing of reinforcement

(i) The number, size, length, shape, type and position of all reinforcing bars, links, spacer bars and other parts of the steel reinforcement shall be in accordance with the Drawings.

(ii) Reinforcements shall be secured against displacement. Unless specified otherwise, the actual concrete cover shall be taken at the intersecting bars which shall be tied together with binding wire and the ends of the wire shall be turned into the main body of the concrete.

(iii) Reinforcement temporarily left projecting from the concrete at construction or other joints shall not be bent out of position during the periods in which concreting is suspended except with the approval of the S.O.

(iv) The Contractor shall take particular care so that the reinforcement is laid out correctly in every aspect and temporarily suspended by annealed wire or supported on concrete blocks or other approved spacers in the forms to prevent displacement during the placing and compacting of concrete. Links shall tightly embrace the longitudinal reinforcement to which they shall be securely wired or spot welded. The top reinforcement in slabs shall be rigidly supported on mild steel 'chairs' or equivalent, spaced in each direction to prevent sagging during concreting.

(v) No concrete shall be placed until the reinforcement has been inspected and approved by the S.O.

9.6.3.3 Splicing

Joints to reinforcement bars shall be in accordance by lapping of bars at positions shown on the Drawings. Where other types of joints are to be used, prior approval of the S.O shall be obtained and their use shall be strictly in accordance with manufacturer's recommendation, at the positions approved by the S.O. Splicing or lapping of bar shall not impair the flow of concrete surrounding the reinforcing bar including the cover in accordance to relevant standards.

9.6.3.4 Supporting and spacer blocks

(i) The size of supporting and spacer blocks required for ensuring that the reinforcement is correctly positioned shall be not more than 50mm x 50mm consistent with their purpose, of a shape approved by the S.O., and designed so that they will not overturn when the concrete is placed.

(ii) The nominal size of aggregates used shall be 10mm. The concrete spacers shall be of at least the same strength and material's source as the concrete to be poured. Wires cast in these blocks for the purpose of tying them to the reinforcement shall be free from any corrosion or any other elements that may affect the integrity of the reinforcing bar.

(iii) Spacers left in-situ shall not impair the desired appearance or durability of the structure by causing spalling, rust staining or allowing the passage of moisture.

(iv) Other types of spacers may be used only with the approval of the S.O.

9.6.3.5 Welding Reinforcement

(i) Welding workmanship, including welder qualification shall comply with Section 12 of this Specification.

(ii) Reinforcement in structures shall not be welded except where detailed in the Drawings or permitted in this Specification.

(iii) Welding shall be carried out in accordance with BS EN 1011 and BS EN 60974. Butt welds shall be of the double V type and two butt weld bond tests shall be carried out on a specimen prepared to represent each form of the butt welded joint used in welding the reinforcement an for each position of welding. The method of making butt weld tests shall be as laid down in BS EN 17637. The specimen shall pass the test to the approval of the S.O. before using the joint, which the specimen represents. Welded joints shall not be made at bends in reinforcement. Unless approved otherwise by the S.O., 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.

(iv) The S.O. shall be informed in advance when welding is to be carried out so that he may supervise and inspect the work. Welding shall not be performed in the field during rain or other adverse conditions.

9.7 FORMWORK AND SURFACE FINISH FOR STRUCTURE

9.7.1 Design and Construction

9.7.1.1 Description

(i) Formwork shall include all temporary or permanent forms required for forming the concrete, together with all temporary construction required for their support.

(ii) The Contractor is deemed to have made a study of the Drawings at tender stage and is aware of all areas of construction, requiring heavy and specially designed propping to provide the support and the necessary bracing for the stability of such propping.

(iii) The design and construction of formwork shall be carried out by a competent person. The Contractor shall identify all critical formwork design and submit the strength and deflection calculations and Drawings or the proposed design, certified by a Professional Engineer to the S.O. for prior approval. Notwithstanding any approval by the S.O. with respect to the design submitted by the Contractor, the responsibility for the adequacy and safety of the design shall remain with the Contractor. The Contractor shall also appoint a competent formwork coordinator whose duties would be similar to those outlined in BS 5975.

(iv) When the use of proprietary type of formwork is proposed

by the Contractor, the design shall be certified by a Professional Engineer.

(v) The formwork shall be sufficiently rigid and tight to prevent loss of grout or mortar from the concrete at all stages of construction and shall be appropriate for the methods of placing and compacting.

(vi) Formwork (including supports) shall be sufficiently rigid to maintain the forms in their correct position, shape, profile and dimensions. The supports shall be designed to withstand the worst combination of forces due to self weight, formwork weight, formwork forces, loads, together with all incidental dynamic effects caused by placing, vibrating and compacting the concrete. Guidance on these loadings is given in The Concrete Society Manual Formwork - Guide to good practice, and in CIRIA Report 108, Concrete Pressure in Formwork, and in BS 5975. Vertical propping to formwork shall be carried down sufficiently far to provide the necessary support without overstressing the completed concrete structure.

(vii) Metal ties may only be used with the prior approval of the S.O. Where metal ties are permitted the use of storey height steel soldiers shall be used to reduce the number of tie bolts required. Tie bolts with rubber or plastic cone against the form face are to be used to prevent unsightly grout loss. No metal part of any device for maintaining formwork in the correct location shall remain permanently within the specified concrete cover to the reinforcement. Except for ties used for anchoring void formers, all ties shall be at least 1.2m apart and through bolts will not be permitted on exposed form finished faces. All holes left by ties shall be made good within one day of the removal of the formwork using a mortar of the same strength as the cast concrete. Metal ties which allow for holes through the concrete being cast shall not be permitted to be used in concrete for water-retaining structure, roof slabs and walls.

(viii) 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, can be retained in position for such period as may be required by the condition of the maturing concrete or the Specification. If a 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. As far as practicable, formwork joints shall coincide with construction joints.

(ix) Slip type of formwork shall be used in accordance to the intended proprietary system. Contractor shall submit to the S.O. the method statement of the slip formwork to be used on site. The method statement shall include materials, method of erection, safety precaution, tolerances and the number of cycles usage.

9.7.1.2 Form lining

The type and treatment of any lining (plywood, metal, plastic, Controlled Permeability Formwork liner, etc) of the forms shall be appropriate to the concrete finish required.

The Controlled Permeability Formwork (CPF) liner shall have the following requirements:

(i) The requirement for a special finish shall be as for traditional formwork finishes except that the formwork shall be covered by a CPF liner.

(ii) CPF liner shall be used on all surfaces as detailed on the Drawings.

(iii) The CPF liner shall be a Water Bylaws Scheme – approved.

(iv) Product for use with potable water in accordance with BS 6920. The CPF liner shall have the following properties:

(a) Compression of less than 10% under a pressure 200 kPa.

(b) Maximum pore size of less than 0.030mm.

(c) Minimum water retention capacity of 0.35 l/m^2.

(d) Results in bleed water from the liner which is free from cement and fine aggregate particles.

(v) The concrete cast against the CPF liner shall have an even uniformly textured matt finish and shall be free of blowholes and other surface blemishes. The use of the CPF liner shall meet the following performance requirements which should be demonstrated by the supply of test certificate:

(a) The mean surface strength for the CPF cast face shall exceed that for the control face by at least 70%.

(b) The mean 10 minute ISAT result for the CPF cast face shall be not more than 15% of that for the control face.

(c) The mean depth of carbonation for the CPF cast face shall be not more than 15% of that for the control face.

(d) The mean concentration of chlorides at a depth of 11mm from the CPF cast face shall be not more than 15% of that for the control face.

(vi) The CPF liner shall be used once only. Release agents shall not be used with the liner and any residual release agent remaining on forms from previous use shall be removed.

(vii) To ensure conformity with the performance requirements, the CPF liner is to be used in accordance with the manufacturer's technical guidelines.

(viii) The CPF liner shall, unless otherwise directed, be left in place on the concrete after formwork removal for the curing period as specified by the S.O. It shall be kept wet and covered with plastic sheeting to promote efficient curing.

9.7.1.3 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 removing forms.

9.7.2 Surface Finishes for Concrete

9.7.2.1 Control of colour

When specified in the Drawings, the Contractor shall obtain each constituent material 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 fine aggregate, shall be maintained constant. The same type of plywood or timber shall be used in formwork throughout similar exposed areas.

9.7.2.2 Formed surfaces

Unless specified otherwise, all exposed concrete surfaces shall be of Class F12 and all unexposed surfaces shall be of Class F1. Other classes of finishes shall be used only where shown on the Drawings or as permitted by S.O. Formed concrete surfaces shall have one of the following classes of finish:

(i) Class F1

This finish shall be obtained by the use of properly designed forms of closely joined sawn timber or other approved material. Small blemishes caused by entrapped air or water may be expected but the surface shall be free from voids and honeycombing.

(ii) Class F2

This finish shall be obtained by the use of properly designed forms of closely jointed wrought boards, approved plywood or other approved material. Only very minor surface blemishes may occur, with no staining or discoloration.

(iii) Class F3

(a) This finish shall be obtained by the use of properly designed steel forms or plastic coated plywood or wrought boards or other approved material.

(b) The surface shall 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 to match the colour of the original concrete. Form release agents shall be carefully chosen to ensure that the surface shall not be stained or discolored. After the concrete has been properly cured, the surface shall be rubbed down where necessary, to produce a smooth and even surface.

(iv) Class F4

The requirements for Class F4 are as for Class F3 except that internal ties and embedded metal parts will be permitted. The ties shall be positioned only in rebates, or in other positions as shown on the Drawings or as agreed by the S.O.

(v) Class F11

The requirements for Class F11 surface finish are identical to those for Class F1 except that it shall be achieved using Controlled Permeability Formliners.

(vi) Class F12

The requirements for Class F12 surface finish are identical to those for Class F2 except that it shall be achieved using Controlled Permeability Formliners.

(vii) Class F13

The requirements for Class F13 surface finish are identical to those for Class F3 except that it shall be achieved using Controlled Permeability Formliners.

(viii) Class F14

The requirements for Class F14 surface finish are identical to those for Class F4 except that it shall be achieved using Controlled Permeability Formliners.

(ix) Class F15

The requirements for Class F15 are as for Class F4 except that plywood shutters lined with an approved patterned formliner shall be used to produce a patterned profile finish. Where possible, full height formliners shall be employed so that no horizontal joints in the liners are required. Tie holes shall be spaced so that they occur at overlap joints in the lining sheet.

9.7.2.3 Unformed surfaces

(i) Class U1

The concrete shall be uniformly leveled and screened to produce a plain, ridged or broom roughened surface. No further work shall be applied to the surface unless it is used as the first stage for a Class U2 or Class U3 finish.

(ii) Class U2

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

(iii) Class U3

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

(iv) Class U4

This finish is for surfaces that are to receive waterproofing systems. The concrete shall be levelled and floated to produce a uniform surface and immediately before the waterproofing operation this surface shall be water jetted or grit blasted to provide a lightly textured finish. The finished surface shall not deviate from the required profile by more than 5mm over a 3m gauge length or have any abrupt irregularities of more than 3mm.

9.7.2.4 Trial panels for exposed form finished surfaces:

(i) In order to ensure that the specified formed finishes can be obtained by the method of construction proposed and to provide a standard by which the finishes in the Works can be assessed trial panels shall be cast on Site. These panels shall be subjected to the S.O.'s approval before similar casting is permitted in the Works.

(ii) The trial panels shall employ the materials, plant and concrete mix proposed for the Works. They shall be at least a storey height and 1m wide. They shall be of similar thickness and similarly reinforced as the elements they represent and shall incorporate all features which contribute to the final appearance of the Works.

9.7.3 Preparation of Forms before Concreting

9.7.3.1 Before concreting, all forms shall be thoroughly cleaned out free from sawdust shavings, dust, mud or other debris. The inside surfaces of forms shall, unless otherwise approved by the S.O., be coated with an approved non-staining form oil or other

approved material to prevent adhesion of the concrete. Such release agents shall be applied strictly in accordance with the manufacturer's recommendation and shall not come into contact with the reinforcement or prestressing tendons and anchorages. For any exposed surface only one release agent shall be used throughout the entire area.

9.7.3.2 All formworks shall be inspected by the S.O. after preparation and immediately prior to depositing concrete and no concrete shall be deposited until approval of the formwork has been obtained. The Contractor shall ensure that all formworks are in proper and correct geometrical position and orientation, within acceptable tolerances and all necessary safety mitigation measures in place, all to the S.O.'s satisfaction and approval.

9.7.4 Removal of Forms

9.7.4.1 The Contractor shall inform the S.O. and obtain his approval before striking any formwork, but such approval shall not relieve the Contractor of his responsibilities for the safety of the work.

9.7.4.2 Formwork shall be removed without such shock or vibration as would damage the concrete. A period of time shall elapse between the placing of concrete and removal of the formwork for various parts of the structure so as to suit the requirements for its curing.

9.7.4.3 The minimum periods between concreting and the removal of forms are given in Table 9.18. The periods stated in this table are based on the use of CEM I. They may be changed with the approval of the S.O., if other types of cement as described in Subsection 9.2.1, admixtures as described in - Subsection 9.2.4 are used. The result of the compressive strength obtained from cube strength at 7 days as described in Subsection 9.3.4.2(ii) may also be used for early removal of forms provided the Contractor provides proof of calculation to the S.O. for approval.

9.7.4.4 For prestressed in-situ components, temporary supports shall not be removed until the components are stressed in accordance to the drawings and to the approval of the S.O. Safety mitigation must be taken to avoid any accidental falling or collapse of any objects from the structures.

9.7.4.5 Where it is intended that forms are to be reused, they shall be cleaned and made good to the approval of the S.O.

9.7.4.6 Following the removal of forms, no further loads shall be imposed upon the concrete until at least after the completion of the curing period or until such later time as in the opinion of the S.O. the concrete shall have attained sufficient strength to safely withstand such loads. Full design loads shall not be applied to any structure until all load bearing concrete is at least 28 days old.

9.7.5 Inspection and Making Good

9.7.5.1 The surface of the concrete shall be inspected for defects and for conformity to the surface finish specified and where appropriate, with approved sample finishes.

9.7.5.2 Subject to the strength and durability of the concrete being unimpaired, the making good of surface defects may be permitted but the level of acceptance shall be appropriate to the type and quality of the finish specified and to ensure satisfactory permanence and durability throughout the design life of the structures.

9.7.5.3 Any remedial treatment of surfaces shall be approved by the S.O. following inspection immediately after removing the formwork and shall be carried out without delay.

9.7.5.4 No forms of honeycombs, excessive pinholes, spalling, chipping, bulging or any surface defect shall presence on the concrete upon the removal of formworks and S.O may instruct the Contractor to rectify any defects that may occur.

9.7.5.5 Any prominent cold joints shall be brought to the attentions of S.O for further advice. Cold joints that affect the integrity of the structures or structures element shall be rectified to the satisfaction of S.O.

9.8 MASS AND LEAN CONCRETE

Mass and lean concrete shall consist of cement, fine aggregate and coarse aggregate in the nominal ratio by volume of 1:3:6 and 1:4:8 respectively. However where a denser and more workable concrete can be produced by a variation in the ratio of the fine aggregate to that of coarse aggregate, this ratio may be varied within the limits (1:1½) and (1:3), provided that the volumes of fine and coarse aggregate, each measured separately, shall nevertheless equal the sum of the volumes of fine and coarse aggregate appropriate to the nominal mix. The concrete shall be mixed as described for reinforced concrete.

9.9 STRUCTURE ACCURACY

After removal of formwork, the Contractor shall take measurements as directed by the S.O. to check the deviation of the reinforced concrete works from specified dimensions as shown on the Drawings. All measurements shall be recorded and submitted to the S.O. Any deviation in structure accuracy shall comply with BS EN 13670 and Subsection 5 of this Specification. All levels, dimensions and measurements shall be captured in the as-built drawings.

9.10 APPARATUS

The Contractor shall provide the following apparatus for use on the Site at all times:

(i) Concrete slump test apparatus or flow test apparatus complying with MS 26. One set of the apparatus shall be provided for each concreting location.

(ii) At least 12 numbers of steel or cast iron moulds for casting 150mm concrete test cubes and six (6) numbers of 100mm mortar or grout test cube moulds complete with tamping bars and base plates in accordance with MS 26. A minimum number shall be provided such that no stripping of

cubes is required prior to 24 hours setting and hardening period.

(iii) Three (3) measuring cylinders of 250ml capacity, graduated to measure to the nearest 2.0ml for determination of silt content (field setting method).

(iv) An approved apparatus for measuring moisture content in fine aggregate.

(v) One (1) electronic calculator with statistical functions.

(vi) One (1) 300mm steel rule.

(vii) One (1) set of sieves in compliance with BS 410.

(viii) Scale or balance 25kg maximum capacity and weights.

(ix) Trowel, shovel, spanner and other tools.

9.11 PRECAST CONCRETE CONSTRUCTION

9.11.1 Manufacture Off-Site

(i) Before commencing concreting the Contractor shall prepare a trial panel of size and surface finish acceptable to the S.O. The panel shall be filled with the proposed concrete, mixed and compacted by the method to be used in the works. As soon as practicable, the forms shall be removed to enable the S.O. to check the surface finish and compaction achieved. Once a trial panel is accepted by the S.O., it shall be displayed on site and will form the basis of accepting or rejecting concrete finish of the same specification.

(ii) After the method of manufacture has been approved, no changes shall be made without the approval of the S.O.

(iii) Precast structure element e.g beams, deck segments, cross head, pier, precast parapets, drainage panel, retaining wall etc. shall, as soon as the formwork is removed, be kept continuously damped by a double layer of gunny bags with excess water for a period of not less than 14 days. After the period of water curing, the segments shall be membrane cured for a period of seven (7) days. During both periods the segments shall be protected from wind, rain and direct sunlight.

(iv) Curing compounds shall not be applied to surfaces to which further concrete or a surface finish is subsequently to be bonded.

(v) Any remedial treatment of surfaces shall be agreed with the S.O. following inspection immediately after removing of formwork and shall be carried out without delay.

(vi) The Contractor shall inform the S.O. in advance of the date of commencement of manufacture and casting of each type of precast concrete component.

(vii) When the S.O. requires tests to be carried out, none of the precast concrete components to which the tests relate shall be dispatched to the site until the tests have been completed and the results approved

by the S.O.

(viii) All precast concrete components shall be indelibly marked to show the identification marking as specified in the Drawings, the production batch on which they were manufactured and the date on which the concrete was casted. If the components are symmetrical, the face that will be uppermost when the member is in its correct position in the work shall be clearly identified.

9.11.2 Storage

(i) When the precast concrete components are stored, they shall be firmly supported only at the points specified in the Drawings. No accumulation of trapped water and deleterious matter shall be allowed in the components. Care shall be taken to avoid rust staining and efflorescence.

(ii) The precast concrete components shall be stacked in such a manner that their removal in correct order of age is facilitated.

9.11.3 Handling And Transport

The precast concrete components shall be lifted only at points specified in the Drawings or otherwise approved by the S.O. 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 components to be handled shall be to the approval of the S.O.

9.11.4 Assembly and Erection

(i) The method of assembly and erection specified in the Drawings shall be strictly adhered to on site.

(ii) Immediately after a unit of precast concrete component is placed in position, and before the lifting equipment is removed, temporary supports or connections between components as necessary, shall be provided. The final structural connections shall be completed as soon as is practicable.

9.11.5 Forming Structural Connections

(i) For structural purposes, cement mortar shall compose of one (1) part of cement to one (1) part of sand (1:1), mixed with water so that the free water: cement ratio does not exceed 0.4 by weight and cement grout shall have a water: cement ratio between 0.4 and 0.6, or such other proportions as shall be directed by the S.O.

(ii) No structural connections shall be made until approval has been given by the S.O.

(iii) Unless otherwise approved by the S.O., the composition and the free 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.

(iv) Leveling devices shall be released or removed only with the approval of the S.O.

(v) Non load bearing joints between precast concrete components and adjoining structures shall be filled with appropriate grout and/or mortar protected by proprietary sealants and backing rod. They shall be waterproofed.

(vi) Load bearing joints and connection shall be grouted, mortar packed or concreted. The respective mix design shall be free of lime and chloride. They shall be durable, waterproof, non-shrink and possess strength higher than that of precast concrete. Curing for at least three (3) days shall be provided. Designed mixes shall be submitted to the S.O. for approval.

(vii) The method of sampling and testing of grout and mortar shall be carried out according to MS 26. The compressive strength shall be determined by crushing test on 100mm cubes. For each casting day and for each grade of grout and mortar, three samples shall be taken from three (3) separate batches. Two (2) cubes shall be cast from each sample for testing at seven (7) and 28 days. The appropriate strength requirement shall be considered to be satisfied if the average strength is greater than the specified characteristic strength.

(viii) Connection by using the shear key shall in accordance to approved drawings or shop drawings and relevant design standards. The edge surface of shear key shall free from any dirt or debris prior to the jointing process. Cracks or cold joints must be inspected by S.O. to the acceptable limits that do not jeopardize the integrity of the structures or structures elements. Any unacceptable cracks or cold joints must be rectified immediately to the satisfaction of S.O.

9.11.6 Protection

At all stages of construction, precast concrete components and other concrete associated therewith shall be properly protected to prevent damage to permanently exposed surfaces, especially arises and other decorative features.

9.12 OTHER CONCRETE WORKS

9.12.1 Abutments, Piers, Pile Caps and Foundation

(i) All reinforced concrete abutments, piers and pile caps shall be constructed according to the Drawings and to the exact depths required. The Contractor shall supply, maintain and remove any necessary planking and strutting, sheet piling and coffer dams, and shall, by pumping or other approved means, keep the excavation free from water. Alternatively, the S.O. may approve the use of self-compacting concrete in accordance to Subsection 9.2 of this specification.

(ii) Before commencing to construct the abutments, piers and pile caps, the Contractor shall check and verify the eccentricities and the cut-off levels of all piling works in the ground are as provided in the Drawings, and shall notify the S.O. in the event of any discrepancy.

(iii) The bottom of excavation shall be cleaned or, if in loose or disturbed ground, well rammed, and the hole shall be approved before it is

covered with a blinding layer of lean concrete not less than 50mm thick. The required cover of concrete under the reinforcement shall be entirely above the blinding layer.

(iv) The Contractor shall straighten the steel reinforcement projecting above the piles for anchoring pile caps, carry out excavation, and erect formwork and temporary timbering for the construction of pile caps.

(v) Reinforced concrete pile cap shall be continuously casted. The Contractor shall comply with Subsection 9.4.8 and provide calculations of the estimated initial and peak temperature of concrete. The S.O. may approve the adoption of concrete cube compressive strengths up to the 56 days to assess compliance of the specified characteristic compressive strength when high blended slag, pulverized-fuel ash cement or high performance concrete type is used to reduce heat in large concrete pours. However, the requirements of structural loading at each construction stage must be complied. A proper curing in accordance to Subsection 9.4.10 of this specification or as requested further by S.O with additional method must be done when dealt with massive volume of concrete.

(vi) All external wall surfaces of abutments in contact with soil shall be waterproofed with three (3) coats of bitumen solution complying with BS 3416 or any other type of waterproofing material as approved by the S.O. The concrete surface shall be thoroughly cleaned and dried before application of the waterproofing material.

(vii) The Contractor shall ensure the stability of the abutment, pier or wall during construction where the height of the structures or element(s) of the structure may cause stability issues. S.O. may require contractor to perform stability check during construction. Prop or other means may be used with the approval of S.O.

9.12.2 Deck Slab

9.12.2.1 Placement of fresh concrete is preferred at late evening or early night. Concrete for bridge decks shall not be placed if the evaporation rate exceeds 0.75kg⁄m^2⁄h or at wind speed exceeding 30 km/h. If placement at the time is imperative, chilled water may be used for mixing concrete, forms and bars cooled before placement to avoid significant increase in concrete temperature and wind speed lowered by shielding.

9.12.2.2 All pipes and fittings encased in the deck concrete shall be provided with sleeves to the approval of the S.O. and shall be built in-situ. No holes shall be left for later incorporation of fittings and no subsequent hacking of deck slab shall be made.

The appropriate deck construction sequence shall be observed as follows:

(i) place complete deck at one time whenever feasible within the limitation of Subsection 9.4.7.

(ii) If multiple placement must be made on simple spans, place each span in one placement.

(iii) If the bridge comprises of simple spans, but cannot be placed in a single placement, then divide the deck longitudinally and make two placements.

(iv) If bridge is of simple spans, and single placement cannot be made over the full span length, then place the center of span segment first and ensure this placement to be as large as possible.

(v) If multiple placements must be made and the bridge is of continuous spans, then place concrete in the center of the sagging moment regions first, and then observe a 72 hour delay between placements.

9.12.2.3 After initial set, the upper surface of concrete decks shall be trowelled smooth with a steel float to true level and even surface. Care shall be taken to ensure that the steel reinforcement is not displaced or lowered during trowelling. In order to prevent cracking of the trowelled surface on drying out, the S.O. may direct a covering to be suspended above the concrete surface to prevent loss of water after compaction.

9.12.2.4 Wet curing should be implemented immediately at areas where concrete has set to reduce the temperature of the concrete surface. Curing shall be by continuously damped double layer of gunny bags or other approved methods with excess water for not less than 7 days.

9.12.2.5 Half-width Construction

Traffic can be maintained on part of the bridge while the other part is under construction if well proportioned, well compacted low slump concrete is approved by the S.O. in accordance to Subsection 9.3. The effect of adjacent traffic may be minimized further by imposing speed limitations on the bridge, as well as restrictions of heavy vehicles including construction vehicles in lanes adjacent to the area under construction.

9.12.3 Shop Drawing

9.12.3.1 The Contractor shall submit detailed shop drawings, including for expansion joints, bearings, forms and form travelers for approval. The shop drawings shall include, but not necessarily limited to, the following information;

(i) Fully and accurately dimensioned views showing the geometry of the items including all projections, recesses, notches, openings, block-outs and other pertinent details.

(ii) Details of steel reinforcement shall be clearly shown as to the size, spacing and location including any special reinforcing required but not shown on the drawings. The post-tensioning layout shall govern over the layout of steel reinforcement and shall be adjusted to clear tendons.

(iii) Size and type of ducts for all post-tensioning tendons and their horizontal and vertical profiles shall be clearly detailed. Duct supports, grout tubes, vents and drains shall be

shown including size, type and locations.

(iv) Details and locations of all other items to be embedded such as inserts, lifting devices and post-tensioning hardware shall be shown.

(v) Prestressing details shall include sizes and properties of tendons, anchorages, plates, assemblies and stressing equipment, as well as details of the stressing procedure and stressing sequence, details and locations of all couplers, and additional reinforcement necessary to resist anchor block stresses.

(vi) A table shall be provided showing elevations and geometry to be used in positioning the forms for the next segment to be casted.

(vii) Graphs, charts or tables showing the theoretical location of each item, as erected or placed, shall be furnished to the S.O. for use in checking the erection of segments. Detailed procedures for making geometry corrections shall be described.

(viii) Details of tie down tendons, temporary and permanent bearing assemblies as required.

9.12.4 Drips

Unless otherwise directed by the S.O., a 15mm wide drip shall be formed along edges of soffits to concrete deck slabs, undersides of parapets, cantilevered beams and other parts of bridge where rain water is likely to adhere in drops.

9.12.5 Openings

Where shown in the Drawings, all cast-in-situ reinforced concrete openings shall be constructed without bolt holes made through the walls or slabs. If such holes are unavoidable then they shall be completely grouted with shrinkage compensating cement mortar and as specified in Subsection 9.11.5 or sealed and waterproofed by other means to prevent leakage, to the approval of the S.O.

9.13 PROTECTIVE COATING SYSTEM

9.13.1 General

Protective coating system shall be applied to the structures or element(s) of the structures as mentioned in the drawings, bill of quantities or as directed by S.O. The protective coating is classified for two purposes namely:

a) Protective coating for durability and/or protection against abrasive and harsh environmental influenced attack to the concrete structures.

b) Protective coating for aesthetical or decorative purpose.

The selection of the type and the intention of the coatings shall be based on

the drawings, bill of quantities or as directed by S.O.

9.13.2 Surface Preparation

9.13.2.1 Prior to application, all surfaces must be dry and free from oil, grease, loose particles, decayed matter, moss or algal growth and general curing compounds. All such contaminations and laitance must be removed by the use of grit blasting, high pressure water jetting or equivalent mechanical means.

9.13.2.2 Before proceeding to apply the protective coatings, all surfaces which are not to be coated but which may be affected by the application of the coating, shall be fully masked and, in particular, flora/fauna shall be protected.

9.13.2.3 Blow holes and areas of pitting shall be made good with a one part modified cementitious material, and allowed to cure in accordance with the manufacturer's recommendations. The application shall be in accordance with the manufacturer's recommendations, particularly with respect to the maximum application thickness of 3mm.

9.13.2.4 Fresh concrete shall be at least 28 days old before receiving the surface preparation.

9.13.3 Coating Materials to (Superstructures): Deck Soffit, Beam/ Girder, R.C. Diaphragms, Capping Beams, Parapet, etc. (for durability protection)

9.13.3.1 The protective coating shall consist of a dual protective system formed by two coats of silane-siloxane based primer or equivalent and two coats of solvent based methacrylate pigmented or equivalent as the top coat.

9.13.3.2 The Contractor is required to adhere strictly to the manufacturer's recommendations regarding the use, storage, application and safety rules in respect of the approved materials.

9.13.3.3 The coating shall be applied by spray, roller or brush to achieve a finish acceptable to the S.O. In all operations of storage, mixing and application, the Contractor is to comply with the Health and Safety recommendations of the manufacturer and governing authorities.

9.13.3.4 Where required by the S.O, trial areas not exposed in the finished work shall first be treated using the selected materials. These trial areas shall be noted on the Drawings and shall be carried out using the type of materials, mixing procedures and applications that will be used in the Contract and shall be approved by the S.O. before Contractor commences with the general work.

9.13.3.5 The material employed for the coating shall comply with the following requirements or equivalent;

Description	Requirements
Wet film thickness	150 microns per coat
Dry film thickness	75 microns per coat
Reduction in water absorption (ASTM C642)	80% minimum @ 28 days
Carbon Dioxide diffusion resistance (Research Laboratories Taywood Engineering Ltd)	A minimum equivalent to 250 metres of air
Water vapour transmission (Research Laboratories Taywood Engineering Ltd)	Shall be more than 13g/m^2/day
Reduction in chloride ion penetration	90% minimum @ 28 days
Freeze/Thaw salt scaling (ASTM C672)	Unaffected by 50 exposure cycles

Notes: Where test methods are not specified, the procedure for establishing compliance with the above criteria shall be agreed with the S.O.

9.13.3.6 Primer shall be applied for at least two flood coats using a low pressure knapsack sprayer. Application shall be repeated until correct coverage is achieved. On very porous surfaces, application shall be repeated until surface is completely saturated. All treated surfaces shall be allowed to dry for at least two (2) hours.

9.13.3.7 When the surface is visibly dry, the Topcoat shall be applied. If the surface is porous, it shall be stabilized by a coat of the appropriate grade diluted with 5% of an approved solvent.

9.13.3.8 A two coat, pinhole free application of the Topcoat shall be applied. Four hours drying between coats shall be allowed.

9.13.3.9 The coating shall have the properties of resistance to weather, ultra-violate light, high temperature and humidity. All layers of coatings shall have the effective service life with warranty of minimum of 20 years.

9.13.4 Coating Materials to All Abutments and Piers (for durability protection)

9.13.4.1 The solvent free based epoxy resin coating shall comply with the following properties;

Description	Requirements
Specify gravity	1.67 (approx.)
Volume Solids	100%
Recommended thickness per coat	dry film thickness (dft) 200 μm. wet film thickness 200 mm.
Theoretical coverage	5m^2/litre (3m^2/kg) for a dft of 200 μm.

Description	Requirements	
Practical coverage	Theoretical coverage is quoted for guidance. Practical coverage may be lower, depending on substrate and application method.	
Number of coats	2	
Pot Life	**at 20 °C** 30-40 mins	**at 35 °C** 12-20 mins
Drying Time Touch dry Fully dry Recoatable	**at 20 °C** 6 hours 7 days 6-24 hours	**at 35 °C** 3 hours 7 days 3-12 hours
Application temperature	Minimum 5 °C	
Resistance of film	The fully cured coat is resistant to :- - Distilled Water - Sea Water - Chlorinated Water - Sodium - Brine 20% - Hydroxide 10% - Marsh Water - Petrol * - Sewage Water - Gas Oil * - Kerosene (*)May cause surface discoloration	

9.13.4.2 The coating shall have the properties of resistance to weather, ultra-violate light, high temperature and humidity. All layers of coatings shall have the effective service life with warranty of minimum of 20 years.

9.13.4.3 Application - Brush shall be used and the first coat must be firmly applied and well-scrubbed into the surface and a continuous coating of uniform thickness shall be ensured. The second coat shall be applied 6 to 24 hours later.

9.13.5 Protective coating for aesthetical or decorative purpose

The protective coating shall consist of a inorganic dual protective system formed by two coats of Acrylic binder or equivalent and two coats of solvent based methacrylate pigmented or equivalent as the top coat and shall be approved by S.O. prior to its application. The surface preparation prior to the coating application shall be in accordance to Subsection 9.13.3 of this specification.

The coating shall have the properties of resistance to weather, ultra-violate light, high temperature and humidity. All layers of coatings shall have the effective service life with warranty of minimum of 10 years. The materials or substrate materials of the coating must not have any detrimental effect or that

may cause chemical reaction to the concrete either internally or externally.

The coating shall be mocked up and approved by S.O. to ascertain its appearance, colour, finishes, etc. The mocked up sample shapes and sizes shall be as instructed by the S.O.

The Contractor is required to adhere strictly to the manufacturer's recommendations regarding the use, storage, application and safety rules in respect of the approved materials.

9.14 HIGH PERFORMANCE (HPC) AND ULTRA-HIGH PERFORMANCE CONCRETE (UHPC)

9.14.1 General Requirements

Designed concrete that has the intended use for its specific strength, durability and high workability can be regarded as High Performance Concrete (HPC). Where compressive strength class of the concrete exceeds C100/115, the concrete can be classified as High Performance Concrete in view of its strength capacity. The use of concrete at compressive strength class of C60/75 or above for the purpose of durability function and specific workability shall also be regarded as High Performance Concrete. Where the characteristic compressive cylinder strength of the concrete attains well beyond 140 N/mm^2 or cube strength of 155 N/mm^2 tested at the age of 28 days, the concrete shall be classified as Ultra-High Performance Concrete (UHPC). Detailed definitions of UHPC shall be referred to standard NF P 18-470 or any established standards to the approval of S.O. when dealt with the UHPC type of concrete.

The concrete mix shall be designed concrete to MS EN 206 unless otherwise stated in the Drawings.

Initial guide for minimum cement content and maximum free water cement ratio for HPC can be based on TABLES 9.6 and TABLE 9.6A. Structures subjected to abrasive and harsh environment, close proximity to the shoreline or open to sea-tidal may have the modification done on the water/cement ratio and cement content in order to provide adequate durability and required permeability.

Unless it can be proven otherwise, high early strength of cement or cement that is deemed to accelerate the rise and rate of hydration shall not be used as the main constituent of HPC as it may cause formation of internal cracks or micro-cracks to the concrete.

When the compressive and/or tensile strength of the concrete is of prime motive, in the case of UHPC, the maximum water cement or binder w/c ratio can be as minimum as 0.18 and the minimum cement content shall be 750 kg/m^3 subjected to S.O approval. The range of water cement ratio and cement content shall be such that the workability and consistency of the concrete is not compromised. Modification to the cement content can be made subject to the approval of S.O. Contractor, fabricators or specialist contractor must provide evidences that the concrete possesses adequate ductility when low water-cement ratio is used in the mix. The S.O. may request the Contractor,

fabricator or specialist contractor to undertake and carry out ductility test to the concrete batch such as three-point bending test or its equivalent. Testing methods shall be based on the current established method as approved by S.O.

The designation of concrete grade of HPC shall have similar notation in accordance to clause Subsection 9.2.9.1 of this specification. Where the flexural strength property is of importance, additional notation that reflects the value of flexural or direct tensile strength can be printed out and shown in the Drawings or/and in the Tender Documents. The Contractor must bring to the attention of the S.O. the value of these strengths for his information and comprehension.

The workability of the fresh concrete shall be judged by its suitability for the condition of handling and placing so that after compaction, it surrounds all reinforcement, tendons and ducts and completely fills the formwork. In general, the workability of HPC and UHPC shall be in accordance to Subsection 9.2.9.3 of this specification. The Contractor may propose higher workability and subject to S.O approval in the case of highly cohesive mixes without reducing the strength and durability requirements. The S.O may reject the product that shows signs of honeycombing due to poor workability.

9.14.2 Material

9.14.2.1 Cement

The cement to be used throughout the Works shall be CEM 1 type of cement to comply with MS EN 197-1 and obtained from an approved manufacturer. Blended cement shall not be used unless it can be prove that it shall not cause any adverse effects to the mix or as directed by S.O. Any specific use of other cement types for the positive improvement, such as to the fluidity, heat generation, hydration, creep and/or shrinkage and chemical resistance or other advantages shall be brought to the attention of S.O for approval. Certificate of Test and Transportation and Storage of Cement material shall comply to Subsection 9.2.1 of this specification.

9.14.2.2 Aggregates

In general, for HPC and UHPC, the aggregate compliance shall be referred to Subsection 9.2.2 of this specification.

In the case of UHPC type of concrete, the fine aggregate or fine sand shall be washed, sieved and kiln dry with maximum granular size not larger than 1.5 mm and complies with the requirement of ASTM C33. The grading of fine aggregates shall be analyzed as described in MS 30 and shall be within the limits specified in Table 9.3B.

9.14.2.3 Water

Water compliance shall be referred to Subsection 9.2.3 of this specification.

9.14.2.4 Admixture

Admixture compliance shall be referred to Subsection 9.2.4 of this specification.

9.14.2.4 Additions and Supplementary Cementitious Material (SCM)

In general, all additions and Supplementary Cementitious Material added to HPC and UHPC shall be in accordance to Subsection 9.2.5 of this specification except wherever mentioned herewith.

Additions used for HPC or UHPC which are not covered in the clause 9.2.5 or exceed the stipulated limits shall be brought to the attention and approval of S.O.

In the case of production of UHPC, the addition of silica fume content shall be not less than 10% and not more than 25% of the cement replacement by weight. Under normal circumstances other types of additive or supplementary cementitious materials are not preferred in the production of HPC unless it can be proven through conformance test that the physical properties of the materials are either equivalent or exceed the value stated in this specification with respect to strength, durability and efficiency.

9.14.2.5 Fibres

HPC and UHPC concrete may have fibres in the form of straight or deformed piece of cold-drawn steel wire or polymer fibres homogeneously mixed with the concrete to improve the toughness, impact resistance and enhancing the tensile capacity of the concrete. Steel fibre materials and properties requirement shall comply with BS EN 14889-1 while polymer fibres shall comply with BS EN 14889-2.

Minimum tensile strength for steel fibre shall be 2300 N/mm^2 which is manufactured from high carbon steel wire and complies with the requirement of DIN 17223 or equivalent.

The Contractor shall provide in detail the following items for S.O. approval prior to the concrete mix production:

a) Method of statement for mixing the fibres
b) Storage method of the fibres
c) Test certificates
d) Calculation of fibres dosage or ratio required in the concrete mix.

Where the fibres content of fresh concrete is to be determined, it shall be taken either as recorded on the print-out of the batch recorder or where recording equipment is not used, from the production record in connection with the batching instruction.

9.14.3 Concrete Conformance and Identity Testing

9.14.3.1 General

In general, concrete conformance and identity testing for HPC and UHPC shall be in accordance to Subsection 9.3 of this specification unless stated otherwise herein. The Contractor shall be responsible for the evaluation of conformance that consists of the initial test and production control including conformance control in accordance to Subsection 9.3.1.1 and 9.3.2 of this specification.

Sampling and testing of HPC concrete shall be in accordance to Subsection 9.3.2.1 of this specification. In case where there is evidence that shows the required strength develops at later than 28 days, more number of specimen can be proposed by the Contractor with the agreement of S.O. This is for the purpose of specifying more tests to be done at later than 28 days. The compliance of strength however is subjected to the discretion and acceptance by the S.O.

9.14.3.2 Flexural strength

Flexural strength test shall be carried out to determine the maximum tensile stress under bending load tested on a beam specimen. Where flexural strength is to be determined, it shall be measured in accordance with EN 12390-5. Tests can be conducted at similar stage and age of concrete as for compressive strength test i.e. 7 days, 14 days or 28 days. The S.O. may request the method and procedural statement for approval prior to the test.

In case of UHPC type of concrete, minimum of 6 units of beam specimens shall be casted as the testing specimens. The flexural strength (or modulus of rupture) shall be measured by testing on beam specimen with nominal size of 100mm x 100mm x 500mm specified in BS EN 12390-5, 2009. Tests shall be carried out in an engineering laboratory or manufacturer plant approved by the S.O. The flexural strength at 7 days shall be tested on two beam specimens from each sample batch. The flexural strength shall not fall below 12 N/mm2. The remaining four prisms from the same sample batch shall be tested for the 28 days flexural strength.

For compliance purpose~~s~~ of the specified flexural strength, both of the following conditions shall be satisfied:

a) The average flexural strength shall not fall below 15 N/mm^2.
b) The characteristic flexural strength tested at 28 days shall not fall below 20 N/mm^2.

9.14.3.3 Tensile splitting strength

Where the tensile splitting strength of UHPC is to be determined, it shall be measured in accordance with EN 12390-6. Unless specified otherwise, the tensile splitting strength is determined on specimens tested at 7 days and 28 days. The S.O may request the method and procedural statement for approval prior to the test.

The characteristic tensile splitting strength of the concrete shall be equal to or greater than the specified characteristic tensile splitting strength.

9.14.3.4 Permeability Test

All HPC and UHPC shall be tested with permeability test. The permeability test shall be in accordance to Subsection 9.3.2.2 of this specification or ASTM C1202-2005. The S.O. may request additional tests based on established standards to ensure that the durability of the concrete cast on-site and during service is not jeopardized. In case of the concrete sample that consists of steel fibres that may be affected by the presence of chloride, other approved test based on established standards to assess the permeability of the concrete may be proposed by the contractor. Such test(s) must be brought to the attention of S.O. complete with procedural method of statements at least 2 months earlier prior to the test date for the approval. The test must ascertain that the performance of the concrete shall not be exposed to the durability issues which may cause the structure or element(s) of the structure to be deteriorated within the designed serviceability period.

9.14.4 Production

9.14.4.1 General

The production of HPC and UHPC shall be in accordance to Subsection 9.4 of this specification unless stated otherwise herein.

No site mix of concretes is allowed for any type of HPC and UHPC at any time during the project duration, or at any stage of construction of any structure.

9.14.4.2 Batching and Mixing

The Contractor shall provide the batching and mixing method of statement for HPC and UHPC and shall not commence any works of batching and mixing without the approval of S.O.

The quantities of cement, silica fume or any other additive or addition and sand shall be measured by weight. A separate weighing machine shall be provided for weighing the cement. The quantity of water shall be measured by weight. Any solid admixtures to be added shall be measured by weight; liquid or paste admixtures shall be measured by volume or weight.

If dry sand is used in the production of HPC or UHPC, the batch weight of the fine aggregate need not to be adjusted to allow for the moisture content. All measuring equipment shall be calibrated on site or their calibration status verified by certificates from accredited laboratories.

Mixers that have been out of use for more than 30 minutes shall be thoroughly cleaned before any fresh blended cement or concrete is mixed. The mixer shall be thoroughly cleaned before

changing from one type of cement to another.

The water content of each batch of concrete may be adjusted so as to produce concrete of the workability required. However, care shall be taken to ensure the free water/ binder ratio is maintained. The total amount of water added to the mix shall be recorded. The initial process shall be witnessed by the S.O. representative prior to further production of concrete.

9.14.4.3 Placing

Placing of HPC and UHPC shall be in accordance to Subsection 9.4.7 of this specification and placement temperature shall be in accordance to Subsection 9.4.8 of this specification.

In fresh state, UHPC with or without fibres shall remain homogeneous and there shall be no segregation of fibres or a solid fraction of the constituents taking account of the means of placing.

Any modification from the stipulated clauses shall be brought to the attention and approval of S.O. including the plan to measure development and control of temperature. The Contractor must exercise due care and control of the final concrete product when placing on the specified whole or part of structure as not to cause any detrimental effect to the concrete hardening process. Any method of placing shall be based on the established standards and must be approved by the S.O.

9.14.4.4 Compaction

Compaction of HPC and UHPC shall be in accordance to Subsection 9.4.9 of this specification.

For fiber reinforced concrete, great care must be exercised during compaction to avoid any fiber sedimentation or segregation from occurring at whole or part of the concrete member. The S.O may request for the plan and method of statement of compaction for this type of concrete and may reject whole or part of structure or concrete member which has shown signs of fiber sedimentations or segregations.

9.14.4.5 Curing and Protection

In general, curing and protection of HPC and UHPC shall be in accordance to Subsection 9.4.10 of this specification.

Where further heat or steam curing of concrete is required after the concrete has set for the purpose to improve strength and durability great care must be taken not to cause any adverse effect to the concrete member due to the temperature difference between the concrete member and the surrounding temperature. The Contractor must submit the plan and method of curing to the S.O. for approval at least 2 weeks before the concreting takes place.

TABLE 9.1: COMPOSITION OF COMMON CEMENTS

Main	Notation of 27 products (types of common cement)		Composition [percentage by mass [a)]]										
			Main constituents										Minor additional constituents
			Clinker	Blast-furnace slag	Silica fume	Pozzolanic		Fly ash		Burnt shale	Limestone		
						Natural	Natural calcine	siliceous	calcareous				
			K	S	D[b]	P	Q	V	W	T	L	LL	
CEM I	Portland cement	CEM I	95 - 100	-	-	-	-	-	-	-	-	-	0 - 5
CEM II	Portland-slag cement	CEM II /A-S	80 - 94	6 - 20	-	-	-	-	-	-	-	-	0 - 5
		CEM II /B-S	65 - 79	21 - 35	-	-	-	-	-	-	-	-	0 - 5
	Portland-silica fume cement	CEM II /A-D	90 - 94	-	6 - 10	-	-	-	-	-	-	-	0 - 5
	Portland types - pozzolana cement	CEM II /A-P	80 - 94	-	-	6 – 20	-	-	-	-	-	-	0 - 5
		CEM II /B-P	65 - 79	-	-	21 - 35	-	-	-	-	-	-	0 - 5
		CEM II /A-Q	80 - 94	-	-	-	6 - 20	-	-	-	-	-	0 - 5
		CEM II /B-Q	65 - 79	-	-	-	21 - 35	-	-	-	-	-	0 - 5
	Portland-fly ash cement	CEM II /A-V	80 - 94	-	-	-	-	6 - 20	-	-	-	-	0 - 5
		CEM II /B-V	65 - 79	-	-	-	-	21 - 35	-	-	-	-	0 - 5
		CEM II /A-W	80 - 94	-	-	-	-	-	6 - 20	-	-	-	0 - 5
		CEM II /B-W	65 - 79	-	-	-	-	-	21 - 35	-	-	-	0 - 5
	Portland-burnt shale cement	CEM II /A-T	80 - 94	-	-	-	-	-	-	6 - 20	-	-	0 - 5
		CEM II /B-T	65 - 79	-	-	-	-	-	-	21 - 35	-	-	0 - 5
	Portland-limestone cement	CEM II /A-L	80 - 94	-	-	-	-	-	-	-	6 - 20	-	0 - 5
		CEM II /B-L	65 - 79	-	-	-	-	-	-	-	21 - 35	-	0 - 5
		CEM II /A-LL	80 - 94	-	-	-	-	-	-	-	-	6 - 20	0 - 5
		CEM II /B-LL	65 - 79	-	-	-	-	-	-	-	-	21 - 35	0 - 5
	Portland-composite cement [c)]	CEM II /A-M	80 - 94	6 to 20									0 - 5
		CEM II /B-M	65 - 79	21 to 25									0 - 5
CEM III	Blast-furnace cement	CEM III /A	35 - 64	36 - 65	-	-	-	-	-	-	-	-	0 - 5
		CEM III /B	20 - 34	66 – 80	-	-	-	-	-	-	-	-	0 - 5
		CEM III /C	5 - 19	81 – 95	-	-	-	-	-	-	-	-	0 - 5
CEM IV	Pozzolanic cement [c)]	CEM IV /A	65 - 89		11 to 35					-	-	-	0 - 5
		CEM IV /B	45 - 64		36 to 66					-	-	-	0 - 5
CEM V	Composite cement [c)]	CEM V /A	40 - 64	18 – 30	-	18 to 30			-	-	-	-	0 - 5
		CEM V /B	20 - 38	31 - 50	-	31 to 50			-	-	-	-	0 - 5

[a)] The values in the table refer to the sum of the main and minor additional constituents
[b)] The proportion of silica fume is limited to 10%
[c)] In Portland –composite cements CEM II/A-M and CEM II/B-M, in Pozzolanic cements CEM IV/A and CEM IV/B and in composite cements CEM V/A and CEM V/B the main constituents other than clinker shall be declared by designation of the cement

TABLE 9.2: TESTING OF AGGREGATES

Properties	Type of Aggregate	Test Methods	Limits
Grading	Both	MS30	Table 3 and Table 4
Elongation Index	Coarse	MS30	Not exceeding 30%
Flakiness Index	Coarse	MS30	Not exceeding 35%
Water Absorption	Both	MS30	Not exceeding 8%
Clay Lumps	Coarse	MS30	Not exceeding 1% by weight
Clay, Silt and Dust	Fine	MS30	Not exceeding 3% by weight or 8% by vol.
Organic Impurities	Fine	MS30	Not exceeding 0.4%
Aggregate Crushing Value	Coarse	MS30	Not exceeding 40%
Soundness Test	Coarse	MS30	Loss in mass after 5 cycles shall not be more than 12% for sodium sulphate or 18% for magnesium sulphate.
Chloride Content	Both	MS30	Not exceeding 0.06% by weight of chloride ions
Sulphate Content	Both	MS30	Not exceeding 0.44% by weight of SO3

TABLE 9.3: GRADING FOR COARSE AGGREGATE

Sieve size (BS410)	Percentage by mass passing BS 410 sieve for nominal sizes					
	Graded Aggregates			Single-sized Aggregate		
	40 mm to 5 mm	20 mm to 5 mm	14 mm to 5 mm	40 mm	20 mm	10 mm
50.0 mm	100	-	-	100	-	-
37.5 mm	90 to 100	100	-	85 to 100	100	-
20.0 mm	35 to 70	90 to 100	100	0 to 25	85 to 100	-
14.0 mm	25 to 55	40 to 80	90 to 100	-	0 to 70	100
10.0 mm	10 to 40	30 to 60	50 to 85	0 to 5	0 to 25	85 to 100
5.0 mm	0 to 5	0 to 10	0 to 10	-	0 to 5	0 to 25
2.36 mm	-	-	-	-	-	0 to 5

TABLE 9.3A: GRADING FOR FINE AGGREGATE

Sieve size (BS410)	Percentage by mass passing BS 410 sieve			
	Overall Limits	Additional limits for grading		
		C	* M	F
10.0 mm	100	-	-	-
5.0 mm	80 to 100	-	-	-
2.36 mm	60 to 100	60 to 100	65 to 100	80 to 100
1.18 mm	30 to 100	30 to 90	45 to 100	70 to 100
600 µm	15 to 100	15 to 45	25 to 80	55 to 100
300 µm	5 to 70	5 to 40	5 to 48	5 to 70
150 µm	0 to 15#	-	-	-

#	Increase to 20% for crushed rock fines, except when they are used for heavy-duty floors.
*	For prescribed mix only Grading Limit M is applicable.
NOTE:	Individual sands may comply with the requirements of more than one grading. Alternatively some sands which satisfy the overall limits but may not fall within any one of the additional limit C, M or F may also be used provided that the supplier can satisfy the S.O that such materials can produce concrete of the required quality.

TABLE 9.3B – GRADING FOR FINE AGGREGATE FOR HPC AND UHPC

Sieve Size (BS410)	Percentage by Mass Passing BS 410
	Limit
2.36 mm	100
1.18 mm	90 – 100
0.6 mm	30 – 50
0.425 mm	25 – 35
0.3 mm	10 – 20
0.15 mm	5 – 10
< 0.15 mm	0 – 5

TABLE 9.4: ADMIXTURE ACCEPTANCE TEST REQUIREMENTS

Categories of Admixture	Water Reduction	Stiffening Time Time from completion of mixing to reach a resistance to penetration of:-			Minimum Strength as a percentage of the control mix	Age	Length change, Maximum shrinkage	
		0.5 N/mm²	3.5 N/mm²	27.5 N/mm²	Compressive		% of control	Increase
Type 1: Accelerator	-	More than 1hr.	Within 1hr.and 3hrs. earlier than control mix	At least 1hr. earlier than control mix	12 5 12 5 10 0	24 hrs. 3 days 7 days 28 days	135	0.010
Type 2: Retarder	-	At least 1hr.later than control mix	Within 1hr.and 3hrs. later than control mix	Not more than 3hrs. later than control mix	9 0 9 0 9	3 days 7 days 28 days	135	0.010
Type 3: Normal water-reducing	At least 5%	Within + 1hr. and - 1hr.of control mix	Within + 1hr. and - 1hr.of control mix	Within + 1hr. and - 1hr.of control mix	11 0 11 0 11	3 days 7 days 28 days	135	0.010
Type 4: Accelerating water-reducing	At least 5%	More than 1hr.	Within 1hr.and 3hrs. earlier than control mix	At least 1hr. earlier than control mix	12 5 12 5 10 0	24 hrs. 3 days 7 days 28 days	135	0.010
Type 5: Retarding water-reducing	At least 5%	At least 1hr.later than control mix	Within 1hr.and 3hrs. earlier than control mix	Not more than 3hrs. later than control mix	11 0 11 0 11 0	3 days 7 days 28 days	135	0.010

TABLE 9.5: PRESCRIBED MIXES FOR GENERAL USE PER CUBIC METER OF CONCRETE BY WEIGHT BATCHING

Grades of Concrete	28 days Strength of Concrete (N/mm^2)	Nominal Max. Size of Aggregate (mm) 20			Max free water cement ratios
		Workability	Medium	High	
		Consistence	25 - 75	75 - 125	
15P	15	CEM I (kg) Total aggregate (kg) *Fine aggregate (%)	280 1800 35 – 50	310 1750 35 – 50	0.6
20P	20	CEM I (kg) Total aggregate (kg) *Fine aggregate (%) CEM I (kg)	320 1800 20 – 40	350 1750 20 – 45	0.55
25P	25	CEM I (kg) Total aggregate (kg) *Fine aggregate (%) CEM I (kg) Total	360 1750 20 – 40	390 1700 30 – 45	0.5
30P	30	Aggregate (kg) *Fine aggregate (%)	400 1700 20 – 40	430 1650 30 - 45	0.45

TABLE 9.5A: PROPORTIONS AND STRENGTH REQUIREMENTS FOR PRESCRIBED MIXES BY VOLUME BATCHING

Proportion (by weight) (Grade)	Slump Limits (mm)	Cubic Meters of Aggregate Per 50 kg of CEM I		Max. Free Water: Cement Ratio	Quantity Of Water (Litres)	Strength of Concrete	
		Fine	Coarse (20mm)			At 7 Days (N/mm^2)	At 28 Days (N/mm^2)
1:1:2(30P)	25 - 50	0.035	0.07	0.45	22.5	20	30
1:1.5:3(25P)	25 - 50	0.05	0.1	0.5	25	17	25
1:2:4(20P)	25 - 50	0.07	0.14	0.55 - 0.6	27.5 - 30	14	20
1:3:6(15P)	25 - 50	0.10	0.20	0.6	30#	11	15

or as approved by S.O

TABLE 9.6: DURABILITY RECOMMENDATIONS FOR REINFORCED OR PRESTRESSED ELEMENTS WITH AN INTENDED WORKING LIFE OF AT LEAST 50 YEARS

Nominal cover [b] mm	Compressive strength class where recommended, maximum water-cement ratio and minimum cement or combination content for normal-weight concrete[c] with 20mm maximum aggregate size[d]								Cement/ combination types
	15 +△c	20+△c	25+△c	30+△c	35+△c	40+△c	45+△c	50+△c	
Corrosion induced by carbonation (XC exposure classes)									
XC 1	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C2	C20/25 0.70 240	All in Table D1
XC2	-	-	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	All in Table D1
XC3	-	C40/50 0.45 340 -	C30/37 0.55 300 C40/50 0.45 340	C28/35 0.60 280 C30/37 0.55 300	C25/30 0.65 260 C28/35 0.60 280	C25/30 0.65 260 C25/30 0.65 260	C25/30 0.65 260 C25/30 0.65 260	C25/30 0.65 260 C25/30 0.65 260	All in Table D1 except IVB-V IVB_V
Corrosion induced by chlorides (XS from sea water, XD other than sea water) Also adequate for any associated carbonation induced corrosion (XC)									
XD1	-	-	C40/50 0.45 360	C32/40 0.55 320	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	All in Table D1
XS1	- - - -	- - - -	- - - -	C45/5 0.35 380 C40/50 0.35 380 C32/40 0.40 380 C32/40 0.40 380	C35/45 0.45 360 C32/40 0.45 360 C25/30 0.50 340 C28/35 0.50 340	C32/40 0.50 340 C28/35 0.50 340 C25/30 0.50 340 C25/30 0.50 340	C32/40 0.50 340 C25/30 0.55 320 C25/30 0.55 320 C25/30 0.55 320	C32/40 0.50 340 C25/30 0.55 320 C25/30 0.55 320 C25/30 0.55 320	CEM I,IIA,IIB-S, SRPC IIB-V, IIIA IIIB IVB-V
XD2 or XS2	- - -	- - -	- - -	C40/50 0.40 380 C35/45 0.40 380 C32/40 0.40 380	C32/40 0.50 340 C28/35 0.50 340 C25/30 0.50 340	C28/35 0.55 320 C25/30 0.55 320 C20/25 0.55 320	C28/35 0.55 320 C25/30 0.55 320 C20/25 0.55 320	C28/35 0.55 320 C25/30 0.55 320 C20/25 0.55 320	CEM I, IIA, IIB-S, SRPC IIB-V, IIIA IIIB, IVB-V
XD3	- - -	- - -	- - -	- - -	- - -	C45/55 0.35 380 C35/45 0.40 380 C32/40 0.40 380	C40/50 0.40 380 C32/40 0.45 360 C28/35 0.45 360	C35/45 0.45 360 C28/35 0.50 340 C25/30 0.50 340	CEM I, IIA, IIB-S, SRPC IIB-V, IIIA IIIB, IVB-V
XS3	- - -	- - -	- - -	- - -	- - -	- C35/45 0.40 380 C32/40 0.40 380	C45/55 0.35 380 C32/40 0.45 360 C28/35 0.45 360	C40/50 0.40 380 C28/35 0.50 340 C25/30 0.50 340	CEM I, IIA, IIB-S, SRPC IIB-V, IIIA IIIB, IVB-V

TABLE 9.6A: MINIMUM CEMENT CONTENT FOR MAXIMUM AGGREGATE SIZES OTHER THAN 20 MM

Limiting values given for 20 mm maximum aggregate size		Maximum aggregate size		
Maximum w/c ratio	Minimum cement or combination content Kg/m^3	≥ 40 mm	14 mm	10 mm
0.70	240	240	260	280
0.65	260	240	280	300
0.60	280	260	300	320
0.55	300	280	320	340
	320	300	340	360
0.50	320	300	340	360
	340	320	360	380
0.45	340	320	360	360
	360	340	380	380
0.40	380	360	380	380
0.35	380	380	380	380

TABLE 9.7: SLUMP CLASSES

Class	Slump in mm
S1	10 to 40
S2	50 to 90
S3	100 to 150
S4	160 to 210
S5	≥ 220

TABLE 9.7A: COMPACTION CLASSES

Class	Degree Of Compactibility
C0	≥ 1.46
C1	1.45 to 1.26
C2	1.25 to 1.11
C3	1.10 to 1.04

TABLE 9.7B: VEBE CLASSES

Class	Vebe Time In Seconds
V0	≥31
V1	30 to 21
V2	20 to 11
V3	10 to 6
V4	5 to 3

TABLE 9.7C: FLOW CLASSES

Class	Flow Diameter In mm
F1	≤ 340
F2	350 to 410
F3	420 to 480
F4	490 to 550
F5	560 to 620
F6	≥ 630

TABLE 9.7D: CONSISTENCE SUITABLE FOR DIFFERENT USES OF IN-SITU CONCRETE

Use of concrete	Form of compaction	Consistence class	
		Normal-weight concrete	Lightweight concrete
Kerb bedding and braking	Tamping	S1	-
Floors and hand placed pavements	Poker or beam vibration	S2	S2
Strip footings, Pile Cap	Poker or beam vibration and/or tamping	S3	-
Mass concrete foundations		S3	-
Blinding		S3	-
Normal reinforced concrete in slabs, beams, walls, piers and columns		S3	S3
Sliding formwork construction		S3	S2
Pumped concrete		S3	F5
Vacuum processed concrete		S3	S3
Trench fill	Self-weight compaction	S4	-
In-situ piling		S4	-

TABLE 9.7E: MAXIMUM TOTAL CHLORIDE

Type or Use of Concrete	Maximum Total Percentage of Chloride Ions by Mass of Cement
Concrete containing embedded metal and made with cement complying with MS522	0.4
Prestressed Concrete and Heat-Cured Concrete containing embedded metal	0.1
Plain, non-structural concrete	No limit

Notes on Table 7:-
(1)% Chloride ions x 1.648 = % equivalent sodium chlorides.
(2)% Chloride ions x 1.56 = % equivalent anhydrous calcium chlorides.

TABLE 9.8: COMPRESSIVE STRENGTH CLASSES FOR NORMAL WEIGHT AND HEAVY WEIGHT CONCRETE

Compressive strength class	Minimum characteristic cylinder strength $f_{ck,cyl}$ N/mm^2	Minimum characteristic cube strength $f_{ck,CUBE}$ N/mm^2
C8/10	8	10
C12/15	12	15
C16/20	16	20
C20/25	20	25
C25/30	25	30
C30/37	30	37
C32/40	32	40
C35/45	35	45
C40/50	40	50
C45/55	45	55
C50/60	50	60
C55/67	55	67
C60/75	60	75
C70/85	70	85
C80/95	80	95
C90/105	90	105

TABLE 9.9: COMPRESSIVE STRENGTH CLASSES FOR LIGHT WEIGHT CONCRETE

Compressive strength class	Minimum characteristic cylinder strength $f_{ck,cyl}$ N/mm^2	Minimum characteristic cube strength $f_{ck,CUBE}$ N/mm^2
LC8/9	8	9
LC12/13	12	13
LC16/18	16	18
LC20/22	20	22
LC25/28	25	28
LC30/33	30	33
LC35/38	35	38
LC40/44	40	44
LC45/50	45	50
LC50/55	50	55
LC55/60	55	60
LC60/66	60	66
LC70/77	70	77
LC80/88	80	88
Other values may be used if the relationship between these and the reference cylinder strength is established with sufficient accuracy and is documented.		

TABLE 9.10: MINIMUM RATE OF SAMPLING FOR ASSESSING CONFORMITY

Production	Minimum rate of sampling for assessing conformity		
	First 50m^3 of production	Subsequent to first 50m^3 of production[a]	
		Concrete with production control certification	Concrete without production control certification
Initial (until at least 35 test results are obtained)	3 samples[b]	1/200m^3 or 2/production week	1/150m^3 or 1/production day
Continuous[c] (when at least 35 test results are available)		1/400m^3 or 1/production week	

[a] Sampling shall be distributed throughout the production and should not be more than 1 sample within each 25 m^3

[b] 1 sample shall be min. of 3 specimens or as directed by S.O.

[c] Where the standard deviation of the last 15 results exceeds 1,37σ, the sampling rate shall be increased to that required for initial production for the next 35 test results

TABLE 9.11: CONFORMITY CRITERIA FOR COMPRESSIVE STRENGTH

Production	Number *n* of test results for compressive strength in the group	Criterion 1	Criterion 2
		Mean of n results (f_{cm}) N/mm^2	Any individual test result (f_{cl}) N/mm^2
Initial	3	$\geq f_{ck}+4$	$\geq f_{ck}-4$
Continuous	15	$\geq f_{ck}+1{,}48\ \sigma$	$\geq f_{ck}-4$

TABLE 9.12: COMPRESSIVE STRENGTH REQUIREMENTS FOR PRESCRIBED MIX

Grades of Concrete	28-day Strength of Concrete N/mm^2	Cube Strength at 7 Days* N/mm^2	Average Cube Strength at 28 Days* N/mm^2
20P	20.0	14	20.0
25P	25.0	17	25.0
30P	30.0	20	30.0

*Only for CEM1

TABLE 9.13: IDENTITY CRITERIA FOR COMPRESSIVE STRENGTH

Number n of test results for compressive strength from the defined volume of concrete	Criterion 1	Criterion2
	Mean of n results (f_{cm}) N/mm^2	Any individual test result (f_{cl}) N/mm^2
1	Not applicable	$\geq f_{ck} - 4$
2-4	$\geq f_{ck} + 1$	$\geq f_{ck} - 4$
5-6	$\geq f_{ck} + 2$	$\geq f_{ck} - 4$

NOTE: The identity criteria of table 13 give probability that a conforming concrete volume is rejected.

TABLE 9.14: IDENTITY CRITERIA FOR SLUMP SPECIFIED AS A SLUMP CLASS

Specified Slump Class	Requirement			
	For composite samples taken in accordance with BS EN 12350-1		For spot samples taken from initial discharge	
	Not less than	Not more than	Not less than	Not more than
S1	0	60	0	70
S2	40	110	30	120
S3	90	170	80	180
S4	150	230	140	240
S5	210	-	200	-

NOTE : Dimension in millimeters

TABLE 9.15: IDENTITY CRITERIA FOR SLUMP SPECIFIED AS A TARGET VALUE

Specified Target Slump	Tolerance	
	For composite samples taken in accordance with BS EN 12350-1	For spot samples taken from initial discharged
≤40	-20, +30	-30, +40
50 to 90	-30, +40	-40, +50
≥100	-40, +50	-50, +60

TABLE 9.16 : RECORDED DATA AND OTHER DOCUMENTS

Subject	Recorded data and other documents
Cements, aggregates, admixture, additions	Name of suppliers
Tests on mixing water (not required for potable water)	Date and place of sampling. Test results
Test on constituent materials	Date and test results
Composition of concrete	Concrete description Record of masses of constituents in batch or load Water/cement ratio Chloride content
Tests on fresh concrete	Date and place of sampling Location in structure Consistence (slump or other methods) Density Concrete temperature Air content Volume of concrete batch or load tested Number and codes of specimens to be tested Water/cement ratio
Tests on hardened concrete	Date of testing Code and ages of specimens Test results for density and strength Special remarks (e.g. unusual failure pattern of specimen)
Evaluation of conformity	Conformity/non-conformity with specifications
Additionally for ready mixed concrete	Location of work Numbers and dates of delivery tickets related to tests Delivery tickets

TABLE 9.17 : CHARACTERISTIC STRENGTH OF STEEL REINFORCEMENT

Type	Nominal Sizes (mm)	Specified Characteristic Strength, fy (N/mm^2)
Hot rolled grade 250 (MS 146)	All sizes	250
Hot rolled grade 460 (MS 146)	All sizes	460
Cold worked (BS 4461)	All sizes	460
Hard drawn steel wire (MS 144)	Up to and including 12	485

TABLE 9.18: MINIMUM PERIODS BETWEEN CONCRETING AND REMOVAL OF FORMS

Vertical faces of beams, culverts, wall, cross-head, columns, piles, foundation, plinths and precast components	3 days
Deck Slabs / Slabs (props left under)	4 days
Removal of props to slab	10 days
Beam/Girder soffits (props left under)	8 days
Removal of props to beams/girders	21 days

Note: This table is applicable only for CEM1 cement. Where other types of cement, admixtures or additional material are to be used, the minimum periods between concreting and removal of forms shall be as approved by the S.O.